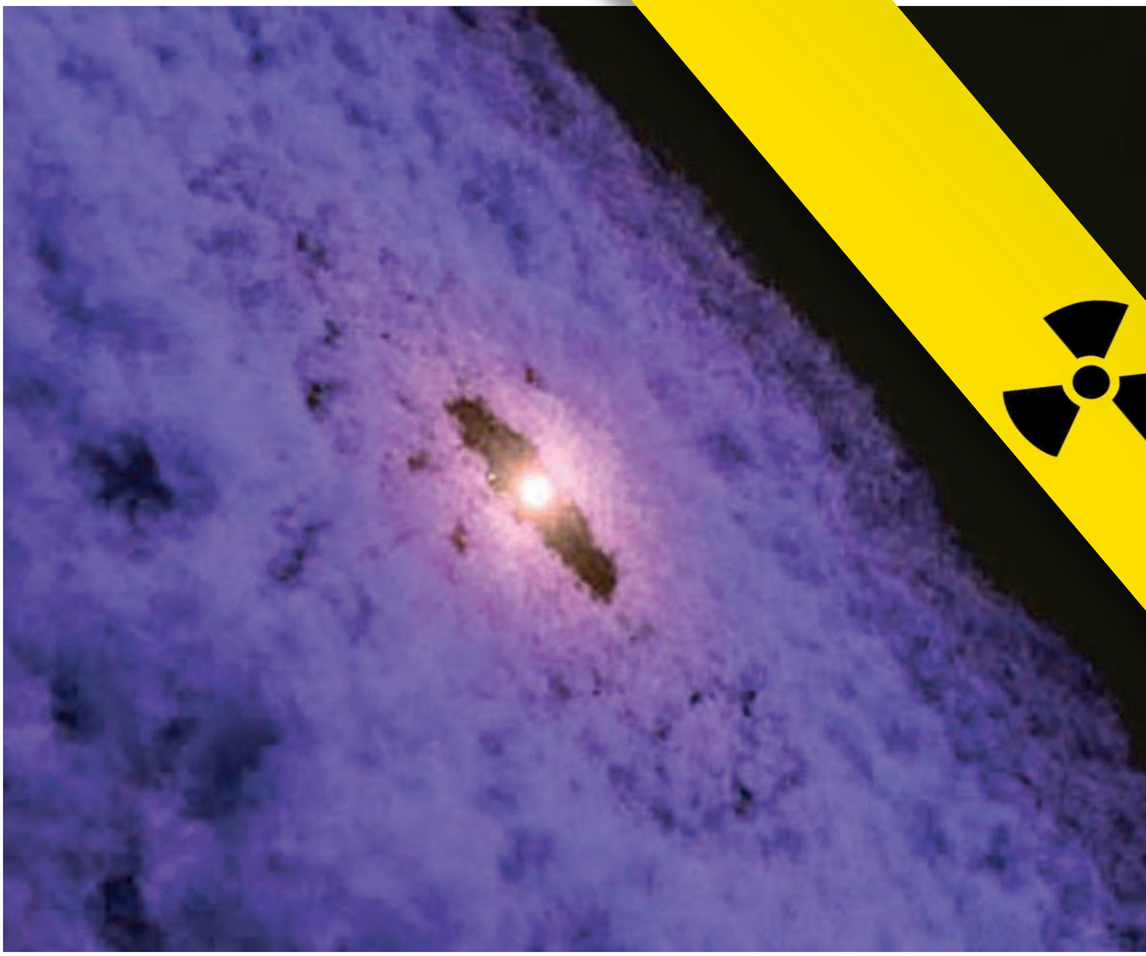


NASA/Swift/Jules Halpern, Columbia University

An expanding halo formed by X-rays coming from the neutron star SGR J1550-5418, as captured by the Swift satellite's X-Ray Telescope (XRT). The halo forms as X-rays from the brightest flares scattered off of intervening dust clouds. For a video of the event, see http://science.nasa.gov/headlines/y2009/10feb_sgr.htm

SCIENCE FOR LEGISLATORS

Is the Fear of Radiation Constitutional?

by Laurence Hecht

A primer to help the present majority of misinformed policymakers and citizens to learn the truth about radiation, and the wonderful power for good that it holds out for mankind.

A recent burst of high-energy X-rays and gamma rays from the Southern Hemisphere constellation Norma, should serve to remind us that the current widespread fear of anything to do with radiation is much out of harmony with those *Laws of Nature and of Nature's God*, famously invoked in our Declaration of Independence. As the rights defined in that document stand, along with our Constitution, as twin pillars of our nation's fundamental law, the question arises: Should not the incitement of such fears against a natural and necessary phenomenon, with the clear intent of misleading a frightened populace down a path of national self-destruction, rise to the level of a Constitutional violation? However that point may ultimately be decided at law, our urgent aim here is to aid that present majority of misinformed policymakers and citizens in general, to learn the truth about nuclear radiation, and the wonderful power for good that it holds out for mankind.

What makes this task urgent is the present, rapidly accelerating economic collapse. Denial of the clear immediate and future benefits to be derived from knowledge of the atomic and subatomic realms (a denial due in significant part to the ignorance and prejudice of the audience we now address), constitutes a serious and immediate threat to the survival of our own people as well as those of other nations.[1] Unless those widespread fears and prejudices respecting nuclear radiation are soon reversed, the threat to human civilization as a whole will be catastrophic. The currently popular proposals to increase our reliance upon so-called renewable energy sources, such as wind and solar, demonstrate a level of incompetence respecting the elementary principles of physical economy, such as to doom to inevitable failure whatever other well-intentioned, even courageous, measures might be forthcoming from the present Administration. Motivated by such urgent considerations as these, we are convinced that the serious reader, even without prior familiarity with the subject matter, can gain a working grasp of the essentials of these matters, and overcome those ill-founded prejudices he or she may have previously accepted without examination.

The human body is full of radioactivity—all natural—from the foods we eat, like citrus fruit or bananas (sources of potassium-40 and carbon-14). Edward Teller used to joke that a man would get more radiation from sleeping with two women than living next door to a nuclear plant.

Now, to the galaxy. As detected by NASA's Swift X-ray Telescope, a small object about 30,000 light years distant, lying within our Milky Way galaxy in the direction of the constellation Norma, began a series of forceful eruptions on Jan. 22, at times producing over 100 X-ray flares in as little as 20 minutes. The most intense of these were estimated to contain more total energy than the Sun produces in 20 years! In addition, the new Fermi Gamma-ray Space Telescope has detected 95 bursts of radiation from the same object in the gamma ray band of the spectrum, the same general type of radiation that comes from radioactive objects on Earth. The object, located about 30,000 light years away, is of a type known as a neutron star.

Despite the large numbers, there is nothing that unusual about these events. Bursts of radiation of this power, and far greater, are normal occurrences in the universe. Much of it ends up in our bodies. Another flux of radiation known as cosmic rays (we shall explain and distinguish the different common types of radiation shortly), is bombarding Earth's atmosphere continuously. This type of radiation consists mostly of very energetic protons (hydrogen nuclei), as well as the nuclei of heavier elements, all the way up the periodic table. The determination of the content of cosmic rays was an important focus of physics for the first half of the 20th Century.

Colliding with atoms in our atmosphere, the cosmic rays transform the elements in a way similar to a particle accelerator, creating many radioactive by-products. Included among these is carbon-14, a radioactive isotope of the element carbon which is found in every molecule of our bodies. Green plants respire this naturally produced carbon-14, and use it to grow. When we eat vegetables, or the meat of animals

Radioactive Elements in the Human Body

Radioactive Isotope	Half-Life (years)	Isotope Mass in the Body (grams)	Element Mass in the Body (grams)	Activity within the Body (Disintegrations/sec)
Potassium 40	1.26×10^{9}	0.0165	140	4,440
Carbon 14	5,715	1.9×10^{-9}	16,000	3,080
Rubidium 87	4.9×10^{10}	0.18	0.68	600
Lead 210	22.3	5.4×10^{-10}	0.12	15
Tritium (^{3}H)	12.43	2×10^{-14}	7,000	7
Uranium 238	4.46×10^{9}	1×10^{-4}	1×10^{-4}	3 - 5
Radium 228	5.76	4.6×10^{-14}	3.6×10^{-11}	5
Radium 226	1,620	3.6×10^{-11}	3.6×10^{-11}	3

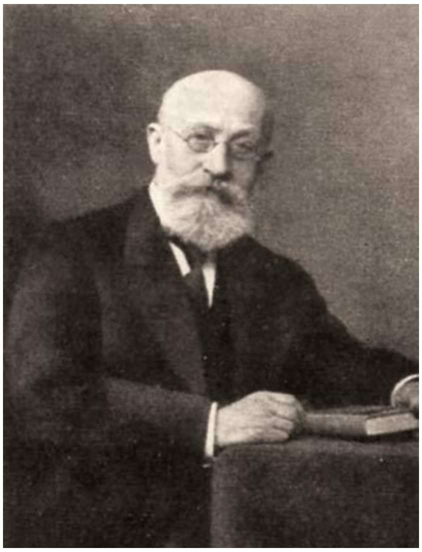
Source: R. E. Rowland, "The Radioactivity of the Normal Adult Body," http://www.rerowland.com/BodyActivity.htm

A conservative estimate of the radioactivity in the human body, showing the isotopes responsible for about 8,000 disintegrations per second. Other sources estimate a total of about 15,000 disintegrations per second.

1. Such potential benefits include, but are not limited to: 1) nuclear-powered generation of electricity and industrial process heat; 2) production of hydrogen-based fuels for replacement of petroleum; 3) production of fresh water by nuclear-powered desalination; 4) nuclear medicine; 5) development of new materials and industrial processes through nuclear research; 6) research and development up to and through the engineering stage of more advanced forms of nuclear energy, including fission-fusion hybrids, and thermonuclear fusion devices of both the inertial and magnetic containment design; 7) research into anomalous phenomena in the subatomic domain, including but not limited to (a) "cold" fusion (low energy nuclear reactions); (b) anomalous coherence phenomena, including self-organizing phenomena in plasma; (c) non-linear spectroscopy, generally; 8) research into insufficiently explored regions of the biotic domain, including, but not limited to (a) biophoton emission and other manifestations of the relationship of life to the electromagnetic spectrum; (b) isotopic anomalies related to living matter; 9) matter/anti-matter reactions.

that have eaten them, and when we breathe fresh air, we take this carbon-14 into our bodies. The carbon-14 present within the average human body is responsible for *more than 3,000 radioactive disintegrations every second*.[2]

Another naturally occurring isotope, potassium-40, is the most abundant radioactive substance in our bodies, responsible for *4,440 disintegrations per second* inside the average adult. Potassium is an essential mineral for cell function, and with every gram of it that we consume, about 1/10 milligram is the radioactive isotope. We obtain potassium from eating fruits, vegetables, and meats. Potatoes, figs, chicken, hamburgers, citrus fruits, and bananas are all high in potassium-40. If every radioactive disintegration represents a cancer threat, as so many people have been led to believe, then perhaps we should consider a legislative ban on cosmic rays and orange juice. Or, might it be wiser to first know a bit more about the whole subject?



Eugen Goldstein, working at the Berlin Observatory, discovered that when small holes are drilled in the cathode, other rays shoot out from the back, like fiery sparks. He called them Kanalstrahlen*, which was translated into English as canal rays.*

1. What Is Radioactivity?

Discovery of the Electron and Proton

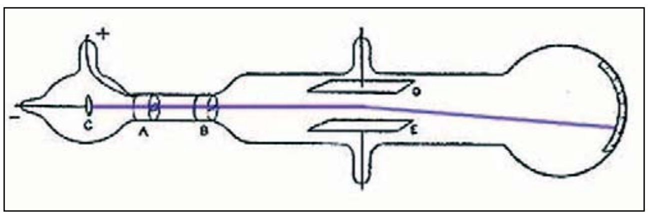
We shall begin by attempting to understand what we mean by such terms as *radioactivity, isotope, proton, gamma ray, etc*. But first a warning. Most of these and other terms we shall employ here are, properly, not things, but concepts. We may, at times, form visual images of them, but we must remember that not only are they not generally perceptible to our senses, but even if they were, our conception of what they are would never be comprehended by a verbal definition. The same methodological warning applies here as to the inevitable failure of any effort to interpret *natural law* in the manner of the strict constructionist. An infinite number of readings of the Constitution will never yield the intent of the framers, if it is not known through other means. The same applies to the terms employed by science. A true understanding of them can only be gotten by studying and repeating the path of experimental discovery. No deep understanding of science is ever attained by any other means.

And so we proceed. We shall start then with the experimental discovery of the *electron* and *proton*. A central focus of scientific investigations in the 1880s and 1890s was the behavior of gases contained within glass tubes, from which most of the air had been sucked out, and an electric potential (voltage) excited between metal wires placed at opposite ends of the tube. Depending on the gas or gases left in the tube, a beautiful, fluorescent glow, ranging from coral pink, to pale green, to a deep indigo blue, is observed. The ray seems to originate from the negatively charged electrode (*cathode*) at one end of the tube, hence the name *cathode rays*. However, despite its resemblance to a light beam, it turned out that the colorful ray, unlike an ordinary light beam, could be deflected by a magnet, or by strongly electrified plates placed parallel to the walls of the tube.

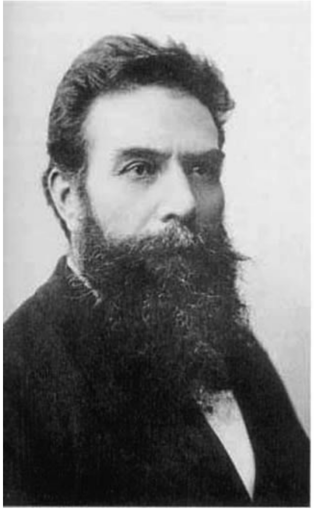
A very strange phenomenon is observed when small holes are drilled in the cathode, and it is placed in the center rather than at one end of the tube. It then occurs that in addition to the *cathode rays*, which pass toward the positive electrode, other rays shoot out from the back side of the cathode, like fiery sparks. Because they seemed to originate from the little holes (channels) drilled in the cathode, these were called *Kanalstrahlen* by Eugen Goldstein, who discovered them in his laboratory at the Berlin Observatory in 1886. The term was translated, somewhat over-literally, into English as *canal rays*, though *channel rays* might have been more accurate.

It turned out that, like the cathode rays, the *canal rays* could also be deflected, although in precisely the opposite direction, by a sufficiently strong magnetic or electric field. It was this common property that proved the key to the initial unmasking of both the cathode and canal rays. For in 1896, the assumption was made by J.J. Thomson at Cambridge University's Cavendish Laboratory, that the cathode rays, unlike light beams, actually consisted of tiny electrified particles of negative charge. Wilhelm Wien in Aachen found similar results, and, in 1898, Wien showed that the canal rays could be considered as positively charged electrical particles.

British scientist J.J. Thomson followed up on work in Germany, which had laid the foundations of studies of the negative and positive rays produced in evacuated glass tubes when an electric current is passed through the tube. In his second experiment (below), Thomson showed that a cathode ray was deflected by electrified plates, indicating that it had a negative charge.



2. R.E. Rowland, "The Radioactivity of the Normal Adult Body," http://www.rerowland.com/BodyActivity.htm




Wilhelm Roentgen caused a scientific sensation by his discovery of what he called X-rays in 1895. He was experimenting with gas discharge tubes, and found that they would light up a screen painted with fluorescent material. He discovered that the X-rays could penetrate many materials, including human tissue. Here is his first X-ray picture: his wife's hand, showing her bones and her wedding ring.

By measuring the amount of deflection produced by an electric or magnetic field of given strength upon the two different types of rays, it was possible to compare the bending of the ray to that of a larger body of known charge and mass experiencing the same amount of electric or magnetic force. After all the measurements and calculations were done, it turned out that the *cathode ray* possessed a mass more than a thousand times smaller than that of the least massive *canal ray* (today we know it more exactly as 1,836 times smaller). The least massive canal ray, it turned out, was that produced when the gas in the tube was hydrogen, and by this and other evidence, *canal rays* came to be seen as electrified versions of ordinary chemical atoms (today called *positive ions*).[3] The hydrogen ion thus became known as the elementary particle of positive electricity, or proton. The *cathode ray* particle, discovered first, became known as the elementary particle of negative electricity, or *electron*.[4]

From X-rays to Radioactivity

Slightly before the results just reported, a professor of physics at the University of Würzburg made an astounding discovery of both theoretical and immediate practical significance. While experimenting with various types of gas discharge tubes in November of 1895, Wilhelm Roentgen noticed that a screen painted with fluorescent material would light up when the tube was activated. A similar phenomenon had been noted by other observers back to 1875, but Roentgen was the first to thoroughly pursue it. He soon discovered that the rays could penetrate many materials. At the end of two weeks of intensive experimentation, eating and sleeping in his laboratory, he produced the world's first *X-ray* picture. It was an image of his wife's hand, showing the bones of the fingers and wedding ring.

Roentgen's discovery was quickly made known worldwide. Just weeks later, physicians in Dartmouth, New Hampshire, used photographs taken with an X-ray tube to set the broken arm of a boy. Roentgen also discovered in this early period that lead served as an effective shield against the radiation, and he used sheets of this metal to protect himself from direct exposure. Roentgen summarized his discoveries in a paper in 1896 calling them "Radiation X," or *X-rays*. They are also known as Roentgen-rays.

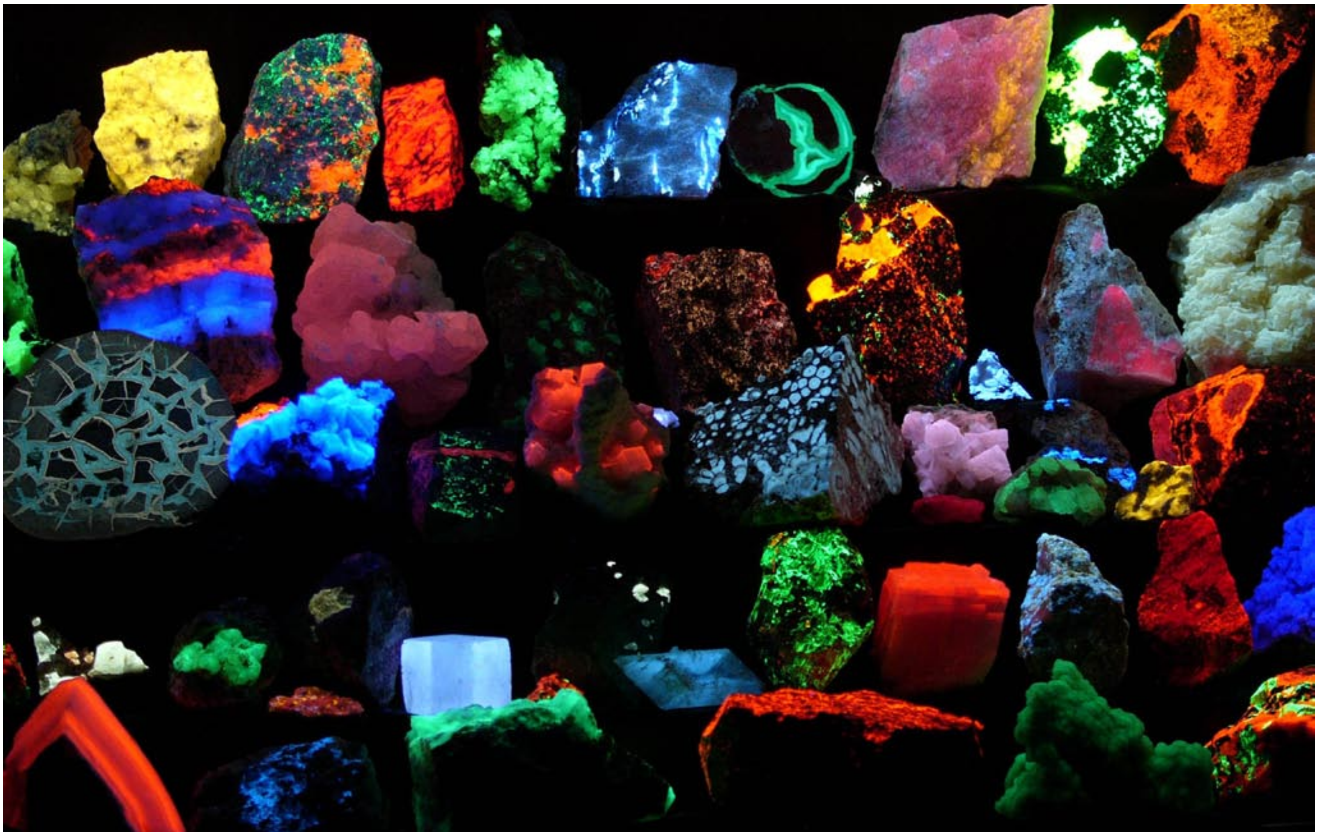
Excited by Roentgen's discovery, just months later Henri Becquerel in Paris discovered what was soon to become known as *radioactivity*. He found it while looking for something else. Henri Becquerel was the third member of his family to occupy the chair of physics at the Museum of Natural History in Paris. His father, Alexandre-Edmond Becquerel, had been the leading authority on the phenomenon of *luminescence*, the property of certain materials to glow in the dark, and Henri himself had written 20 scholarly papers on the topic. Observing an experimental apparatus for producing X-rays which was exhibited at a weekly meeting of the French Academy of Sciences, Becquerel thought that the unusual radiation might emanate from a part of the glass vacuum tube which glowed when struck by the cathode rays. He suspected that luminescence might be a prerequisite for the production of X-rays, and he thus began to examine various luminescent materials for X-ray production. Many rocks and minerals can be made to glow in the dark after exposure to sunlight, and others, by immediate exposure to ul-

Henri Becquerel, inspired by a demonstration of Roentgen's rays, suspected that luminescence might be involved, and thus investigated rocks and minerals that were known to glow in the dark after being exposed to sunlight. He inadvertently discovered that uranium rocks produced rays even when they were not exposed to sunlight!

3. Remarkably, the tiny mass of the hydrogen atom was already known, thanks to the hypothesis put forward by Count Amedeo Avogadro in 1811, that equal volumes of gases all possess the same number of molecules, and the work of the Austrian physical chemist Josef Loschmidt in calculating in 1865 what this number actually was.

4. The assumption made by the Cambridge scientists, that the cathode rays consisted of particles, was seriously doubted at first by most researchers. However, the experimental results could not be disputed, and the concept of *electron mass* took hold. Later it turned out that there had been some basis for the hesitations, for it was demonstrated in 1926 that the electron did indeed behave like a light wave, in being capable of refraction by a crystal and exhibiting interference patterns, and so the paradox of wave vs. particle was reborn, never yet to be put to rest.

This experimental proof carried out by Davisson and Germer at the Bell Laboratories was confirmation of a hypothesis proposed several years earlier by Count Louis de Broglie. Later it was seen that not only the electron, but also the heavier particles, such as the proton and neutron, showed wavelike characteristics, and from then on had to be thought of in a somewhat ambiguous way as particle/waves.



Hannes Grobe

A collection of various fluorescent minerals under UV-A, UV-B, and UV-C light. At first, Becquerel thought luminescence might be the origin of X-rays. For identification of the minerals, see upload.wikimedia.org/wikipedia/commons/b/b5/UV_minerals-des_hg.png.

traviolet light. Today these phenomena are termed *phosphorescence* when the light emission is delayed, and fluorescence when it occurs immediately; *luminescence* is the general term.

Among the materials Becquerel examined for X-ray production, were rocks containing a uranium compound known to be phosphorescent. His procedure was to expose the uranium rocks to sunlight, then wrap them in black paper, place them on top of a photographic plate, and store them in a dark place for a time. If the photographic plate became exposed, he might assume that *X-rays* were somehow being generated, and penetrating through the black wrapping paper onto the photographic plate. Sometimes he placed a coin or other object next to the rock sample, in order to see if its outline would be imaged on the photograph. Samples of the uranium-bearing mineral potassium uranyl sulfate showed an exceptional capability to penetrate the black paper and leave an image on the photograph.

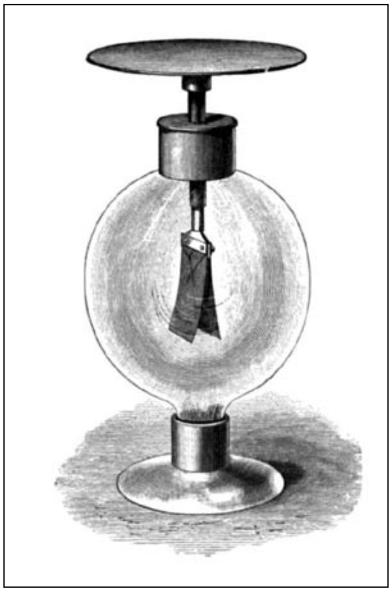
By chance, a spell of bad weather caused him to leave some of the rocks in a drawer, wrapped in black paper next to photographic plates, but not exposed to sunlight. When his curiosity provoked him to develop these, he found that they too showed a photographic image. Yet the rocks had not been stimulated to emission by previous exposure to sunlight.

Within a few months, Becquerel had become certain that previous exposure to sunlight was not required to cause the rocks to radiate. Furthermore, even samples of uranium compounds that did not exhibit any phosphorescence were able to produce an image on the photographic plates. Finally, experimenting with a sample of nearly pure uranium metal, he found the power to expose photographs was greatly increased. That was convincing proof that the radiations were not related to luminescence, but were a property of the element uranium.

It was now late Spring of the year 1896. News of Becquerel's experiments travelled fast, and created a great conundrum among chemists and physicists. Where did the power of the rays come from? In phosphorescence, the energy for the light production was seen as coming from an external source of energy, the Sun. As long as the power to produce light seemed to derive from prior exposure to sunlight, the principle of the conservation of energy was not violated. The energy of the sunlight was stored in the rock and emitted later. Once that hypothesis was dashed, some new cause had to be found for the energy of the rays. Some began to suspect that some new power existed within the interior of matter. Perhaps the concept of the atom, the indivisible substance which had served chemistry so well for nearly a century, needed to be modified.

Some bold minds began already to suspect that perhaps the atom itself consisted of smaller parts. Perhaps the ordinary chemical means would not allow access to these, but by some other means not yet known, their powers could be released. But this was only speculation. Such a bold suggestion would first have to be proven experimentally.

It was not yet clear if the *Becquerel rays*, as they had come to



In a gold leaf electroscope, two thin strips of gold leaf are placed in contact with each other, and are hung from a metallic clip inside a glass container. The clip is electrically charged by a conductive ball or disk outside the container. When an electrically charged object is put in contact with the ball, the charge is communicated to the gold leaf, and the two strips, because they are of the same charge, repel each other, rising into the air in opposite directions. As the charge dissipates, the strips fall back to their original position.

Roentgen showed that his X-rays could discharge the electroscope, and later Becquerel showed that a uranium sample caused a discharge. But it was not known initially what caused the uranium to have this effect.

be called, were X-rays, or some new kind of radiation. One of Becquerel's experiments had been to observe the effect of the uranium rays on an instrument known as an *electroscope*. Two thin strips of gold leaf, placed in contact with each other, are allowed to hang from a metallic clip which is placed within a glass container. Electrical contact is maintained from the metallic clip to a conductive ball or disk outside the container. (See drawing.) When an electrically charged object is put in contact with the ball, the charge is communicated to the gold leaf, and the two strips, being of the same charge, repel each other, rising into the air in opposite directions like spreading wings.

Over time, the charge dissipates, and the strips fall back to the vertical position. When the air in the surrounding atmosphere is more conductive, the charge will dissipate faster, causing the strips of gold leaf to droop sooner. Roentgen had already shown that his X-rays had the power to discharge the electroscope, causing the gold leaf to droop. When Becquerel brought a uranium sample near to a charged electroscope, it too caused a discharge. Was the effect caused by X-rays, somehow produced within the uranium ore, or was it by some other power?

Two New Elements

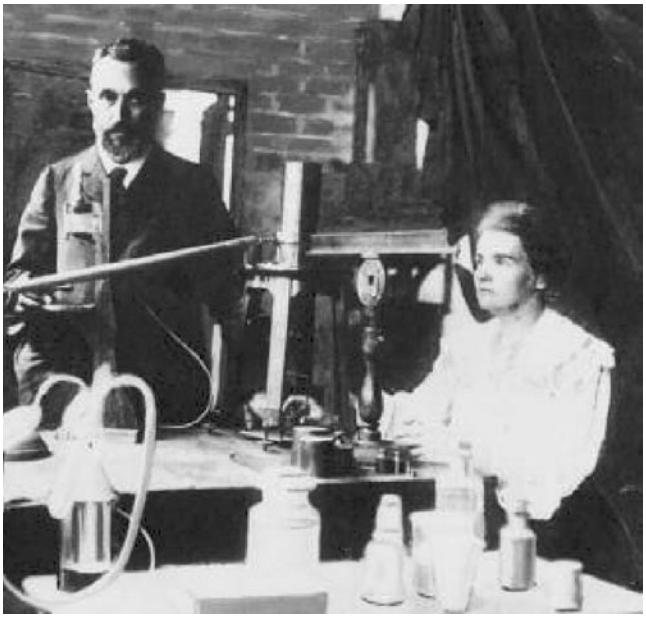
It was going to take further investigation to determine the nature of the new Becquerel rays. By the Fall of 1896, another investigator, a young woman by the name of Marie Sklodowska Curie, had entered the search. Recently married to the physicist Pierre Curie, theirs was a marriage of true minds, built on an intellectual and scientific collaboration conjoined with the deepest love. She conceived the idea of applying a device, which her husband and his brother had invented 15 years earlier for another purpose, to the investigation of the *Becquerel rays*. The *electroscope* is capable only of a rough measurement of the strength of charge by the degree of deflection of the gold leaves. The ability of different substances to discharge the electroscope, known as the *ionizing power*, could be roughly estimated by the length of time it took for a sample held at a certain distance to accomplish this.

The Curie electrometer, invented by Pierre Curie and his brother, Jacques, used a quartz electrobalance to detect extremely small changes in electrical currents produced when rays from uranium ionize the surrounding air.

A sample of pitchblende, the ore containing uranium that Marie and Pierre Curie obtained from Bohemia. The Curies devised a way to separate out the uranium from the mass of pitchblende and were astonished to find that the remaining ore exhibited more radioactivity than did the pure uranium.

Cogema

Uranium oxide (known as yellowcake), is the raw material processed into nuclear fuel. It is converted to a gas and then "enriched" through gaseous diffusion or centrifuge processing to concentrate the fissionable uranium isotope, U-235. The non-fissionable isotope, U-238, constitutes all but 0.7 percent of natural uranium. Reactor fuel generally requires about 3-5 percent of U-235.



Pierre and Marie Curie in the unheated shed in the courtyard of the School of Physics and Chemistry, which they used as a laboratory to process the pitchblende ore. On the table is Pierre's quartz piezoelectrometer.

The inspiring story of the Curies' work on radioactivity can be found in "Marie Sklodowska Curie: The Woman Who Opened The Nuclear Age," by Denise Ham, 21st Century Science & Technology, *Winter 2002-2003. http://www.21stcenturysciencetech.com/articles/ wint02-03/Marie_Curie.pdf*

However, with the new device known as the *Curie electrometer*, the measurement of the ionizing power of any material could be precisely measured.

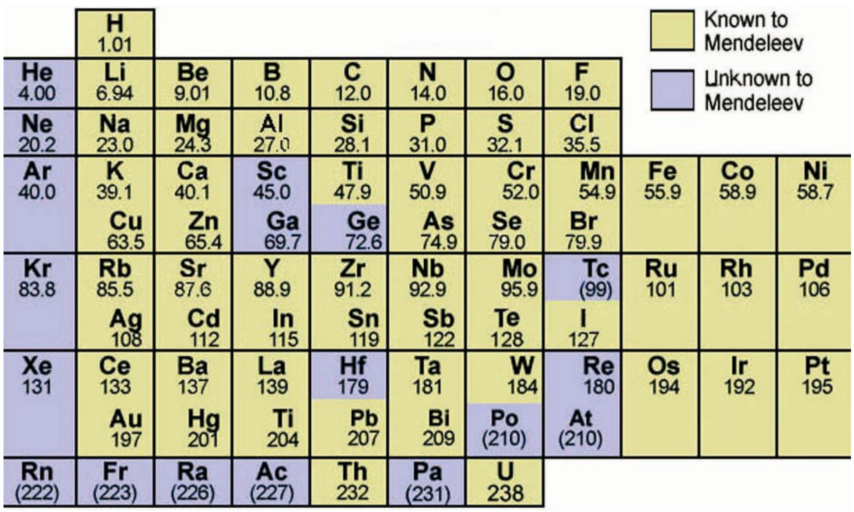
By now the two Curies were partners in the quest to understand the curious powers of uranium. Pierre and Marie Curie soon began experiments with samples of uranium ore (pitchblende), most of them obtained from mines in Bohemia, then part of Austria. While still supposing that the effect might be due to the "Radiation X" identified by Roentgen, they soon came upon a crucial anomaly. Being accomplished chemists, the Curies tried experiments to remove the uranium from the pitchblende ore. By subjecting samples of the ore to acid, they could cause much of the uranium to precipitate out as a salt. When samples of the ore with most of the uranium removed were placed in the measuring device, a remarkable thing happened. They showed more ionizing power than the ore samples containing uranium.

The Curies then isolated pure uranium metal from the ore and compared its activity. The ore samples with the uranium removed showed an ionizing power three to four times greater than the pure uranium. They became convinced that a new element, many times more active than uranium, must be present in the ore. To find it, they began a process of chemical separation. Aided by the Curie electrometer, they were able to separate out the portions of the ore which showed greatest ionizing power. By June 1898, they had separated a substance with 300 times the activity of uranium. They supposed they had found a new element which they named polonium, after Marie Sklodowska Curie's embattled Poland. There was still some doubt as to whether it was a new element. It had not been isolated yet, but always appeared together with the already known element bismuth. But continued work finally showed the polonium to be distinct.

By December of 1898, the Curies had separated another product from the Bohemian ores, which also showed strong ionizing power. This one appeared in combination with the known element barium, and behaved chemically much like barium. Again, it had not yet been isolated in a pure form, and there was uncertainty as to whether it was a distinct element. Spectral analysis showed mostly the spectral lines characteristic of barium, but their friend, the skilled spectroscopist Eugène-Anatole Demarçay, had detected a very faint indication of another line not seen before.[5] On the basis of the chemical and spectral evidence, and its strong ionizing power, the Curies supposed it to be a new element, which fit in the empty space in the second column (Group II) of Mendeleyev's periodic table, below barium. They named it radium.

The Curies now dedicated themselves to obtaining pure samples of these new elements. It took four years of dedicated la-

5. Upon heating, each chemical element shows a characteristic color. Most people have seen the green color produced in a flame by a copper-bottomed pot. If the light produced when the element is heated be passed through a prism, it is dispersed into a band of color, just as sunlight passing through a prism forms a rainbow. Within the colorful band, known as a spectrum, certain sharp and diffuse lines appear. Bunsen and Kirchoff began work in 1858 which established a means for identifying each element by its flame spectrum.



Mendeleyev had devised the Periodic Table arranging the elements known at that time into columns that sorted them by atomic weight into families with similar attributes. Later, new elements were discovered that fit into the "holes" left in Mendeleyev's original design. The Curies were able to place their newly discovered elements into Mendeleyev's Table.

bor, working in an unheated shed behind the University of Paris, to isolate the first sample of pure radium. Polonium proved even more difficult. While they were engaged in this effort, research was under way in other locations, sparked by the earlier papers of Becquerel, and by the Curies' announcement of two new elements with such extraordinary powers.

Some time in the course of these discoveries, it was felt that a new name ought to be given for the unusual ionizing power of these new elements. Marie Curie proposed the term *radioactivity*.

2. Transmutation and Radioactive Isotopes

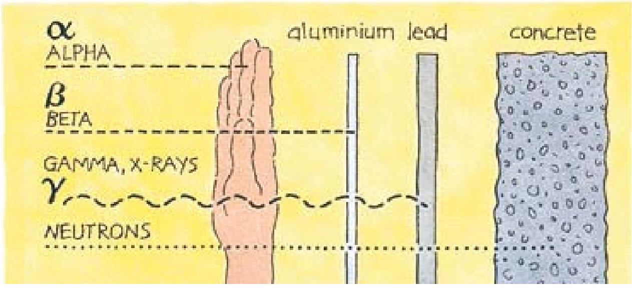
Alpha, Beta, and Gamma Rays

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*).



World Nuclear Association

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.

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

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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 Planck ($E = h\nu$) and Einstein ($E = mc^2$), 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.

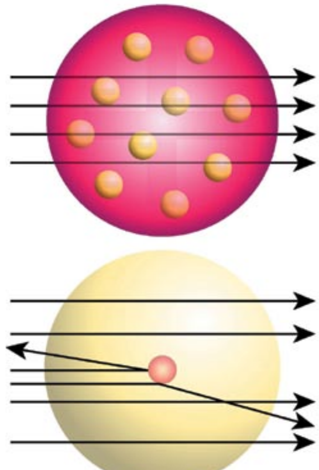
The number of wave crests passing a particular point in a second is known as the *frequency,* and thus is inversely proportional to the wavelength. It also turns out that at this higher frequency, or shorter wavelength, light does more work in the course of a second than that of lower frequency, and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

Not only light, but heat, radio waves, and high-energy radiation, such as X-rays 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.

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).

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, X-rays 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 powerful 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.

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



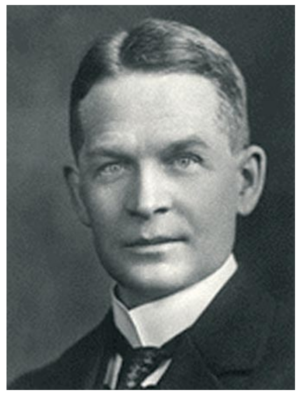
In Rutherford's experiments, alpha particles from a radioactive substance were aimed at a very thin layer of gold foil. Most of the positively charged particles passed through the foil (top), but about 1 in 8,000 particles was deflected backward at an angle greater than 90 degrees (bottom). This indicated 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.

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.

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. Eventually it was realized that it was usually not the whole sample of the element, but certain of its isotopic parts, that were changing. In undergoing this *transmutation*, a sample of a certain isotope would emit a characteristic radiation, the alpha, beta, or gamma ray. (A fourth mode of radiation, the positive electron or *positron*, was discovered later.)

By about 1910, the sequence of spontaneous changes of the elements from uranium to lead, known as *radioactive decay*, had been well mapped out by the careful chemical analysis of Soddy and other investigators. It turned out that there were, not one, but three different paths, known as *decay chains*, that the elements could follow. A fourth decay chain, not found in nature, was discovered several decades later, after the discovery of nuclear fission, and the creation of the first artificial elements. Then it was seen that the four decay chains could be categorized, like the arithmetic numbers, into series of 4n, 4n+1, 4n+2, and 4n+3. Further, the mass number of all the isotopes belonging to a particular decay chain must possess the same arithmetic residue modulus 4.[9]



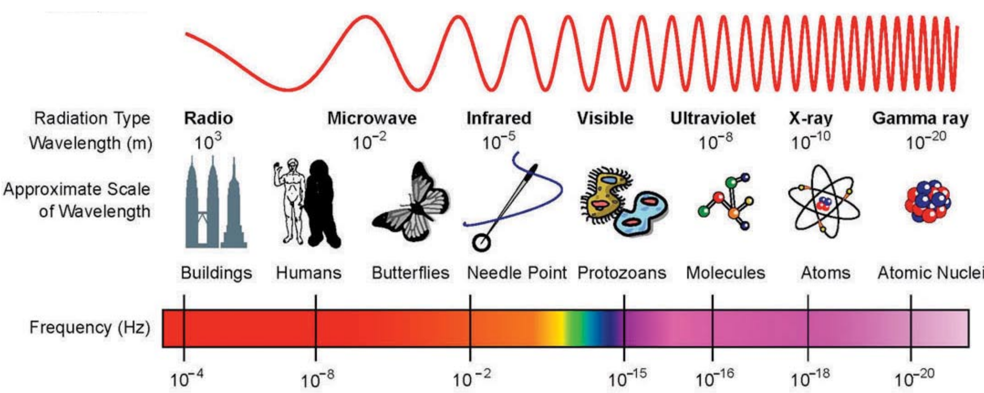
Chemist Frederick Soddy, who worked with Rutherford, determined that radioactive thorium decayed into radium, a process he named transmutation. He and others later mapped out the types of spontaneous transmutation that occurred in the periodic table.

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. Of the four principal types of radiation emitted in nuclear decay, only one, the alpha particle, significantly changes the mass of the substance. The *alpha particle* weighs approximately four times the mass of the proton, which is nearly the unit of mass number. (Recall that studies had shown the cathode ray particles [electrons or beta rays] had only 1/1,836 the mass of the proton, and that the gamma ray was virtually massless.) Thus, whatever the mass number of the initial isotope in the decay chain (U-238, for example), the final one (Pb-206, in this case) and all of the intermediate ones would have a mass number of the form 4n+2. The deeper significance of this correspondence is perhaps yet to be discovered.

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



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.

The amount of radiation emitted is always proportional to the amount of mass of the radioactive substance which is transmuted. The rate of disappearance of the original mass is measured by its *half-life*, which will be different for each isotope. The *half-life* is the amount of time it takes for one half of the mass of the radioactive substance to transmute into its new form. Whether the sample is large or small, the time it takes for half of it to disappear is always the same, but the amount that has transmuted (and thus the amount of radiation emitted) is proportional to the size of the sample. Radioactive decay is thus describable mathematically by an exponential function, like the compound interest on a mortgage or car loan, but in reverse. (Some might find an analogy to the present reverse-leveraged collapse of our financial system. The difference is that the products of radioactive decay can be very useful.)

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.[10] By analyzing how the positively charged 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 number) by 2 units.

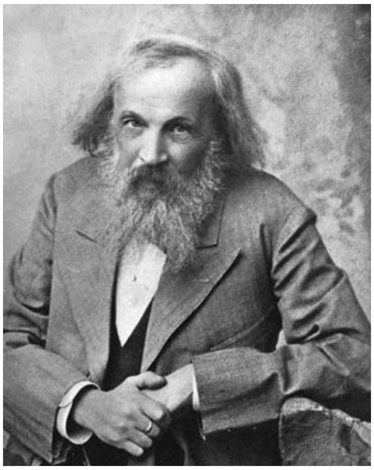
Alpha emission is typical of the heavier elements. Another common form of radiation, the beta decay, can occur anywhere on the periodic table. The emission of a beta particle (electron), being only about 1/2,000 of the mass of a proton, scarcely changes the atomic mass of the substance. However, it causes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

What Is an Isotope?

An isotope is a variation on an element, so named because all the isotopes of an element occupy the same position (*iso + topos*) within the periodic table. When Dmitri Mendeleyev first

10. 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.



Dmitri Mendeleyev's work on the periodic table in the 1860s, and his prediction of future elements to be found, were an invaluable guide for later scientists.

deduced the periodic table of elements, the existence of isotopes was not known. The isotopes of a given element behave almost the same chemically, and thus are very difficult to detect by chemical means. The discovery of radioactivity, and studies of the radioactive decay process at the beginning of the 20th Century, led to the suspicion that elements may exist in different isotopic forms. However, the first proof of the existence of isotopes was not obtained until the time of World War I.[11]

Now it is known that, of the 92 elements in the periodic table, the majority have at least one other naturally occurring isotopic variant, and the number of natural isotopes reaches 10 for the element tin.

An isotope may or may not be radioactive. However, by exposure to radiation, artificial isotopes of every element can now be created. As all species of a given element have the same number of protons, the isotopes differ by the number of neutrons found within their nucleus. The number appearing after the hyphen in an isotope's name (e.g., carbon-14) refers to the combined number of protons and neutrons in the isotope's nucleus.

To understand the meaning and use of isotopes, let us look more deeply into carbon-14. Most elements naturally appear in various isotopic forms. Carbon, for example, is found on Earth in two stable forms, carbon-12 (98.9 percent) and carbon-13 (1.1 percent), and the radioactive carbon-14 (.0000000001 percent). The percentage distribution of the different isotopes of an element, which is almost the same anywhere on Earth that it is found, is known as its natural abundance.

A common form of carbon—anthracite coal.

Carbon-14 is thus a radioactive isotope of the common element carbon, often called the building block of life, because the molecules in every living thing must contain it. The isotope was discovered in 1940 by two chemists at the Berkeley Radiation Laboratory, Martin Kamen and Sam Ruben, who had been working for a decade to discover the path of carbon in photosynthesis. In 1942, they passed on the samples of carbon-14 which they had isolated to a young chemist, Andrew Benson, who used it in studies that first unraveled the secrets of the carbon pathway.[12]

Carbon-14 is produced in the upper layers of the atmosphere, when neutrons arising from cosmic ray collisions transmute atmospheric nitrogen. The nitrogen absorbs a neutron, yielding carbon-14 plus a proton (hydrogen nucleus). This is expressed by the formula

$$^{1}n + {}^{14}N = {}^{14}C + {}^{1}H$$

The carbon-14 then mixes in the atmosphere, and reacts with

USGS

The radioactive carbon-14 isotope is found in every living thing, and thus is often called a building block of life. Produced in the upper atmosphere layers, carbon-14 reacts with oxygen to produce carbon dioxide. About 1 in every trillion carbon dioxide molecules is formed of radioactive carbon-14. Although this is a small proportion of the total, its prevalence results in the occurrence of about 3,000 radioactive disintegrations per second of carbon-14 in the average human body.

Carbon-14's ubiquitousness and its long half-life enable it to be used by scientists to date artifacts.

Here, carbon samples are converted to acetylene gas by combustion in a vacuum line. The acetylene gas is then analyzed in a mass spectrometer to determine its carbon isotopic composition. The proportion of carbon-14 to other isotopes is used for dating objects.

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11. The detection of two isotopes of neon in positive rays of the gas was reported in 1913 by J.J. Thomson of the Cavendish Laboratory in England, but only conclusively demonstrated after 1919 in Francis Aston's *mass spectrograph*. Evidence for the existence of two isotopes of chlorine was achieved by W.D. Harkins and collaborators at the University of Chicago between 1915 and 1920, using separation by diffusion of the gas through various membranes. Harkins was thus the first to obtain chemically significant samples of isotopically enriched species.

12. After the war, Kamen was falsely accused of leaking atomic secrets to the Russians. The charge arose after he helped an official of the Russian consulate in San Francisco in obtaining experimental leukemia treatment for a friend. Kamen, an amateur violist, had met the Russian official in 1944 at a party given by his friend Isaac Stern, the world-famous violinist whom Kamen sometimes accompanied. Kamen later won a libel suit against the *Chicago Tribune* for naming him as a suspected spy. But for the false accusation, the groundbreaking discovery would most probably have led to greater fame and a Nobel prize.

Lawrence Berkeley Laboratory

Martin Kamen (left) and Sam Ruben (right), working at the Radiation Laboratory of what is now Lawrence Berkeley National Laboratory, discovered carbon-14 in 1940.

oxygen to produce carbon dioxide. About 1 in every trillion carbon dioxide molecules is formed of radioactive carbon-14. Although this is a small proportion of the total, the prevalence of carbon derived from the atmosphere in all living molecules leads to the result that about 3,000 radioactive disintegrations per second of carbon-14 occur in the average human body. The carbon-14 decays within your body by emitting a beta particle (electron), the same form of radiation produced by many of the reactions in a nuclear reactor. As a result of the decay, the carbon-14 is transmuted back to nitrogen.

The rate of decay of a radioactive isotope can be assessed by knowing the *half-life*. That is the time that it will take half of the substance to be transmuted into what is called its *daughter product*. The shorter the half-life, the more radiation is being emitted. Carbon-14 has a half-life of 5,730 years. Potassium-40, which is responsible for even more radioactive disintegrations within our body (averaging about 4,440 per second), has a half-life of 1.25 billion years. The potassium-40 produces more radioactivity than the carbon-14, because there is much more of it in the body. Radioactive potassium-40 makes up more than 1 part in 10,000 of naturally occurring potassium, compared to 1 part in 1 trillion for carbon-14. So, although the total mass of carbon in the body is about 100 times greater than the mass of potassium, the mass of radioactive potassium is almost 10 million times greater than that of radioactive carbon.

Natural Sources of Radiation

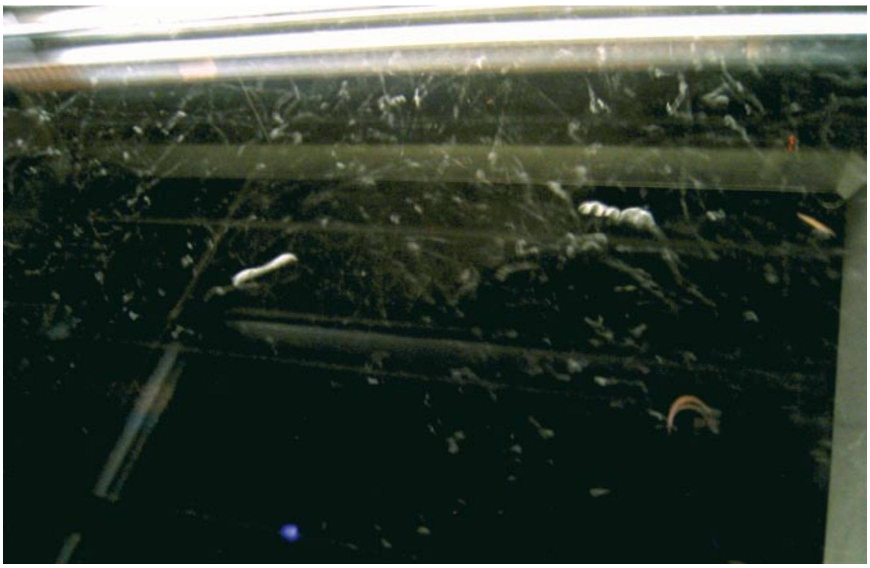
There are many other natural sources of radiation which reach us all the time. Some of the principal ones are shown in the accompanying table. These naturally occurring radioactive isotopes enter our bodies either through our food and water, or from the atmosphere. A certain amount of body radiation 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 by-products 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.

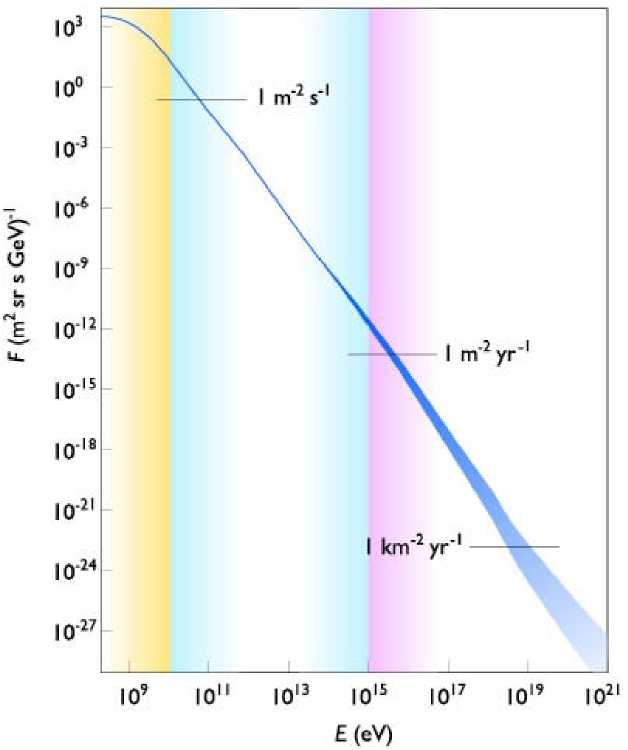
A simplified cloud chamber is easy to build, often forming the subject of a high school science project. A closed container, like a small aquarium tank, and some dry ice are the principal materials required. When the proper conditions are created inside the tank, the collision of these high-speed protons 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.

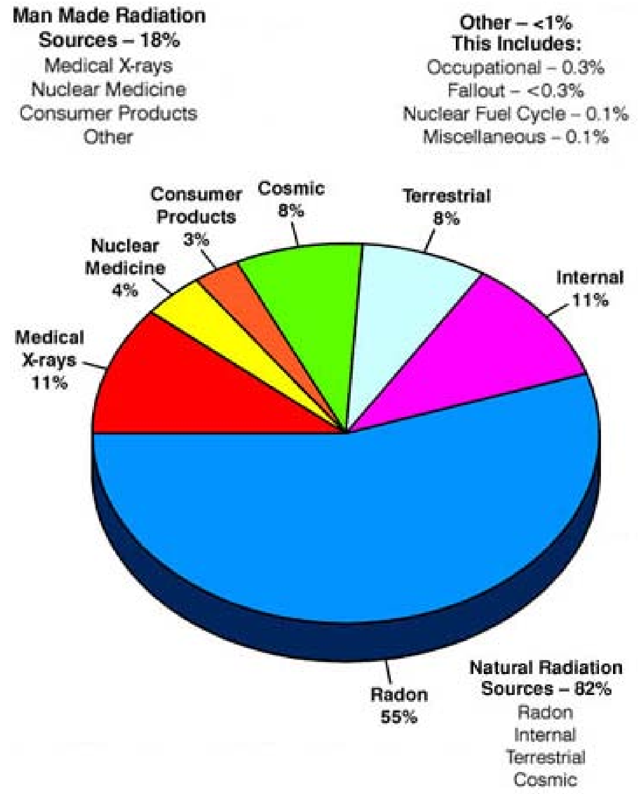
Some locations on Earth are much more radioactive than others. In some parts of the United States it is possible to obtain



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.



All natural cosmic rays are constantly colliding with atoms in our atmosphere, transforming elements and creating radioactive by-products. Depicted here is the flux of cosmic ray particles as a function of their energy. The flux for the lowest energies (yellow zone) are mainly attributed to solar cosmic rays, intermediate energies (blue) to galactic cosmic rays, and highest energies (purple) to extragalactic cosmic rays.



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.

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 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.

3. So, Why Are You Afraid?

The principal cover story for promoting radiation fears is a piece of pseudoscience known as the Linear No-Threshold (LNT) hypothesis. To call it a hypothesis may be gross exaggeration. According to the Linear No-Threshold argument, unlike any other known biological process, the response of the body to radiation is directly proportional to dose. Because radiation in large doses is dangerous or deadly, the LNT argument is simply that radiation in any dose is therefore dangerous or deadly. Thus, if a certain exposure to radiation produces 1 cancer in a population of 100 people, then, according to the Linear No-Threshold view, one-tenth that amount of radiation will produce 1 cancer in a population of 1,000.

By the same type of reasoning one could argue that, if 25 cups of water forced down the throat will generally cause a person to die of drowning, then drinking 1 cup of water would produce a 1 in 25 chance of drowning. At root, the LNT argument is that simple—and ridiculous. Yet LNT is the basis on which decisions are made as to what levels of radiation are safe, or what levels might even be beneficial (*none,* according to the LNT proponents).

The data for estimating radiation cancer risks come from long-term studies of survivors of the atomic bombings in Hiroshima and Nagasaki, as well as studies of smaller human populations accidentally exposed to high doses of radiation. After plotting the statistics available from these cases of high exposure, a straight line is drawn on the graph back toward zero. The assumption is thus made—not deduced from the data, but imposed on it—that any lesser dosage will produce the same deadly results in a proportionally smaller number of people. The massive evidence that radiation dosage below a certain threshold is beneficial, not harmful, is ignored, as are the experimental data showing that some level of radiation may be necessary for life to exist at all.

Naturally, LNT has not gone unchallenged. Every review of the issue produces opposition from specialists in the field who raise cogent arguments but are ultimately overridden. A hypothesis which makes no sense is sustained by the popular fear of radiation.

Radiation Hormesis

A great number of human and animal studies show that not only is radiation at low levels not dangerous, but it is actually beneficial. Studies of large populations exposed to higher than average levels of radiation show increased longevity and lower mortality from cancers.

In the May 1961 *Journal of the American Medical Association* (*JAMA*), Dr. Hugh Henry, then at Oak Ridge National Laboratory, reported on all low-dose studies, saying that the results show consistent life-lengthening. He reported on early animal studies that showed hormetic (beneficial) effects from uranium and plutonium injections, feeding of uranium compounds, and exposure to external gamma and X-radiation. Henry concluded:

> The preponderance of data better supports the hypothesis that low chronic exposures result in an increased longevity than it supports the opposite hypothesis of decreased longevity. . . . Increased vitality at low exposures to materials that are toxic at high exposures is a well-recognized phenomenon.[13]

In a 1990 study of nuclear medicine, Marshall Brucer, M.D., reported:

> During the 1960s and 1970s about 40 articles per year described hormesis. In 1963, the AEC [Atomic Energy Commission] repeatedly confirmed lower mortality in guinea pigs, rats, and mice irradiated at low dose. In 1964, the cows exposed to about 150 rads after the Trinity A-bomb in 1946 were quietly euthanized because of extreme old age. . . . No experimental evidence of damage at low doses existed; self-serving extrapolations from high dose-data dominated health physics.[14]

13. H.F. Henry, 1961. "Is All Nuclear Radiation Harmful?," *J. Am. Med. Assoc.*, Vol. 176, p. 671.

There is voluminous peer-reviewed scientific literature documenting the evidence for radiation hormesis. Dr. T.D. Luckey, Professor Emeritus of the University of Missouri School of Medicine, compiled more than 2,000 references.[15] Yet, the regulatory agencies ignore this evidence.

One of the largest and most thorough studies of the effects of low-level radiation was the Nuclear Shipyard Workers Study, funded by the Department of Energy, but never published. As reported by James Muckerheide, State Nuclear Engineer for the Commonwealth of Massachusetts:

> This 10-year, $10-million study of 39,004 nuclear workers, carefully matched with 33,352 non-nuclear workers, was completed in 1987.[16] After pressure on the DOE, which had chosen not to publish the data and conclusions, the Department finally, in 1991, issued a contractor's report on the study, with a two-page press release. . . . In the summary, the Nuclear Shipyard Workers Study reports that the high-dose mortality rate of the nuclear workers was 0.76 that of the non-nuclear workers in the control group. Of special significance is the fact that the summary report did not include "all cancer" mortality, which is a most common factor, and of most interest in any such study. However, Myron Pollycove, M.D., of the Nuclear Regulatory Commission, documented that the "all cancer" mortality in the detailed tables is also statistically significantly lower among nuclear workers than among the non-nuclear workers.[17]

The Radon Follies

The Linear No-Threshold Hypothesis was put to an extensive statistical test beginning in the 1980s by Dr. Bernard Cohen of the University of Pittsburgh. Cohen carried out a massive data

14. M. Brucer, 1990. *A Chronology of Nuclear Medicine* (St. Louis: Heritage Publications).

15. T.D. Luckey, 1990. *Hormesis with Ionizing Radiation* (Boca Raton, Fla.: CRC Press). Also in Japanese (Tokyo: Soft Science, Inc., 1980). In addition, see T.D. Luckey, 1995. "Test of the Linear-No Threshold Theory of Radiation Carcinogenesis for Inhaled Radon Decay Products," *Health Phys.,* Vol. 68, pp. 157-174.

16. J.R. Cameron, 1992. "The Good News about Low Level Radiation Exposure: Health Effects of Low Level Radiation in Shipyard Workers," *Health Phys. Soc. Newsletter*, Vol. 20, p. 9.

17. James Muckerheide, "It's Time to Tell the Truth About the Health Benefits of Low-Dose Radiation," *21st Century Science & Technology* (Summer 2000) www.21stcenturysciencetech.com/articles/nuclear.html

Muckerheide continued in his report of Summer 2000: "After long negotiations, Dr. Genevieve Matanoski, Principal Investigator for the shipyard worker study, received another substantial contract from DOE in 1994, and retired as Head of Epidemiology at Johns Hopkins University. Now, more than 5 years later (and about 12 years since the completion of the study), no papers have been published. There is no report to Congress, the shipyard workers, radiation protection agencies, or to the public. There is substantial concern about the integrity of the data, which have been kept under wraps. Further, this most definitive nuclear workers study was not included in a study of "all" U.S., U.K., and Canadian nuclear workers, contracted by DOE with the International Association for Research on Cancer (IARC)."

collection effort, analyzing radon levels in 272,000 homes in the most populous U.S. counties and comparing them to lung cancer incidence.

The basis of the great household radon scare was (and remains) that high levels of this radioactive gas, released during the natural decay of uranium in the ground, would contribute to increased risk of lung cancer. Cohen's results showed the opposite: the higher the radon levels, the lower the incidence of lung cancer![18]

Dr. Graham Colditz of Harvard University, a world renowned epidemiologist, contributed to an interim analysis of the same data by counties. He confirmed the validity of the epidemiological analysis of these data.[19]

Dr. Kenneth Bogen at Lawrence Livermore National Laboratory independently compared 1950-1954 lung cancer mortality for women of ages 40 to 80 and 60 to 80 (who had smoked little), by county, with EPA county environmental radon data. Bogen also confirmed the inverse correlation between lung cancer and radon.[20]

Health Benefits of Radiation

Proponents of the Linear No-Threshold theory argue from a very simplistic model, that every particle or quantum of ionizing radiation (e.g., alpha, beta, gamma, or X-ray) is likely to damage the DNA within the cell, producing mutations which lead to cancer. As there are about 1 billion radioactive decays every day within the average adult body, it is hard to imagine why we are not all sick from cancer from a very young age.

However, knowledge gained in recent decades has shown that there is a natural process of DNA repair. It turns out that radiation is not the principal cause of damage to the DNA. Body heat is. The mutations from unrepaired or misrepaired damage to the DNA caused by the natural metabolism outnumber those caused by natural radiation by 10-million fold.[21] Every time you exercise, digest your food, or just breathe, you are generating atoms or molecules with unpaired electrons (known as free radicals), active little creatures ardently in search of something to combine with by donating their free electrons. One of the things they will combine with are the molecular components of the DNA known as nucleotides. The marriage (known as *oxidation*) causes a change of the DNA chain, a mutation, which sometimes cannot be properly repaired.

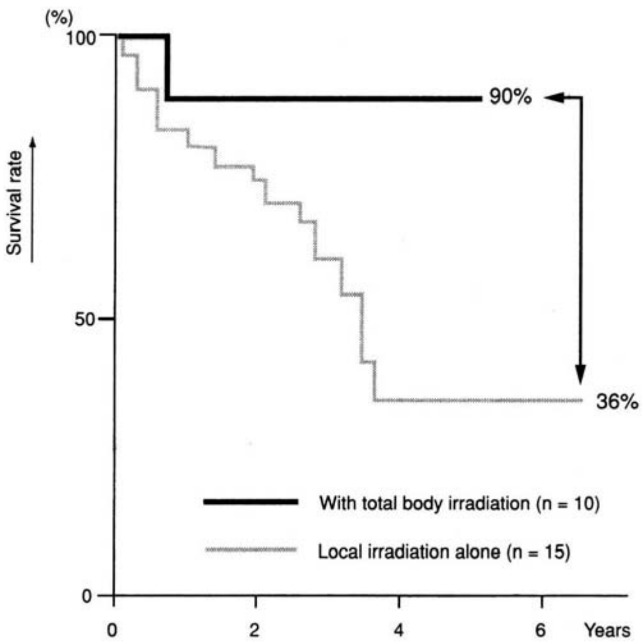
Normal cell division and DNA replication also contribute somewhat to the number of mutations. If you want to stop this process, just stop eating, breathing, and exercising (in whatever order you choose).

Fortunately it isn't necessary to take such extreme measures. A great variety of molecules, known as anti-oxidants, are always present to prevent the damage. These may be vitamins, enzymes, or other natural substances. Some enzymes are present to aid in continually repairing damaged nucleotides in the DNA, and a process of removal of the irreparably damaged chains is also at work.

Studies of specific immune responses in animals suggest that low-dose radiation helps

Dr. Sadao Hattori, a leader in Japan's research into low-dose radiation.

Survival Rates of Non-Hodgkin's Lymphoma Patients With and Without Total Body Irradiation



Source: Dr. K. Sakamoto, Tohoku University

Lymphoma patients who were given a total body irradiation of 10 centigray by X-ray, three times a week, in addition to the standard local high-dose irradiation treatment for this cancer, had a 90% six-year survival rate as of 1997. The control group, which received only the local high-dose treatment, had a 36% six-year survival rate.

The benefits of this treatment are prevented from being used in the United States and elsewhere in order to protect the myth that radiation is dangerous at any dose.

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18. B.L. Cohen, 1987. "Tests of the Linear, No-Threshold Dose-Response Relationship for High-Level Radiation," *Health Phys.*, Vol. 52, p. 629. See also: B.L. Cohen, 1989. "Expected Indoor ^{222}Rn Levels in Counties with Very High and Very Low Lung Cancer Rates," *Health Phys.*, Vol. 57, p. 897; and B.L. Cohen, 1995, "Test of the Linear-No Threshold Theory of Radiation Carcinogenesis for Inhaled Radon Decay Products," *Health Phys.*, Vol. 68, pp. 157-174.

19. B.L. Cohen, and G.A. Colditz, 1994. "Tests of the Linear-No Threshold Theory for Lung Cancer Induced by Exposure to Radon," *Environmental Res.*, Vol. 64, p. 65.

20. K. Bogen, 1996. "A Cytodynamic Two-Stage Model That Predicts Radon Hormesis (Decreased, then Increased Lung-Cancer Risk vs. Exposure)" (Livermore, Calif.: Lawrence Livermore National Laboratory), Preprint UCRL-JC-123219 (40 pp. with 150 references).

21. D. Billen, 1990. "Spontaneous DNA Damage and Its Significance for the 'Negligible Dose' Controversy in Radiation Protection," *Radiation Research*, Vol. 124, pp. 242-245.

Even high-level radiation adds only a few more mutations to the millions that are occurring each day from natural metabolism. Radiation causes more double breaks per event than normal metabolism, but even given this difference, the mutations caused by metabolism are 10-million fold greater.

to stimulate the immune system. Positive results in cancer treatment using low-dose radiation have been reported by Dr. Sadao Hattori of Japan from the work of Drs. Sakamoto, Miyamoto, Takai, and others. Work in Japan, and in the United States, has shown that 10 to 15 cGy full-body or half-body X-ray doses, delivered in 1 to 2 minutes, several days apart, stimulate the body's defense mechanisms. (The cGy, or *centigray*, is the modern unit used to measure the estimated absorbed dose of radiation, equal to 1 *rad* in the older units.)

A long-term clinical trial of non-Hodgkin's lymphoma patients has confirmed that the group that received low-dose radiation substantially outlived the control group at 5 years and 10 years.[22]

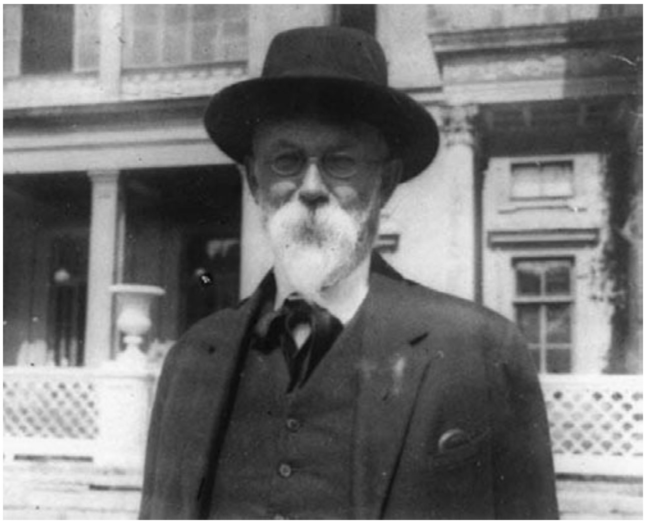
No Life Without Radiation

As radiation is a natural part of our environment—and life has never existed without it—might it be possible that the potassium-40, carbon-14, and other radioactive isotopes found within our bodies are performing a necessary function? An important question, but one that has never been permitted to be freely explored. The hysterical insistence on the Linear No-Threshold hypothesis has actually shut off productive lines of research in this direction. Yet, all the evidence points to the fact that there is no life without radiation.

In the 1950s, samples of natural potassium were processed at Oak Ridge National Laboratory to separate out the radioactive potassium in order to conduct radiobiology experiments. Animals were than fed a diet containing the processed potassium which lacked the radioactive component. The animals did poorly, but they recovered when the extracted potassium-40 or natural potassium was added back to the diet.

Forty years later, Charles Willis, who had participated in those experiments, spoke of them before a March 1996 meeting of the U.S. Nuclear Regulatory Commission of which he was a member:

> . . . [I]t's clear to many of us that we are not seeing the predicted ill effects at low doses, as has been pointed out to you. I personally came to this hormesis observation fairly late in the game. It wasn't until 1958 that I was working with the laboratory [Oak Ridge National Laboratory] situation where we were doing experiments with below background levels of radiation, taking the potassium-40 out and seeing what the effects would be on the cellular level, when we saw that the cells looked good but they didn't function. So we couldn't publish the results, another ill effect of the paradigm about the linear hypothesis.[23]



Vladimir Ivanovich Vernadsky. The most crucial unanswered question of 20th Century science remains the proper understanding of the relationship of the biotic to the abiotic domain, as that question was first defined nearly a century ago by the Ukrainian-Russian Academician Vernadsky.

The Oak Ridge finding is consistent with a wide variety of experiments with organisms that were shielded from background radiation. For example, organisms grown on glass slides were repeatedly found to grow differently. It was eventually found that organisms grown on glass slides that contained lesser quantities of the naturally occurring radioactive element thorium were deficient.[24]

There are now indications that natural radiation may serve as a substitute for sunlight for deep sea and sub-surface organisms. For example, laboratory evidence indicates that gamma radiation can stimulate photosynthesis in algae denied natural light.[25]

Life is now thought to have appeared on our planet at least 3 billion years ago. At that time the radiation dose from ingested potassium would have been 6 to 7 times higher than present levels. Doses from the decay of uranium-238 would have been nearly twice present levels. This can be deduced from the known half-life of potassium-40 and uranium-238. Similar analysis of the periodic table shows that many other radioactive substances were also more abundant in the early Earth.[26]

The evidence is clear enough: Life has never existed without radiation, and probably cannot exist without it. Shall we run around like Chicken Little, in perpetual fear of natural phenomena, or shall we try to understand and master them? The decision is a very important one, as it touches on the distinction of

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22. Interview with Sadao Hattori, "Using Low-dose Radiation for Cancer Suppression and Revitalization," *21st Century Science & Technology,* Summer 1997. Also, the following references:

Y. Takai, 1990. "Direct Anti-Tumor Effect of Low Dose Total (or Half) Body Irradiation and Changes of the Functional Subset of Peripheral Blood Lymphocytes in Non-Hodgkin's Lymphoma Patients after TBI (HBI)," *J. Jpn. Soc. Ther. Radiol. Oncol.*, Vol. 3, pp. 9-18.

S. Hattori, 1997. "State of Research and Perspective on Adaptive Response to Low Doses of Ionizing Radiation in Japan," in *Low Doses of Ionizing Radiation: Biological Effects and Regulatory Control,* IAEA-TECDOC-976, IAEA-CN-67/126, pp. 402-405.

23. ACRS/ACNW, 1996. U.S. Nuclear Regulatory Commission, Advisory Committee on Reactor Safeguards and Advisory Committee on Nuclear Waste Joint Subcommittee: First Meeting, Rockville, Maryland, March 26, 1996.

24. *Op. cit.*, footnote 17.

25. T.D. Luckey, "Evidence for Gamma Ray Photosynthesis," *21st Century Science & Technology* (Fall-Winter 2008) http://www.21stcenturysciencetech.com/ Articlesn %202008/F-W_2008/Research_Communication.pdf

26. The existence of species of radioresistant bacteria, such as *D. radiourans,* discovered as a survivor in foods thought to have been sterilized by high doses of gamma radiation, may be leftovers of an earlier epoch of high radiation.

www.thermaltours.hu

The water in this thermal bath at Miskolctapolca, Hungary, contains calcium, magnesium-hydrogen-carbonic, iodine, bromide, and radon (which provides the heat). Since the Middle Ages, people have come to this radioactive bath to treat health problems.

Harper's magazine, 1878

For 200 years, people have visited Hot Springs, Arkansas, to bathe in the therapeutic waters from its radon/radium thermal springs. The Hot Springs Reservation was created by Congress in 1832, and the government provided for free baths until the 1950s. Depicted here is the public bathouse.

man from the beast. The application of nuclear power to human need, is but the most obvious of the benefits which the discovery of atomic and nuclear science has bequeathed mankind. Beyond the promise of nuclear power, for lifting the presently immiserated majority of humankind out of a life of perpetual poverty, lies the promise of future discovery.

The most crucial unanswered question of 20th-Century science remains the proper understanding of the relationship of the biotic to the abiotic domain, as that question was first defined nearly a century ago by the Ukrainian-Russian Academician Vladimir Ivanovich Vernadsky.[27] One of the crucial and still insufficiently explored paths to understanding involves the study of the fractionation of isotopes, not necessarily radioactive, by living processes.

Since the mass spectroscopic studies of American spectroscopist A.K. Brewer in the 1930s, which suggested a fractionation of the potassium isotopes in species of kelp, this subject has been a topic of controversy among biologists and physical chemists.[28] Despite attempts to disprove Brewer's original work with more advanced techniques of mass spectroscopy, more recent evidence continues to confirm the existence of significant isotopic fractionation in living processes. Among the most conclusive are the studies carried out at the Swiss Federal Institute of Technology, showing a high degree of enrichment of the lighter isotopes of iron in the human blood, as compared to non-biological samples.[29] Variations as high as 5 percent in the ratios of deuterium to ordinary hydrogen found among different fractions of water in the leaves of ivy and sunflower plants are also highly suggestive.[30] Similarly, the evidence for calcium isotope fractionation in bone and shell as compared to the dietary sources.[31]

Whether or not the fractionation can ultimately be explained as a result of a physical chemical process, the question remains, in what way is the living organism making use of the isotopic variation? What might careful observations of such isotopic shifts teach us about that scientifically crucial distinction among the three domains of the non-living, living, and noëtic, as first clearly enunciated for modern science by Academician V.I. Vernadsky? What fundamental distinction between the living and non-living domains demands a shift in the abundance distribution of the isotopes from that observed in the abiotic domain, and what insight into the still unresolved questions of atomic science might be gained from knowing it?

Herein lies the importance of overcoming the fear of radiation.

Laurence Hecht is editor-in-chief of 21st Century. *This article was completed on March 11, 2009, and a version of it appeared in the* Executive Intelligence Review, *May 29, 2009.*

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27. See for example: V.I. Vernadsky, "On the Fundamental Material-energetic Distinction between Living and Nonliving Natural Bodies of the Biosphere," English translation in *21st Century Science & Technology* (Winter 2000-2001), pp. 20-39. http://www.21stcenturysciencetech.com/ articles/ProblemsBiogeochemistry.pdf

28. Cf. Lasnitzki and Brewer, "A Study of the Isotopic Constitution of Potassium in Various Rat Tissues," *Biochem J.*, January 1941, Vol. 35, Nos. 1-2, pp. 144-151. http://www.pubmedcentral.nih.gov/articlerender. fcgi?artid=1265476

29. Walczyk and von Blanckenburg, 2005. "Deciphering the iron isotope message of the human body," *International Journal of Mass Spectrometry*, Vol. 242, pp. 117-134. http://www.sciencedirect.com/science?_ob=Article URL&_udi=B6VND-4FC3S60-1&_user=10&_rdoc=1&_fmt=&_ orig=search&_sort=d&view=c&_acct=C000050221&_ version=1&_urlVersion=0&_userid=10&md5= f6d1c44806d1b47e28801df759d9606b

30. Yakir, DeNiro, and Rundel, 1989. "Isotopic inhomogeneity of leaf water: evidence and implications for the use of isotopic signals transduced by plants," *Geochimica et Cosmochimica Acta*, Vol. 53, pp. 2769-2773.

31. Skulan and DePaolo, 1999. "Calcium isotope fractionation between soft and mineralized tissues as a monitor of calcium use in vertebrates," *PNAS*, Vol. 96, no. 24 (Nov. 23), pp. 13709-13713. http://www.pnas.org/content/96/24/13709. full.pdf+html