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NIKOLA TESLA AND MEDICINE: 160TH ANNIVERSARY OF THE BIRTH OF THE GENIUS WHO GAVE LIGHT TO THE WORLD - PART I

NIKOLA TESLA I MEDICINA – 160 GODINA OD ROĐENJA GENIJA KOJI JE SVETU PODARIO SVETLOST – I DEO

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Summary

Introduction. The interest in Nikola Tesla, a scientist, physicist, engineer and inventor, is constantly growing. In the millennia-long history of human civilization, it is almost impossible to find another person whose life and work has been under so much scrutiny of such a wide range of researchers, medical professionals included. Although Tesla was not primarily dedicated to biomedical research, his work significantly contributed to the development of radiology, and high frequency electrotherapy. This paper deals with the impact of Tesla's work on the development of a new medical branch - radiology. **Nikola Tesla and the Discovery of X-ray radiation.** Tesla pioneered the use of X-rays for medical purposes, practically laying the foundations of radiology. Namely, since 1887, Tesla periodically experimented with X-rays, at that time still unknown and unnamed, which he called "shadowgraphs". Moreover, at the end of 1894, he conducted extensive research focusing on X-rays, but unfortunately it was interrupted after the fire burning down his laboratory in 1895. In 1896 and 1897, Tesla published ten papers on the biologic effects of X-ray radiation. All his studies on X-rays were experimental. During 1896 and 1897, Tesla continued improving X-ray devices. Apart from this, Tesla was the first to point out the harmful effects of exposure to X-ray radiation on human body. **Conclusion.** Nikola Tesla was a visionary genius of the future. Tesla's pioneer steps, made more than a century ago in the domain of radiology, are still being used today.

Key words: History of Medicine; Famous Persons; Portraits as Topic; Radiology; X-Rays; Radiography; Radiation Effects

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Sažetak

Uvod. Interesovanje za Nikolu Teslu, naučnika, fizičara, inženjera i pronalazača, neprestano raste. Na milenijumskoj skali postojanja ljudske civilizacije, danas je gotovo nemoguće naći neku drugu ličnost čiji život i delo pobuđuju tako širok spektar zanimanja najrazličitijih istraživača, uključujući i pripadnike medicinske struke. Mada Tesla nije primarno bio posvećen biomedicinskim istraživanjima, njegov rad je značajno doprineo radiologiji i visokofrekventnoj elektroterapiji. U ovom članku je prikazan uticaj Teslinih istraživanja na razvoj radiologije kao nove grane u medicini. **Nikola Tesla i otkriće X-zračenja.** Tesla je prvi primenio X-zračenje u medicinske svrhe i time praktično postavio temelje radiologije. Naime, Tesla je povremeno eksperimentisao sa X-zračenjem još od 1887. godine. Ovo nepoznato zračenje on je nazvao „grafici senki“. Štaviše, Tesla je preduzeo opsežno istraživanje ove teme krajem 1894. godine koje je, nažalost, prekinuto zbog požara koji je izbio u njegovoj laboratoriji 1895. godine. Tesla je zatim 1896. i 1897. godine objavio deset radova u kojima je opisao biološke efekte X-zračenja. Svi Teslini radovi o X-zračenju bili su eksperimentalni. U toku 1896. i 1897. godine, Tesla je nastavio da unapređuje rad rendgenskih uređaja. Uz to, Nikola Tesla je prvi ukazao na postojanje štetnog dejstva X-zračenja na ljudski organizam. **Zaključak.** Nikola Tesla je bio nenadmašni vizionar budućnosti. Njegovi pionirski koraci, koje je pre više od jednog veka načinio u domenu radiologije, u današnje vreme takođe imaju svoju punu primenu.

Ključne reči: istorija medicine; poznate ličnosti; portreti; radiologija; x-zraci; radiografija; efekti radijacije

Introduction

The nature and the laws of nature lay hidden in the darkness.

And God said: "Let there be Tesla", and there was light.

Bernard A. Behrend

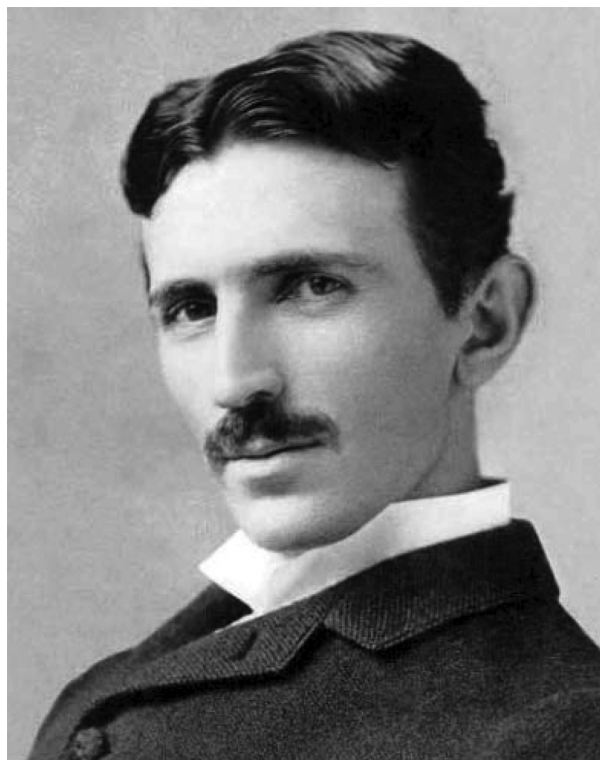


Figure 1. Nikola Tesla, 1894 - 1895

Source: The Nikola Tesla Museum, document no. MNT, VI/V, 10.

Slika 1. Nikola Tesla, 1894–1895.

Izvor: Muzej Nikole Tesle, dokument br. MNT, VI/V, 10.

It has been estimated that in the history of civilization, from 3.500 B. C. to the late 20th century, there were about 15,000 inventions in the field of natural sciences [1]. In the vast treasury of discoveries, about 200 inventions, so-called “lightning spirits of ingenious people”, are in the category of epochal inventions due to their significance [1–3]. The epochal inventions of Nikola Tesla include polyphase alternating current system of generators, undoubtedly the greatest invention in the history of electrical technology, and the discovery of high-frequency alternating current [1, 4–7].

Nikola Tesla, born in Smiljan on July 10, 1856, died in New York on January 7, 1943, (**Figure 1**) is a unique figure in the scientific history of civilization. His brilliant mind was proclaimed one of the seven wonders of the intellectual world [8]. According to *Life Magazine's* special issue in 1997, Tesla was among the 100 most famous people in the world [4]. A survey conducted by publicists promoting world science (*Explorer*, 2002), based on the applicability of inventions, Nikola Tesla took the first place [9]. In 2013, the *Wall Street Journal* presented Nikola Tesla as one of the greatest scientists ever [10]. Similarly, a national technology news website, the *GeekWire*, organized a Geek Madness Championship in 2013: Who is the greatest geek of all time? Among the world famous sci-

entists and inventors, Tesla was announced the greatest geek ever [4].

An unequalled genius, Tesla dedicated his life to inventions and science - the “noble, bright, enormous, faithful goddess that tolerates no liars” [11]. Nikola Tesla published 73 articles in various scientific journals [12, 13], devoted solely to the welfare of mankind. Unlike his countrymen, also world famous scientists, Milutin Milanković and Mihajlo Pupin, whose scientific papers are still cited, Nikola Tesla has been much less cited as an author [14]. The main reason lies in the fact that inventions were Tesla's greatest achievements, and they were described and incorporated into his patents, not in scientific papers [14–22]. Nikola Tesla was granted 116 basic patents, of which 109 in the United States of America, and 7 in the United Kingdom of Great Britain. In addition, he patented 181 analog or repeated patents in countries around the world, so that according to the latest research of the *Office of Intellectual Property* of the Republic of Serbia, the total number of registered Tesla's patents is 297. However, the exact number of applications and inventions he intended to patent is unknown [23].

Apart from diligent scientific and experimental laboratory work, Nikola Tesla also promoted his achievements, giving spectacular lectures in the most prestigious scientific institutions in the United States, United Kingdom and France [2, 4, 5, 23]. His outstanding results were recognized and rewarded. For decades of persistent, hard work in the field of technical and natural sciences, Nikola Tesla was awarded numerous honorary doctoral degrees from a number of universities including: *Columbia University*, 1894, *Vienna University of Technology* (K.K. *Technische Hochschule in Wien*), 1908, *Technical University of Belgrade*, 1926, *University of Zagreb*, 1926, *Czech Technical University in Prague* (*Česka Vysoká Učeni technické*), 1936, *Paris Sorbonne University* (*Université de Paris*), 1937, *University of Poitiers* (*Université de Poitiers*), 1937, *Polytechnic Institute in Graz* (*Technische und Montanistische Hochschule in Graz*), 1937, *University of Technology of Dr. Edvard Beneš in Brno* (*Vysoká škola Technická dr Edvard Beneš*), 1937, *Polytechnic School in Bucharest King Carol II* (*Scoala Politehnica Regele Carol II*), 1937, *University of Grenoble*, 1938, *Sofia University St. Kliment Ohridski* (*Universitet Sv. Kliment Ohridski*), 1939, [13, 24, 25] and *Yale University*, 1894. In 1896, this erudite, polyglot and cosmopolitan became an honorary member of the *Yugoslav Academy of Arts and Sciences* (current *Croatian Academy of Sciences and Arts*, HAZU) and the *American Philosophical Society* in Philadelphia. Nikola Tesla was also a long-term associate of the *New York Academy of Sciences*, and in 1907 was elected an active member. In 1894, he became a corresponding member of the *Serbian Royal Academy* (SRA), (current *Serbian Academy of Sciences and Arts*, SANU); the famous scientist Milutin Milanković proposed him for full

membership and he was elected a full member of SRA in 1937 [13, 24].

During six decades of continuous work in the field of electrical engineering, mechanical engineering and physics, Nikola Tesla initiated the second technological revolution in the second half of the 19th century, and marked the early 20th century by numerous technological inventions [24]. In 1893, Tesla was awarded the *Elliott Cresson Gold Medal* of the *Benjamin Franklin Institute of Technology*, Philadelphia, the *Thomas A. Edison Gold Medal* in 1917, handed to him by his colleagues, members of AIEE (*American Institute of Electrical Engineers*), as well as the *John Scott Medal* in 1934 [13, 25]. He was also nominated for the Nobel Prize for physics in 1937 [25, 26]. However, the Nobel Committee rejected the nomination on the grounds that, although Tesla's inventions of high frequency currents and rotating magnetic field were ingenious, they had been accomplished forty years before [26].

Tesla's greatest inventions were made in the 19th century [27–29]. The use of these inventions marked the 20th century, and Tesla's visionary solutions and pioneering steps, which were made a century ago in the field of remote control, radio technology, high-frequency electricity and wireless technologies, have not reached full implementation till the present time [29]. Among other things, Nikola Tesla was a visionary inventor in the field of charged particles, electromagnetic radiation and conductors, as well as the *forerunner* in the discovery of electrons, X-rays, radar, electronic microscope, cosmic radiation and induced radioactivity [2-8, 12, 13, 23, 25, 27-34] (**Table 1**).

So far, this fact has not been adequately evaluated in the world of scientific history [27], and Tesla himself commented on it in his way: *"The present is yours, but the future is mine. I don't care that they stole my ideas... I care that they don't have any of their own!"* [10]. *"In a thousand years there will be many Nobel Prize winners. And I have four dozen papers which bear my name in technical literature... These honors real and permanent which are bestowed not by a few who are apt to err, but by the whole world which seldom makes a mistake, and for any one of them I would give all the Nobel Prizes that will be awarded during the next several thousand years..."* [26].

Were we to eliminate the results of Tesla's work, the wheels of industry would cease to turn [35]. There is no area of human activity where products of Tesla's mind are not involved in the progress, restoration, prosperity, knowledge, preservation of youth and longevity, happy and glorious future of humanity [30]. Hence, no wonder that interest in Nikola Tesla is constantly growing [9, 10, 29]. Today, it is almost impossible to find another figure whose life and work have attracted so much attention of a wide range of researchers: from historians of science, electrical, mechanical and information technology engineers, experts in the fields of tele-

communication, aviation, military science to medical experts, ecologists, psychologists and philosophers [29]. In addition, Nikola Tesla has become an icon of popular culture and constant inspiration for artists and their work [11, 36–50]. The man who invented the 20th century, "inventist" ("inventor plus artist" a word coined by Laza Kostić for Nikola Tesla, bearing in mind that the Tesla's perception of art was built into his work), inventor, master-inventor of dreams, visionary, humanist, idealists, man out of time, colossus of science, divine lightning in the darkness of time, creator of the modern era, one of the most useful men ever, master of lightning, modern Prometheus, the only thunder-man who lived among people, wizard of electricity, poet of electricity, genius of light and spirit, time traveler, keeper of the last cosmic secrets, are just some of the poetic metaphors used by his numerous admirers used to express their admiration and gratitude [36, 51–54].

Nikola Tesla and the Discovery of X-ray Radiation

It is almost impossible to exclude Tesla's inventions that are only partly related to medicine from those specific for medicine [32]. Current diagnosis and therapy are unimaginable without his numerous inventions [2–7, 12, 13, 23, 27, 28, 30, 32, 33].

The sensational discovery of X-ray radiation (a form of electromagnetic radiation that occurs when high velocity electrons collide with a metal target within a glass vacuum tube), officially attributed to Wilhelm Conrad Roentgen, a German physicist and professor at several universities in Germany, led to increased interweaving between physics and medicine and gave impetus to further research in these scientific fields [12, 25, 28, 31]. *Roentgen* was already working on the effects of *cathode rays* during 1895; he wrapped some black cardboard around a Crookes tube and noticed a fluorescent effect on a small paper screen painted with barium platino-cyanide [28, 55]. Roentgen concluded that the tube was producing invisible radiation of an unknown nature, which he called X-rays [28]. Exploring this new phenomenon, Roentgen found that the new rays passed through most substances, and that photographic plates were also sensitive to X-rays [27, 28]. Because of the apparent connection between X-rays and fluorescence, he made a radiograph of his wife's hand [28]. In November 1895, Roentgen read about his discovery before the *Würzburg Physical and Medical Society*, and on the 28th of December he submitted his manuscript "On a New Kind of Ray" to the *Bulletin of the Berlin Academy* [13, 28, 56, 57]. On January 6, 1896, the *New York Sun* reported that Roentgen discovered "the light that never was", which can take images of hidden things such as bones inside a body [28, 58–60]. Shortly after this event, the whole world heard about Roentgen's work, and X-rays were named after him – Roentgen rays, whereas a few years later, in

Table 1. Nikola Tesla as a forerunner of relevant discoveries
Tabela 1. Nikola Tesla kao preteča značajnih otkrića

Discovery forerunner <i>Preteča otkrića</i>	Discovery <i>Otkriće</i>	Scientific award winners <i>Dobitnici naučnih priznanja</i>
Nikola Tesla, in 1891. <i>Nikola Tesla, 1891. godine.</i>	Accelerator for increasing the kinetic energies of charged particles <i>Akcelerator čestica</i> Cyclotron <i>Ciklotron</i>	Ernest Orlando Lawrence, in 1931; Nobel Prize, in 1939. <i>Ernest Orlando Lorens, 1931. godine; Nobelova nagrada 1939. godine.</i> Sir John Douglas Cockroft and Ernest Thomas Sinton Walton, in 1932; Nobel Prize, in 1951./ <i>Džon Kokroft i Ernest Volton, 1932. godine; Nobelova nagrada 1951. godine.</i>
Nikola Tesla, in 1891. <i>Nikola Tesla, 1891. godine.</i>	Electron microscope <i>Elektronski mikroskop</i> Scanning tunnelling microscope (STM) <i>Skenirajući tunelski mikroskop (STM)</i>	Ernst August Friedrich Ruska, in 1931; Nobel Prize, in 1986./ <i>Ernst Ruska, 1931. godine; Nobelova nagrada 1986. godine.</i> Heinrich Rohrer and Gerd Binnig, in 1981; Nobel Prize, in 1986./ <i>Hajnrh Rorer i Gerd Binig, 1981. godine; Nobelova nagrada 1986. godine.</i>
Nikola Tesla, in 1891. <i>Nikola Tesla, 1891. godine.</i>	Electron <i>Elektron</i>	Sir Joseph John Thomson, in 1897; Nobel Prize, in 1906. <i>Džozef Džon Tomson, 1897. godine; Nobelova nagrada 1906. godine.</i>
Nikola Tesla, in 1893. <i>Nikola Tesla, 1893. godine.</i>	Laser (light amplification by stimulated emission of radiation) <i>Laser</i>	Charles Hard Townes, Nicolay Gennadiyevich Basov, and Aleksandr Prokhorov, in 1952; Nobel Prize, in 1964. <i>Čarls Tauns, Aleksandar Mihailovič Prohorov i Nikolaj Genadijevič Basov 1952. godine; Nobelova nagrada 1964. godine.</i>
Nikola Tesla, in 1894. <i>Nikola Tesla, 1894. godine.</i>	X- rays <i>X-zračenje</i>	Wilhelm Conrad Röntgen, in 1895; Nobel Prize, in 1901. <i>Vilhelm Konrad Rendgen, 1895. godine; Nobelova nagrada 1901. godine.</i>
Nikola Tesla, in 1897. <i>Nikola Tesla, 1897. godine.</i>	Cosmic rays <i>Kosmičko zračenje</i> Positrons <i>Pozitroni</i>	Victor Franz Hess, in 1912; Nobel Prize, in 1936. <i>Viktor Hes, 1912. godine; Nobelova nagrada 1936. godine.</i> Carl David Anderson, in 1932; Nobel Prize, in 1936. <i>Karl Anderson, 1932. godine; Nobelova nagrada 1936. godine.</i>
Nikola Tesla, in 1898. <i>Nikola Tesla, 1898. godine.</i>	Radio <i>Radio</i>	Guglielmo Marchese Marconi, in 1901; Nobel Prize, in 1909./ <i>Guljelmo Markoni, 1901. godine; Nobelova nagrada 1909. godine.</i> Karl Ferdinand Braun, Nobel Prize, in 1909./ <i>Karl Ferdinand Braun, Nobelova nagrada 1909. godine.</i>
Nikola Tesla, in 1899. <i>Nikola Tesla, 1899. godine.</i>	Artificial radioactivity <i>Indukovana radioaktivnost</i>	Irene Joliot-Curie, in 1934; Nobel Prize, in 1935./ <i>Irena Žolio-Kiri, 1934. godine; Nobelova nagrada 1935. godine.</i>
Nikola Tesla, in 1903. <i>Nikola Tesla, 1903. godine.</i>	Radar (radio detection and ranging)/ <i>Radar</i>	Émile Girardeau, in 1934. <i>Emil Žirardo, 1934. godine.</i>

1901, he was awarded the first-ever *Nobel Prize in Physics* [55].

Nikola Tesla experimented with X-ray radiation since 1887 [25, 31, 57]. According to many sources, he was the first to discover *Roentgen radiation*, and named it ‘*special radiation*’ [2, 4, 6, 12, 13, 23, 27, 28, 30, 32, 55, 57, 61–63], since a few years before the discovery of X-rays he investigated the phenomenon of glowing tubes with diluted gas in order to obtain low cost lighting [55]. Tesla’s light bulbs without wires are well known - single-wire tubes with high vacuum and a molten metal ball of poorly soluble metal, as well as wireless vacuum tubes shining in strong field of high-frequency waves [30, 55, 57]. In this regard, in his lectures at the *Royal Society* of Great Britain in London in 1892, Tesla noticed that his oscillators emitted “*ordinary visible and two types of invisible waves and these are*

ordinary dark waves of all lengths, and, in addition, waves of a well defined character” [23]. That same year, Tesla made an X-ray of his hand [30]. However, due to lack of equipment and resources, as well as involvement in other projects, at this point Tesla stopped his studies of “*special radiation*” [23, 28, 30]. A thorough study of this phenomenon started in late 1894 when Tesla conducted experiments with phosphorescent and fluorescent substances and their use in producing light bulbs [23, 28]. Using one of his high-frequency oscillators, he charged Crookes tubes and tubes he designed himself with one electrode or without electrodes [23]. He realized that these tubes exerted different effects on photographic plates in the laboratory, placed aside, with blurred shadows and stains, probably originating from some unknown radiation from the tubes [23, 28, 30]. Unfortunately, he did not describe “*special*



Figure 2. Mark Twain and Nikola Tesla in Tesla's New York lab in 1894 Source: T.C.M., "Tesla's Oscillator and Other Inventions", *The Century Magazine* 49:916-33. (April 1895), photograph no. 13.

Slika 2. Mark Tven i Nikola Tesla u Teslinoj laboratoriji u Njujorku 1894. godine. Izvor: T.C.M., *Tesla's Oscillator and Other Inventions*, *The Century Magazine* 49:916-33. (april 1895), slika br. 13.

radiation" in any articles he published in this period [2]. In the early 1895, Tesla continued his work on this phenomenon with great enthusiasm, but due to the fire in his laboratory at Houston Street New York, on March 13, 1895, he was forced to stop his work again [30]. If there had been no fire to burn down his lab at this critical moment, it is almost certain that X-rays would be called Tesla-rays, and Tesla would probably have been the first Nobel Prize winner in physics [27].

Interestingly, although Tesla was well known for his extraordinary intuition, when it comes to initial investigations of X-ray radiation, he succeeded only after two missed opportunities [23, 28]. This is vividly described by Bernard Carlson in his book "Tesla: Inventor of the Electrical Age": "At the end of 1894, Tesla decided to investigate whether his lamps affected photographic plates in the same way as light coming from the sun or other sources of illumination. To do so, he sought the assistance of a photographer employed by Tonnele & Company. Over a period of several months they tried a great variety of phosphorescent lamps, Crookes tubes, and vacuum bulbs with different kinds of electrodes. Since this was not a major project, Tesla and Alley worked on it periodically, and Alley stored spare glass photographic plates in a corner of the laboratory. However, they noticed that the unexposed plates had "uncountable marks and defects" indicating that they had somehow been spoiled. Tesla wondered, in passing, if the plates might have been affected by cathodic rays, which were a stream of charged particles that passed between the electrodes in some of his vacuum tubes when a voltage was

applied across the electrodes. Tesla had recently read reports about how a Hungarian student of Heinrich Hertz, Philipp Lenard, was getting interesting results using tubes with an aluminium window that allowed the rays to pass out of the tube. However, before he could follow up on this hunch, the laboratory fire occurred and depression kept Tesla from working" [28].

"The second missed opportunity came a few months later. In 1895, Tesla was discussing these photographic experiments with Edward Ringwood Hewitt, who was the son of the mayor of New York, Abraham Hewitt, and brother of Peter Cooper Hewitt, who would invent the mercury vapor lamp in 1902. Through his brother's research, Edward was familiar with Crookes tubes, and in the course of conversation Tesla and Edward decided to try taking some photographs using these tubes as the light source. Perhaps knowing that Mark Twain had posed for a similar photograph (**Figure 2**), Hewitt arranged for Twain to come to the lab. Because the light coming from Crookes tube was weak, Twain had to sit still for fifteen-minute exposure with his head supported by a headrest. A few days later, Hewitt checked to see how the portrait had turned out, and Tesla reported that the experiment failed as the glass photographic plate had somehow been spoiled" [28].

"Hewitt let the matter drop until he heard a few months later about the discovery of X-rays. Upon reading about Roentgen's discovery, Hewitt rushed to Tesla's laboratory and begged to see the photographic plate taken a few months earlier" [28]. This is how Hewitt remembered those moments: "Tesla brought it out of the dark room and held it up to the light. There I saw the picture of the circle of the lens, with the adjusting screw at the side – also round dots, which represented the metal wood screws in front of the wooden camera. Tesla gave one look. Then he slammed the plate on the floor, breaking it into thousand pieces, exclaiming: "Damned fool! I never saw it" [28, 63].

"What Tesla and Hewitt had missed was that the Geissler tube had produced not only visible light, but also invisible radiation – X-rays – that had spoiled the plate before the cap had even been taken off the lens and the exposure begun." "Too late", Tesla lamented, "I realized that my guiding spirit had again prompted me and that I failed to comprehend his mysterious signs" [28].

Although the lab fire in South Fifth Avenue, as mentioned before, may have distracted Tesla from discovering X-rays before Roentgen, Tesla gave Roentgen full credit for the finding [2, 23, 27, 30, 32] and was fascinated by this mysterious radiation: "Roentgen advanced modestly his results, warning against too much hope. Fortunately his apprehensions were groundless, for, although we have to all appearance to deal with mere shadow projections, the possibilities of the application of his discovery are vast. These discoveries of Roentgen, exactly of the order of the telescope and microscope, his seeing

through a great thickness of an opaque substance, his recording on a sensitive plate of objects otherwise invisible, were so beautiful and fascinating, so full of promise, that all restraint was put aside, and every one abandoned himself to the pleasures of speculation and experiment. Would but every new and worthy idea find such an echo! I am happy to have contributed to the development of the great art he has created [56, 57, 61].

When he found out about the discovery of X-ray radiation, Tesla decided to make up for lost time and immediately undertook a series of experiments to examine the nature of this radiation [2, 23, 27, 28, 30, 32]. A few weeks later he told the *New York Times* that he had begun his experiments “half an hour after the news of Prof. Roentgen’s discovery was cabled to this country” [28]. Tesla was using high-frequency waves of highest power at the time, and he was convinced that his radiation and X-ray radiation were very similar, although his X-ray radiation was obtained in a different way [57]. In fact, from the beginning of January 1896, in his experiments Tesla used his own transformer (coil), which would later be named after him “Tesla coil” [23, 30, 57, 64] (**Figure 3**).

Tesla was using an oscillating transformer, which he transformed during 1895 and 1896 into a compact device, which could be supplied from existing electrical networks and raise the voltage and current frequency [28]. Tesla then used this improved oscillating transformer to power a new vacuum tube lamp, which he claimed gave out more light [2, 13, 23, 32, 36, 56, 57, 61]. To demonstrate the power of his new lamp, Tesla posed for a portrait, but the exposition took only two seconds [28] (**Figure 4**).

Having checked the experiments of Professor Roentgen, Tesla wrote: “I’ve dedicated all my energy to research the nature of radiation and to perfecting the means of its production” [61]. After new experiments, Tesla sent Professor Roentgen shadowgraphs obtained by using “special radiation”. Professor Roentgen replied with enthusiasm: “The pictures are very interesting. Would you be so kind as to disclose the manner in which you obtained them?” [2, 6, 32, 57].

The advantage of Nikola Tesla in the study of the nature of the X-ray radiation was that at that time only he produced this radiation in the tube with alternating current power, while others used direct current [56, 57, 61]. Having this in mind, Roentgen also used Tesla’s coil and alternating currents in order to obtain clear shadows on the radiograph [23, 61]. Thus, in the article “On a New Form of Radiation”, published on April 24, 1896, in the journal *Electrician*, Roentgen wrote: “In many cases, it is useful to insert a Tesla coil between the X-ray generator and Ruhmkorff coil” [23, 30].

In 1896, Tesla published a series of articles on new radiation in the American journal *Electrical Review*, and by August 11, 1897, he had published a total of ten papers all in this field [4, 6, 13, 28, 32, 56, 57, 65–74]. All Tesla’s papers on X-ray radiation were experimental [57, 65–74]. The articles described in detail



Figure 3. Tesla transformer (Tesla coil) Source: www.tesla-museum.org

Slika 3. Teslin transformator (Teslin kalem) Izvor: www.tesla-museum.org

the technique of making radiographs and included X-rays that he himself made [32, 62]. Images of human body parts made by means of his mighty apparatus, Tesla called “shadowgraphs”, effectively laying the foundations of radiology and radiography [28, 57].

One of the first images showed a man’s right shoulder, his ribs, shoulder bone and upper arm bones [28]. On the application and beauty of the resulting X-ray, Nikola Tesla wrote: “Through the body of the experimenter the shadows of small buttons and alike objects are quickly obtained, while with an exposure from one hour and a half the ribs, shoulder bones and the bones of the upper arm appear clearly on the sensitized plate. It is now demonstrated beyond any doubt that small metallic objects or bony or chalky deposits can be infallibly detected in any part of the body” [30, 56, 57]. “Clear shadows of the bones of human limbs are obtained by exposures ranging from a quarter of an hour, and some plates have shown such an amount of detail that it is almost impossible to believe that we have to deal with shadows only” [28, 57].

When analyzing another image of a foot with a shoe, Nikola Tesla stated the following: “A picture of a foot with a shoe on shows every fold of the leather, trousers, stocking, etc., while the flesh and bones stand out sharply” [25, 28, 31, 56, 57, 61] (**Figure 5**).



Figure 4. Nikola Tesla in his New York lab in 1896, reading Ruder Bošković's book "Theory of Natural Philosophy", seated in front of the spiral coil of his high-frequency transformer. Source: The Nikola Tesla Museum, document no. MNT, VI/V, 14.

Slika 4. Nikola Tesla čita knjigu Rudera Boškovića „Teorija prirodne filozofije“ u svojoj laboratoriji u Njujorku 1896. godine. U pozadini je njegov visokofrekventni transformator sa spiralnom zavojnicom. Izvor: Muzej Nikole Tesle, dokument br. MNT, VI/V, 14.

Undoubtedly aware of the fact that Edison had seen only “curvilinear murkiness” when he X-rayed the brain for *New York Journal*, Tesla has made clear outlines of the skull exposing his own head to radiation between twenty and forty minutes [28]. In this regard Tesla wrote: “An outline of the skull is easily obtained with an exposure of twenty to forty minutes. In an instance an exposure gave clearly not only the outline, but the cavity of the eye, the chin and the cheek and nasal bones, the lower jaw and connections to the upper one, the vertebral column and connections to the skull, the flesh and even the hair” [30].

Another area related to medicine was the focus of Tesla's research - X-ray tubes different from those used by Roentgen [75]. Tesla experimented with Crookes tube and designed his own vacuum tube for producing X-ray radiation [13]. As mentioned earlier, Tesla immediately noticed that other researchers were limited by the use of weak Ruhmkorff coils or electrostatic generators, so he started using his new compact oscillating transformer (Tesla transformer) [28]. In his published papers, Tesla explained how his tube worked using alternating current power. Thus, during each alternating current half-cycle, cathode and anode operate normally (cathode is negative and anode

is positive), but in the next half-cycle it all changes (anode becomes negative, and cathode positive), and this process is alternately repeated [61, 65–74]. Using the advantages of higher voltage and frequency of his apparatus, Tesla was able to create far more powerful X-ray radiation than most of his contemporaries [28, 30]: “I make shots from a distance of 13 meters. I repeat, 13 meters and more”, reported Tesla in March of 1896 [28, 30, 66]. In the following few months, Tesla hired a glassblower, as he experimented with dozens of different tubes, and corresponded with Hewitt on the methods of their testing [28]. In his article, published in April 1896, Tesla explained, for the first time, the technical details based on which he improved X-ray devices, with special emphasis on the maintenance and regulation of the vacuum in the X-ray tubes [13, 23, 30, 32, 68]. In addition, Tesla designed a cooling system for X-ray tubes [13].

On April 6, 1897, Tesla gave a lecture before the *New York Academy of Sciences* and presented his X-ray devices [23, 30]. After that, in the same year, he published a paper dealing with the sources of X-ray radiation and wrote the following: “I have for some time felt that a few indications in regard to the practical construction of Lenard tubes of improved designs, a great number of which I have recently exhibited before the *New York Academy of Sciences*, would be useful and timely, particularly as by their proper construction and use much of the danger attending the experimentation with the rays may be avoided... My efforts were directed to finding answers to the following questions: First, is it necessary that the impact body should be within the tube? Second, is it required that the obstacle in the

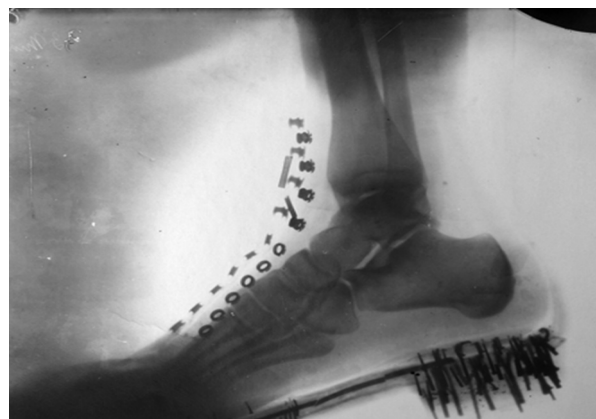


Figure 5. A shadowgraph of a human foot with a shoe on. Tesla made this image in 1896 with X-rays generated by his own vacuum tube, at a distance of 2.5 meters. Source: The Nikola Tesla Museum, document no. MNT, VI/II, 122. <http://radiographics.rsna.org/content/28/4/1189.full>

Slika 5. Snimak ljudskog stopala u cipeli napravljen u Teslinjoj laboratoriji 1896. godine. Zračenje je generisano pomoću vakuumske cevi na rastojanju od oko 2,5 metara. Izvor: Muzej Nikole Tesle, dokument br. MNT, VI/II, 122. <http://radiographics.rsna.org/content/28/4/1189.full>

path of the cathodic stream should be a solid or liquid? And, third, to what extent is the velocity of the stream necessary for the generation of and influence upon the character of the rays emitted... In the hollow aluminum cap A of a tube, I placed a half-dollar silver piece, supporting it at a small distance from and parallel to the window or bottom of the cap by strips of mica in such a manner that it was not touching the metal of the tube, an air space being left all around it" [30, 74].

Tesla was investigating how different conditions (length of exposition and distance) affected the quality of X-rays [13]. Like other researchers, in the beginning he considered X-radiation harmless [28], and he proposed its use in the detection of lung disease and foreign bodies in the body [13]. However, he and his assistants soon experienced eyestrain, headaches, and burns on the hands [13, 28]. Moreover, in the spring of 1897, Nikola Tesla was sick for several weeks and said that his disease was caused by X-radiation [57]. At first Tesla attributed these injuries to the ozone produced when running the tubes at high voltages, but he came to realize that the rays themselves were causing damage [28]. Tesla was particularly upset when "a dear and zealous assistant" suffered severe burns on his abdomen after being exposed for five minutes to an X-ray tube positioned thirty centimeters from his body [28, 73]. "Fortunately", he wrote, "frequent warm baths, free application of Vaseline, cleaning and general bodily care soon repaired the ravages of the destructive agent, and I breathed again freely" [28]. Soon after that, Nikola Tesla was the first to point out the harmful effects of X-radiation on the human body [13, 23, 28, 30, 57, 64, 73]: "The use of X-rays should not be avoided, but one needs to be cautious, because the knowledge about these rays is still incomplete. However, ignoring the danger is also not recommended, now that we know that under certain circumstances, it really exists. In my opinion, it is much more necessary to be aware of these dangers, as I presume new devices will be developed, capable to create radiation of unpredictably higher power. In scientific laboratories these instruments are usually handled by persons who are trained to do so, capable to roughly estimate the effects, so at the present state of our knowledge we need not be afraid, even without necessary precautions" [30, 57].

Tesla had carefully noted the visible effects of X-radiation on the body: "When the head is exposed to strong radiation, some unusual effects occur. For example, I feel drowsy and it seems as if time passes quickly. There is a general soothing effect, and I have felt a sensation of warmth in the upper part of the head" [28, 30, 57]. The feeling of somnolence, registered by Tesla, is called "radiological hangover" [57].

In his following papers on X-ray radiation, Tesla was the first to recommend using a grounded aluminum shield around the X-ray tube to protect doctors from X-ray radiation, as well as avoiding getting too close to the tube, and limiting the exposure time [13, 23, 28, 30, 57, 64, 73, 74]. In order to provide radiation protection, he was also the first to point to the importance of the square law (it states that the further the point source of radiation, the intensity is reduced by four times (two squared) [57]. In addition, Tesla had experimentally proved that high energy natural radiations also produce X-radiation [23, 30, 64]. Tesla also experimented with reflected x-rays, using different materials [13]. Apart from direct reflection of X-rays, Tesla had produced a secondary effect, today known as Back Scattering Electrons (BSE) [27]. He believed that the produced rays were minute particles, and he put a lot of effort to obtain experimental evidence; this hypothesis was found partially justified only after the acceptance of the concept of dual (corpuscular and wave) nature of radiation in 1923 [23, 64].

Conclusion

Nikola Tesla was a visionary genius of the future. His pioneer steps, made more than a century ago, especially in the domain of radiology, are still being used today.

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