Summary
This paper is intended to celebrate the 120th anniversary of the discovery of X-rays. X-rays (Roentgen-rays) were discovered on the 8th of November, 1895 by the German physicist Wilhelm Conrad Roentgen. Fifty days after the discovery of X-ray, on December 28, 1895, Wilhelm Conrad Roentgen published a paper about the discovery of X-rays - “On a new kind of rays” (Wilhelm Conrad Roentgen: Über eine neue Art von Strahlen. In: Sitzungsberichte der Würzburger Physik.-Medic.-Gesellschaft. 1895.). Therefore, the date of 28th of December, 1895 was taken as the date of X-rays discovery. This paper describes the work of Wilhelm Conrad Roentgen, Nikola Tesla, Mihajlo Pupin and Maria Sklodowska-Curie about the nature of X-rays. The fantastic four - Wilhelm Conrad Roentgen, Nikola Tesla, Mihajlo Idvorski Pupin and Maria Sklodovska Kiri, set the foundation of radiology with their discovery and study of X-rays. Five years after the discovery of X-rays, in 1900, Dr Avram Vinaver had the first X-ray machine installed in Šabac, in Serbia at the time when many developed countries did not have an X-ray machine and thus set the foundation of radiology in Serbia.

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

Introduction
The 120th anniversary of the discovery of X-rays, which are called roentgen rays in the honor of Wilhelm Roentgen, was celebrated on the 28th of December 2015. The nature of X-rays itself (roentgen rays) speaks about what kind of discovery it is. They are the electromagnetic waves of a wavelength (λ) ranging from 0.01 - 10 nanometers, which are in the spectrum of electromagnetic radiation between the ultraviolet and gamma (γ-) radiation; they carry a lot of energy and have power to ionize atoms which makes it a type of ionizing radiation [1–26]. The application of X-rays for medical purposes made revolutionary advances in medicine, the approach of doctors to patients has changed since the doctors could visualize the inside of the patient’s body for the first time without surgical opening. Radiology today, along with the energy of X-ray (X-ray diagnosis and computed tomography) uses the energy of radioisotopes (nuclear medicine), ultrasound (ultrasonography and color Doppler) and electromagnetic field (magnetic resonance imaging).

The fantastic four - Wilhelm Conrad Roentgen (1845-1923), Nikola Tesla (1856-1943), Pupin (1854 - 1935.) and Maria Sklodowska-Curie (1867-1934), who had worked independently of each other, did not know that their work on the nature of X-rays would set the foundation of the new branch of medicine - radiology and contribute to its evolution, without which the modern medicine cannot even be imagined [1–27].
Nikola Tesla thought that Roentgen’s discovery of X-rays was as important as the invention of the telescope and microscope because it enabled seeing through an opaque substance of great thickness and making an image of objects otherwise invisible on a sensitive plate, which were so beautiful and fascinating and promising at the same time that everybody was delighted to think about them and make experiments. He only wished that every new idea would have such an echo.

Wilhelm Roentgen - Discovery of X-rays

Wilhelm Roentgen (German: Wilhelm Conrad Roentgen, 27 March 1845, Lenepa, Prussia – 10 February 1923, Munich, Germany; Figure 1a) was a German physicist who discovered X-rays, on the 8th of November, 1895. He studied mechanical engineering at the University of Utrecht (Utrecht, Netherlands) and the Technical University of Zurich (Eidgenössische Technische Hochschule Zürich, Switzerland), from which

<table>
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he graduated. He received his Ph.D. at the University of Zurich in 1869 [1, 2].

During 1895 Roentgen was investigating the effects of high voltage on electrical discharge in diluted gases in vacuum tubes. There was a bag with barium platinocyanide on the desk where he worked. In the dark, one meter from the apparatus, Roentgen noticed some sort of faint shimmering on the desk whenever he turned on the camera (the 8th of November, 1895). The shimmering came from the bag containing the barium platinocyanide prepared for one of his experiments. Roentgen did not come out from his laboratory in the following weeks. He worked in his laboratory day and night on experiments, eating and sleeping there. He speculated that this was a new kind of radiation. Since he did not know what kind of radiation it was, he called it X-rays.

In one of his repeated experiments while investigating the ability of various materials to stop the rays, Roentgen brought his hand incidentally to the shield and saw his own bones. This picture made a strong impression on him and he decided to continue his experiments in secrecy.

Fifty days after the discovery of X-rays, on the 28th of December, 1895 Roentgen published a paper on the X-rays - “On a new kind of rays” (Wilhelm Conrad Roentgen: Über eine neue Art von Strahlen. In: Sitzungsberichte der Würzburger Physik.-Medic.-Gesellschaft. 1895.; Figure 1b) [2]. This date – the 28th of December 1895 was to be taken as the date of the discovery of X-rays.

One of the first X-ray images that Wilhelm Roentgen made was a radiograph of the hands of the Swiss anatomist and psychologist Albert von Kolliker (German: Albert Von Kolliker, 6 July 1817 – 2 November 1905, Figure 1c).

In 1901 Roentgen was awarded the first Nobel Prize in Physics and he donated the money he received to his university where he worked. He refused to patent his invention for moral reasons. X-rays are called after his name – Roentgen rays. In November 2004 the International Union of Pure and Applied Chemistry named 111th elementary element of the Periodic System roentgenium (Rg).

**Nikola Tesla – about the X-rays**

Nikola Tesla (10 July 1856, Smiljan, the Austro-Hungarian Empire - January 7 1943, New York, USA; Figure 2a), was a Serbian Orthodox, inventor and scientist with over 1,000 inventions and patents, such as asynchronous motor and transmission of electricity (the 12th of October, 1887), generator and transformer of polyphase current, induction motor with short circuit and contact rings (the 30th of November, 1887), high-frequency transformer (1891). He announced the basic concept of radio techniques in lectures in London and Paris (on the 3rd and 19th of February, 1891).

Nikola Tesla studied the X-rays as well and laid the basic principles of radiology, later to be introduced into everyday use by radiologists and manufacturers of X-ray apparatus.

Tesla made only experiments with X-rays, that being specific to his work. His advantage when studying the nature of X-rays was that he used the alternating current (AC) to make his tubes function. At that time, it was only Tesla who worked on the production of X-rays in tubes with AC while the rest of the world worked with direct current. Nikola Tesla was the only one who could invent that.

In 1892, Nikola Tesla observed the “visible light, the black light, and a special kind of radiation” in his bulb for molecular bombardment [8]. Tesla did not explain the nature of that radiation until the discovery of X-rays by Wilhelm Konrad Roentgen (December 1895).

Nikola Tesla first tested the experiment of Prof. Roentgen and got the same results as Roentgen. Having finished the experiments, Tesla sent the images of shadows he had obtained by means of this radiation to Prof. Wilhelm Roentgen who responded that the pictures were very interesting and asked Tesla to explain how he got them [8]. In 1896 Roentgen emphasized the importance of Tesla’s transformer and AC power as a relevant means for obtaining the clear shadows.

On the 11th of March, 1896 Nikola Tesla published the first paper on X-rays, to be followed by ten papers in this area by the 11th of August 1897:

- On Roentgen rays (1) Electrical Review, March 11, 1896;
- On Roentgen rays (2) Electrical Review, March 18, 1896;
- On reflected Roentgen rays, Electrical Review April 1, 1896;
On Roentgen radiations, Electrical Review, April 8, 1896;

− Roentgen ray investigations, Electrical Review, April 22, 1896;

− An interesting feature of X-ray radiations, Electrical Review, July 8, 1896;

− Roentgen rays or streams, Electrical Review, August 12, 1896;

− On the Roentgen streams, Electrical Review, December 1, 1896;

− On the hurtful actions of Lenard and Roentgen tubes, Electrical Review, May 5, 1897;

− On the source of Roentgen rays and the practical construction and safe operation of Lenard tubes, Electrical Review, August 11, 1897.

Tesla’s experimental work in the field of X-ray was aimed at explaining what the X-rays were, what their nature was, whether they were particles or waves. Tesla was convinced that the X-rays were particles. However, later research in the field of quantum mechanics confirmed that X-rays had corpuscular-wave dualism, i.e. they had at the same time the property of corpuscular particle and of electromagnetic wave, suggesting the question - what to say about Tesla’s understanding of the nature of X-rays (X-ray material particle), who claimed that the X-rays were particles many years before Compton?!

Tesla was delighted with the nature of X-rays because Roentgen’s discovery had enabled seeing through an opaque material by means of fluorescent screen and visualising metal objects, bones and calcareous shadows in every part of the body [7].

Speaking of the value and beauty of radiographs (Figure 2b), Nikola Tesla wrote that the clear shadows of human limb bones had been obtained by exposing them for 15 to 60 minutes and some of the images showed such an amount of details that was almost impossible to believe they were only shadows. For example, the image of a foot with the shoe revealed every fold of skin, pants, socks, etc., while the muscles and bones were sharply shown [7, 9].

Nikola Tesla was the first who recognized harmful effects of X-ray on the living cell. He carefully recorded the visible effects of X-rays on the human body and tried to give an explanation of the harmful effects of X-rays. Nikola Tesla wrote that some strange effects had been observed when the head was exposed to strong radiation such as feeling sleepy and having the impression of time passing quickly. The general effect was the one of calmness and the sensation of warmth in the upper part of the head [7].

In the spring of 1897 Tesla mysteriously got ill and was ill for several weeks, and claimed that X-rays had caused a shock to his eyes and that they made him ill [8]. He thought that dangers resulting from this radiation should not be ignored. In order to get protection against harmful effects of X-ray, Nikola Tesla tried to find a protection shield. He suggested the use of aluminum plate placed between the person exposed to the X-rays and X-ray tubes and pointed to the importance of inverse square law.

In honor of Nikola Tesla the term “tesla” was introduced as the unit measure for magnetic field strength (T). Tesla is an SI derived unit. Tesla is magnetic induction of homogeneous magnetic field with acting force of 1 N (Newton) on the line conductor 1 meter long, placed perpendicularly to the field when the conductor current is 1 A (ampere) or 1 T = 1 N/1 m • 1A. A smaller unit for magnetic induction is Gauss (Gs), where 1 Gs = 10^{-4} T.

Tesla can be displayed via Weber. Weber (Wb) is a unit of magnetic flux. This is an SI derived unit. Weber is magnetic flux through the flat surface of 1 m² (square meter), which is perpendicular to the direction of the homogeneous magnetic field induction of 1 T (tesla) or 1 WB = 1 T • 1 m². A smaller unit of Weber is Maxwell (Mx) where 1 Wb = 10⁶ Mx. Using the analogy of Tesla, it is easy to conclude that 1 Mx = Gs • cm².

Today, the power of magnetic resonance apparatus (MR) is expressed in units of tesla (T), so there are magnetic resonance apparatus of 0.5 T, 1.0 T, 1.5 T.

In honor of Nikola Tesla, a banknote of 100 dinars, blue colored, with his portrait was issued by the National Bank of Yugoslavia in 2000. It is still in use; although this one was issued by the National Bank of Serbia [26].

Pupin - invention of fast recording by means of X-ray

Pupin (October 9, 1854, Idvor, the Austro-Hungarian Empire - March 12, 1935, New York, USA; Figure 3a) was a Serbian Orthodox, inventor, scientist, professor at Columbia University (Columbia University in the city of New York, USA), holder of

![Figure 2. a) Nikola Tesla (born - July 10, 1856 Smiljan Austro-Hungarian Empire – died January 7, 1943, New York, USA), b) one of the radiographs made by Nikola Tesla and his comment: “the image of a foot with the shoe revealing every fold of skin, pants, socks, etc., while the muscles and bones are sharply shown”](image-url)
the Yugoslav Order of the White eagle - first class, winner of the Pulitzer Prize (1924 for autobiography - From Immigrant to Inventor), member of the American Academy of Sciences, the royal Serbian Academy, honorable doctor of science at 18 universities and honorable consul of Serbia in the United States [12–16]. He patented 34 inventions (Table 1).

Immediately after the discovery of X-rays in February 1896, Pupin began his research on X-rays, X-fluoroscopy and shortening of the exposure time. During this research Pupin discovered the secondary X-rays, calling them “H-rays” and informed the Academy of Sciences (the 6th of April, 1896) about them [12–16].

The secondary X-rays are widely applied in medicine and nuclear physics. Each chemical element irradiated by X-rays reflects electromagnetic waves of a certain wavelength with characteristic spectrum which corresponds only to that chemical element. Today, this Pupin’s discovery is applied in space research as well as in radiology. The film used nowadays in rentgenography emit the light of a certain wavelength, i.e. the brightness of a specific color to which the film is sensitive. This enables the transfer of latent X-ray image as the brightness from the film to X-ray film, thus making it visible [10–13].

During the X-ray illumination of the body of patients Pupin managed to shorten the exposure time, calling it “the invention of fast recording by means of X-rays.” Pupin made this discovery by placing a photographic plate behind the fluorescent screen, thereby reducing the exposure time from about an hour to a few seconds.

In his autobiography, “From Immigrant to Inventor” [16] Pupin disclosed details about his contribution to the development of radiology, which was a new branch of medicine at that time, in the section “My invention of fast recording by means of X-rays.” Pupin says: “On the 7th of February 1896, the famous surgeon Dr. Bull sent me a patient with almost hundred lead balls in his hand. His and my friends asked me to obtain an X-ray image so Dr. Bull could find and take out all of the lead balls. The first attempt failed because the patient was too weak to stand still for nearly an hour which is the time it took to get an X-ray photo at the time. My good friend Thomas Edison sent me a few extraordinary fluorescent cardboards (screens), and using their fluorescent light we could see the numerous small balls. On first sight it was clear that the combination of fluorescent cardboard and eyes is more sensitive than photographic plate. That is why I tried to combine Edison’s fluorescent screen with photographic plate. I put the fluorescent screen on the photographic plate and the patient’s hand on the screen. X-rays passed through the patients hand and caused the screen to fluoresce, which then exposed the photographic plate. It turned out much better than I expected. A fairly good image was obtained with an exposure of only a few seconds. On photographic plate appeared many balls, as if drawn with pen and ink” [15, 16]. This Pupin’s invention of fast recording using X-ray, which shortened the exposure time from an hour to a few seconds, was both ingenious and simple and is widely used today. Pupin invented “fast recording by means of X-rays” 40 days after Roentgen had discovered X-rays. Pupin did not patent this invention.

The 7th of February, 1896, the day when Pupin took the radiograph of the hand of a patient referred to him by Dr. Bull is considered as the date when the first radiograph was taken in the United States of America (Figure 3b). At the same time, it is also the date when the first surgery using the radiographs was performed in United States. Therefore, Pupin is considered the father of American Radiology [12].

Marie Sklodowska Curie - the mobile hall with X-rays

Marie Sklodowska Curie (Polish: Maria Sklodowska-Curie, November 7, 1867 Warsaw, Poland - 4 July 1934 Salans, France; Figure 4a) is a famous Polish and naturalized-French who studied the physical and chemical properties of radioactive elements, radioactivity and discovered radioactive elements - polonium (84Po210), thorium (90Th232) and radium (88Ra226). She spent most of her life in France, where she started a scientific career. She was the first woman in France who acquired a scientific degree of Doctor of Science, the first woman to become a professor at the University of Paris, Sorbonne (1908), the first and only woman in the world who won the Nobel Prize twice – in 1903 Marie Sklodowska Curie shared the Nobel Prize in Physics with Pierre Curie and Henri Becquerel for research on the radiation. In 1911

Figure 3. a) Mihajlo Idvorski Pupin (born October 1854, Idvor, Austro-Hungarian Empire – died March 12, 1935, New York, USA), b) a radiograph of a hand of a patients made by means of the Pupin’s invention “X-ray fast recording” on February 7, 1896, that being the date of the very first radiograph made in the USA

Slika 3. a) Mihajlo Idvorski Pupin (9. oktobar 1854. g., Idvor, Austrougarska Carevina – 12. mart 1935. g., Njujork, USA); b) rendgenogram šake boleznika sa mnogobrojnim dramljijama učinjen Pupinovim pronalaskom “brzog snimanja pomoću X-zraka” 7. februara 1896. godine – to je datum prvog načinjenog rendgenograma u USA
Today, many armies of the world have modern mobile radiological services. For example, the army of the former USSR had a truck with X-ray machines and mini-labs, which were made in our Electronic Industry in Nis (SFR Yugoslavia, today: the Republic of Serbia).

Nowadays, manufacturers of X-ray machines produce and install the standard X-ray machines, computed tomography apparatus, magnetic resonance imaging machine in truck trailers (Figure 4c) with or without echo apparatus, making them mobile and available to all communities, in all weather conditions, during war or peacetime. Well, are not the buses with fluorographic apparatus, which were used to examine the population in the prevention of tuberculosis, what Marie Sklodowska Curie imagined, created and implemented in practice [17–19]? 

Dr. Avram Josif Vinaver - a pioneer of radiology in Serbia

Dr. Avram Josif Vinaver (1862, Warsaw, Poland - August 24, 1915, Gevgelija, Serbia, Macedonia today; Figure 5a) was a Polish Jew, Serbian pioneer in radiology, who contributed to the development of health services in Serbia, especially in Sabac, Macva district (Serbia, Macedonia today). He finished primary and secondary school in his hometown, where he graduated from the Faculty of Medicine in 1887. After acquiring his academic title, Dr. Avram J. Vinaver settled in Sabac (1890), in the former Kingdom of Serbia, where he worked and lived. Dr. Avram Vinaver spoke Hebrew, German, French, Polish, Russian and Serbian. He participated in the Balkan wars and the First World War. After the victory of the Serbian army in the Battle of Cer and Kolubara, Dr. Avram Josif Vinaver arrived with his unit in Gevgelija (Serbia, Macedonia today). Exhausted from myocardial typhus, he suffered from malaria and died in 1915. He was buried in a common grave at his own request.

Dr. Avram Vinaver set the foundation of today’s radiology in Serbia. In 1900, Dr. Avram Vinaver brought the first X-ray machine in Sabac, just five years after the discovery of X-rays, at the time when many developed countries of the world did not have an X-ray machine. It was an X-ray machine with gas (ion) tube, bought in Vienna, placed in a building which was next to the apartment of Dr. Abraham Vinaver. Thus, Sabac became the first city in the Kingdom of Serbia which had an X-ray machine. However, it should be emphasized that an X-ray machine had already been purchased for the Military Hospital in Belgrade by the Serbian Army in 1897. However, that X-ray machine was used only for the purposes of army, while the X-ray machine, which was owned by Dr. Avram Vinaver was the first X-ray machine in Serbia used in diagnostics and development of health care of the civilian population of Serbia, and therefore the date of purchasing the X-ray machine in 1900 by Dr. Abraham Vinaver is taken to be the date of the first X-ray machine in Serbia.
Dr. Vinaver wrote about his experience with X-rays, diagnostic and therapeutic possibilities of X-rays in the first published papers, which he presented at the “First Congress of Serbian physicians and naturalists under the highest protection of His Majesty King Peter I”, held in Belgrade from the 5th to the 7th of September 1904. The papers from the Congress were published in the Proceedings of the “First Congress of Serbian physicians and naturalists under the highest protection of His Majesty King Peter I in Belgrade, held on the 5th, 6th and 7th of September 1904, printed in the state printing house of the Kingdom of Serbia 1905”.

The following papers were presented: “Diagnostic importance of X-ray beams in diseases of the lungs, especially in the initial tuberculosis”, “Five years of treatment with Roentgen rays” and “Several contributions to solving the question whether the father’s syphilis is hereditary” [22–24].

Dr. Vinaver’s papers of “Diagnostic importance of X-ray beams in diseases of the lungs, especially in the initial tuberculosis” [22] and “Five years of treatment with Roentgen rays” [23] were the first studies within radiology in Serbia, and among the first publications of this type in the world.

In “Diagnostic importance of X-ray beams in diseases of the lungs, especially in the initial tuberculosis” [22], Dr. Avram Vinaver wrote that X-rays were meant to make a breakthrough in this field as well but they had not yet become available to the general population in spite of being a valuable diagnostic tool.

Dr. Avram Vinaver gave the axiom of the overall radiological diagnostics: “It is not the X-rays but the intellect of a doctor that establishes a diagnosis.”

Dr. Avram Vinaver prophesied that X-rays and X-ray diagnostic application were the method of future. In his study “Five years of treatment with Roentgen rays” [23] Dr. Avram Vinaver presented therapeutic options of X-ray used on 62 treated patients where he quoted Prof. Holzknecht from Vienna who was one of the eminent radiologists of the world at that time.

Dr. Avram Vinaver concluded that it would be an unforgivable sin against our patients to remain indifferent to the Roentgen-therapy and not make it possible for them to be treated and cured by means of X-rays.

Conclusion

This paper is dedicated to the 120th anniversary of the discovery of X-rays. Wilhelm Roentgen (1845-1923) discovered the X-rays (Roentgen rays) on the 28th of December, 1895. The nature of the X-ray was studied by Nikola Tesla (1856-1943), Pupin (1854-1923) and Maria Sklodowska Curie (1867-1934). The Fantastic Four - Wilhelm Conrad Roentgen, Nikola Tesla, Pupin and Maria Sklodowska Curie set the foundation of a new branch of medicine - radiology.

Five years after the discovery of X-rays, in 1900, Dr. Avram Vinaver (1862-1915) had the first X-ray machine installed in Sabac, in Serbia, at the time when many developed countries of the world did not have an X-ray machine and thus set the foundation of radiology in Serbia. The papers of Dr. Vinaver “Diagnostic importance of X-ray beams in diseases of the lungs, especially in the initial tuberculosis” and “Five years of treatment with Roentgen rays” were the first studies within radiology in Serbia, and among the first publications of this type in the world.

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