Nikola Tesla -- His Life and Legacy

PBS/NOVA

Tesla's Early Years

Nikola Tesla was born a subject of the Austro-Hungarian Empire in 1856 in a mountainous area of the Balkan Peninsula known as Lika. His father Milutin and his mother Djuka were both Serbian by origin.

Tesla's father was a stern-but-loving Orthodox priest who was also a gifted writer and poet. At a young age, Tesla immersed himself in his father's library. Tesla's mother was a hard working woman of many talents who created appliances to help with home and farm responsibilities. One of these was a mechanical eggbeater. Tesla attributed all of his inventive instincts to his mother.

Tesla began his education at home and later attended gymnasium in Carlstadt, Croatia excelling in his studies along the way. An early sign of his genius, he was able to perform integral calculus in his mind, prompting his teachers to think he was cheating. During this period, young "Niko" saw a steel engraving of Niagara Falls. In his imagination, there appeared a huge water wheel being turned by the powerful cataract. He said to an uncle that he would go to America one day and capture energy in this way. 30 years later, he did exactly that. Despite his early creativity, Tesla did not begin to think of himself as an inventor until he was a young adult.

Passionate about mathematics and sciences, Tesla had his heart set on becoming an engineer but was "constantly oppressed" by his father's insistence that he enter the priesthood. At age 17, Tesla contracted cholera and craftily exacted an important concession from his father. The older Tesla promised his son that if he survived, he would be allowed to attend the renowned Austrian Polytechnic School at Graz to study engineering. Tesla's wish became a reality.

At the Polytechnic school Tesla began his studies in mechanical and electrical engineering. One day a physics teacher showed Tesla's class a new Gramme dynamo that by employing direct current could be used as both a motor and a generator. After watching it for a time, Tesla suggested it might be possible to do away with a set of inefficient sparking connections known as commutators. This, his amused professor said, would be like building a perpetual motion machine! Not even Tesla could hope to achieve such a feat. For the next several years, the challenge obsessed Tesla who instinctively knew that the solution lay in electric currents that alternated.

It wasn't until age 24 when Tesla was living in Budapest and working for the Central Telephone Exchange that the answer came to him.

"One afternoon -- which is ever present in my recollection -- I was enjoying a walk with my friend in the city park and reciting poetry. At that age, I knew entire books by heart word-for-word. One of these was Goethe's Faust. The Sun was just setting and reminded me of a glorious passage:

> The glow retreats, done is the day of toil;
> It yonder hastes, new fields of life exploring;
> Ah, that no wing can lift me from the soil
> Upon its track to follow, follow soaring!

As I uttered these inspiring words, the idea came like a flash of lightning and in an instant the truth was revealed. I drew with a stick on the sand the diagram shown 6 years later in my address before the American Institute of Electrical Engineers."

This was the invention of the **induction motor** -- a technological advance that would soon change the World.

Coming To America

Following his discovery in Budapest, Tesla was hired by electric power companies in Strasbourg and Paris to improve their DC generation facilities. In Germany and France, he attempted to interest investors in his concept for an AC motor but had no success. It was clear that in order to realize his idea, he would have to meet the greatest electrical engineer in the World -- Thomas Alva Edison.

At age 28, Nikola Tesla arrived in New York City and was shocked by what he discovered. "What I had left was beautiful, artistic and fascinating in every way. What I saw here was machined, rough and unattractive. America is a century behind Europe in civilization."

The Serbian immigrant had 4 cents in his pocket; some mathematical computations; a drawing of an idea for a flying machine; and a letter of introduction from Charles Batchelor, one of Edison's business associates in Europe.

Electricity was first introduced to New York in the late 1870s. Edison's incandescent lamp had created an astonishing demand for electric power. And his DC power station on Pearl Street in lower Manhattan was quickly becoming a monopoly. On the streets, single poles carried dozens of crooked crossbeams supporting sagging wires and the exposed electrical wiring was a constant danger. Unsuspecting children would scale the poles only to meet an untimely electrical demise. The residents of Brooklyn became so accustomed to dodging shocks from electric trolley tracks that their baseball team was called the Brooklyn Dodgers. In spite of the perils, wealthy New Yorkers rushed to have their homes wired -- the most important being the banker J.P. Morgan who had invested heavily in Edison.

It was into this state of affairs that the 6'4" immigrant from Eastern Europe entered Edison's office. Thrilled and terrified to meet his hero, Tesla handed Edison his letter of recommendation. It read: "My Dear Edison: I know two great men and you are one of them. The other is this young man!" Tesla proceeded to describe the engineering work he had done and his plans for an alternating current motor.

Edison knew little of alternating current and did not care to learn more about it. In short, AC power sounded like competition to Edison. But there was something different about Tesla and Edison immediately hired him to make improvements in his DC generation plants. Tesla claimed that Edison promised him $50,000 if he succeeded, perhaps thinking it an impossible undertaking. But the potential of so much money appealed mightily to the impoverished immigrant.

Both Tesla and Edison shared a common trait of genius in that neither of them seemed to need much sleep. Edison could go for days, taking occasional catnaps on a sofa in his office. Tesla claimed that his working hours at the Edison Machine Works were 10:30 a.m. till 5 a.m. the next day. Even into old age, Tesla said that he only slept 2-or-3 hours a night.

That's where the similarity ended. Tesla relied on moments of inspiration, perceiving the invention in his brain in precise detail before moving to the construction stage. Edison was a trial-and-error man who described invention as 5 percent inspiration and 95 percent perspiration. Edison was self-taught. Tesla had a formal European education. It was only a matter of time until their differences would lead to conflict.

Several months after Edison employed him, Tesla announced that his work was successfully completed. When Tesla asked to be paid, however, Edison seemed astonished. He explained that the offer of $50,000 had been made in jest. "When you become a full-fledged American, you will appreciate an American joke," Edison said. Shocked and disgusted, Tesla immediately resigned.

Word began to spread that a foreigner of unusual talent was digging ditches to stay alive. Investors approached Tesla and asked him to develop an improved method for arc lighting. Although this was not the opportunity he had hoped for, the group was willing to finance the Tesla Electric Light Company. The proud new owner set to work and invented a unique arc lamp of beautiful design and efficiency. Unfortunately, all of the money earned went to the investors and all that Tesla got was a stack of worthless stock certificates.

But his luck was about to change. Mr. A.K. Brown of the Western Union Company agreed to invest in Tesla's idea for an AC motor. In a small laboratory just a short distance from Edison's office, Tesla quickly developed all the components for the system of AC power generation and transmission that is used universally throughout the World today.

"The motors I build there," said Tesla, "were exactly as I imagined them. I made no attempt to improve the design but merely reproduced the pictures as they appeared to my vision and the operation was always as I expected."

The battle to produce his motor was over. But the struggle to introduce it commercially was only just beginning.

War of the Currents

In November and December of 1887, Tesla filed for 7 U.S. patents in the field of polyphase AC motors and power transmission. These comprised a complete system of generators, transformers, transmission lines, motors, and lighting. So original were the ideas that they were issued without a successful challenge and would turn out to be the most valuable patents since the telephone.

An adventurous Pittsburgh industrialist named George Westinghouse (inventor of railroad air brakes) heard about Tesla's invention and thought it could be the missing link in long-distance power transmission. He came to Tesla's lab and made an offer, purchasing the patents for $60,000 which included $5,000 in cash and 150 shares of stock in the Westinghouse Corporation. He also agreed to pay royalties of $2.50 per horsepower of electrical capacity sold. With more inventions in mind, Tesla quickly spent half of his newfound wealth on a new laboratory.

With the breakthrough provided by Tesla's patents, a full-scale industrial war erupted. At stake, in effect, was the future of industrial development in the United States and whether Westinghouse's alternating current or Edison's direct current would be the chosen technology.

It was at this time that Edison launched a propaganda war against alternating current. Westinghouse recalled:

> "I remember Tom [Edison] telling them that direct current was like a river flowing peacefully to the sea while alternating current was like a torrent rushing violently over a precipice. Imagine that! Why they even had a professor named Harold Brown who went around talking to audiences... and electrocuting dogs and old horses right on stage to show how dangerous alternating current was."

Meanwhile, a murderer was about to be executed in the first electric chair at New York's Auburn State Prison. Professor Brown had succeeded in illegally purchasing a used Westinghouse generator in order to demonstrate once-and-for-all the extreme danger of alternating current. The guinea pig was William Kemmler, a convicted ax-murderer, who died horribly on August 6, 1890 in "an awful spectacle, far worse than hanging." The technique was later dubbed "Westinghousing".

In spite of the bad press, good things were happening for Westinghouse and Tesla. The Westinghouse Corporation won the bid for illuminating The Chicago World's Fair, the first all-electric fair in history. The fair was also called the Columbian Exposition in celebration of the 400th Anniversary of Columbus discovering America. Up against the newly-formed General Electric Company (the company that had taken over the Edison Company), Westinghouse undercut GE's million-dollar bid by half. Much of GE's proposed expenses were tied to the amount of copper wire necessary to utilize DC power. Westinghouse's winning bid proposed a more efficient, cost-effective AC system.

The Columbian Exposition opened on May 1, 1893. That evening, President Grover Cleveland pushed a button and a hundred thousand incandescent lamps illuminated the fairground's neoclassical buildings. This "City of Light" was the work of Tesla, Westinghouse, and 12 new thousand-horsepower AC generation units located in the Hall of Machinery. In the Great Hall of Electricity, the Tesla polyphase system of alternating current power generation and transmission was proudly displayed. **[StealthSkater note: I cannot be sure, of course. But the above description makes me wonder if it provided inspiration for the "Doc Savage" adventure *"World's Fair Goblin"* doc pdf URL .]**

For the 27 million people who attended the fair, it was dramatically clear that the power of the Future was AC. From that point forward, more than 80 percent of all the electrical devices ordered in the United States were for alternating current.

Harnessing Niagara

The Niagara Falls Power Project was an act of pure technological optimism. Americans had dreamed of pressing the Falls into "an honest day's work" since the first pioneer sawmill had been built there in 1725. But schemes for extracting power had never been adequately conceived.

Since his childhood, Tesla himself had dreamed of harnessing the power of the great natural wonder. And in late 1893, his dream became a reality when Westinghouse was awarded the contract to create the powerhouse.

The contract came as a result of a failed competition spearheaded by the international Niagara Falls Commission. The commission -- charged with planning the power project -- had solicited proposals from experts around the World only to reject them all. The schemes ranged from a system using pneumatic pressure to one requiring ropes, springs, and pulleys. And there were proposals to transmit DC electricity (one endorsed by Edison). At the head of the commission was Lord Kelvin (the famous British physicist) who had been as opposed to alternating current as Edison until he attended the Chicago Exposition. Now a strong convert to AC, Kelvin and his commission asked Westinghouse to use alternating current to harness the power of the Falls.

The construction period was traumatic for engineers, mechanics, and workers. But it weighed most heavily on investors. Project backers included several of the wealthiest men in America and Europe, including J. P. Morgan, John Jacob Astor, Lord Rothschild, and W. K. Vanderbilt. After a 5-year nightmare of doubt and financial crises, the project approached completion. Tesla had not doubted the results for a moment. The investors, however, were not at all sure the system would work. While the machines were running smoothly in Tesla's 3-dimensional imagination, they were still unproved and expensive.

But the worries were unwarranted. When the switch was thrown, the first power reached Buffalo at midnight, November 16, 1896. The *Niagara Falls Gazette* reported that day: "The turning of a switch in the big powerhouse at Niagara completed a circuit which caused the Niagara River to flow uphill."

The first 1,000 horsepower of electricity surging to Buffalo was claimed by the street railway company. But already the local power company had orders from residents for 5,000 more. Within a few years, the number of generators at Niagara Falls reached the planned ten(10) and power lines were electrifying New York City. Broadway was ablaze with lights. The elevated, street railways, and subway system rumbled and even the Edison systems converted to alternating current.

But there were complications. Both the Westinghouse and General Electric corporations were morally and financially drained by the "War of the Currents". Years of litigation, the absorption of Edison's company and others by professional managers at GE, and the financial teetering of Westinghouse all contributed to a takeover. This was the era of the Robber Barons and one of the biggest was ready to make his move. J. P. Morgan -- hoping to bring all U.S. hydroelectric power under his control -- proceeded to manipulate stock market forces with the intention of starving out Westinghouse and buying the Tesla patents. Thanks in part to Tesla, this did not happen.

Westinghouse called on the inventor, pleading for an escape from the initial contract that gave Tesla generous royalties. In a magnanimous and history-making gesture, Tesla said he tore up the contract. He was, after all, grateful to the one man who had believed in his invention. And he was convinced that greater inventions lay ahead. The Westinghouse Electric Company was saved for future triumphs. Although sharing the glory, Tesla was left forever afterward in recurring financial difficulties.

High Frequency

After the success of Niagara, Tesla resumed his favorite work -- experimentation. Back at his laboratory on Grand Street in New York City, Tesla engrossed himself in the exploration of high-frequency electricity.

A number of scientific breakthroughs had already shed light on the high-frequency phenomenon. In 1873, James Clerk Maxwell in England had proven mathematically that light was electromagnetic radiation. Light was electricity vibrating at an extremely high frequency. In 1888, Heinrich Hertz of Germany confirmed experimentally that an electric spark propagates electromagnetic waves into space.

These discoveries identified radio waves and prompted intense speculation about new possibilities for Electricity.

Tesla began to search for a device that could transport him to this unexplored territory. He knew that higher frequencies would have many technical advantages. Lamps could glow brighter; energy could be transmitted more efficiently; and this would all be less dangerous because the energy could pass harmlessly across the body.

Tesla's initial goal was to approximate the frequency of sunlight and create lamps of revolutionary brightness and configuration. This, he hoped, would eliminate Edison's incandescent lamp which utilized only 5 percent of the available energy.

Tesla began his high-frequency investigations by building rotary AC generators that could run at higher speeds. But as he approached 20,000 cycles per second, the machines began to fly apart, leaving him far short of his goal. The answer came with a remarkable device still known today as a **Tesla coil**. Patented in 1891, this invention took ordinary 60-cycle per second household current and stepped it up to extremely high frequencies (into the hundreds of thousands of cycles per second). In addition to high frequencies, the coil could also generate extremely high voltages.

With high frequencies, Tesla developed some of the first neon and fluorescent illumination. He also took the first X-ray photographs. But these discoveries paled when compared to his discovery of November 1890 when he illuminated a vacuum tube wirelessly having transmitted energy through the air.

This was the beginning of Tesla's lifelong obsession -- **the wireless transmission of energy**.

Who Invented Radio?

With his newly created Tesla coils, the inventor soon discovered that he could transmit and receive powerful radio signals when they were tuned to resonate at the same frequency. When a coil is tuned to a signal of a particular frequency, it literally magnifies the incoming electrical energy through resonant action. By early 1895, Tesla was ready to transmit a signal 50 miles to West Point, New York..

But in that same year, disaster struck. A building fire consumed Tesla's lab, destroying his work.

The timing could not have been worse. In England, a young Italian experimenter named Guglielmo Marconi had been hard at work building a device for wireless telegraphy. The young Marconi had taken out the first wireless telegraphy patent in England in 1896. His device had only a 2-circuit system which some said could not transmit "across a pond". Later, Marconi set up long-distance demonstrations using a Tesla oscillator to transmit the signals across the English Channel.

Tesla filed his own basic radio patent applications in 1897. They were granted in 1900. Marconi's first patent application in America filed on November 10, 1900 was turned down. Marconi's revised applications over the next 3 years were repeatedly rejected because of the priority of Tesla and other inventors. The Patent Office made the following comment in 1903:

> Many of the claims are not patentable over Tesla patent numbers 645,576 and 649,621, of record, the amendment to overcome said references as well as Marconi's pretended ignorance of the nature of a "Tesla oscillator" being little short of absurd... the term "Tesla oscillator" has become a household word on both continents [Europe and North America].

But no patent is truly safe as Tesla's career demonstrates. In 1900, the Marconi Wireless Telegraph Company, Ltd. began thriving in the stock markets due primarily to Marconi's family connections with English aristocracy. British Marconi stock soared from $3 to $22 per share and the glamorous young Italian nobleman was internationally acclaimed. Both Edison and Andrew Carnegie invested in Marconi and Edison became a consulting engineer of American Marconi. Then,on December 12, 1901, Marconi for the first time transmitted and received signals across the Atlantic Ocean.

Otis Pond (an engineer then working for Tesla) said: "Looks as if Marconi got the jump on you." Tesla replied: "Marconi is a good fellow. Let him continue. He is using 17 of my patents."

But Tesla's calm confidence was shattered in 1904 when the U.S. Patent Office suddenly and surprisingly reversed its previous decisions and gave Marconi a patent for the invention of radio. The reasons for this have never been fully explained. But the powerful financial backing for Marconi in the United States suggests one possible explanation.

Tesla was embroiled in other problems at the time. But when Marconi won the Nobel Prize in 1911, Tesla was furious. He sued the Marconi Company for infringement in 1915 but was in no financial condition to litigate a case against a major corporation. It wasn't until 1943 (a few months after Tesla's death) that the U.S. Supreme Court upheld Tesla's radio patent number 645,576. The Court had a selfish reason for doing so. The Marconi Company was suing the United States Government for use of its patents in World War I. The Court simply avoided the action by restoring the priority of Tesla's patent over Marconi.

Race of Robots

Tesla wanted an extraordinary way to demonstrate the potential of his system for wireless transmission of energy (i.e., radio). In 1898 at an electrical exhibition in the recently completed Madison Square Garden, he made a demonstration of the World's first radio-controlled vessel. Everyone expected surprises from Tesla. But few were prepared for the sight of a small, odd-looking, iron-hulled boat scooting across an indoor pond (specially built for the display). The boat was equipped with (as Tesla described) "a borrowed mind".

"When first shown... it created a sensation such as no other invention of mine has ever produced," wrote Tesla. As happened fairly often with his inventions, many of those present were unsure how to react, whether to laugh or take flight. He had cleverly devised a means of putting the audience at ease, encouraging onlookers to ask questions of the boat.

For instance, in response to the question "What is the cube root of 64?", lights on the boat flashed 4 times. In an era when only a handful of people knew about radio waves, some thought that Tesla was controlling the small ship with his mind. In actuality, he was sending signals to the mechanism using a small box with control levers on the side.

Tesla's U.S. patent number 613,809 describes the first device anywhere for wireless remote control. The working model -- or "teleautomaton" -- responded to radio signals and was powered with an internal battery.

Tesla did not limit his method to boats but generalized the invention's potential to include vehicles of any sort and mechanisms to be actuated for any purpose. He envisioned one operator or several operators simultaneously directing 50 or 100 vessels or machines through differently tuned radio transmitters and receivers.

When a *New York Times* writer suggested that Tesla could make the boat submerge and carry dynamite as a weapon of war, the inventor himself exploded. Tesla quickly corrected the reporter: "You do not see there a wireless torpedo. You see there the first of a race of robots. Mechanical men which will do the laborious work of the human race."

Tesla's device was literally the birth of robotics although he is seldom recognized for this accomplishment. The inventor was trained in electrical and mechanical engineering and these skills merged beautifully in this remote-controlled boat. Unfortunately, the invention was so far ahead of its time that those who observed it could not imagine its practical applications.

Colorado Springs

By the end of the 1890s, Tesla had come to the conclusion that it might be possible to transmit electrical power without wires at high altitudes. There the air was thinner and therefore more conductive.

A friend and patent lawyer, Leonard E. Curtis, on being advised of Tesla's work, offered to find land and provide power for the research from the El Paso Power Company of Colorado Springs. The next supporter to come forward was Colonel John Jacob Astor. With $30,000 from Astor, the inventor prepared at once to move to Colorado and begin building a new experimental station near Pikes Peak. Joining Tesla were several assistants who were not fully informed of the inventor's plans.

Arriving at Colorado Springs in May 1899, Tesla went to inspect the acreage. It was some miles out in the prairie. He told reporters that he intended to send a radio signal from Pikes Peak to Paris but furnished no details.

In the midst of Colorado's own incredible electrical displays, Tesla would sit taking measurements. He soon found the Earth to be "literally alive with electrical vibrations." Tesla came to think that when lightning struck the ground, it set up powerful waves that moved from one side of the Earth to the other. If the Earth was indeed a great conductor, Tesla hypothesized that he could transmit unlimited amounts of power to any place on Earth with virtually no loss. But to test this theory, he would have to become the first man to create electrical effects on the scale of lightning.

The laboratory that rose from the prairie floor was both wired and weird, a contraption with a roof that rolled back to prevent it from catching fire, and a wooden tower that soared up 80 feet. Above it was a 142-foot metal mast supporting a large copper ball. Inside the strange wooden structure, technicians began to assemble an enormous Tesla coil, specially designed to send powerful electrical impulses into the Earth.

On the evening of the experiment, each piece of equipment was first carefully checked. Then Tesla alerted his mechanic Czito to open the switch for only 1-second. The secondary coil began to sparkle and crack and an eerie blue **corona** formed in the air around it.

Satisfied with the result, Tesla ordered Czito to close the switch until told to cease. Huge arcs of blue **electricity** snaked up and down the center coil. Bolts of man-made lightning more than a 100 feet in length shot out from the mast atop the station. Tesla's experiment burned out the dynamo at the El Paso Electric Company and the entire city lost power. The power station manager was livid and insisted that Tesla pay for and repair the damage.

For 9 months, Tesla conducted experiments at Colorado Springs. Though he kept a day-to-day diary that was rich in detail, the results of his experiments are not clear. One question has never been definitively answered: Did Tesla actually transmit wireless power at Pikes Peak?

There are some reports that he did transmit a signal several miles powerful enough to illuminate vacuum tubes planted in the ground. But this can be attributed to conductive properties in the ground at Colorado Springs.

Another approach pursued by Tesla was to transmit extra-low-frequency signals through the space between the surface of the Earth and the Ionosphere. Tesla calculated that the resonant frequency of this area was approximately 8-hertz. It was not until the 1950s that this idea was taken seriously and researchers were surprised to discover that the resonant frequency of this space was indeed in the range of 8-hertz.

A third approach for wireless power transmission was to transmit electrical power to the area 80-kilometers above the Earth known as the Ionosphere. Tesla speculated that his region of the atmosphere would be highly conductive and again his suspicions were correct. What he needed was the technical means to send electrical power to such a high altitude.

One night in his laboratory, Tesla noticed a repeating signal being picked-up by his transmitter. To his own amazement, he believed that he was receiving a signal from Outer Space. Tesla was widely ridiculed when he announced this discovery. But it is possible that he was the first man to detect radio waves from space. **[StealthSkater note: see doc pdf URL]**

A great deal of mystery still surrounds Tesla's work at Colorado Springs. It is not clear from his notes or his comments exactly how he intended to transmit wireless power. But it is clear that he returned back to New York City fully convinced that he could accomplish it.

Tower of Dreams

When Tesla returned from Colorado Springs to New York, he wrote a sensational article for *Century Magazine.* In this detailed futuristic vision, he described a means of tapping the Sun's energy with an antenna. He suggested that it would be possible to control the weather with electrical energy. He predicted machines that would make war an impossibility. And he proposed a global system of wireless communications.

To most people, the ideas were almost incomprehensible. But Tesla was a man who could not be underestimated.

The article caught the attention of one of the World's most powerful men -- J. P. Morgan. A frequent guest in Morgan's home, Tesla proposed a scheme that must have sounded like science-fiction. A "world system" of wireless communications to relay telephone messages across the ocean; to broadcast news, music, stock market reports, private messages, secure military communications, and even pictures to any part of the world. "When wireless is fully applied, the Earth will be converted into a huge brain capable of response in every one of its parts," Tesla told Morgan.

Morgan offered Tesla $150,000 to build a transmission tower and power plant. A more realistic sum would have been $1,000,000. But Tesla took what was available and went to work immediately. In spite of what he told his investor, Tesla's actual plan was to make a large-scale demonstration of electrical power transmission without wires. This turned out to be a fatal mistake.

For his new construction project, Tesla acquired land on the cliffs of Long Island Sound. The site was called **Wardenclyffe**. By 1901 the Wardenclyffe project was under construction, the most challenging task being the erection of an enormous tower rising 187 feet in the air and supporting on its top a 55-ton sphere made of steel. Beneath the tower, a well-like shaft plunged 120 feet into the ground. 16 iron pipes were driven 300 feet deeper so that currents could pass through them and seize hold of the Earth. "In this system that I have invented," Tesla explained, "it is necessary for the machine to get a grip of the Earth. Otherwise it cannot shake the Earth. It has to have a grip... so that the whole of this Globe can quiver."

As the tower construction slowly increased, it became evident that more funds were sorely needed. But Morgan was not quick to respond. Then on December 12, 1901, the World awoke to the news that Marconi had signaled the letter "S" across the Atlantic from Cornwall, England to Newfoundland. Tesla, unruffled by the accomplishment, explained that the Italian used 17 Tesla patents to accomplish the transmission. But Morgan began to doubt Tesla. Marconi's system not only worked; it was also inexpensive.

Tesla pleaded with Morgan for more financial support but the investor soundly refused. To make matters worse, the stock market crashed and prices for the tower's materials doubled. High prices combined with Tesla's inability to find enough willing investors eventually led to the demise of the project.

In 1905 after some amazing electrical displays, Tesla and his team had to abandon the project forever. The newspapers called it "Tesla's million-dollar folly."

Humiliated and defeated, Tesla experienced a complete nervous breakdown. "It is not a dream," he protested. "It is a simple feat of scientific electrical engineering, only expensive... blind, faint-hearted, doubting World."

Poet and Visionary

In 1909, Guglielmo Marconi was awarded a Nobel Prize for his development of radio. From this point on, the history books began to refer to him as "the Father of Radio." But in fact, radio had many inventors, not the least of which was Nikola Tesla. But Marconi was now a wealthy man and Tesla was penniless.

"My enemies have been so successful in portraying me as a poet and a visionary," said Tesla, "that I must put out something commercial without delay."

In 1912, Tesla tested a revolutionary new kind of turbine engine. Both Westinghouse Manufacturing and the General Electric Company had spent millions developing bladed turbine designs which were essentially powerful windmills in a housing. Tesla's design was something altogether different. In it, a series of closely-spaced discs were keyed to a shaft. With only one moving part, Tesla's design was of ideal simplicity (much like the AC motor he had invented years earlier). Fuels such as steam or vaporized gas were injected into the spaces between the discs spinning the motor at a high rate-of-speed. In fact, the turbine operated at such high revolutions to the minute that the metal in the discs distorted from the heat. Eventually, Tesla abandoned the project.

With no great prospects to speak of, Tesla began visiting the local parks more often, rescuing injured pigeons, and often taking them back to his hotel room to nurse them. Years later when he lived at the Hotel New Yorker, he had the hotel chef prepare a special mix of seed for his pigeons which he hoped to sell commercially. Naturally, this prompted speculation about his mental well-being. His aversion to

germs also heightened in this period and he began to wash his hands compulsively and would eat only boiled foods.

In spite of his growing eccentricity, fruitful ideas continued to spring from his imagination. At the beginning of World War I, Tesla described a means for detecting ships at sea. His idea was to transmit high-frequency radio waves that would reflect off the hulls of vessels and appear on a fluorescent screen. The idea was too far ahead of its day. But it was one of the first descriptions of what we now call **radar**. Tesla was also the first to warn of an era when flying vehicles without wings could be remotely controlled to land with an explosive charge on an unsuspecting enemy.

In 1922 at 65 years of age, Tesla still dressed impeccably. Yet friends observed that his clothing like his scientific theories now appeared old-fashioned. He managed to make a living by working as a consulting engineer. But more often than not, he delivered plans that his clients deemed impractical.

During this period, Tesla spoke out vehemently against the new theories of Albert Einstein, insisting that energy is not contained in matter but in the space between the particles of an atom.

In the late 1920s, Tesla began to develop a friendship with George Sylvester Viereck, a well-known German poet and mystic. Though nearly a recluse, Tesla occasionally attended dinner parties held by Viereck and his wife. Competitive by nature, Tesla wrote a strange poem that he dedicated to his friend. It was called "Fragments of Olympian Gossip" and poked vitriolic fun at the scientific establishment of the day.

Tesla's business with the U. S. Patent Office was still not finished. In 1928 at the age of 72, he received his last patent -- number 6,555,114, "Apparatus For Aerial Transportation." This brilliantly-designed flying machine resembled both a helicopter and an airplane. According to the inventor, the device would weigh 800 pounds. It would rise from a garage, a roof, or a window as desired and would sell at $1,000 for both military and consumer uses. This novel invention was the progenitor of today's tiltrotor or **VSTOL** (vertical short takeoff and landing) plane. Unfortunately, Tesla never had the money to build a prototype.

A Weapon To End War

Tesla inherited from his father a deep hatred of war. Throughout his life, he sought a technological way to end warfare. He thought that war could be converted into "a mere spectacle of machines."

In 1931, Tesla announced to reporters at a press conference that he was on the verge of discovering an entirely new source of energy. Asked to explain the nature of the power, he replied: "The idea first came upon me as a tremendous shock... I can only say at this time that it will come from an entirely new and unsuspected source."

War clouds were again darkening Europe. On July 11, 1934 the headline on the front page of the *New York Times* read "TESLA, AT 78, BARES NEW **'DEATH BEAM'**. " The article reported that the new invention "will send concentrated beams of particles through the free air of such tremendous energy that they will bring down a fleet of 10,000 enemy airplanes at a distance of 250 miles..." Tesla stated that the death beam would make war impossible by offering every country an "invisible Chinese wall."

The idea generated considerable interest and controversy. Tesla went immediately to J. P. Morgan, Jr. in search of financing to build a prototype of his invention. Morgan was unconvinced. Tesla also attempted to deal directly with Prime Minister Neville Chamberlain of Great Britain. But when

Chamberlain resigned upon discovering that he had been out-maneuvered by Hitler at Munich, interest in Tesla's anti-war weapon eventually collapsed.

By 1937, it was clear that war would soon break out in Europe. Frustrated in his attempts to generate interest and financing for his "peace beam", he sent an elaborate technical paper (including diagrams) to a number of Allied nations including the United States, Canada, England, France, the Soviet Union, and Yugoslavia. Titled "New Art of Projecting Concentrated Non-Dispersive Energy Through Natural Media," the paper provided the first technical description of what is today called a **charged particle beam weapon**.

What set Tesla's proposal apart from the usual run of fantasy "death rays" was a unique vacuum chamber with one end open to the atmosphere. Tesla devised a unique vacuum seal by directing a high-velocity air stream at the tip of his gun to maintain "high vacua". The necessary pumping action would be accomplished with a large Tesla turbine.

Of all the countries to receive Tesla's proposal, the greatest interest came from the Soviet Union. In 1937, Tesla presented a plan to the Amtorg Trading Corporation (an alleged Soviet arms front in New York City). 2 years later in 1939, one stage of the plan was tested in the USSR and Tesla received a check for $25,000.

Tesla hoped that his invention would be used for purely defensive purposes and thus would become an anti-war machine. His system required a series of power plants located along a country's coast that would scan the skies in search of enemy aircraft. Since the beam was projected in a straight line, it was only effective for about 200 miles (the distance of the curvature of the Earth).

Tesla also contemplated peacetime applications for his particle beam, one being to transmit power without wires over long distances. Another radical notion he proposed was to heat up portions of the upper atmosphere to light the sky at night (i.e., a man-made Aurora Borealis).

Whether Tesla's idea was ever taken seriously is still a matter of conjecture. Most experts today consider his idea infeasible although his death beam bears an uncanny resemblance to the charged-particle beam weapon developed by both the United States and the Soviet Union during the Cold War. Nonetheless, Tesla's dream for a technological means to end war seems as impossible now as it did when he proposed the idea in the 1930s.

The Missing Papers

One of the more controversial topics involving Nikola Tesla is what became of many of his technical and scientific papers after he died in 1943. Just before his death at the height of World War II, he claimed that he had perfected his so-called "death beam". So it was natural that the FBI and other U.S. Government agencies would be interested in any scientific ideas involving weaponry. Some were concerned that Tesla's papers might fall into the hands of the Axis powers or the Soviets.

The morning after the inventor's death, his nephew Sava Kosanovic´ hurried to his uncle's room at the Hotel New Yorker. He was an up-and-coming Yugoslav official with suspected connections to the communist party in his country. By the time he arrived, Tesla's body had already been removed and Kosanovic´ suspected that someone had already gone through his uncle's effects. Technical papers were missing as well as a black notebook that he knew Tesla kept. A notebook with several hundred pages, some of which were marked "Government".

P.E. Foxworth, assistant director of the New York FBI office, was called in to investigate. According to Foxworth, the Government was "vitally interested" in preserving Tesla's papers. 2 days after Tesla's death, representatives of the Office of Alien Property went to his room at the New Yorker Hotel and seized all his possessions. [Samples of Documents from Tesla's FBI File => http://www.pbs.org/tesla/ll/ll_mispapers.html]

Dr. John G. Trump, an electrical engineer with the National Defense Research Committee of the Office of Scientific Research and Development, was called in to analyze the Tesla papers in OAP custody. Following a 3-day investigation, Dr. Trump concluded:

> "His [Tesla's] thoughts and efforts during at least the past 15 years were primarily of a speculative, philosophical, and somewhat promotional character often concerned with the production and wireless transmission of power. But did not include new, sound, workable principles or methods for realizing such results."

Just after World War II, there was a renewed interest in beam weapons. Copies of Tesla's papers on particle beam weaponry were sent to Patterson Air Force Base in Dayton, Ohio. An operation code-named "**Project Nick**" was heavily funded and placed under the command of Brigadier General L.C. Craigie to test the feasibility of Tesla's concept. Details of the experiments were never published and the project was apparently discontinued.

But something peculiar happened. The copies of Tesla's papers disappeared and nobody knows what happened to them.

In 1952, Tesla's remaining papers and possessions were released to Sava Kosanovic´ and returned to Belgrade, Yugoslavia where a museum was created in the inventor's honor. For many years under Tito's communist regime, it was extremely difficult for Western journalists and scholars to gain access to the Tesla archive in Yugoslavia even then they were allowed to see only selected papers. This was not the case for Soviet scientists who came in delegations during the 1950s. Concerns increased in 1960 when Soviet Premier Khrushchev announced to the Supreme Soviet that "a new and fantastic weapon was in the hatching stage."

Work on beam weapons also continued in the United States. In 1958, the Defense Advanced Research Projects Agency (DARPA) initiated a top-secret project code-named "Seesaw" at Lawrence Livermore Laboratory to develop a charged-particle beam weapon. More than 10 years and 27 million dollars later, the project was abandoned "because of the projected high costs associated with implementation as well as the formidable technical problems associated with propagating a beam through very long ranges in the atmosphere." Scientists associated with the project had no knowledge of Tesla's papers.

In the late 1970s, there was fear that the Soviets may have achieved a technological breakthrough. Some U.S. defense analysts concluded that a large beam weapon facility was under construction near the Sino-Soviet border in Southern Russia.

The American response to this "technological surprise" was the Strategic Defense Initiative announced by President Ronald Reagan in 1983. Teams of government scientists were urged to "turn their great talents now to the cause of mankind and world peace, to give us the means of rendering these nuclear weapons impotent and obsolete."

Today after a half-century of research and billions-of-dollars of investment, the SDI program is generally considered a failure and there is still no realistic means of defense against a nuclear missile attack.

For many years, scientists and researchers have sought for Tesla's missing papers with no apparent success. It is conceivable that if Nikola Tesla knew a means for accurately projecting lethal beams of energy through the atmosphere, he may have taken it to the grave with him.

Inside the Lab

http://www.pbs.org/tesla/ins/index.html

AC Motor

AC motors can operate without any moving electrical contacts and without first converting alternating current (delivered by the power company) to direct current. Tesla patented 20 distinctive kinds of AC motors and generators within 2 years of his first along with many patents for improved motor components and power supply.

Anatomy of a Motor

From an idealized viewpoint, any electrical motor consists of 2 sets of magnets (one set stationary, one set free to move) placed in special geometric relation to one another.

For most practical motors, electromagnets are employed. They don't weaken as permanent magnets do but must be energized with currents to have any magnetic force at all. T hese electromagnets are generally mounted in 2 rings (one set within the other) and connected up so that polarities will alternate north-south in each ring of pole projections. As to which set of magnets is to move (the rotor) and which to stand still (the stator), either will do. Though most familiar motors spin the inner array, some other designs rotate the entire outer circumference around a stationary center.

Magnets (even electromagnets) have no natural need to keep moving. A rotor with 12 sets of poles mounted on a shaft so as to nearly contact 12 sets of surrounding stator windings would move itself just enough to tug attracting North-South pairs into closest alignment. And there the arrangement would sit humming quietly, wasting electricity, and going nowhere.

To become a motor, the useless device imagined above must constantly reverse the North-South polarity of its electromagnets. We'll suppose in a particular motor the rotor poles remain constant while the stator's switch constantly. Then the rotor's unchanging poles cannot find a resting place. Each is pulled a little distance toward an opposite pole only to have it reverse just as the 2 poles reach alignment. The rotor pole is then repelled, sent in the direction of the next stator pole, which happens, moreover, to be rebuilding its field at the attractive polarity. It's an electrical con game, bait and switch, taking place many times each second that makes a motor turn.

AC and DC Motors

AC motors before Tesla were rare laboratory devices. Curiosities. They never ran smoothly, perhaps because a good design needed to anticipate and utilize the rather more complex, dynamic rules that govern currents and fields in AC circuits.

Direct current was the name of the game prior to Tesla. Yet direct current motors have one obvious drawback. Reversing current direction through magnet windings can happen only with some sort of switching that swaps current direction end for end. In practice, this is normally done by applying power through a pair of stubby contacts (called "brushes") that ride against the spinning rotor shaft, against a ring of contacts (the "commutator"). The commutator thus is always rotating its connections with the brushes, sending current through the rotor windings first in one direction and then the other.

Tesla's Invention

What Tesla conceived is essentially this. An alternating current fed to stator windings would create poles that reversed themselves without any mechanical aid. Though the stator remains motionless, its fields are in effect whirling around its interior from one pole face to the next.

He understood as well that no physical power connection need be applied to the rotor. Rotor poles might be made to generate their currents by induction from the stator fields. A tricky proposition in 1888 because the conditions of voltage, current, and field must be choreographed very closely.

AC motors proved both durable and adaptable. Within the space of 2 years, Tesla had patented over 20 useful modifications of his new motors. To start up under heavy loads, to run at variable speed, or at constant speed, or with polyphase power supply to mention a few.

The great advantage of polyphase motors is for a given number of poles, a smoother, more intense whirling field. Such motors in myriad forms launched the electrical age of heavy industry. A somewhat more modest lineage of AC motors has powered most of the familiar appliances of 20th Century life from refrigerators to coffee grinders.

Tesla Coil

The Tesla coil transforms an input voltage into brief pulses of extremely high voltages. Tesla's largest coil built at his Colorado Springs lab in 1899 was 52 feet in diameter and generated pulses as high as 12MV. This invention was patented as part of a high-frequency lighting system.

To investigate the electrical realm of high-frequency and high-voltage, Tesla invented an apparatus that pushed the limits of electrical understanding. None of the circuit's typical components were unknown at the time. But its design and operation together achieved unique results. Not the least because of Tesla's masterful refinements in construction of key elements -- most particularly of a special transformer or coil which is at the heart of the circuit's performance.

Such a device first appeared in Tesla's US patent No. 454,622 (1891) for use in new, more efficient lighting systems. In its basic form, the circuit calls for a power supply, a large capacitor, the coil (transformer) itself, and adjustable spark-gap electrodes. Why these components and what do they accomplish?

Oscillators

Capacitors (or condensers) and inductors (or coils) are, electrically-speaking, somewhat opposite in operation. Whereas current builds quickly in a capacitor as it charges up, voltage lags. In an inductor, voltage is felt immediately while current is retarded as it works against the magnetic field its own passage builds in the coil.

If a coil and condenser are sized and selected to act with exactly opposite timing -- with voltage peaking in the coil just as it reaches a minimum in the capacitor -- then the circuit may never reach an electrically quiet stable state. A bit like the sloshing of water back-and-forth in a tub, current and voltage can be made to chase each other back-and-forth from end-to-end of the circuit. (An oscillator of this kind is often called a "tank circuit".)

Spark Gaps

To set his oscillator "ringing", Tesla employed sudden discharges (sparks) across an adjustable gap between 2 electrodes. Voltage on a capacitor builds until it reaches a level at which air in the gap breaks down as an insulator. (Precision screws set the gap clearance so that a larger or smaller gap selects a larger or smaller breakdown voltage.)

The initial impulse is very powerful. All the energy stored over several microseconds is released in a rush and that impulse is itself transformed to a somewhat higher voltage in passing from the primary coil windings to those of its secondary. This, of course, completes but a single cycle in the circuit's operation. The air gap restores itself as an insulator and the capacitor begins to charge until it reaches a breakdown value once again. The whole process can repeat itself many thousand times per second.

The transformer's secondary is rather special too, designed by Tesla to react quickly to a sudden energy spike and -- most importantly -- to concentrate voltage at one end as a standing wave. Its length is calculated so that wave crests as they reach the end and are reflected back, meet, and exactly reinforce the waves behind them. The net effect is a wave -- a voltage peak -- that appears to stand still.

Applications

If (as happened in practice) Tesla made an antenna of the high-voltage end of his secondary, it became a powerful radio transmitter. In fact, in the early decades of radio, most practicable radios utilized Tesla coils in their transmission antennas. Tesla himself used larger or smaller versions of his invention to investigate fluorescence, X-rays, radio, wireless power, biological effects, and even the electromagnetic nature of the Earth and its atmosphere.

Today, high-voltage labs often operate such devices and amateur enthusiasts around the World build smaller ones to create arcing, streaming electrical displays. It is not difficult to reach a quarter million volts. (One of the very first particle accelerator designs by Rolf Wideroe in 1928 generated its high voltage in a Tesla coil.) The coil has become a commonplace in electronics, used to supply high voltage to the front of television picture tubes, in a form known as the "flyback transformer".

Radio

In 1895, Tesla began experimentally monitoring the radio emissions of his high-frequency generators, first picking up signals around New York City and later 30 miles up the Hudson River. Though Marconi was given credit for inventing radio, the U.S. Supreme Court later recognized (though not until 1943) Tesla's patent as having priority over Marconi's.

Fundamentals of Radio

In the usual sense, radio refers to equipment used to send or receive electromagnetic waves in the range of frequencies lying more-or-less between 1-Hertz and a few Gigahertz.

Electromagnetic radiation occurs in wave form. That is, in a train of regularly rising and falling strengths. Distance from one crest to the next makes up one wavelength. In an ordinary AM broadcast signal (say 1000 kHz on your AM dial), wave crests are spaced at about 969 feet apart. The number of crests going by in one second is called the "frequency" of the wave. Thus if the speed of a wave is known (it's light speed, of course, for radio waves), then wavelength and frequency may be calculated one from the other according to the formula **v = fw** where **v** stands for velocity, **f** for frequency, and **w** for wavelength.

The height of a wave is its amplitude. Usually that's expressed in volts for a radio wave. Common sense suggests that for waves of the same amplitude, those of higher frequency, more of them arriving in each second, are more intense, more powerful. Indeed, this is the case. A single gamma ray (extremely high in frequency) packs a concentrated wallop while a wave of energy spread out in time across longer wavelengths doesn't knock things apart.

Early Radio Concepts and Equipment

Radio communication requires (at the very least) a transmitter that produces, amplifies, and radiates power at a useful radio frequency while at the same time incorporating some kind of information into its signal and a receiver that can detect the selected frequency, separate the signal's information content, and present it to a recipient.

Once Physics had advanced far enough to understand and describe electromagnetic waves, the biggest hurdle for practical use lay in achieving sufficiently high frequencies and voltages for radio transmission. Tesla obtained both with his versatile resonant and "magnifier" coils (Tesla coils). Getting information into-and-out of a radio wave remained, however, a rather clumsy process until the development of electronic vacuum tubes (most notably Lee De Forest's triode in 1906).

For a decade-or-two after radio had become an accomplished fact, signals worked more-or-less like Morse dots and dashes (either 'on' or 'off'). A train of pulses separated by intervals made up the message. To know whether a signal was present or not, early receivers often relied on devices called "coherers". In effect, just switches that turned 'on' when a pulse excited an antenna and had to reset themselves before the next pulse arrived. No one ever invented a coherer that was really satisfactory including Tesla. But in his visionary way, he solved another problem in communications whose implications reach right through modern computing and encryption techniques.

Tesla's Individualization

Tesla understood immediately from the construction of the first radio transmitter that a confusing welter of signals would soon cover the World. With this in mind, he invented circuits that would respond only when a preselected set of frequencies were detected at the same time or in a specific sequence. A sender, thereby, could feel assured that messages would be received only at their intended destinations and would remain identifiable against a noisy background of unrelated radio traffic.

His designs for "individualization" (Tesla's term) operate in the same way (indeed they introduced the principle) as logic gates in computer circuitry. And the idea of breaking up signals, moving them around in frequency or time, lies at the heart of present-day communications security.

Remote Control

Tesla described his radio-controlled boat as the first "teleautomaton". The first of many robots that would serve humankind. In 1898, an astonished group of potential investors watched Tesla demonstrate his remote-control boat at Madison Square Garden in New York City. Tesla's radio control system was patented that same year.

A Revolutionary Demonstration

In Madison Square Garden at the Electrical Exhibition of 1898, Tesla staged a scientific tour de force -- a demonstration completely beyond the generally accepted limits of technology. His invention -

- covered in patent No. 613,809 (1898) -- took the form of a radio-controlled boat. It was a heavy, low-lying, steel craft about 4 feet long.

Inasmuch as radio hadn't been officially patented yet (Tesla's basic radio patent was filed in September 1897 but granted in March 1900), examiners from the U.S. Patent Office were reluctant to recognize improbable claims made in the application "Method of and Apparatus for Controlling Mechanism of Moving Vessels or Vehicles." Confronted with a working model, however, examiners quickly issued approval.

In fact, Tesla had been walking around New York City since 1895 picking up radio signals generated in various high-frequency experiments. He had received them as far as 30 miles away at West Point. With the invention or improvement of several more control elements, he was able in short time to put them to use.

The Boat

Tesla's tub-like craft powered itself. Tthere were several large batteries on board. Radio signals controlled switches which energized the boat's propeller, rudder, and scaled-down running lights. Simple enough in concept but quite difficult to accomplish with existing devices. Even registering the arrival of a radio signal pulse taxed the rudimentary technology.

Tesla invented a new kind of "coherer" (a radio-activated switch) for this purpose. It was essentially a canister with a little metal oxide powder in it. The powder orients itself in the presence of an electromagnetic field (like radio waves) and becomes conductive. If the canister is flipped over after the pulse's passage, the powder is restored to a random nonconductive state.

Tesla contrived for a number of things to happen when the coherer conducted, most importantly for a disk bearing several differently organized sets of contacts to advance itself one step. Thus if the contacts had previously connected the combination "right rudder/propeller forward full/light off", the next step might combine "rudder center/propeller stop/lights on". And with the aid of a few levers, gears, springs, and motors all would be accomplished, including a final step, flipping the coherer over so that it was ready to receive the next instruction.

Applications

The World of 1898 had little understanding or use for Tesla's brilliant idea. Though he rather darkly imagined a military clamor for such things as radio-guided torpedoes, Government interest did not materialize. (In one of history's curious footnotes, Tesla's good friend Mark Twain wrote immediately to say he was anxious to represent Tesla in the sale of this "destructive terror which you have been inventing" to England and Germany.) The Navy did finance some trials in 1916. But the money went to one of Tesla's competitors. He remarked bitterly he could find no listeners until his patent had expired.

Tesla's fears (and Twain's business hopes) were misplaced. The World's military establishments discovered many destructive terrors. But radio-controlled devices didn't number among them in any significant way until late in the 20th Century with refinements in rocketry and guided bombs. Radio control remained a novelty -- an exciting field for experimentalists and specialists -- until the launching of the Space Age and the orbiting of myriad commercial and military satellites, all under remote control.

Improved Lighting

Tesla's high-frequency, high-voltage lighting produced brighter, more efficient light with less heat. At the 1893 Chicago World's Fair, he displayed his own phosphorescent lighting powered without wires by high-frequency fields. A first.

Early Lighting

The various inventors of early electric lights knew essentially of 2 ways to produce illumination. By running currents through wires or fibers until they glowed or discharging arcs between electrodes.

Arcs have never been suitable for general lighting purposes although they are intense sources. As to filaments, most materials don't behave well when heated near their melting points. They will oxidize unless surrounded by vacuum or inert gas. And they destroy themselves through internal stress.

Discovering durable filaments, however, does not solve a deeper problem in the physics of incandescent bodies. Which is to say they radiate a broad spectrum of energies (or frequencies). In the case of a common 60-watt bulb, no more than a few percent of the total radiated energy is in the light-frequency range. Most of the remainder is lost as heat. It would be far more efficient to excite electrons (which are responsible for all the emissions) more selectively instead of heating everything up until there's enough brightness to read by.

It had occurred to many early investigators of Electricity (when its properties and nature were still quite puzzling) to run currents through or into substances just to see what happened. As improved vacuum pumps, better glass manufacture, and higher-frequency sources were invented, the search moved away from brute incandescent effects. Alexandre-Edmond Becquerel was perhaps the first to collide a tiny stream of electrons (inside an evacuated tube) with a fluorescent coating, resulting in a relatively cold glow (1859). Fluorescent substances emit light immediately when excited by high voltage or ultraviolet energy.

Tesla's Inventions and Innovations

Credit for the first practical phosphorescent lamp belongs to Tesla. Phosphorescent substances are slower to emit light than fluorescent ones and they continue to glow for some time after the power is turned off.

Tesla's earliest lighting inventions had operated as conventional filament or arc devices but with high-frequency currents supplying power. As he quickly discovered, such currents could be made to bring diffuse gases to incandescence or cause light emission in various solid materials. His innovations in this field -- though influential and disclosed in a series of celebrated lectures -- were seldom patented.

Inasmuch as Tesla created for himself more powerful apparatus to operate at higher frequency and voltage than was available to anyone else, he was capable by 1890 of generating fields that would light up -- without any wires -- phosphorescent tubes across his laboratory. (His assistants recall these lamps strewn casually around the lab and working by their eerie ***green*** glow.) The energy is just long wavelength radio from Tesla's high-frequency generators. Though in this case, the signal is very strong. Strong enough to be useful as **power** rather than as a means of communication.

His first demonstrations of wireless power (presented always with superb showmanship) left the electrical profession agog. And the general public -- exposed to these mysteries at Tesla's lighting exhibit in the Columbian Exposition of 1893 -- came away with the impression that an age of scientific miracles was dawning.

Further Lighting Developments

It's easy to understand the fascination pioneers such as Becquerel, Tesla, Wilhelm Roentgen, P.A. Lenard, and J.J. Thompson felt in their personal work with electromagnetism inside curiously shaped glass worlds. New lighting was only the first result.

In 1897, Thompson identified the streaming "cathode rays" responsible for so many diverse effects as electrons. At ever-higher energies where electrons occasionally run into nuclei, Roentgen and Tesla found electrons were jettisoning very powerful photons indeed called X-rays. And John Fleming discovered a useful way of controlling electric currents inside a vacuum tube (the first electronic diode; 1904), inaugurating modern electronics.

"Tesla Tries To Prevent World War II"

(The unpublished Chapter 34 of Prodigal Genius by John J. O'Neill
http://www.pbs.org/tesla/res/res_art12.html

When Tesla was talking as a scientist, he was opposed to wars on moral, economic, and all practical and theoretical grounds. But like most scientists, when he stopped thinking as a scientist and let his emotions rule his thoughts, he found exceptions in which he felt some wars and situations were justifiable.

As a scientist, he was unwilling to have the discoveries of scientists applied to the purposes of war makers. But when in the emotional phase of his nature took the ruling position, he was then willing to apply his genius to devising measures that would prevent wars by supplying protective devices. This attitude is exemplified in the following statement which he prepared in the 1920s but did not publish:

> "At present, many of the ablest minds are trying to devise expedients for preventing a repetition of the awful conflict which is only theoretically ended and the duration and main issues of which I correctly predicted in an article printed in the *Sun* of December 20, 1914. The League is not a remedy but -- on the contrary -- in the opinion of a number of competent men may bring about results just the opposite.
>
> "It is particularly regrettable that a punitive policy was adopted in framing the terms of peace because a few years hence it will be possible for nations to fight without armies, ships or guns, by weapons far more terrible, to the destructive action and range of which there is virtually no limit. Any city at any distance whatsoever from the enemy can be destroyed by him and no power on Earth can stop him from doing so. If we want to avert an impending calamity and a state of things which may transform this globe into an inferno, we should push the development of flying machines and wireless transmission of energy without an instant's delay and with all the power and resources of the nation."

Tesla saw preventative possibilities in his new invention which embodied "death ray" characteristics and which was made several years after the foregoing statement was written. He saw it providing a curtain of protection which any country (no matter how small) could use as a protection against invasion. While he might offer it as a defensive weapon, however, there would be nothing to stop military men from using it as a weapon of offense [1].

While I did not know the nature of Tesla's plan, I was convinced that it did embody many discoveries that would be of commercial value. And these were the angles he should seek to develop. I felt that if he could be induced to develop some minor phase of his work that would have immediate

commercial use, he could derive an income from it which would enable him to proceed with his more elaborate plans. To this end, I sought to gain some insight into his thoughts that would enable me to get a practical plan into operation. This was no secret to Tesla and he successfully parried every thrust I made.

The clearest conception I got (and that was largely from scattered remarks and by making deductions from them) concerned a possible manner in which one phase of his curtain of protection might operate. This was a "war" angle and as such it did not interest me. But since it involved "**lightning balls**" or "**fireballs**", I was very curious. Fireballs had always fascinated me and I had read everything I could lay my hands on about them.

A "fireball" is a strange phenomenon associated with lightning. Some of the energy of the lightning stroke appears to become locked into a ball-shaped structure which may be of any size from a couple-of-inches to a foot in diameter. It looks like a perfect sphere, brightly incandescent and floats like a bubble, being easily carried by air currents. They may last for a short time from a fraction-of-a-second to many seconds. In this interval during which they stay fairly close to the ground, they may come close to many objects without damaging them or being damaged by them. Suddenly for no known reason, the ball explodes doing as much damage as a bomb if close to structures and no damage if in the open.

The fireball looked to me like a gigantically-enlarged model of the tiny electron (one of the building blocks of matter) which acts as if it were just a spherical area of space in which an amount of energy was crystallized to give it structure. I felt that if it were possible to discover how a large amount of energy was stored in this fairy bubble structure of a fireball, a new insight might be gained into the structure of the electron and other fundamental particles of matter. Also this method of storing energy could be applied to a thousand useful purposes.

When I approached Tesla with pleas along this line to develop this possible phase of his discovery, he would evade direct reply by indulging in a not-always tolerant lecture on my gullibility in believing theories about the complex structure of the atom. While he had in earlier years discussed some of his experiences with fireballs in his laboratory at Colorado Springs and explained his theory of their formation, he would not in later years permit himself to be drawn into a discussion of them as a possible part of his system.

This, of course, made me suspicious that the clue was "hot". But I could be completely wrong in my conclusions. Tesla was very quick in detecting my technique when I sought to narrow the field down by trying to get him to deny statements when he was adamant to direct questions.

Tesla became familiar with the destructive characteristics of fireballs in his experiments at Colorado Springs in 1899. He produced them quite by accident and saw them (more than once) explode and shatter his tall mast and also destroy apparatus within his laboratory. The destructive action accompanying the disintegration of a fireball, he declared, takes place with inconceivable violence.

He studied the process by which they were produced. Not because he wanted to produce them but in order to eliminate the conditions in which they were created. It is not pleasant, he related, to have fireballs explode in your vicinity for they will destroy anything they come in contact with.

It will be necessary to reconstruct his statements from very fragmentary notes and a long-distance memory.

Parasitic oscillations or circuits within the main circuit were a source of danger from this cause. Points of resistance in the main circuits could result in minor oscillating circuits between terminals or

between 2 points of resistance and these minor circuits would have a very much higher period of oscillation than the main circuit and could be set into oscillation by the main current of lower frequency.

Even when the principle oscillating circuit was adjusted for the greatest efficiency of operation by the diminution of all sources of losses, the fireballs continued to occur but these were due to stray high frequency charges from random earth currents.

From these experiences, it became apparent that the fireballs resulted from the interaction of 2 frequencies -- a stray higher frequency wave imposed on the lower frequency free oscillations of the main circuit.

As the free oscillation of the main circuit builds up from the zero point to the quarter-wave length node, it passes through various rates of change. In a current of shorter wavelength, the rates of change will be steeper. When the 2 currents react on each other, the resultant complex will contain a wave in which there is an extremely steep rate of change and for the briefest instant, currents may move at a tremendous rate at the rate of millions of horsepower.

This condition acts as a trigger which may cause the total energy of the powerful longer wave to be discharged in an infinitesimally small interval of time and at a proportionally tremendously great rate of energy movement which cannot confine itself to the metal circuit and is released into surrounding space with inconceivable violence.

It is but a step from learning how a high frequency current can explosively discharge a lower frequency current to using the principle to design a system in which these explosions can be produced by intent. The following process appears a possible one. But no evidence is available that it is the one Tesla evolved.

An oscillator (such as he used to send power wirelessly around the Earth at Colorado Springs) is set in operation at a frequency to which a given warship is resonant. The complex structure of a ship would provide a great number of spots in which electrical oscillations will be set up of a much higher frequency than those coursing through the ship as a whole. These parasite currents will react on the main current causing the production of fireballs which by their explosions will destroy the ship, even more effectively than the explosion of the magazine which would also take place. A second oscillator may be used to transmit the shorter wavelength current.

Somewhat later, I learned the reason for Tesla's reticence to discuss the details. This came shortly after Stanley Baldwin replaced Neville Chamberlin as Prime Minister of Great Britain.

Tesla revealed that he had carried on negotiations with Prime Minister Chamberlin for the sale of his ray system to Great Britain for $30,000,000 on the basis of his presentation that the device would provide complete protection for the British Isles against any enemy approaching by sea or air and would provide an offensive weapon to which there was no defense. He was convinced, he declared, of the sincerity of Mr. Chamberlin and his intent to adopt the device as it would have prevented the outbreak of the then threatening war and would have made possible the continuation (under the duress which this weapon would have made possible) of the working agreement involving France, Germany and Britain to maintain the status quo in Europe.

When Chamberlin failed at the Munich conference to retain this state of European equilibrium, it was necessary to get rid of Chamberlin and install a new Prime Minister who could make the effort to shift one corner of the triangle from Germany to Russia. Baldwin found no virtue in Tesla's plan and preemptorially ended negotiations.

Tesla was greatly disappointed by the collapse of his negotiations with the British Government. With it, there collapsed his hopes of providing a demonstration of his most recent and -- what he considered -- his most important discoveries. He did not, however, dwell on the subject. Beyond the single conversation, he did not mention the matter again. He did not get another chance to finance the demonstration of these discoveries.

During the period in which the negotiations were being carried on, Tesla declared that efforts had been made to steal the invention. His room had been entered and his papers examined. But the thieves or spies left empty handed. There was no danger, he said, that his invention could be stolen for he had at no time committed any part of it to paper. He could trust his memory to preserve every fine detail of his investigations. This was true, he said, of all of his later major discoveries.

The nature of his system makes little difference now. He has gone and has taken it with him. Perhaps if there is any communication from beyond the veil that separates this life from whatever exists hereafter, Tesla may look down upon Earth's struggling mortals and find some way of dropping a hint concerning what he accomplished. But if the situation is such that this cannot take place, then we must await until the human race produces another Tesla.

1. * The "death ray" was Tesla's particle-beam defense weapon, or "teleforce." Refer to "Nikola Tesla's Proposals for Teleforce & Telegeodynamics" (Twenty First Century Books, Breckenridge, Colo., 1998).

[StealthSkater note: more about "fireballs" and Tesla-type weapons is at doc pdf URL]

Remarks from Experts on Tesla

http://www.pbs.org/tesla/dis/index.html

Margaret Cheney / Tesla biographer

Why I Wrote About Tesla

In school, I never heard of Tesla at all. And when I did hear about him, I was intrigued by the mystery about him.

There are several reasons why Tesla is not well known. One was that he was a man who never married and had children. He never worked for universities or for corporations. He was very independent. And he was so far ahead of his time -- so much a visionary -- that his contemporary scientists really didn't understand what he was doing.

The Smithsonian Institution has never adequately credited Tesla for his invention of radio. They have tended to call Marconi the "Father of Radio" and they have tended to give Edison credit for Tesla's work in alternating current although Edison didn't work in that area at all.

So there are many reasons why we have not learned as much as we should about Tesla.

Childhood

His childhood made him an extremely intense student at a very early age because his older brother (who was thought to be a genius) died when Tesla was about 5 years old. As a result, he always felt that his parents missed this older son and he had to work extremely hard to make them appreciate him.

When he was a very young child, he developed certain talents related to introspection such a pre-visioning and intuitiveness. Tesla had this tremendous power to visualize things. He felt that **thought could be photographed ultimately**. He believed that we would develop ways to "see thought" and that people would communicate with their thoughts. **[StealthSkater note: Finnish theoretical physicist Matti Pitkanen briefly had this ability during a hospital stay. It would change his life forever =>** **doc** **pdf** **URL** **]**

One of Tesla's delightful ideas as a child was to build a circle around the Earth at the equator and then remove the scaffolding... so that the circle would orbit at the same speed as the Earth itself. The idea was that you could climb up and get on this and ride around the whole World in one day.

Tesla certainly did have some strange illnesses as a young man. He went through a period of hypersensitivity to sound and feelings. He could hear a fly land in the next room, (o he claimed). And if a train passed, it jarred him terribly. They finally put his bed on rubber cushions.

Eccentricities

Tesla did have some very strange eating habits. He always sat at the same table in the dining room at the Waldorf Astoria or whichever hotel he was able to afford to stay at. He would sit down and the waiter would bring him 18 napkins and he would start polishing his silver and glasses and plates with them, although of course they were immaculate.

He had a terrific fear of germs, a compulsion about them. The reason he had 18 napkins was because that was a number divisible by 3 and '3' was the magic number. When he started doing something such as starting to walk around the block, he had to go all the way around. If he started anything like reading a book, he had to read all of the author's books.

He had so many phobias that he couldn't have had close relationships with women. He didn't like most of the jewelry that they wore or the perfume and he couldn't bear to touch hair. In fact, he didn't like to shake hands.

the Mystique of Tesla

Well, Tesla is an endlessly fascinating personality. He seemed to think that anything people could conceive they would be able to achieve. So I think that what his story gives us is a sense of endless possibilities. Especially with Electricity.

Jim Hardesty

The Tesla Coil

The Tesla coil is an instrument that can step up voltages to high voltages at high frequencies.

Tesla worked with alternating current (energy moving back-and-forth). He worked with low frequencies at Niagara Falls (60 cycles per second). But he needed to have high voltage at high frequencies to do his experiments with wireless transmission (60,000 cycles per second and higher).

He realized that James Clerk Maxwell predicted that waves could propagate with antennas. In order to do this, he needed to build equipment to make high-frequency currents.

So if you want to talk about the genius of the Tesla coil, I think it is couched in Tesla's dreams and visions of the work he was going to do.

Tesla was a man who understood what no other scientist of the time understood. He understood **electrical resonance**. He understood the idea that energy passed back and forth in an electrical system.

The Tesla coil as we know it in the 1890s is a very good example of a resonant system using low kilohertz and a double tuned circuit so energy can be transferred between 2 systems — that essentially transmits a radio signal.

Radio

If you want to get a radio signal to radiate into the atmosphere, you want it to travel through the air strong enough to detect as a voltage.

So in that way alone, Tesla created a system of tuned circuits that he would cause waves from an antenna system to radiate out into the atmosphere. Therefore, Tesla's system was the one that made radio possible.

Marconi

Marconi used Hertz's system initially. But sending the signal "S" across the Atlantic would not have been possible with that system. So it became obvious to Marconi and other experimenters of the time that Tesla's system was an efficient, powerful resonator that produced waves you could work with.

The simple fact about Marconi's "S" is that he used the Tesla system to transmit signals and claimed that these were ideas he had developed himself. At the Marconi site on Cape Cod, the placards state clearly that Marconi used the Tesla oscillator to send signals.

Marconi was a good businessman. He built the first practical equipment. And for that reason, his name is the one people remember when they think of radio.

Tesla The Visionary

Tesla was a visionary genius. There aren't many of them. And he was willing to give his life to his visions. And for that reason, he probed deeply into the secrets of Nature and gave us the contributions that he did.

Dr. Dennis Papadopoulos

Professor of Physics, University of Maryland
Senior Science Advisor, H.A.A.R.P (High-Frequency Active Auroral Research Program

Tesla's Importance

Tesla was a genius because way before anybody knew or even understood the Earth and what we call today the Ionosphere which is a layer of ionized particles about 80 kilometers above the Earth. He conceived it and he tried to use it to produce a variety of new concepts.

Tesla is extremely underrated. I mean, there are a lot of people that don't know Tesla today. And that includes physicists, I would say. Although the Tesla unit is extensively used and the Tesla coil which is one of his most ingenious inventions, it's also extensively used.

Wireless Transmission

We have wireless transmission of energy all the time. The people that are listening to your TV station are listening to wireless transmission of power. The issue is how much power can you transmit through empty space. And how can you channel it because... if you think of a lake and you drop a pebble, what you are going to see is that this disturbance you make dies as you go around because it moves in 2 dimensions. If you make it into a channel, then it lasts longer and longer.

So the wireless transmission of energy is to try and find the channel so that the energy doesn't spread all over the place but it goes in a particular direction. Tesla understood, before knowing — before satellites and the other discoveries — realized that there was a conductor above the Earth because the Sun creates a set of ionized particles so we have the ground which is a conductor. And above that we have another conductor at about 80 kilometers. And if you send radio waves of low frequency, they get combined in that channel and they can propagate. This is called the Earth ionospheric wave guide. Without any knowledge he visualized that. And he said since I have this wave guide, I can repeat what I am doing in the laboratory.

His major defect was that he was dreaming and was doing very few calculations on paper. Because on paper he could have realized that because the dimensions of the wave guide are so enormous, you can

transmit power. But not very much power. You can transfer power to hear the radio, or for television, or for a telephone. But once you want to start turning on lights in which you really need high currents, the power gets diluted because the space is very large. It's a standard defect of dreamers, geniuses (not like Einstein, the other type of geniuses), the inventors who visualize things but have difficulty putting numbers [on paper]. And actually, I think that was his downfall.

Propagating Current

There are 2 ways of propagating. One is by bouncing between the Earth and the Ionosphere. Which means that you create a current on the Earth and a current in the Ionosphere. And that's what carries it. So you get 2 charges positive and negative and they move along.

The second one is you forget the Ionosphere and the current is carried only by the Earth... Both modes of propagation have been very fine, we know that. The problem with both modes in terms of really sending a lot of energy is that they attenuate a lot. When you have current, if the Earth and the Ionosphere were superconductors, wonderful, we'd be able to do it. But they are poor conductors. So what happens is a lot of energy goes into heating the ground or heating the Ionosphere. So when I'm going to send energy from Long Island to Paris, I'm going to lose a lot.

Tesla's idea of propagation is perfectly valid... Tesla's intuition was absolutely unbelievable. Because we had problems really persuading people about this concept in the 1970s... And Tesla -- without knowledge of satellites or solar UV radiation, all those things -- he could really visualize the correct mode of propagation. Stunning!

HAARP

HAARP is the latest Ionospheric modification facility, Ionospheric heater. It's nothing more than a radio station which sends power at 10 megahertz. Television (for example, PBS) is at 100 megahertz. HAARP sends power at between 3 and 10 megahertz and sends it up in the Ionosphere.

What happens is it operates like a microwave oven. As soon as it finds ionized particles (charged particles which start existing at 70 kilometers), this electric field shakes them up-and-down. When they shake up-and-down, they collide with a lot of neutral particles and it makes them hotter. So the region where you are focusing your energy... becomes hotter than the rest of the region. That changes the property of the medium.

There are 3 things I can think about Tesla when I'm talking about this particular project. The first ... we should think of Tesla every time we look at a microwave oven. Again, the radiation frequency of the microwave oven and the concept of the microwave oven was Tesla's.

The second thing is that it is a frequency transformer. Tesla -- with the Tesla coil -- changes one frequency to another frequency. What we are doing up there, we're taking at 5 megahertz a frequency which radiates in the ground and we transform it into 1 hertz, 5 hertz, 10 hertz, or whatever it is. So we have really a frequency transformer similar to what Tesla was thinking.

Third -- and most important -- once we create the waves, they propagate exactly the way Tesla conceived it through the Earth ionosphere waveguide.

Changing the Weather

Tesla proposed that it might be possible to modify the weather by using radio waves. I believe that this is impossible. I mean if I take really the most powerful facility in the World (which is actually the Voice of America) and I look at the power that it sends, it's about one-billionth of the power in a tornado. So it is the equivalent of trying to have a fly stop a tank. It's impossible -- energetically -- with radio waves.

There is another reason. Radio waves do not couple to the neutral atmosphere. They go straight through.

So it's impossible in terms of energy. It's impossible in terms of Physics. It's pure nonsense that any radio facility even a million times stronger than HAARP would be able to change the weather.

Inspiration

I have been inspired by Tesla. The man thought big; he had revolutionary ideas. He was a risk taker. He had high risk, high payoff ideas. You expect if you're lucky to have one percent of these ideas be true, then you've made a tremendous contribution. Tesla had much more than one percent of his ideas being true. I would be lucky if I had one percent of my ideas being utilized (even one hundredth of what Tesla has succeeded).

Bernard Finn
Curator, Division of Electricity and Modern Physics
National Museum of American History /Smithsonian Institution

Tesla and the Electrical Age

Tesla was a fascinating person. He was clearly a genius. He had a mind that functioned (if we are to believe him at all) in some very remarkable ways and had insights that were also quite remarkable.

He was also peculiar. I mean he had idiosyncrasies that were bizarre at best, especially later in life. And that really adds to the mystique.

To me as a historian, I find Tesla interesting because it was Tesla and 5-or-6 other people who, if you like, created the electrical age, the power age, and then lived on within it.

In the mid to late 1870s, all of a sudden, high power became available; the self-excited dynamo was invented; and now we had something that could give us lots of electricity and therefore the opportunity to use this in some way. The way you used it primarily was motors and then lighting. And this is what happened at the beginning of the 80's...

So now you had an electric power industry. There was Edison and there was Elihu Thompson and there was Nikola Tesla and a couple of other people... who through their efforts created this new industry.

Here's a comparison of Edison and Tesla that I think is very interesting. Edison, in living on into this new age, couldn't deal with radio and certain other things. He didn't want to retool. So he kept on with the old technology. He improved the phonograph; he put his efforts into the battery; he did things that were mechanical/electrical that he knew well and he continued to contribute in these ways.

Tesla was coming into this new age that he helped to create. One of the features of this new age was it was an age of large laboratories, industrial laboratories, of the engineering schools and so forth, a new breed coming in. I think one of Tesla's difficulties in dealing with this new age is that this was not the way he operated. When he goes to the Westinghouse laboratories to help introduce his motor, he simply doesn't get along with these fellows. He can't cope in this kind of an environment. He works best alone or with a single assistant where he sets the agenda...

His genius was such that it was very difficult (maybe impossible) for him to engage in the sort of give-and-take with others that I think would have made an enormous difference.

Tesla and History

I think Nikola Tesla deserves to be known better by scholars and by ordinary people. I think his place in the development of electrical technology was significant, important.

But I think the reason to know him transcends that. Among the inventors of his generation at a terribly critical time for electricity in particular and for industrialization in this country, he was special, unique. He was unusual in all sorts of ways. If we are to understand our own creativity -- our own ability to invent whether it's the brilliant breakthroughs of civilization or just those daily inventions and ways of coping with Life that we all face -- it helps enormously to understand the full range of invention and creativity. Tesla's was unique enough that I think there's an awful lot to be learned by studying the way in which he created.

We can't visualize the way Tesla did. But we all have our own visualization. We all look at things and see them in certain ways. So to understand how he took that ability he had and transformed it into an invention maybe helps us to understand how we can take our more limited gifts and translate them... You take this all together and you understand how science, technology, and invention fit into the structure of society, fit into American history.

...Our history is of people. It's not just inventions and developments. Edison is interesting not just because he invented... but beyond that, how did he do it? What was it about society that allowed him to do it? How did he interact with society?

And in the same way, what was it about America that allowed and encouraged a person like Nikola Tesla to come here, to thrive here, to interact with bankers and others?... How could he be this lone inventor and still contribute in various ways?

That's the way we should understand him. Within that broader context.

Questions and Responses

http://www.pbs.org/tesla/dis/responses.html

1. I was just wondering why are there no notes or anything of that sort on Tesla's work? There should be something somewhere.

Response by Robert Uth :

There are actually many notes on Tesla's work. A representative sample of Tesla's writings can be found in references on this website. If you are referring to the clandestine activities that took place after Tesla's death, there is also a great amount of research material. For instance, you can

use the Freedom of Information Act to obtain Tesla's complete FBI file. Samples are included in 'Missing Papers' chapter on this site.

Are there Tesla papers that are still missing? The answer is no one knows for sure. But a lot of people are looking.

2. Do the guest narrators have any knowledge about Telsa's relationship with John Jacob Astor? Resources have told me that Mr. Astor did fund Tesla's work but only to the amount of a few thousand dollars (if that).

Response by Margaret Cheney :

John Jacob Astor contributed $30,000 to Tesla's research station at Colorado Springs and may have given money to him for the construction of Wardenclyffe Tower. Although the extent of his involvement in the latter project is unknown, 500 shares of stock in the Nikola Tesla Company were found in Astor's estate when it was appraised in 1913. (Tesla: Man Out of Time by Margaret Cheney, pp. 132-133, 156)

3. Can spark plugs be considered miniature Tesla coils? If they can't, please explain why.

Response by Jim Hardesty:

A spark plug cannot be considered a miniature Tesla coil. But it might be used as part of a Tesla coil (namely, the spark gap). To use a spark plug as a spark gap in a Tesla coil system, the Tesla coil system would need to be very low power because a spark plug is not constructed to handle very much power and would operate very poorly in quenching a powerful spark and therefore would not permit the secondary coil to resonate freely.

A spark plug and a Tesla coil are 2 different things. A spark plug is not a coil. It is merely a high-voltage insulator with a gap at its tip that permits high-voltage electricity to discharge within the cylinder of an automobile. A Tesla coil is a quarter-wave helical resonator that is most often constructed of a number of turns of wire wrapped around a low-loss form. The size of the form and the length of the wire determine, in part, the Tesla coil's operating frequency.

Often these wound forms are terminated with a metallic sphere or torroidal form which we call an "end load". The end load has a number of functions. One of these functions is to prevent the top winding of the coil from discharging into the air and thus damaging some portion of that winding. The size of the end load also determines the Tesla coil's operating frequency.

4. How was 60 cycles per second decided on as the U.S. standard power frequency? Who made this decision? Was a higher frequency considered and why is Europe 50 cps?

Response by Dennis Papadopoulos:

An important issue in deciding the number of cycles per second for the AC current is the availability, practicality, cost, and durability of the device that transforms mechanical energy to electric energy. This device is called the generator and its reverse is the motor (see the Encyclopedia Brittanica article on the electric generator.)

Tesla -- and independently the Italian Galileo Ferraris -- are considered the fathers of the induction motor. The generator includes a rotating part (the "rotor") similar to the rotor that charges your car battery. The size, inertia, and other practical issues at the beginning of the 20th Century constrained the rotating speed to few tens-of-rotations per second. There is essentially no difference

between 50 or 60 cycles. As far as I know, it was a matter of choice dictated by availability and price of the components at the time.

5. Your excellent program included pictures of some of Tesla's mystical writings. One showed some kind of anagram or other "word play" that began with SATOR. What did Tesla believe these words meant?

Response by Robert Uth:

Tesla's interest in *mysticism* is intriguing. Some people regard him as a virtual seer. My opinion is that Tesla was interested in anything that inspired him to have an idea. Like other Victorian scientists, Tesla did believe that there was probably a scientific explanation for phenomenon that could not be explained such as ghosts and *telepathy*.

The "word play" document you refer to in the program is a mathematical puzzle. Tesla loved to play with complicated math problems. What is unusual about this particular puzzle is that it is known in *mystic* circles as "the Key of Solomon" -- a secret form of energy. You can read some of Tesla's mystic musings in an article contained in the 'Resources' section of this website called "How Cosmic Forces Shape our Destiny".

6. Is that true that one of Tesla's unknown inventions directly triggered a huge explosion near Tunguska back in the early 1900s?

Response by Margaret Cheney:

I have seen no evidence of an unknown Tesla invention triggering an explosion at Tunguska in the early 1900s.

7. I have often heard that Tesla believed efficient high-power wireless transmission of power was possible by means of non-Hertzian electromagnetic waves. One might assume that by "non-Hertzian", he meant longitudinal E and B components. Yet in many of his works, it appears he associates Hertzian with atmospheric waves and non-Hertzian with trans-terrestrial or perhaps surface waves.

It has also been conjectured that Tesla envisioned producing high-energy density induced changes in local permeability and permativity such that evanescent waves serve as a substantial mechanism in energy transmission. Can you shed any light on Tesla's notion of non-Hertzian waves? Also, is there any evidence that Tesla was familiar with Hamiton's quaterion algebra or the early quaterion formulations of Maxwell or work of Buee? [**StealthSkater note: this would seem to approach what Tom Beaden scalar electromagnetic =>** http://www.stealthskater.com/Bearden.htm **]**

Response by Jim Hardesty:

Because you seem to have considerable knowledge of the subject and particularly of Maxwell's equations, I will direct you to a very important book called Wireless Telegraphy by Dr. J. Zenneck (New York: McGraw-Hill, 1915). In Chapter 10, "Propagation of the Waves Over the Earth's Surface," Zenneck provided some very useful information about ground waves. Tesla indicated that Zenneck's ground wave was the non-Hertzian wave he was talking about. The Zenneck-Sommerfeld solution to Maxwell's equations is another area for you to check.

It is known that one of the books that Tesla's most used was a copy of Maxwell's original work. Because much of that appears in quaterions, one can assume that Tesla had considerable familiarity with them. I will leave you with this. Have fun!

8. If changing the weather is impossible as stated by one of the experts, then what is HAARP doing? What justifies spending on it? Are there other applications for transmission of energy through the atmosphere?

Response by Dennis Papadopoulos:

As I mentioned, changing the weather with any type of Ionospheric heating facility is equivalent to stopping a truck by bouncing it off a fly. It is impossible both not only in terms of energy but also in terms of the principles of Physics. To put it into energy or power prospective, the weather is driven by the energy of the sun which sends in the upper atmosphere of the Earth an average power of about 10^{16} Watts. Even operating 24 hours-a-day, HAARP can only send a maximum of 10^{6} Watts (10 orders of magnitude less).

Notice that lightning whose energy is absorbed by the atmosphere in a similar fashion with HAARP send an average of 10^{11} Watts while the *Aurora Borealis* anywhere between 10^{10}-to-10^{11} Watts. HAARP cannot compete with any of these sources.

As to energy transmission applications, HAARP has too low a frequency (3-to-10 MHz) and cannot transmit efficiently through the Ionosphere. Frequencies upwards of 2-to-100 GHz or lasers in frequency windows transparent to the atmosphere would have to be used.

The purpose of HAARP is scientific aimed at studying the properties and behavior of the Ionosphere with particular emphasis on being able to understand and use it to enhance communications and surveillance systems for both civilian and defense purposes. In addition, the HAARP facility will be useful for a variety of other research purposes including underground exploration for oil and minerals, the study of glob warming and ozone depletion, etc.

A similar facility operated in the past in Arecibo, Puerto Rico under the auspices of the National Science Foundation. Another is currently operating in Tromso, Norway. HAARP is simply the most modern of such facilities and has the potential to transition quickly theories and basic research to applications. An excellent review of the HAARP facility can be found in http://www.haarp.alaska.edu/haarp/gen.html and of ionospheric to http://www.haarp.alaska.edu/haarp/ion2.html .

9. Does the Smithsonian Institution have in its possession the first-ever electric motor -- a DC motor invented by a man named Thomas Davenport? I believe it was invented and patented by Davenport, a blacksmith about the 1840s. Please advise.

Response by Bernard Finn:

We have a Patent Office model of Davenport's motor (view a photograph). It is on exhibit about 15 feet from one of Tesla's motors (one of the very few items we have directly related to Tesla). That is, if you care to walk through a partition instead of around it (in which case it's more like 100 feet).

Davenport was a blacksmith in Brandon Vermont, not far from Albany where Joseph Henry was designing and constructing powerful electromagnets. In 1833, he purchased one of Henry's magnets and by the following year had built a motor that is arguably the first to have all of the basic elements (e.g., field magnets, rotating armature, commutator).

The model that he submitted with his patent application in 1835 was destroyed in a fire at the Patent Office. We have his replacement. He subsequently built motors that could be used in practical applications like running a lathe or even powering a small train. But the lack of an efficient

power source (all that was available was a battery) meant that these never became economically successful.

10. Now this is only an idea. A few friends and myself were considering rebuilding Wardenclyffe after seeing the original up close. We decided the building itself is the easy part. Finding a location that's safe and free of overpopulation -- that's the hard part. I would really love it if one of you could tell me how much in today's money — the building, the tower, and the land would all come to. Hey, who knows! Maybe we will continue what he didn't get a chance to.

Response by Robert Uth:

There is no need to build Tesla's Wardenclyffe facility all over again. The original power plant is still standing on Long Island. The property was privately purchased by a photo finishing company. But now there are issues about soil contamination around the building. A group known as the "Tesla Wardenclyffe Project" has been formed to turn the power station into a science museum and research facility. But the necessary funding has been slow in coming.

Those interested in helping turn Tesla's Wardenclyffe Power Station on Long Island into a science museum should visit http://www.teslascience.org and write to the address listed on the homepage.

11. What does it take to get public schools to include Tesla in the history books? We were only told of Edison and Marconi in school.

Response by Jim Hardesty:

This is a very good question and one that many science historians ponder with some dismay. The history of scientific discoveries often is inaccurately presented and poorly explained because responsible people have not done their homework. Although Tesla's contributions are many and great, neither teachers nor students are likely to learn about Tesla when they read most history books or visit some of our most prestigious historical museums. Documentaries such as "Tesla: Master of Lightning" (which bring out the truth) are important means of getting the public to realize that Tesla and his works do belong in our history books. Once people have this important information, they can exercise their freedom of speech to demand that schools teach it to our young people.

However, shifting a paradigm can be as difficult as shifting gears on an old Ford that has been rusting in a junkyard for 40 years and many academics do not like to let go of the power they wield. I personally think that the sign of a truly great scholar is the willingness to admit that a long-held belief no longer is valid in the light of new information. In a tribute to Albert Einstein, the British humorist George Bernard Shaw pointed out that the universe created by Aristotle lasted 1500 years; the universe created by Newton lasted 300 years; and no one knows how long the universe created by Einstein will last. Newton and Einstein were the first to admit that their ideas would last only until they were replaced by better ideas.

Edison (who believed that "inventing required 98 percent perspiration and 2 percent inspiration") was a person whose character fit the American work ethic of his day. It was said that if you gave Edison 10 haystacks and told him that there was a needle in one of them, he would hire workers to examine every straw in those haystacks until the needle was found.

Tesla, on the other hand, would think through a problem until he arrived at a highly efficient way of solving it. His work method was to first construct and test his inventions in his mind and then built them in physical reality. Tesla was a visionary genius who was not well understood in his own time but who perhaps may be better understood today.

Edison was a businessman who only undertook projects that he expected to be financially profitable. General Electric (the corporation he created) still exists today. Tesla was not a businessman. He was a scientist and engineer who pursued the mysteries of Nature with the goal of alleviating human suffering. He put forth ideas, some of which still are not completely understood.

Although both Edison and Tesla prepared people for the 20th Century, I believe that Tesla's work also is preparing us for the 21st Century. If young people learn about his accomplishments, many of them will be inspired to build on those accomplishments in their lifetimes.

12. I have heard that Tesla was able to create and manipulate ball lightning in his lab. I have also heard that this feat has not ever been reproduced by modern labs. Is this true and can you describe exactly what ball lightning is?

Response by Dennis Papadopoulos:

Ball lightning is a luminous spherical object observed and very rarely photographed during thunderstorms. According to eyewitness reports, it is most often red although other colors such as white, blue, and green have also been reported. Its radius varies about 5-to-10 cm.

Contrary to ordinary lightning, it moves horizontally with low velocity (~few m/sec). It might stop momentarily and change direction. While ordinary lightning lasts about 0.1-to-0.01 seconds, ball lightning exists over several seconds and sometimes minutes. It often enters indoors through windows and chimneys. Unconfirmed reports mention propagation through walls. The energy content is of the order of about 2-to-10 Megajoules (i.e., 2-10 million joules). Ball lightning has been observed to cause damage by burning or melting.

The physics of the phenomenon is not understood despite interesting work by Kapitza and others. Even its very existence is strongly debated. To my knowledge, there has not been any laboratory production of ball lightning. Understanding and generating ball lightning in the laboratory will go a long way towards achieving **thermonuclear fu**sion. I personally believe that the claims that Tesla manipulated ball lightning is simply part of his folklore. There is no evidence that he actually did it. For more information, see http://www-bprc.mps.ohio-state.edu/~bdaye/balligh.html.

13. John W. Wagner claims that the Smithsonian has deliberately minimalized Tesla's contributions to electrical science. According to Wagner:

> "Its curator essentially credits Edison for our worldwide system of electricity. He also credits Marconi for the invention of radio. This is a deliberate assault on factual history and needs to be challenged."

Is Wagner's claim correct? What might the motivation be for the Smithsonian to credit others with Tesla's inventions?

Response by Bernard Finn:

John Wagner is a school teacher in Michigan who has been remarkably successful in using Tesla as a role model for his 3rd grade students. A few years ago, the father of one of the students sculpted a bust of Tesla which the class then offered to the Smithsonian for permanent exhibition. Unfortunately, our general policy is to accept busts that have been done from life. And in any case, we would have been unwilling to make such a long-term commitment. I understand that since then, copies of the bust have been placed in other locations.

Mr. Wagner has a website where he continues to press his case for the bust. He would like us to exhibit more material related to Tesla and he claims that we misrepresent Tesla (usually in favor of Edison) in our present exhibits.

We have, in fact, for several years been contemplating an exhibit on Tesla. Since we lack appropriate objects in the museum here, we contacted the Tesla Museum in Belgrade and began discussions about a joint project. We organized a conference of scholars and developed some core ideas. The situation in Yugoslavia has been such that further progress was not possible. However, with the recent political changes we expect that early next year we will have a small display of artifacts, in the hope that this will lead to full-scale exhibition.

Mr. Wagner's comments about our present exhibits are somewhat misleading. We have an exhibition on electric lighting which features Edison. Towards the end of it, we suggest that lighting was a key stimulus to the development of large power plants (specifically at Niagara Falls). We include a nameplate from one of the Niagara generators (with Tesla's patents listed) and a Tesla motor and we describe his role briefly in accompanying text. This text can be viewed on our website http://americanhistory.si.edu/lighting.

In a separate exhibition on the "Information Age", we group Tesla with Marconi, de Forest, and others (each with a short account of his contributions). Having no artifact for Tesla, we show a picture of the Wardenclyffe tower.

Unfortunately, the Smithsonian cannot be comprehensive in its exhibits. Our collections are very good. But in many instances, we lack critical items. And we certainly lack the space. As a consequence, we tend either to take a broad, almost superficial approach (as with the Information Age) in which many people and events are treated briefly; or we treat one subject in depth (as with Lighting).

14. Is that true that Tesla was the genius behind the US Navy's famous top secret project the "Philadelphia Experiment" back in 1943?

Response by Robert Uth:

Tesla's name has been associated with the project called "The Philadelphia Experiment". It took place several months after the inventor's death in 1943. The existence of this experiment is documented but rumors about the results are highly speculative.

The purpose of the experiment conduced in the Naval Shipyard in Philadelphia was to find an effective way to degauss the iron hulls of ships. This would ships less susceptible to detection by radar. According to a few authors, the experiment created such powerful electromagnetic fields inside the ship that some technicians were either killed or injured. There is also a claim that some of those involved in the experiment experienced a distorted sense of time during the experiment. But there is not enough information to separate fact from fiction.

In our own research, we have come across no evidence that Tesla was associated with "The Philadelphia Experiment." **[StealthSkater note: more on the Philadelphia Experiment and its alleged successor the Montauk Project is archived at http://www.stealthskater.com/PX.htm]**

15. From what materials I have read, I had the idea that Tesla's later life was given over to flights of fancy. Your program revealed to me for the first time that he remained grounded in reality in his later years.

Response by Robert Uth:

Historians have tended to regard Tesla's later ideas as impractical. Many have also concluded that the inventor lost touch with reality as he aged.

I would suggest that Tesla lost touch with practicality. His ideas were simply too big and too expensive for him to realize. Especially after the failure of his Wardenclyffe Project and the loss of his major financial backers. Tesla stated on numerous occasions that he knew that his ideas would be put to use in the Future. The development of today's particle beam weapons (some very similar to Tesla's concept) suggests that his thinking in later life was fundamentally sound.

16. Among people who have read and studied Tesla and his work, it is often agreed that he is perhaps the greatest inventor of all time. How is it that almost no-one has ever heard of him? How is it that since 1943 Marconi's name is the one connected to wireless? Why is his name in no scientific textbooks used in America's high schools?

Response by Margaret Cheney:

You ask the most vexing question about Tesla: How could the most versatile and productive genius in history have been lost to textbooks in America? I might add how is it that in 1970 a friend of mine with a doctorate in physics from UC Berkeley responded to a question: "Tesla coil? Isn't that some kind of toy?" How is it that even today, electrical engineers at UCB (and presumably elsewhere) can describe Tesla as a "cultist" who invented "a little motor". This might have been excused a generation ago. But today with all the documentation of Tesla's achievements, it boils down in my opinion to a combination of ignorance and professional arrogance.

To go back to the basic problem: He was not closely associated with universities or corporations (except for Westinghouse); had no family to carry on his name; had little patience with electrical and radio engineers who were usually mystified by his work; was himself eccentric, arrogant, and a loner given to making exorbitant claims to the Press. And when Tesla's AC system was used to harness Niagara Falls, the "War of the Currents" ended with industrial jealousy and enduring bitterness. We see this today in those who still champion Edison for his electrical system and Marconi for inventing radio. These men were commercializers of Tesla patents and Tesla was a poor businessman. He understood that full appreciation of his work awaited future generations and this has proved correct. (Ref.: Tesla - Man Out of Time, 1981, Cheney; Tesla - Master of Lightning, 1999, Cheney & Uth).

17. I've seen the discharge of a Tesla coil going in all directions. But can you make it stationary without another terminal being near?

Response by Jim Hardesty:

If you wish to direct the discharge of a Tesla coil (presuming that your Tesla coil is end-loaded with a sphere or torroidal form), you need to place a corona point at any place on the top of the end load form. The corona point can be a needle, a nail, or a short wire provided that it rests on the end load in such a way that its point protrudes into the air.

With the corona point in place, the spark discharges of the Tesla coil will issue from the corona point which you can direct to point in any direction. If you use a wire as your corona point, take care that it is only a few inches in length because a point that is a foot-or-more in length will detune the coil.

When the end load of the Tesla coil has a spherical or torroidal shape, it acts as a capacitance to ground. And like a capacitor, it will charge up and then discharge at an appropriate rate. The corona point offers far less capacity than the end load and sparks will discharge relatively continuously from

it. You will also notice that sparks issuing from the corona point will be shorter than sparks issuing from a spherical or torroidal shape. This obviously is a result of the difference in the capacity of each of these 2 systems.

18. Do you know if there have been any recent Freedom of Information Act (FOIA) requests to either the FBI or the Department of Defense (DoD) for release of the Tesla papers that these 2 entities currently hold? If so, what is the disposition of the requests? Successful or unsuccessful?

Response by Robert Uth:

You can get FOIA requests from the FBI, the DOD, the State Department, and the CIA. The agencies are very responsive to requests. But the information supplied does **[SS: doesn't??]** answer many of the questions about the location and use of Tesla's technical ideas after his death.

19. Do you think that this controversy has to do with a point-of-view that says recognizing foreign-born Tesla would make Thomas Edison (America's homegrown genius) look bad? Or perhaps to honor Tesla would be perceived as to diminish the contributions of so many others? What is it that has made Tesla more of a "cult figure", rather than a universally recognized genius?

Response by Robert Uth:

I think in traditional science and technology circles, there has been a concern that in praising Tesla you diminish Edison, Marconi, and others. But this is clearly not the case. Both Edison and Marconi were remarkable people who accomplished remarkable things and no one can take that away from them. But it also seems important that Tesla be remembered for his contributions. Particularly if we are to make sense of the electronic age we live in.

20. The "magic" number '3' was mentioned. Was this mere superstition or did Tesla have a basis for believing '3' to be special?

Response by Margaret Cheney:

The "magic" number of '3' was apparently just superstition.

21. Do we (you) know more details about Tesla's ideas about and use of electrical currents for healing the human body? Or about helping the body the way he thought he was doing with the treatments he gave himself?

Response by Margaret Cheney:

Tesla's ideas on medical treatment with electricity are in widespread use today as in diathermy or deep-heat for injuries, arthritis, etc.; the application of X-rays, microwave, and radiowave to destroy cancer cells; and for healing bones and tissues. The magnetic resonance imaging machine (MRI) is measured in Tesla Units.

Tesla's idea of bathing in "cold fire" or a low-power therapeutic device is believed to have a psychosomatic effect beyond the mechanical. (For more on this: Tesla, Man Out of Time, Cheney; Tesla, Master of Lightning, Cheney and Uth.)

22. It seems that the rightful source of the riches that were due to Tesla should have come from the Westinghouse Company. Their use of Tesla's inventions -- offering the practical secrets of power generation and transmission at Niagara Falls -- was the single most important element that propelled Westinghouse from 19th Century business customs into what became one of the 20th Century's largest multinational conglomerates.

Westinghouse could have (arguably) gone the direction of buggy whip manufacturers and other leftovers of the 19th Century manufacturing world if it they had not met up with Nikola Tesla. My question is could a corporation of Today take a process or series of processes and patents from an individual (paying some tiny fraction of their true value) and go on to make billions of dollars from these inventions without further liability to the inventor?

Response by Bernard Finn:

The question of just compensation to inventors is a difficult one. The patent system was designed to provide protection for a period of time long enough for a person to make a reasonable profit from an idea. But clearly there are wide variations. Some inventions can go to market immediately while others may take so long in the developmental stage that by the time it is possible to make some money the patent has lapsed. And there are many other variables that become significant.

Some inventors make a lot of money out of what seem to be very minor patents that just happen to fit into an important manufacturing niche. And some patents (even though probably invalid) are never challenged because it is easier for a user to pay a small royalty than to go to court.

Some inventors that make significant contributions get little in the way of compensation because they can't afford to defend the patent or competitors manage to get around the patent by doing something that is similar but not quite the same. Many inventors work for corporations and patent rights go directly to the company with nothing to the inventor except perhaps a bonus at the end of the year. Some patents are "sleepers" where the true value may not be apparent immediately and where the inventor may sell off all or part of the rights at the beginning.

In a word, the problems that Tesla faced are still with us. Some the same and some in slightly different.

23. If Tesla was alive today, what would be the one question you would ask him?

Response by Robert Uth:

Did he transmit wireless power?

Response by Bernard Finn:

How did your interest in <u>poetry</u> affect your technical activities? Was it simply mental relaxation, a release from tension? Or did it focus your mind in some way that helped the process of invention? Do you see these as compatible features of one part of the brain? Or as quite different aspects that may sometimes complement and sometimes conflict with each other?

24. In reading Tesla's thoughts about man's actions being controlled from the outside and not the inside, I was strongly reminded of the ideas of GI Gurdjieff and Ouspensky. Do you know of any contact between these contemporaries?

Response by Margaret Cheney:

Writings and ideas of Gurdjieff and Ouspensky affecting Tesla? Tesla's belief in man as a machine (sans free will) seemed to change over the years. He later wrote that his willpower had been fundamental to his achievement. But the mechanistic view was for a time accepted in European philosophy and undoubtedly he was aware of this.

He claimed for a time to trace everything he did to external events. Later he believed that thought would one day be projected directly onto a screen. And he became captivated by the Eastern philosophy of Swami Vivikendanda, which he considered consonant with his theories of Science.

25. Where can I get some details on the demise of the Tesla Museum formerly located in Colorado Springs, Colorado? I seem to recall reading an article that said (I think) the artifacts sort of disappeared. Is that really what happened?

Response by Robert Uth:

The Tesla Museum in Colorado Springs was part of the Tesla International Society. This society disbanded several years ago and so did the museum. The displays in the museum did not use actual Tesla devices.

26. You said that he was never able to transmit power. And yet I remember reading in one of the books that he had lit about 100 light bulbs around 20 miles away from his Colorado Springs laboratory. Isn't that true? Also you should mention the museum there in Colorado Springs. It's small but very well worth the visit for those who are Tesla fans.

Response by Robert Uth:

This is one of the many unanswered questions about Tesla's experiments at Colorado Springs. First, the only comment Tesla made was that he illuminated lamps in the earth at a distance of 2 miles from his transmitter. The comment about 20 miles and 100dred lamps originated from an early biography on Tesla by John J. O'Neill called Prodigal Genius.

Some suggest that at a distance of 2 miles with an extremely powerful transmitter, the lamps could have illuminated by induction rather than the radio transmission of power. Others disagree.

Selected Articles on Tesla

http://www.pbs.org/tesla/res/res_arts.html

1. Some Personal Recollections, Scientific American, June 15, 1915

2. "A New System of Alternating Current -- Motors and Transformers"; address before the American Institute of Electrical Engineers; May 16, 1888

3. The Wonder World To Be Created By Electricity; *Manufacturer's Record*, September 9, 1915

4. "On Electricity" -- the address on the occasion of the commemoration of the introduction of Niagara Falls power in Buffalo at the Ellicot Club, January 12, 1897; *Electrical Review*, January 27, 1897

5. "Experiments with Alternating Currents of High Potential and High Frequency", lecture delivered before the I.E.E., London, February, 1892.

6. The True Wireless, May 1919

7. Nikola Tesla On His Work With Alternating Currents: Their Application to Wireless Telegraphy, Telephony, and Transmission of Power, 1994

8. The Transmission Of Electric Energy Without Wires, *The Electrical World and Engineer*

9. The Problem Of Increasing Human Energy, *The Century Illustrated Monthly Magazine*, June 1900

10. How Cosmic Forces Shape our Destinies, 1915

11. A Machine to End War, 1937

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