Alec Lauterbach
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Rolf Wideroe

Abstract:

Rolf Wideroe was a brilliant inventor and physicist and greatly advanced accelerator physics during his time. Born in Olso, Norway on July 1902, Rolf was constantly changing location. In Germany he went to study electrical engineering at Technische Hoschule Karlsruhem. Intrigued by the principles of electrostatics, Wideroe transferred to the technical university of Aachen, attempting to construct the first ever accelerator. This attempt failed, but sparked a career of trial and error that would greatly advance particle physics. Unfortunately, many discoveries were made under the Nazi rule in Germany, but fortunately the Germans provided Wideroe with state of the art facilities that he utilized to make discoveries. In 1927, Wideroe developed plans for the world's first linear accelerator. Linear accelerators are still widely used today. Building off of the linear accelerator, Wideroe designed what is known as the betatron, which uses a vortex field surrounding a magnetic field to accelerate electrons in a tube. Betatrons were in high demand because their x-rays could be used for medical use. During his lifetime, Wideroe published over 180 scientific and engineering journals, and filed over 200 patents. A truly inspiring man, Wideroe inspired numerous other scientists, such as Ernest Lawrence and Donald Kerst, to forward the particle acceleration field. The following paper will cover how Wideroe, the father of accelerators, expanded accelerator physics and left a lasting legacy.[8]

Any scientist truly passionate about his field has to make difficult life choices. These choices can alienate, they can reconcile, but ultimately a true scientist makes choices with potential for creating a better world. Rolf Wideroe was such a man. Wideroe was truly inspiring- a man whose constant pursuit and dedication to the scientific field caused him great backlash yet great success. Wideroe has published over 180 scientific and engineering journals and filed over 200 patents in his lifetime, yet is relatively unheard of.[5] It is due to the circumstances he was put in, his love for his family, and the choices that he made, that such a brilliant mind is not well known amongst most people. Even Norway, his home country, refuses to acknowledge his vast array of great successes and astounding accomplishments. This paper aims to make known not only Rolf Wideroe's feats, but also his character, personal life, and history.

As a young child, Rolf showed clear signs of acute smartness and wisdom. In an autobiographical manuscript, he was described as "no ordinary man."[9] He had a certain presence to him, an aura. For all who knew him it was clear that they were excited to talk about him. He was "a mixture of the socially awkward, almost psychopathic,

always-far-away-in-his own-thoughts nerd and the sensitive."[9] Some say he was so caught up in his research that it became of sole importance to him. Yet he was sociable, eccentric, excitable, and naive about almost anything. He was the eldest of a family of six children, and somewhat of a leader to them. Whenever a question was asked to Rolf's father, his father would refer that question to Rolf. He was clever and he respected others as well as himself. It was eminent in his character that he wasn't one to hold grudges- an important characteristic that comes into play later in his life. Using the engineering skills he had acquired, he would make tons of excellent repairs around the house. His family noted that whenever an electrician would come to fix something, he would ask who had done the previous repairs. The electricians were astounded- the repairs were done so well that they could not conceive that it was one of them who could've done it.[11]

Curiosity had urged Rolf to explore how nature works, and to seek out knowledge that was yet unknown to him. In this regard, he was very similar to his younger brother, Viggo. Viggo and him had a strong brotherly bond forged by their passion to design and create. They would go on biking trips frequently and talk about and build upon their aspirations- Rolf to be an engineer and Viggo to be the designer of airplanes. The love held between these two brothers was the backbone of what had pushed them to wholeheartedly seek what inspired them. Against the wishes of his father, Viggo would go on to pursue his dreams and become a leader in the Norwegian airline industry.[11] Wideroe, respected as a genius by his family and his professors, had passed all of his exams at a very early age. At the time, Germany was seen as a center of innovation and culture. Ready to study what he loved, Wideroe felt a strong urge to go to the prestigious technical university of Karlsruhe in Germany.

In the year of 1920, Wideroe left Norway to study electrical engineering in Germany. At the technical university of Karlsruhe he was allowed to pursue his interests and soon fell in love with particle physics. While he was there he wondered if the same principle that applied to an ordinary electrical transformer of changing current from one voltage to another could be applied to accelerating electrons.[9] Wideroe continued research on a machine that could do exactly that: accelerate elementary particles. But first he had to focus on getting his degree. By the time he completed his dissertation and a quick six months practical work period in the field, Wideroe was ready to be taken on as a doctorate student and finally focus on creating a machine that could successfully accelerate electrons in a circle. He would later call this the betatron. However, upon his visit back at the Technical University at Karlsruhe, his proposal for the betatron was completely shot down by a highly esteemed professor of physics. This professor would not accept a project as contemporary and risk-filled as Rolf's betatron, and instead offered him further study on a different theme.[7] Rolf, confident in his abilities, would not give up. He wouldn't go back to Karlsruhe. If he couldn't complete

his project there, he would go elsewhere to accomplish his goals. With his back straight and head held high he looked towards another prestigious technical university- one in Aachen, Germany that had even better facilities.[9]

Wideroe started his work anew at the University of Aachen in 1926. He was thrown into a slightly unconventional environment, in which his eccentric self thrived. He met some esteemed colleagues, including Ernst Sommerfield, son of famous physicist Arnold Sommerfeld. Ernst and Rolf became great friends and his expertise in patent registration came in handy later with Rolf's over 200 patents.[9] However, complications occurred with the project. Rolf figured that in order for the particles to remain on a circular path then magnetic forces would have to be at play. A problem he pondered until "he developed a theory of how the magnetic fields must be placed in relationship to each other so that they would propel and steer the electrons round the circle." This would later be known as the Wideroe condition. But things were still not panning out for the eager Wideroe. He would get the electrons to go a full circuit and a half until they came to a complete halt. He simply could not put it into practice. His failure was later discovered to be because of a lack of transverse focusing[4]. Prevented from getting his doctorate due to this defeat, Wideroe was at a huge loss. Nonetheless, young Rolf was a determined strategist who would not give up. He decided to put circular accelerators aside, and focus on an alternative linear method of particle acceleration. He had come across a method called "multiple acceleration" (repeated bursts of acceleration), of which he used to create the world's first linear accelerator in 1927.[1] The invention of the linear accelerator would come to revolutionize the treatment of cancer and help millions of people around the world.[9]

After writing his thesis on the linear accelerator, Rolf began to take up work. In the year 1928 Rolf left the field of accelerators to work at Allgemeine Elecktrizitats Gesellschaft (AEG) in Berlin[7]. This was a time when industry was starting to expand. Electrical power grid lines that allowed for electrical relays were popping up everywhere. During his time in the industry Rolf was able to focus on technology and leave an impact by strengthening power lines and electrical relays throughout most of eastern Europe. This brought him lots of attention in the scientific world. Meanwhile, Rolf had not dropped his gaze in the world of accelerators. Scientist Ernest Lawrence had successfully built an operational cyclotron of Wideroe's design, and was awarded the nobel prize in physics in 1939.[9] It was disputed whether Rolf had deserved credit for the prize, but nonetheless Rolf was thrilled that his design had been put into practice. He was overjoyed in the fact that his theory was correct after all! Soon thereof, Nazi power took control of Germany. A once forward-thinking nation became corrupted by fascism, and drove Wideroe out of Germany and into Norway. Wideroe joined N. Jacobsen's electrical works in Olso, and continued to make great strides in electrical relays. Eventually, Rolf became known as the maker of the world's best relays- relays that

could react in within 1/25th of a second.[8] At the same time, Rolf had met the woman of his dreams. He had been taking dance classes at “Miss Fearnley’s Dance School” to learn the newest dances (and admittedly to find himself a wife). At this dance school he met Ragnhild Christiansen, who lived close to his own childhood home. They were soon married November 14th, 1934. In 1941, they had their first child, Rolf junior. According to a true story, Ranghild worked alongside Rolf at AEG, and they would often stay working late at night. So absorbed in his calculations, Rolf went to the adjoining room, looked in, and said “You can go home now, miss Christiansen.” Rolf had completely forgotten they were married eight months after the wedding. Ragnhild apparently never let him live it down.[9]

Wideroe continued with his fascination for electricity and started to write articles on atomic energy. He saw it as an immense source of power, if only people could harness it. He enthusiastically wrote: *“Thus we understand that the massive energy concentrated in atomic nuclei represents an Eldorado, an immeasurable and inexhaustible source of energy which, if it can be utilised, could satisfy humanity’s hunger for energy for all time.”*[9] Inspired by new developments in particle acceleration (Lawrence had built a second, bigger cyclotron, and Donald Kerst’s development of a 2.3MeV betatron)[10], Rolf wrote several articles that covered the potential of nuclear energies. He sent his articles to the Journal of Electrical engineering in Norway, as well as in Berlin. This caught the eye of the nazi government in Germany.

Meanwhile, Rolf’s brother, Viggo, was making great progress in the airline industry. Wideroe airlines was allowing for commercial use and gained great popularity in Norway. Viggo would go on long expeditions to Antarctica via airplane to map out parts of the Arctic coast. However, his success did not last long. Operation Weserubung, the German invasion of Norway, had taken place. Soon enough, Viggo had left his business to take a key leadership role in the Norwegian resistance against the Nazis. However, because of his status he was quickly caught by the gestapo and sent to prison in 1941.[11] It was a scary time for the Wideroe family- no one knew what would be the fate of Viggo. Later, in 1942, Rolf was suddenly approached by members of the German government and taken to the grand hotel. In this meeting, Rolf was offered the chance to lead a project of great prestige with complete freedom and an essentially limitless budget. He was skeptical at first. Rolf was no nazi. And he understood that he could quite possibly be creating a wonder weapon. However, the Nazis had his dear brother. Rolf had no choice but to play along in order to preserve Viggo’s safety. He was sent to Berlin immediately.[11] In the long run, this Nazi manipulation of Wideroe can actually be seen as beneficial. It allowed Wideroe to concentrate on his passion for atomic energy and particle accelerators. He was given access to the most up to date facilities in existence at the time with the privilege to

conduct research of which he pleased. As it turns out, Rolf was at the front lines of the developing German technology that the Americans feared so much.

It was around the time of Rolf's new employment when Germany was developing powerful new military technology that was heavily used in war. German U-boats were terrorizing the seas, preventing allied ships from transporting goods and men. The destructive U-boats were part of the reason the United States entered the war. Germany also had made several sophisticated models of jet fighters and bombers. The Arado Ar-234 utilized aerospace engineering technologies that made it virtually impossible to intercept. The Horton HO 229 was a swift bomber with a low radar profile that was made to covertly drop bombs with hardly a sign of warning.[6] Along with this powerful new aircraft came powerful new explosives. In response to the overwhelming power of allied tanks, the nazis developed the panzerfaust. This was an extremely mighty warhead that had penetration capabilities of up to around 8 inches[3]**.** Along with this was the dreaded V2 missiles. These missiles could travel at speeds faster than the speed of sound and possessed a large explosion radius. These missiles were used to weaken the allied powers by causing mass destruction in the cities of Antwerp, Belgium, and London[6].Aware of the importance of advancements in technology during war, the Nazi's focused much of their attention to growing sciences. Nuclear technology is where they set their eyes on next, with the idea of an extremely powerful radiation-emitting weapon in mind. Rolf Wideroe's extensive knowledge in this field was why he was very sought after by high up German authority.

It was clear that the Germans wanted a betatron to be built. It was vital for them to be ahead of the competition in both industry and technology. This meant constant surveillance of the latest allied technology. Everybody was watching everybody else. Knowledge of Kerst's 2.3 MeV betatron caused them to search for notable scientists that could construct a rival, bigger machine.[10] Rolf was one of them. Having done a thorough background check on Rolf, They considered him to be an expert of the technology, and made him leader of the project. In a sense, Rolf was his own boss. Rolf, captivated by the idea of a 15MeV betatron with stronger capabilities in therapeutic treatment, poured all of his efforts onto the project.[9]

As for his family life, Rolf had systematically worked out the arrangements. His family was allowed to remain in Norway and Rolf would visit his wife and children as much as he could. The Germans offered him air travel and allowed Rolf to work on all theoretical aspects of the project in Norway with his family (When it was time to build the accelerator he would have to go to Germany to supervise the work). They even allowed him to keep his job with the Norwegian company NEBB. As for his brother, Rolf ran into obstacles when searching for ways to getting him out of trouble. The men who recruited him and his co-workers claimed they didn't have the authority over the matter.[8] Then he met a man high up in german rank, by the name of Director Schwartz, who

hinted that Rolf write something with a pro-german attitude in order to help his brother's situation. What Rolf wrote next was a detailed description of a 12 day excursion with fellow engineers. It was filled with technical analysis of power systems, but also filled with a sense of German nationalism. It was a "professional enthusiasm for the way the Germans had organised and linked their power supplies, which he warmly recommended."[9] Overall, his article definitely contained pro-nazi sentiment, enough for Director Schwartz to help him. But was this Rolf playing his cards right, or was he gaining a sense of appreciation for the Germans?

While working in Germany on the project, Rolf was treated with respect and given the chance to work with many other brilliant mines like his own. Collaboration with several brilliant physicists allowed Rolf to further his conceptualization of particle accelerators. During this time in the summer of 1943 Rolf had discovered the concept of a particle collider.[7] He was staring up at the sky, looking up at the clouds, when suddenly it came to him. The beams should be made to collide just like two clouds of massive proportions. Physicists for a long time had been interested in studying the atomic properties of the nucleus. Wideroe would make a special device called a "storage ring" to store accelerated particles and shoot the rays of particles against each other.[9] Then one would be able to observe the reactions that would occur. Wideroe submitted this idea to be patented. He knew that it would be extremely challenging to keep beams of the same charge stable enough in the same tube, so he thought of the idea of using two separate rings with magnetic fields to steer the particles.[1] Rolf knew, however, that technology was not advanced enough yet for a particle collider. But he hoped, as he hoped with much of his later patents, that such a feat could be achieved in the near future. Meanwhile, Rolf had been working on other things as well. In July he had submitted his very first betatron patent concerning the injection system for the betatron. In September he submitted two other patents concerning "electric lenses" and "pre-magnetisation" for the betatron. Soon after he patented "betatron no. 4 for counter-magnetisation." Rolf, hard at work, had completed 13 patents altogether from the year 1943 to 1945. Unbeknownst to the Germans, he kept these patents under wraps for his own reasons.[9]

Rolf moved forward with his betatron project in three phases. The first phase was to complete the manufacturing of the 15MeV betatron in Hamburg. The second phase was the design and manufacturing of a much more powerful 200 MeV betatron. The third phase would be to design a massive test laboratory in Ostgrossheim that could be used for even bigger projects in the future.[9] It was surrounding the third phase in the project when Rolf started to figure out the intentions of his higher ups. Without his knowledge, Rolf was part of a larger project in creating a death ray in Ostgrossheim. This project came from the idea of creating a massive X-ray cannon that could theoretically annihilate a target from long range. The capability of destroying enemy

fighter planes at ease with rays of radiation was fascinating to the Germans, and this was why they needed Rolf and his radiation-emitting betatron. However, things began to fall apart. The idea for a death ray was highly criticized and eventually deemed impractical and simply impossible. Schiebold was the leader of this project, and once his idea failed all funding and concentration was given to Wideroe.[8] The German leaders had not lost interest in radiation technology, but instead demanded something of it. So Rolf's project was secure in not dealing with deadly rays but in life-giving ones. With hard work Rolf and his team had successfully built a betatron that emitted 15MeV of radiation.[9] This development was the cornerstone of further developments in physics and had profound medical use surrounding x-ray technology and radiation treatment.[2]

It was 1945 when suddenly Rolf was approached by the treasurer, a man named Hollnack, who paid him a large sum of money and told him to go home. He was paid around 800,000 kroner- the equivalent of around 100,000 current day USD. Without hesitation Rolf left Germany forever. The war had finally come to a close and Hitler was soon taken from power. Be that as it may this was not particularly good news for Rolf. Once the British started occupying German land all work on the betatron project ceased.[9] So much for Rolf's dream of a 200MeV betatron. Also, in Norway huge problems arose for Rolf. Promptly after he went home to a Norway he was arrested by the Norwegian government for treason. On top of that, he was accused for taking part in the designing of the deadly V2 rockets that had been used on the allies during the war.[11] The company Rolf had been working for (NEBB) had fired him because he was risk to the company's reputation. Rolf was stuck in prison for around 50 days, living in terrible conditions. The prisoners were cold, not given enough food or water, and treated like animals.[11] After he was released, Rolf was subjected to numerous court hearings and interrogations. They thoroughly investigated whether he had aided any aspect of the German military during the war. Rolf's brother Viggo may have been of some help to him. The police sought out a statement from Viggo of which he complied in his brother's defense. He stated: "my brother visited me autumn 1943. He told me then that he had been forced to work in a factory in Hamburg making high-voltage equipment."[9] Eventually, with proper evidence it was found that Rolf had purely intellectual interests in mind and had not helped develop German military technology. It would be a full 18 months after he was arrested, in the year 1946, when a verdict would be made. Rolf was fined, lost his voting rights, and prevented from serving in the military.[5] Though he faced immense scrutiny, a dark chapter in his life was finally closed. A silver lining: Rolf used time in jail to keep working. While in jail, he fathomed a design for the world's first synchrotron. This is a circular machine that is capable of accelerating certain particles up to faster speeds than in a betatron. Shortly after he was released from prison, he submitted his first swiss patent concerning the synchrotron.[1]

Unfortunately, all of the post-war commotion had led to the slandering of Rolf's good name. He was a brilliant scientist with tons of outstanding accomplishments, yet when a man is accused of being a traitor it is hard to relinquish this title. In the eyes of the public Rolf Wideroe was a mad nazi scientist. Thus, although his innocence was proven by the expert committee, his home country viewed him as a traitor. To this day, in Norway little information can be found on Rolf. When news had spread that Rolf was given a passport and had used it to travel to Switzerland, outrage filled the air. Despite the fact that this passport was only valid for one month and could only be used for travel to Switzerland, headlines arose claiming: "'Norwegian Nazi Atomic Expert Goes to Switzerland' and 'Fine and Confiscation Await Rolf on his Return Home.'"[9] It is quite a shame that Rolf's reputation was so severely blackened. Yet this did not stop him. He held his head high and continued with research.

The question arose of whether Rolf was bothered by all the scrutiny that occured after the war. And was he frustrated with what happened during the war? Many of his family members don't believe that he was. Rolf was a man who would get carried away in his thoughts. Whether he was given a choice to work for the Germans or not, Rolf saw it as an opportunity to continue research on the project of his dreams. He was given outstanding facilities with an almost endless budget, of course he would be excited. When his sister was questioned about Rolf being seen in a bad light for taking the job in Germany, she replied - "Rolf wasn't interested in politics, he was absorbed in his life's work. There was no use in talking with him. And you can't talk down to a grown man."[9] Rolf was also a man who didn't care much about what others thought of him. He met some wild accusations that were directed at him with a laugh. His status as a scientist whose primary goal is to further his understanding of the natural world simply trumped concern over who had or hadn't slandered his name. Rolf never thought of himself as pro-axis powers or pro-allied powers, he just wanted to design and build. Furthermore, Rolf thought his investigation was relatively fair. He claimed that he didn't care much nor give much thought to them- he knew that the truth would find him innocent.[11]

Soon after moving to Switzerland, Rolf continued fervent work on another betatron. This betatron would be able to reach 31MeV with the ability to penetrate through 10 cm of water. This was for the purpose of reaching body tissue in which the radiation would be able to deliver therapeutic effects.[8] It was noted that the conditions in which they worked were not optimal. Every once and a while the generator's coils would overheat and cause unbreathable vapours to flood the air. Overhead machines would make it impossible to hear. Additionally, due to the limited spatial conditions in the laboratory Rolf and his team had to drive to the hospital once a week to have themselves checked for radiation poisoning. Nevertheless, Rolf and his team were able to successfully build the 31MeV betatron despite some obstacles along the way. This

was soon implemented in a hospital, ready to treat patients.[2] Before long, hospitals were sending mail to Rolf requesting a betatron. Rolf made several more betatrons, and perfected his technique by making betatrons that were able to deliver two beams simultaneously in opposite directions. This allowed two patients to be treated at once. These betatrons continued to be made until 1986, of which BBC (the company Rolf worked for) had made 78 of them. By that time he had also submitted 53 patents for BBC, and about 200 by the end of his career.[8]

Betatrons had become a great success for Wideroe, but he later realized that it was not practical to use a betatron to achieve higher levels of energy. In America, Kerst had successfully built a 300MeV betatron, but that was about as powerful as a betatron could get.[10] A betatron would have to be too big and expensive to achieve more powerful results. Rather, physicists turned to the synchrotron. Rolf, hearing about developments in synchrotron technology, aimed to build a 100MeV synchrotron at BBC. The synchrotron required an injector, or a machine that preliminarily accelerates the particles in preparation of being injected. Rolf also faced obstacles with secondary electrons that appeared on the inner wall of the tube. He and his team dealt with this by coating the drift tube with a layer of graphite in order to add electrical resistance. In 1959, he and his team built a 105MeV synchrotron ready for experimentation. Although later on relatively simpler linear accelerators were built in this energy range, it was extremely important to Wideroe that the synchrotron had proven itself in practice.[8]

Back in 1951, with world war 2 ended, nations around the world started to come together to form what is known today as CERN (“Conseil Européen pour la Recherche Nucléaire”)(121). The idea of the scientific collaboration of hundreds of people for the sake of nuclear research and particle acceleration enticed Wideroe. Wideroe was appointed as a consultant at Cern between the years 1952-1956. He took part in projects including the designing of a 10GeV weak focusing proton-synchrotron, as well as a 28GeV strong focusing machine.[8] Progress was being made. Eventually, in 1971 CERN had made a machine in which 30GeV protons were fired against each other. This made an abundance of research possible. CERN is also currently home to the largest storage ring in existence. Thanks to the principles Rolf had developed, a storage ring called the “Large Electron Positron Storage Ring” (LEP) with a circumference of 27Km was created. This storage ring has the capabilities of accelerating particles up to 100GeV. Many of the advancements of CERN could not have been made possible without Rolf’s ingenious ideas.[8]

Later in his life, Rolf started focusing on cancer treatment with radiation therapy. In his eyes, this was the most important application of a particle accelerator. In 1959 Rolf went to the International Radiology Congress in Munich and was adamant about the healing effects of his betatrons. At this congress he firmly states, “The use of anything other than betatrons for the treatment of deeply situated cancerous tumours

should be forbidden by law."[8] It took many years for his ideas to spread (people are always resistant to change) but eventually hospitals would change their practices. A lot of interest went to the subject of ionisation. When fast charged particles penetrate through material, they have the potential to collide with other electrons belonging to the "electron cloud" of molecules. During this process the electron beam gains numerous electrons that densens the beam and ultimately causes it to come to a halt. Ionisation is higher at lower speeds because the electrical forces have more time to act. Ionisation on living cells can have deadly, irreparable consequences. This is why radiation treatment is so effective on tumours. With much research into the effectiveness of radiation, Rolf created a formula known as the BenderGooch-Wideröe formula. It provides the probability of survival of cells given a radiation of dose D. This formula takes into account alpha and beta effects. The alpha effect has a strong ionising effect on molecules, while the beta effect has a lower ionising effect on molecules.[8] It was the use of this formula and experimentation on human kidneys that decided the most effective way of treating cancer. Rolf discovered that use of beta radiation is far more effective and less harmful than alpha radiation. By this time, radiation therapy was in widespread usage. About half of all cancer patients in Western Europe and America were treated with radiation therapy alongside chemotherapy and surgery.[8] Survival rates drastically increased because of this technology. Rolf received many honours for his work in the field of radiation, in fact more honours than he had received for his particle accelerators. He received the Röntgen Medal (1969), Röntgen prize (1972), and the JRC gold medal (1973).[5]

Rolf Wideroe career certainly was an interesting one. He was a brilliant man who poured his heart and soul into his research. The groundbreaking, first of its kind work on particle accelerators is why he is deemed the founding father of the accelerator. He never ceased with his determination to design, build and innovate even when others demoralised and brought him down. Rolf was a dreamer. He dreamed to create, make something, do something nobody else has ever done, make his mark. Rolf followed his dream. His purpose. This is why he was able to accomplish so much. On October 11, 1996 Rolf Wideroe died in Obersiggenthal, Switzerland at the age of 94.[11] He had lived a long and fulfilling life, with three children and a loving a supportive wife. The world was a much better place because of him. He had left a lasting legacy that would affect the field of physics forever. His inventions and patents led to the discovery of a vast amount of new particles. Accelerators are vital for producing a range of radioisotopes necessary for medical treatments and diagnostics. In 2009 synchrotron light sources were used to discover how ribosomes translates DNA information into life. Synchrotron light sources also allow scientists to analyze protein structures quickly and accurately, allowing for creation of specialized treatments. Studies have even shown how particle beams from

an accelerator can clean up sewage water and effectively clean polluted air.[12] Rolf's invention of the particle accelerator continues to help people to this day.

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