2

The World Awaits

19th August 1946. A family of mother, father and three children—two boys and one girl—pack their car and leave Oslo. They are going to a new life, in a new land. First by boat to Antwerp, then on through Holland and Luxembourg. The war is over. The world awaits. Father has been offered a management position at Brown Boveri's head office in Switzerland. Mother sees this as the way ahead. She is the oil in the machine, the hub in the wheel, the person everybody turns to, the one who runs the household. Her husband has always travelled a lot, but now the whole family is on the move. The appointment is for three years. The children are to go to the Steiner School there, and the house in Røa in Oslo is being leased out to his sister and her husband.

'He' is Rolf. 'She' is Ragnhild. 'The children' are Unn, Arild and little Rolf, born towards the end of the war. They are moving into a little flat in Zurich. Their new life is beginning. It's exciting for them all.

Rolf had gone to Switzerland before Easter to negotiate his appointment. He had flown there, even though they could scarcely afford it at that time. Indeed, he had had to sell about thirty of his patent rights that year. The firm he worked for in Oslo, NEBB, a daughter company of the Swiss company Brown Boveri, had bought them from him. During his visit he had met one of the Boveri brothers, Walter Boveri, and his first assignment was to build a big betatron for the hospital in Zurich. Neither of them believed that such a powerful betatron could be built in Norway. The technical equipment was not good enough, there were no glassblowers capable of making the tube, and technology to make the tube airtight was unavailable.

A. Sørheim, *Obsessed by a Dream*, Springer Biographies,
https://doi.org/10.1007/978-3-030-26338-6_2

Rolf had taken quite detailed construction plans with him on his preliminary visit, and preparatory work started while he was there. This was obviously a prestigious project that was given high priority. Brown Boveri wanted to show the world what they could do, and they had got hold of exactly the person they wanted. The Americans were in the lead in technology after the war, and many of the best European researchers had gone to the USA to improve their prospects. Europe was left with a brain-drain problem. The company wanted him to start as soon as possible. As he himself said years later in an interview, the company thought that the betatron was as good a way as any to compete.[1]

In October-November he was back in Oslo to sort out various formalities. Then it was just a matter of pressing on with the job. It was up to him now. But to develop an idea into reality involves many days devoted to an endless list of small details, and this affected the whole family. He hardly travelled at all during the first three or four years. Everything depended on building the betatron. If he succeeded, it would be the first of this special type of radiotherapy machine in Europe. He had to succeed. His professional reputation depended on it.

Sound, Stench and Knitted Mitts

By spring, the betatron was beginning to take shape. It was being built in an inspection tunnel under a big assembly hall where generators were tested. The tunnel also served as a conduit for air conditioning and heating equipment, with all the associated smells and sounds. Such working conditions would not be acceptable today. The noise bothered him most. When machinery was running in the hall above, the people in the tunnel below couldn't hear each other speak. From time to time the generators were coated with various types of insulation material, and it became difficult to breathe because of the fumes seeping into the tunnel[2].

Fifty or sixty years later, Rolf himself found it difficult to believe that he had really got the Zurich betatron to work at last. He had made a smaller one during the war, but it was sent to England and disappeared. He had dreamt of this new one for so long. Toiled over it; there was no lack of effort. Needed it; for his reputation, for his livelihood.

Radiation hazard had been a problem. More than just a problem, a real danger, even though he himself was not so scared of it. They didn't have much protection against the radiation, and once a week he and the staff had to drive 30 km to the hospital to have their white blood cells counted. If the

level was lower than 3,000 per cubic millimetre they would need to 'have a little holiday,' as he described it. Then when they increased the power of the machine even further the radiation level also became too high for the workers on the floor above. But nothing is without some good, for this led to them getting their own radiation laboratory that was not only safer but also better equipped. They were glad to see the light of day, and in his lectures he used to point out that 'developing a betatron was 95 per cent sweat and 5 per cent inspiration, though he did add that 'Sometimes you really need that inspiration.'

Nor was their flat anything to boast about. It was small and gloomy, and as autumn progressed into winter they soon realised that it was also cold. The children found some things familiar and some rather different from what they were accustomed to, but with enough novelty to whet their interest, such as downhill skiing in the Alps using cross-country skis. Using the ski-hoist was out of the question, and the wind blew right through their home-knitted woollen mitts.

The Secret Room in the Attic

Their time in Norway had had dramatic moments too, with a war on and much happening that they hadn't understood. Father had only been home in the holidays, plus a few days now and again. Now that they had moved to Switzerland he was home all the time. The children later came to realise that mother had not had an easy time in Norway. Her husband was constantly on the move without her being able to say very much about it. Plus three small children, everything rationed, rumours of Nazi affiliations—and uncertainty, uncertainty.

Arild, the eldest, remembers best and has thought about it since. When asked how his mother had fared in Norway during the war, he replied:

> It was certainly difficult for my mother, for I know that we had lots of home front newspapers stored in a secret attic in our house in 8 Melumveien. I know exactly where. And that was risky.
>
> *Were they for onward distribution?*
>
> Yes, they were passed on further.
>
> *So bundles of newspapers came to your house?*
>
> Yes.
>
> *Who distributed them then?*
>
> That I don 't know.

Someone came and fetched them?

Yes, someone certainly came to fetch them. I reckon my mother had connections with the home front, otherwise that wouldn't have happened. I'm sure of it. It's not just something I have suddenly discovered.

What was the paper called?

I don't know. I just know that the house had a type of annexe on the first floor, a dormer, where father had a sort of office, which was the guest room and in there we had two secret spaces that you didn't see right away.[3]

That was a lot for a little boy to think about. Some of life's questions remain unanswered even as an adult.

BBC Becomes ABB

The business Rolf worked for after the war was not just any company. BBC was not something to do with British broadcasting, but stood for Brown Boveri and Co. Charles Brown and Walter Boveri had founded it as early as 1891 and had started building their first generator factory in Switzerland that year. The firm played an important role in the electrification of the European rail network, which started with BBC taking responsibility for a 20 km stretch in Switzerland at their own risk. The next big development was steam turbines. Shortly before the First World War the company delivered what was till then the biggest steam turbine in the world, at 40,000 horsepower. The company soon outgrew the home market and started establishing daughter companies throughout the world. Shortly before celebrating its centenary, BBC had almost 100,000 employees and an annual turnover equivalent to about 7 billion US dollars in today's values. Rolf came on the scene about half-way through the company's first century with responsibility for the development of betatrons, which remained one of their major specialties for several decades. They were in competition with Siemens, another global firm with a rich tradition.

If you drive into Baden today you will see the company's buildings grouped almost like a little town within the municipality. *Brown Boveri Strasse* runs as it did then past the original brick building that now faces a modern reception area in glass and steel across the road. The name on the reception building is no longer BBC, but ABB in red, illuminated letters with the logo's characteristic square pattern of thin white lines binding them together.

In 1988 Brown Boveri merged with the Swedish company ASEA to become ABB, ASEA Brown Boveri Ltd. Percy Barnevik from ASEA

continued as chairman of the combined company, turnover soared and for a while the firm made repeated appearances in jubilant headlines in the Norwegian press. ASEA had secured a majority shareholding in the Norwegian telecommunications and industrial concern *Elektrisk Bureau A/S*, which was among the leaders in the Norwegian electronic and telecommunications industry and until then had supplied telephone apparatus to most Norwegian households. These were significant times in Norwegian and European industrial history.

Norsk Elektrisk and Brown Boveri A/S, better known as NEBB, had been a daughter company of Brown Boveri ever since 1908. Among other things, they had built locomotives for the Norwegian Railways in their factories near Oslo. The company had its origins in 1874, as Frognerkilens Fabrikk and changed name in 1894 to Norsk Elektrisk A/S. Collaboration with BBC had started in 1905 and in 1908 the two companies had merged to become NEBB.

Skabo Railway Carriage Factory joined the group in 1948. Then in 1973 the Skabo Railway Carriage Factory was closed down and the assets transferred to Strømmens Værksted, which was bought up by NEBB six years later in 1979. Nine years after that, in 1988, NEBB became part of ABB when the parent company merged with ASEA.

NEBB had a proud history by the time the Swiss company came into the picture. The Solberg family had owned the famous Frognerkilens Fabrikk for several generations, and they continued to lead the business long after the firm was taken over by NEBB. When Rolf was employed in their factory at Skøyen in 1940 the manager was Sven Adolf Solberg, one of the third generation of the family. He and Rolf were about the same age, and they became good friends for the rest of their lives. Sven Adolf had the same name as his grandfather who founded the company. He had qualified as an engineer at the same technical college in Zurich where Rolf later taught for many years. Immediately on qualifying he had taken up employment in the mother company in Baden until four years later when his apprenticeship was complete and he came home to join the family business in Oslo, where he became managing director in 1926.

A New Ford and a Free Hand

Now, in 1946, it was Rolf's turn to take up a position at BBC's head office, where he was given a free hand. The company wanted to establish its reputation in atomic physics and particle physics in competition with Siemens

and the rest of the world, and the management supported him in all his enterprises. He was clearly the leading expert on betatrons in the whole of Europe. Rolf himself thought that the wide authority he was given was largely thanks to Professor Scherrer, whom he had met during his visit in the spring and who was an ardent advocate of betatrons and a good friend of Walter Boveri. Scherrer was a great scientist who later had a research institute named after him, and he was a good friend and helper to Rolf.

Although the betatron was primarily designed for medical use, the management at BBC saw it as a means of getting into atomic physics, which was now the big thing in science. At a time when the atom bomb dropped on Japan had affected the whole world and stimulated the industry, the idea of a 31 million electron volt accelerator had a certain psychological effect even on people who knew nothing at all about physics. The exact figure of 31 million electron volts was chosen because that strength could pass through 10 cm of human tissue, which Rolf at that time thought would be sufficient. He developed a good working relationship with Dr. Hans Rudolf Schinz at the University of Zurich, who was also an enthusiastic supporter of the new treatment machine. In addition to his university appointment, Schinz was also head of the radiotherapy department in the town hospital. So Rolf had all the supporters he needed: in the company management, because the senior director knew a professor who was positive about it; at the university, because they saw the scientific potential; and at the hospital, because they needed the machine and were willing to pay for it.

That didn't mean that the task of building it was easy, however. There were major technical problems at the start, and it was difficult to get the machine to work as it should. Rolf tried to build it similarly to how he had built his smaller machine several years before, and he studied the American Kerst's latest machine. Six months later, in January 1948, he found the solution. The project gathered speed. In 1949, after three years in Switzerland, he renewed his contract. Didn't return home as he and Ragnhild had expected. Stayed on in Switzerland. That was where the opportunities were. And the children's schoolmates, and their own friends, and the tennis court. Moreover, he had to see the betatron fully installed and in use in the hospital that had ordered it.

The machine had now come to a stage of construction when it could be moved to the hospital. The business of mounting and calibrating it began in a special room there, paradoxically at the same time as Rolf and family moved house in the opposite direction, out of the town. The family of five moved into a house nearer the factory, in the town of Ennetbaden. There was still a lot of work to be done, particularly on radiation shielding, and

various modifications were made to protect people from stray radiation. These mainly involved the use of sheets of lead to protect against X-rays, but machines such as this also produce neutrons. Protection against these was more complicated, because of the need to distinguish between fast and slow neutrons, each of which had to be dealt with differently.

Testing continued. It was a race against time as the customer began to get impatient. When Dr. Schinz came to inspect the work one day and saw Rolf lying under the machine, he said jokingly but not without some sting, 'There lies my worst enemy,' and poked him with his walking stick. But Rolf reached his goal at last. Europe's very first high-energy radiotherapy betatron was ready. There was great enthusiasm, and the first patients were treated in April 1951. Rolf and Dr. Schinz continued to work together and wrote several articles on high-energy radiation.

The investment paid off. Rolf's son Arild says that Rolf got a pay rise when the betatron was ready. They had now been in Switzerland for five years. Arild was then 13 years old, and he remembers it well. His father sold the old Chevrolet and bought a brand-new Ford.

Arild *(eldest son)*
When Norway was occupied by the Germans, the Norwegian defence forces had already requisitioned private cars, because they didn't have enough vehicles of their own. At that time my father had an American Ford, a '36 or '37 vintage, that he had to let go. But, man that he was, my father went straight into town and bought a new car. A Chevrolet, that wasn't registered. It just sat in the garage. Without wheels. Under a tarpaulin. Nobody knew about it. At least, the defence forces didn't know that there was a car there. It just stood there until the war was over. So my father was one of the first people to drive a car in Oslo after the war.

Arild *(eldest son)*
In 1951 we drove to Norway in the old Chevrolet, left the car behind in Norway and took the train back to Switzerland. We stood almost the whole way. We did have seats, but we youngsters, we stood, for there were masses of Germans invalided by the war who needed to sit. My brother, little-Rolf, he always stood in the car too, stood from Switzerland to Norway. There was really no room to sit on the back seat, because we had so much baggage there, so he stood over the universal joint, and so he saw better too.

Rolf jnr *(youngest son)*
The car that we drove when we moved to Switzerland, we had it until 1951. Then Dad bought a car here, a new Ford. And the Chevrolet was sold to an in-law, Egil Reksten. That was when the first betatron had been sold, and he was given some money. He had sold his patents to Brown Boveri and he had

an agreement with them that if it was a success and they managed to sell the machine, he would get a commission. And the first thing he bought with that money was the car.

Rolf jnr *(youngest son)*
I think I remember us being on the boat. But maybe I remember it because I've seen photos.
Did you know why you were moving?
'Because my father had got a job in Baden.'

Arild *(eldest son)*
My mother told me later that it was she who had decided that we would live in Zurich, even though my father was working here in Baden. She thought that there would be nothing to do in Baden. She wanted to go to Zurich which was a proper town, not just an ordinary little village. But she regretted it later, for when we moved to Baden she made good friends there and joined the tennis club and all her social life was based in Baden.

Rolf jnr *(youngest son)*
The Steiner School was on the other side of Zurich, near the University Hospital. We could get the tram there but in the summer I saved, I think it was five centimes, every time I used my scooter.

Arild *(eldest son)*
He was good with us children too. I remember we were allowed to be there when the first betatron was installed at the hospital. There had been a lot of night work, for they were behind schedule, and Sunday work too. And then we were allowed to come too – at any rate I was – and we were in the hospital and looked around and there were many strange things to see there. But I have thought since that perhaps it was not just to be kind to us, it may also have been to stir up a little excitement. He wanted to show that he had done it at last. The invention back in 1927 when he did his doctoral thesis, that was just pure theory. But here is my life's work! Which now works at last. And it can help people who are ill, by curing cancer, or at least by trying to cure cancer, without causing so much scarring around the tumour.

Bergen V. Oslo

Meanwhile, another race was taking place in Norway, where two of the nation's leading hospitals were vying for prestige. The hospital at Haukeland in Bergen was trying to get ahead of the Radium Hospital in Oslo. Both institutions wanted to be up-to-date in providing high-energy radiotherapy for their cancer patients. But how to obtain such a machine? There is no competition more fierce than a struggle between Oslo and Bergen, and both

cities armed themselves with international expertise about the various types of high-voltage equipment then being tested in America and in Europe.

During the war, Haukeland Hospital in Bergen had decided that they would build a Van de Graaff generator. Local man Odd Dahl, who would later come to know Rolf, was to be responsible for making it. Odd was a colourful and self-taught practical man, an engineer and an aviator. He had been a pilot on the Maud Expedition with Roald Amundsen, worked as an assistant at the Carnegie Institute in the USA and earned a reputation for constructing various types of instruments. He was now employed at the Christian Michelsen Institute. Dahl played a leading role in the technical development of nuclear physics in Norway and later took part in the planning and construction of the first Norwegian atomic reactor at Kjeller.

Early in 1938 the Bergen district of the Norwegian Red Cross had set up a Committee Against Cancer, to take up the fight against the disease that was then causing more deaths per year than tuberculosis, as Dahl wrote in his book:

> They launched an appeal for money to buy radium for cancer treatment at Haukeland, but the price of radium was so ridiculously high that it became clear that nothing less than a million kroner banknote would suffice. That was when the idea of a high-voltage generator was proposed.[4]

Many universities throughout the world were now setting up atomic research groups as a natural consequence of accelerators having been developed. Dahl considered that a high-energy installation would increase Bergen's status as a scientific centre and would support the campaign to establish a university there. Surely Oslo shouldn't be the only Norwegian city to have a university? The Technical College in Trondheim was also working on high-energy radiation and had already built the country's first accelerator, a Van de Graaff generator that Haukeland Hospital thought was too small.

The generator project in Bergen was regarded sceptically both by the medical profession and by others who didn't hesitate to express their doubts, as Dahl recalled:

> The plans were hotly debated in the press, where the majority opinion was that it would be throwing money away on something that would never give results. "Do these people in Bergen think they can achieve something nobody else has done?' seemed to be the feeling in the capital.[5]

He and his colleagues went to Philips in Holland, but came back disappointed. The Van de Graaff generator was too expensive. If there were to

be any apparatus, they would need to build it themselves. Dahl had been involved with such machines at the Carnegie Institute, and he asked his Norwegian-American colleagues Tuve and Hafstad to look at the plans. These were well enough advanced for building to begin, and in 1941 the Van de Graaff machine in Bergen was ready for use.

However, developments were proceeding elsewhere in the world, and by the end of the war Haukeland Hospital needed even more equipment. Again the problem was money, though this problem was solved in an unexpected manner. They won the equipment, but lost the race with Oslo. The man who pulled the strings was the chairman of the board of the Radium Hospital, and this is how it came about that Bergen's competitor became their rescuer:

> The Radium Hospital in Oslo, who had expressed strong opposition to the high-voltage plans at Haukeland before the war, had seen that the apparatus had fully proved its worth. "So we must have one too," they thought, and I readily accepted their invitation to build them a machine like the one at Haukeland. This work was well under way by the time the management at the Radium Hospital learned that Rolf Widerøe had been appointed at Brown Boveri and Co. in Switzerland to develop betatrons for commercial sale to hospitals. They decided that was the type of machine they wanted. I said I was willing to build one for them, but they preferred to buy one from Switzerland so that they could be sure it would work. The situation was resolved by Schibsted, the editor of *Aftenposten*, who was also chairman of the board of the Radium Hospital. He arranged for the high-voltage machine that they had ordered from me and on which I had started work to be fully paid for and presented to Bergen.[6]

Moscow also took note of Bergen's interest in atomic physics. World War 2 was followed by the Cold War, when anything to do with atomic power was hot news. The foreign commentator of the *Red Star* wrote what seems to us a rather distorted account of the situation:

> Norwegian scientists have for some time been taking part in the work on nuclear fission that is being done in the United States. This work is now also taking place in Norway. In Bergen there is a specialised institute where the Norwegians are researching nuclear fission under the direction of American colleagues.[7]

The Radium Hospital Changes Direction

Oslo also needed to renew its radiotherapy equipment. They too contacted Philips in Holland to enquire about a Van de Graaff machine. They came to the same conclusion as Bergen; it was too expensive. Then a new and

even better possibility arose; a Brown Boveri betatron. The first and so far the only one of these in Europe had been built in Switzerland. Professor Tor Brustad, who has had a long career at the Radium Hospital, tells the story:

> 'Much of it happened by coincidence. It started in 1949 when the Radium Hospital appointed a physicist from Oslo University, Olav Netteland. Brown Boveri had delivered their first betatron to the hospital in Zurich that year, and Rolf Widerøe knew Netteland from when they had both taken part in rescuing the newly started physics journal before the war.
>
> Many years later, Netteland told me that in 1950 he had received a letter from Rolf Widerøe in Switzerland, saying that he had succeeded in building the first betatron for use in radiotherapy and that it had been delivered to the hospital in Zurich. Brown Boveri was going to build another machine and if the Radium Hospital was interested they would need to act fast as several hospitals around the world had already been in contact with the company. Netteland was so interested in this that he informed the director of the hospital, Reidar Eker. The director was a businessman and he decided to send both Netteland and a senior doctor to look at the machine and find out whether it was suitable for the Norwegian situation. They came back very enthusiastic, went to the director and told him not only that he must order a machine but also that he must do it immediately.[8]

Brustad told me that he spoke about this with Rolf many years later and that Rolf said that the order from the Radium Hospital was the strangest order that Brown Boveri had ever received. It simply read: 'We are ordering a betatron.' Full stop, followed by the date and the director's signature. No specifications, no indication of the energy level required. No mention of radiation intensity, voltage, radiation shielding and so on; none of the details normally included in an order.

> When Rolf Widerøe told me this, he laughed and said "So we built a 31 MeV betatron for them." It was delivered on time in 1952, a machine exactly like the one supplied to the hospital in Zurich. In the meantime the Radium Hospital had built a special bunker to house the wonder-machine. The test period after installation lasted until the end of the year, before it was applied to routine treatment schedules from the start of the new year. So the Radium Hospital had acquired Europe's second betatron to provide radiotherapy for cancer patients. The fact that we took part so early in the development of radiotherapy – you could call it a revolution – put the Radium Hospital right in front. Accelerator-generated radiation was clearly the big new advance.

Brustad, who told me this, was a newly appointed research worker when the Widerøe machine was purchased. He later became a professor and was head

simultaneously of the cancer research institute's biophysics department and the hospital's department of medical physics and technology.

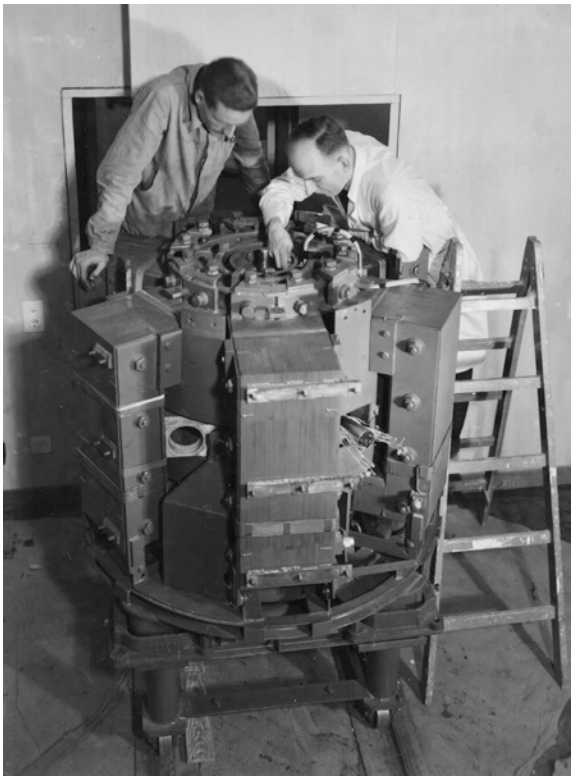
In Rolf's Own Words

Rolf himself has also told the story behind the Radium Hospital's order and what was going on in Bergen, and the story becomes no less dramatic when it emerges that Siemens had also been involved.

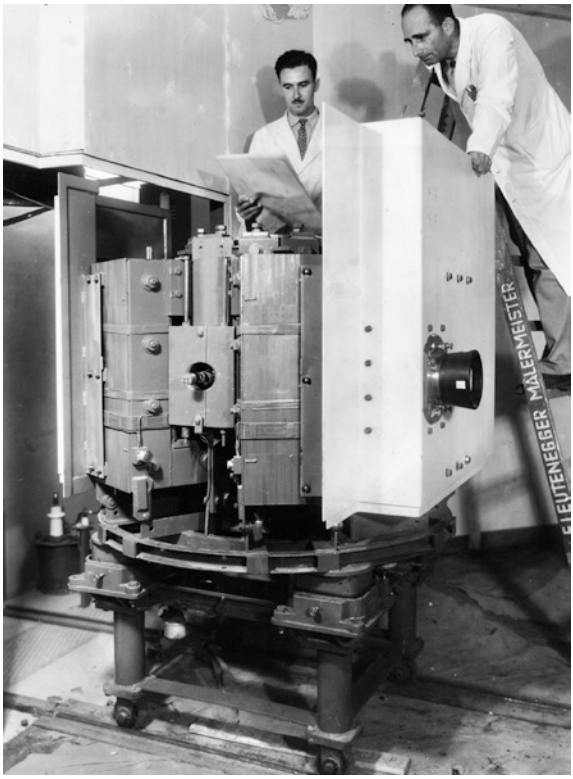
At first, the people in Bergen had tried to get hold of a Philips machine, which they found they couldn't afford. They had only managed to collect 150,000 kroner. 'We must remember that a Van de Graaff machine like this could generate radiation equivalent to the output of one gram of radium. And at that time a gram of radium cost about a million kroner,' Rolf explained in an interview. But Philips had advised that they could build a machine themselves, especially as Odd Dahl could take charge of the technical process of manufacture. He had already built and operated high-voltage machines in the USA. The Van de Graaff machine for Haukeland Hospital was completed in 1941 and was able to generate 1.7 million volts. Then Dahl went on to lead the work on a new machine of the same type, which went up to 2 million volts. Eventually the Radium Hospital in Oslo asked if they could have a machine like that, and work was started. But then things began to happen:

> When betatrons became topical in 1948 the senior doctor at the Radium Hospital, Dr. Bull-Engelstad, ordered one from Siemens in Erlangen. It was to have an energy level of 6 MeV and to be delivered in 1949. (…) The parts for the Van de Graaff machine that was already under construction were given to the University in Bergen as a gift. That was the situation when Olav Netteland started working at the Radium Hospital in September 1949. That autumn, Netteland went to Erlangen to look at the betatron. Siemens had already started developing a betatron of 12 or possibly up to 18 MeV.
>
> By that time Brown Boveri in Baden were well advanced with the 31 MeV machine they were building for the hospital in Zurich. Siemens presented their 6 MeV machine at a radiology conference in 1950 in London. It was discovered later that the equipment exhibited had been non-operational and that the machine had never had a drift tube. Olav Netteland then got in touch with me, and in September 1951 he and a doctor, Dr. Steen, came

to Switzerland to look at our 31 MeV betatron that was already up and running at the regional hospital. I went to Erlangen later that autumn, when all Siemens could show me was their 6 MeV betatron. They were still a long way short of completing their 12 MeV machine. I had no difficulty arranging for the Siemens order to be cancelled, and Professor Eker immediately ordered "a betatron" from Brown Boveri. We delivered a 31 MeV machine in summer 1952, and it was in use six months later.[9]

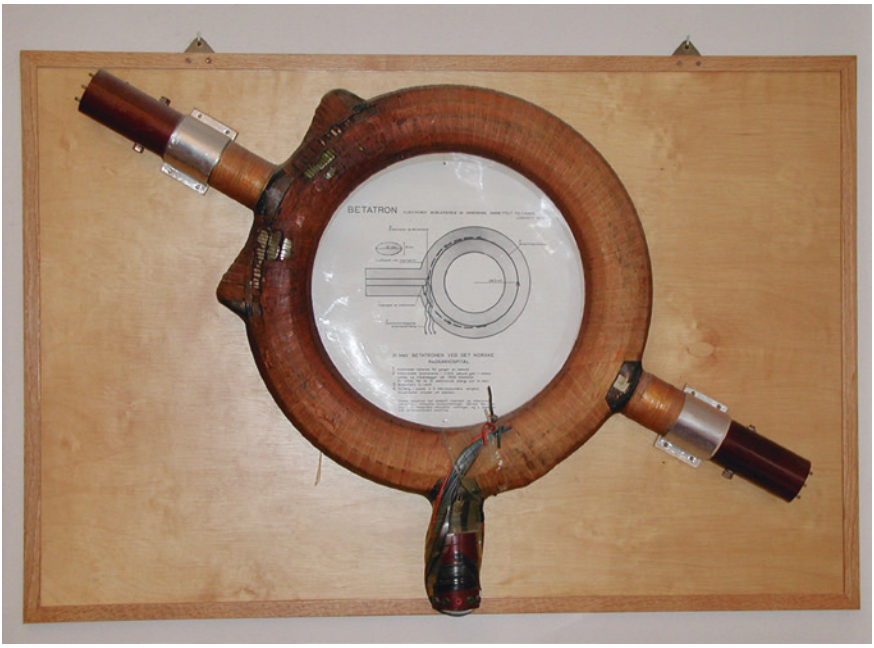


The work on the first medical betatron, a 31 MeV machine, took four or five years up to 1950. Rolf Widerøe participated actively all the time. (*Photo* ABB Archives)

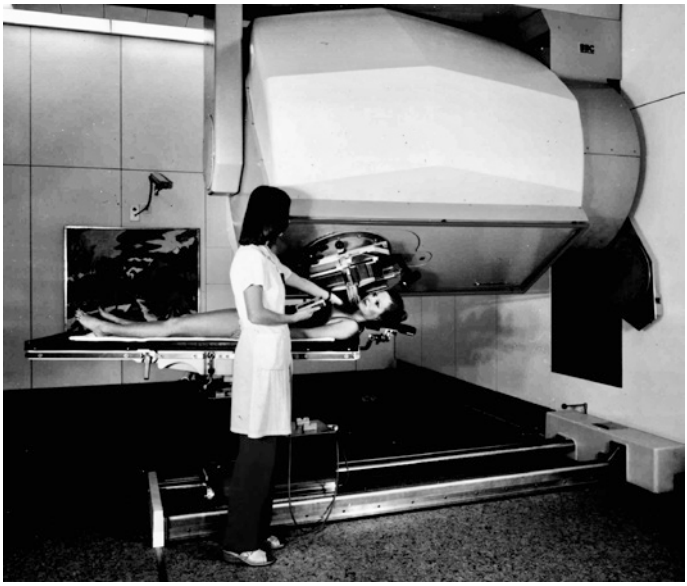


The first medical betatron was a machine for the hospital in Zurich. On the left: D. Gamper. (*Photo* ABB Archives)

Rolf Widerøe at the control panel of the betatron that was developed for the Norwegian Radium Hospital, his second 31 MeV betatron, which was delivered in 1952. (*Photo* NTB scanpix)



The acceleration tube from the Norwegian Radium Hospital's first betatron, on display in a glass cabinet in the hospital vestibule. (*Photo* Knut Bjerkan)



The Inselspital University Hospital in Berne in 1952 got their first medical betatron, number three in the series of 31 MeV machines. (*Photo* ABB Archives)

Throughout the next few years Rolf was in contact with the Radium Hospital several times to ensure that the glass tubes were as they should be. It was during one of these visits that the research worker Tor Brustad got to know him. The tubes that were available at that time lasted only about 500 h, or perhaps sometimes as much as 1,000 h. That was not nearly enough. They experimented with different types of tube but Rolf was not satisfied, even though Netteland thought that there had been an improvement after the first year. The problem was not resolved until autumn 1957 when Rolf himself went to Philips in Eindhoven, who recommended their own patented method. From then on, the tubes were always supplied by Philips. The life of the tubes rose to over 20,000 h, and sometimes as high as 40,000 h. Subsequently, tubes were developed that could last 25 years or more.

Another part of the history of the Radium Hospital's famous first betatron is that the experts were concerned about the radiation hazard the operators were exposed to. The betatron came to be referred to as 'the sterilising machine.' Rolf forthrightly rejected their fears.

French Chateaux and Norwegian Summers

The first two or three years in Switzerland were quite hard for the family. Rolf was very taken up with his work, and holidays like those of former days were infrequent. Norway was a long way distant, and Ragnhild took the children on her own for summer holidays in Norway. The war had ended only a few years before, and travel was still difficult and exciting, as Arild recalls. He was aged ten at that time and travelled on the back seat.

> We drove through Germany, which was quite problematic at that time. It was impossible to buy petrol, and so we had depots in various places and always carried 40 litres in two spare cans. Our route went through Basel and on to Heidelberg. An old student friend of father's lived there, a director of Brown Boveri in Mannheim. We stayed overnight with him, as there were no hotels. Or rather, they were all full of Americans or English. It depended which zone you were in. Heidelberg was in the American zone, and we got petrol there. Then on to the next depot, where we filled the petrol tank again. That lasted us as far as Northeim, where we were able to fill up again at the Norwegian military base. That was enough to take us to Hamburg. He had another friend there who was called Seifert, and we stayed there overnight too. And then we were soon in Denmark. But the journey took a long time in those days, as the motorways were narrower and people didn't drive so fast. Many bridges had been destroyed, blown up by the Germans themselves to block the American

> and English advance. Almost every second bridge had been damaged, and there were numerous diversions. It took five or six days to get to Norway. My mother usually drove at first when father didn't have time to come with us. So then my mother arranged either for one of her sisters to come, or sometimes it was an uncle who came down to visit us and drove us back up, or the other way round and someone drove us down again.

Starting from Switzerland, other continental countries were quite near. In the short spring and autumn holidays the family went by car to, among other places, the neighbouring country of France, where Rolf's father had business connections. The children were very impressed by their visits to the wine chateaux, as they have later recalled. This was a time of new experiences for young and old. Hard work for father, yes, but full of excitement for them all. Throughout the year, despite work and everything else, Sunday was kept as a free day for the family, and that meant going out on a trip. Both Rolf and Ragnhild took many photographs, as is evident from their albums: eating sausages; quiet lakes amid the forest; mountaintops and ski trips.

After an intensive induction period in the first few years, Rolf began travelling abroad for Brown Boveri. His travels really took off in 1952, when he was away every month to some place or another and usually to several. This continued for the rest of his career at Brown Boveri, with visits to more and more new countries. Altogether, he visited about fifty different countries where he delivered lectures, attended conferences or discussed betatrons one way or another.

He enjoyed travelling, but he also liked having people coming to visit. 'You must come down to visit us' was a repeated refrain when he was talking with the family in Norway. And they did, young and old, alone and together. 1950 was the start of a social era which lasted more or less for the next half century. Welcome! Bring your friends! We have room for all! They came: siblings; brothers-in-law; sisters-in-law; nieces and nephews. They all thought it fun to travel abroad and visit Rolf. Didn't he do it really well? He had a lovely house, and was always so welcoming. But they did realise that he worked hard. One of the nephews on his wife's side, Jørgen Holmboe, uses the word 'inclusive' when he recalls these days:

> They kept really close ties with Norway. We were in regular contact and visited them many times, and they always came to Norway in summer, to visit the family and stay at the holiday home on Skjæløy. It was like part of our family tradition in summer. I'm not a Widerøe, but it's as if I was married into the

family, as Ragnhild was my mother's sister. That's not really a close family tie, but I do know several of the Widerøe family, such as Rolf's brother Viggo and sister Else for example. My extended links with the family show that when Rolf and Ragnhild, were home they were very inclusive. I have also visited old Mrs. Widerøe at the house on Skjæløy. Why would I have done that? I'm only a rather distant relative. They have nurtured these wide family ties. Their home was a staging post for everybody who travelled abroad. There was always somebody visiting them in Switzerland. I would say that we had closer contact with them than one often has with families living in Norway.

They also kept their house in Røa in Oslo for a long time, plus a vacant site next to it that they also owned. At first they rented the house out to other members of the family, until their daughter moved to Norway and lived there for several years with her family. At home, they always spoke Norwegian. They had never quite "moved away." They were always Norwegians in Switzerland, even though their friends and social circle were obviously Swiss. They brought these Swiss friends to Norway, their own friends and the children's friends. They came every summer with their Swiss friends to show them this beautiful country. They maintained really strong links with Norway and regular travel to Norway at every possible opportunity. They were and remained Norwegian émigrés, not Swiss.

Plus-Fours and Dreams

Another nephew, Aasmund Berner, Rolf's sister Grethe's son, also recalls a hospitable uncle of the old school whom he had visited in Switzerland on his honeymoon:

I grew up in his house in Røa. My parents rented it until they took over my mother's childhood home in Vinderen, where Rolf had also grown up, in Borgenveien 30. When we married, my wife and I drove down through Europe by car and visited him in Zurich. And then we saw how typical he was – so really Norwegian, with old leather boots and plus-fours and a wind jacket and a rucksack with a proper frame as they were at that time, and really striding out.

Rolf and Ragnhild had been at their wedding in Oslo, where Uncle Rolf had made a speech. He started by introducing himself courteously and correctly as the eldest family member present, and went on to wish the bridal couple success. He conveyed greetings from his mother, who was the bridegroom's grandmother and unfortunately not well enough to be present. Greetings

also from his three children Unn, Arild and Rolf. Then he continued on a more personal note to say that he had not met the bride before, 'but I have met you often before, Aasmund, and your father has kept me well informed about your life and your activities.' He then went on to say that in the morning he had been chopping wood, and had philosophised about the old problem of spirit and matter:

> Now you may well think that chopping wood doesn't have much to do with spirit, but that is surely a mistake, for the mind is freed and thoughts go their own way. Nowadays bodily, material considerations occupy the driving seat. Other values are recognised but they are given lesser status. There are many who believe like me that this is a mistake, and that everything here in the world moves like a wave and the perception will undoubtedly change – possibly as soon as the next generation. Over-emphasis on material things is surely an important cause of many of the difficulties we have to contend with today, and on the other hand an over-emphasis on spiritual things can also lead us astray.
>
> The task therefore is to find a healthy balance, and this applies as much to ones own life as to the higher entity – marriage. I should imagine, Aasmund, that in the course of your studies you will already have noticed what a decisive role spirituality plays for a doctor. A true doctor understands that he is working at the boundary between the two realms and that when life is at stake the patient's own spiritual reserves need to be identified and brought into play.
>
> A marriage is also a journey that regularly crosses the border region between the spiritual world of feelings and imagination and the material world represented by physical chemistry, bronchial carcinomas, broken bones, tax returns and parking fines. So my advice to you is this: Find a healthy and natural balance between the two realms, remember that the boundary lines are not the same for two people and that they change constantly. Don't forget that dreams and the spiritual world are at least as important as, indeed today perhaps more important than all the little details in the material world. Try to understand each other and show patience.

Dancing Feet

Rolf enjoyed company. The family was important. Friends were important. He and Ragnhild were friendly with ten or twelve other couples whom they met regularly. Often at their own home, especially after they built their own house in Nussbaumen in 1956. Here they had their own 'fireside sitting room without a fireplace but with parquet flooring,' as they described it, and it was in frequent use. They also went to dance classes together, because

they enjoyed dancing, wanted to learn more and were thoroughly sociable. Modern ballroom dancing was becoming very popular throughout Europe, with both North American and Latin-American influences. Charleston and swing obviously, but samba and rumba and cha-cha-cha were also part of continental European social life at that time.

Peter Hug *(a neighbour's son in Switzerland)*
I can remember Rolf Widerøe dancing at the side of their swimming pool once when they had company. And then I got to go to Norway with them on summer holiday because I was a friend of their youngest son.

Egil Reksten *(brother-in-law, married to Ragnhild's sister Louise)*
They had lots of parties down there. A wide social circle, and I don't know how often, but they were constantly visiting each other. We in the Norwegian family were there only a few days when we were passing through.

Arild *(eldest son)*
I've been told that your parents were very sociable.
Yes, now that I think about it, so they were. They really were. They had frequent parties, especially after they got the bigger house. In Ennetbaden we lived in a flat. But then in 1955 they bought an empty plot and built a house in Nussbaumen – a little further north, nearer the German border, but not far from Baden, about four kilometres. They had a basement living room there. It wasn't very big, but it was big enough for a table with over twenty guests, so they had a lot of parties there. And they also went to dance classes. Father was not the type of scientist to be totally tied up in his research, though he did work very hard.

Rolf jnr *(youngest son)*
They went to dance classes together, for a long time, with friends. They must have got to know many of their friends at these classes. There were certainly 20–25 they socialised with. I remember once when they were going to a class in Waldshut, and it was the middle of winter, and their car was out of action, and I had a 2CV van that they borrowed. But it had no left-hand door, and they drove over to Waldshut in the open CV to go dancing.

Martin Hug *(a neighbour's son in Switzerland)*
Rolf Widerøe was interested in music, especially classical music. Having a stereo apparatus was something to be admired at that time, and I was very impressed when he told me that he had made marks on the floor to show him where to put his chair so that he sat in exactly the right position to make the most of the stereo sound.

Arild *(eldest son)*
He wasn't just working all the time. He was a good family man too. Sundays were sacred for him. We would always go out for a trip in the woods then,

taking a pack lunch with us. He always took an old, brown case with plastic plates and so on, and a methylated spirit stove for warming sausages. And my mother always brought a potato salad. We drove out to somewhere in the woods, went for a long walk and came back to the car for lunch. We often had family and friends visiting, and then we usually drove towards Lucerne or to Bürgenstock – always with the case. Or sometimes we went up into the Alps, to the Klausen Pass or the Susten Pass and such places that impressed Norwegians at that time.'

Rolf jnr *(youngest son)*
Yes, he was not an extreme athlete or anything like that, but he was fit and he did help me to build a ski-jump when I was a boy and he jumped it himself when he was over fifty.

Rolf jnr *(youngest son)*
I started playing the piano when I was ten or eleven years old, when he was about fifty. I tried very hard to learn, but he just sat down beside me and played a duet with me. He could still do that. I knew that they had had a grand piano in his parents' house, but I didn't know that he could play and that he could read music.'

Musicality and dancing feet ran in the family. The daughter, Unn, became a ballroom dancing teacher after first trying engineering like her father. She married an architect. The eldest son, Arild, became a jazz promoter and music producer. An artistic profession, far removed from the physics laboratories. Rolf, the scientist and technologist, received new stimuli in the liberal arts through his children, and his own curiosity and drive were often reflected in the choices the younger generation made. The youngest member of the family eventually gave up engineering to become a business consultant and broker. The eldest son said that his enduring dream had been to become a pilot like his role-model, Uncle Viggo. His father and his uncle watched him take off in other directions. Independence was also part of the Widerøe family tradition. Instead, it was Viggo's own daughter, Turi Widerøe, who spread her wings to become the first female pilot in a western commercial airline.

Rolf's sons still keep close contact with their relatives in the old country and maintain the tradition of summer holidays in Norway. All the nephews and nieces were invited when Rolf celebrated his 70th birthday and Arild is still in touch with his childhood friends from Oslo.

I'm very glad that my parents kept in such close contact with Norway, and particularly that we went to Norway every summer. There was no question of

> doing anything else. I had – and I still have – a best friend who became a priest. We were best friends from early childhood, and we have managed to hold onto that, thanks to the fact that I was allowed to stay with them when we visited Norway. We continued to meet regularly when we grew up.

Rolf's sons settled just a few kilometres from their parents' house in Switzerland. The daughter, Unn, died in a car accident at the age of 36. Rolf junior's youngest son, Stian, inherited the vacant plot next to his grandparents' house in Røa and returned to the family's roots in Oslo.

The Asklepitron

In the late 1950s, a time when the children were still at home, Rolf was working on a greatly improved version of the betatron, that would move round the patient so that the radiation was always directed to the right location. This machine was completed in 1959. It was named the 'Asklepitron', after Asclepius, the Greek God of Medicine, often portrayed as a man with a beard, a hat and sandals who wandered around in ancient Greece accompanied by his pupils and who according to mythology could restore the dead to life. Temples to Asclepius were built both in Greece and throughout the Roman Empire. Sick people flocked to these, and there are many stories of healing and miracles.

The first client to buy this modernised version of the betatron was a private hospital in Milan. The Radium Hospital in Oslo bought an Asklepitron in 1963, the third betatron they had bought from Brown Boveri.

Rolf also developed an accelerator that could direct streams of electrons from different sources in a chosen direction to the part of the body that needed to be irradiated. This was built with a special magnetic lens that could be adjusted to direct the electron flow. The engineer had used his experience with relays in power supply grids to build a machine to direct the radiation even more accurately and further reduce the risk of damage to healthy tissue. The accelerator was a success medically and a prestige product for Brown Boveri commercially. Many hospitals that bought betatrons came to prefer those that had this type of lens.

As Rolf was striving to develop and improve his own design of betatron, competition was happening elsewhere. Mainly but not exclusively among Americans; Siemens in Germany were a big challenge to Rolf, as his son Arild explains:

> My father always knew exactly, or more or less exactly, how far the Americans had come. He also always knew what Siemens were up to. They were Brown Boveri's main competitor here in Europe. But the Siemens machines were never anything like as good as the betatron. So it's difficult to say whether it was a real contest, I really don't think so.

More impartial sources support Arild's view, and the sales figures also confirm that the Swiss betatrons were in a class of their own.

None Better?

Betatrons are classified according to how high a radiation level they can generate. Anybody wanting to acquire a radiotherapy machine would need to take many factors into consideration. In the early 1950s, the best choice for a client wanting a relatively compact machine with high energy and good precision was a machine like the one Rolf had made for the hospital in Zurich. However, the technology was developing fast and what was a powerful machine one decade could be considered a weak one the next. Price was obviously important, alongside effectiveness, dosage, radiation hazard and all the other variables that led to medicine, physics and technology coming together and gradually merging into one subject, as at the Norwegian Technical College in Trondheim in 1970.

In America, Kerst had written a comprehensive history of the various developments that had led to modern betatrons, in an article in *Nature* in 1946, the year Rolf had moved to Switzerland.[10] He summarised both earlier published material and other work he had heard about. From this, Rolf concluded that many physicists had been working in recent years with the same aim of making a betatron that worked, but without knowing about each other. Kerst himself had been the first to achieve this, in 1940, using the theory that Rolf had initiated in his doctoral thesis in 1927. Kerst did give credit to Rolf for this. It appeared that the basic idea of building a betatron had arisen independently in different places at the same time. Industry was quick off the mark when new technology arose and saw the market potential of the betatron both for medical use and for materials testing. Even during the war, far-sighted development projects were set in motion both in Europe and in the USA with a view to sales when freedom came.

Big American companies such as General Electric, Westinghouse and Allis-Chalmers were all in the race. Kerst had been working with General

Electric when he built his first betatron, but prior to that Joseph Slepian at Westinghouse had secured the patent on an important preliminary step towards building a betatron. Allis-Chalmers were also promoting their 20 MeV betatrons commercially. In Europe, Konrad Gund at the Siemens factory in Erlangen was developing small betatrons.[11] These were later developed further into 18 MeV machines. Philips in the Netherlands was the company that both Haukeland Hospital and the Radium Hospital had approached with a view to obtaining a Van de Graaff generator, but they were also major competitors in building betatrons and their interest in this area was already apparent at the end of the war.

In Switzerland, Rolf was developing and manufacturing more and more advanced machines at Brown Boveri. In the 1960s they were able to increase the energy level to 35 MeV, and in 1970 they had reached 45 MeV. Such a level was decisive in being able to use the machine for materials testing. At one time there was talk of making betatrons right up to 200 MeV and possibly even more. Machines between 31 and 45 MeV were a big commercial success for Brown Boveri. Rolf knew from experience that there were many good reasons not to try to reach higher energies. A machine of 31 MeV already gave problems with fast neutrons, and these problems increased in machines with even higher energy. At the same time, the market for betatrons was beginning to become saturated and demand declined throughout the 1970s. By that time, Brown Boveri were working to produce a type of smaller linear accelerator that was simpler and therefore cheaper than a betatron and in many respects just as suitable.

Similar progress was being made in the USA. Donald Kerst had succeeded in producing his second betatron, rated at 20 MeV, in 1942. Then General Electric set about building a 100 MeV betatron, which they achieved in 1945. In the meantime, Kerst had returned to the University of Illinois where he started by building a prototype machine of 80 MeV before going on to build a gigantic, 300 MeV betatron. This was the biggest machine of this type that had ever been built, and it was considered to be the final step in the development of betatrons.

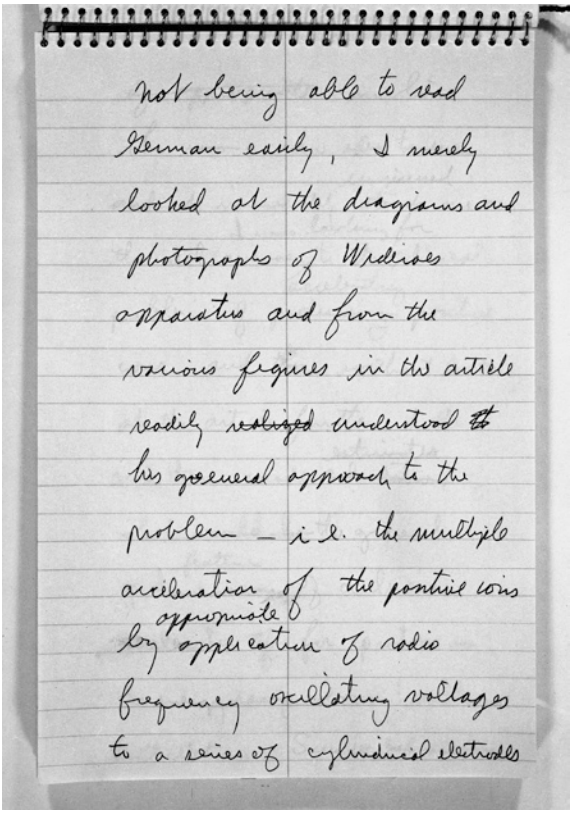
A newer machine was not always better, however. Different models had different functions and areas of use. In an article in 1962, Rolf compared three types of hospital betatrons and explained the differences between them. These were the machines from Siemens in Germany, Allis-Chalmers in the USA and Brown Boveri in Switzerland. He also described various linear accelerators that were then being produced, with many promising capacities for treating cancer.[12]

After the Betatron Came the Synchrotron

In the meantime, another type of accelerator had come on the scene. It was not necessarily better, but it met a different need which it fulfilled better than the betatron. The synchrotron was more successful than the betatron both in size and in price. Betatrons turned out to be most suitable for applications needing less than 50 MeV. For uses requiring lower energies, linear accelerators remained the preferred machines, especially in clinical use.[13]

So can we perhaps say that after the betatron came the synchrotron? Yes and no. Rolf played a part in both, or even prior to both. In this context we might well ask which came first, the chicken or the egg. Rolf himself considered and subsequent history has confirmed that the highlight of his career was the invention and perfection of the betatron. He reckoned that his next most important contribution was the synchrotron.[14] At the same time that he and others were developing and refining the betatron, he was also one of those working on a new method of achieving high energy—the synchrotron. In fact, he had been working on this issue from the very start. He was concerned to improve the stability of the path for the charged particles. His work on this led to a patent granted in January 1946 that included many of the formulae and the most important ideas needed for the construction of a synchrotron.

Particles can go round in a ring for as long as one is able to direct them. There is a third category of accelerator, with which Rolf was also involved. The cyclotron was invented by Lawrence, after he had been inspired by Rolf's sketches. So the cyclotron was really the first working particle accelerator with a non-straight path. At the risk of slight over-simplification, we could say that the betatron that Kerst invented in 1940—also inspired by Rolf's ideas—was a type of cyclotron.


not being able to read
German easily, I merely
looked at the diagrams and
photographs of Wideroes
apparatus and from the
various figures in the article
readily ~~reduced~~ understood ~~the~~
his general approach to the
problem – i.e. the multiple
acceleration of the positive ions
by application of radio
frequency oscillating voltages
to a series of cylindrical electrodes

Ernest O Lawrence was always careful to acknowledge Rolf Widerøe. He knew where the theory came from, and he never discarded his hand-written notes from when he had come across Widerøe's method of accelerating electrically charged atoms. Lawrence's note reads: '… not being able to read German easily, I merely looked at the diagrams and photographs of Widerøe's apparatus and from the various figures in the article readily understood his general approach to the problem—i.e. the multiple acceleration of positive ions …'. (*Courtesy* Brookhaven National Laboratory)

If we were to set up timelines of the developments, they would read as follows:

The idea of the betatron (Widerøe)
A working cyclotron (Lawrence)
A working betatron (Kerst)
The idea of the synchrotron (Widerøe/Oliphant/Veksler)
A working synchrotron (McMillan).

The similarity of the names 'cyclotron' and 'synchrotron' can be confusing, especially as these two types of machine are not the most technically alike. There are three main types of circle-shaped accelerator: betatrons, synchrotrons and cyclotrons. Betatrons and synchrotrons are close relatives, in that they both accelerate particles on a circular course. Magnetic and electrical fields are put in place around this circular path to accelerate the particles and to hold them on course. The cyclotron is a low, round 'cake shape' in which particles are accelerated in a spiral path from the centre outwards by an electric field and held on course by a system of magnets. This is a simpler type of machine, with limitations on how high an energy level it can achieve. So it is logical that this was the type of machine that anybody first managed to get to work.

Something in the Air

There were rumours from the USA that Rolf had gone to Tandberg's Patent Office in Oslo in the winter of 1945–46 with his ideas for a synchrotron. He had been working intensively on these ideas over the previous few months. Things had been difficult for him in his private life that autumn, and it was good for him to be absorbed in his work. The text of the patent application was complicated and it included formulae that he said fifty years later he himself no longer understood.[15] But everybody who had understood it at that time realised that it was important for the development of the synchrotron. Many also understood that the basic idea was a ring-shaped vacuum tube surrounded by a magnetic field that increased in strength in relation to the energy of the particles and held them on course. There were hundreds of other details that only few people were able to understand and that made this apparatus different from other accelerators. We could say that the patent defined a synchrotron, or even that it converted a betatron into a synchrotron. Rolf was especially proud of this patent.

He later heard that other people had had the same idea, and he became fascinated by the thought that an idea could, so to speak, float in the air in

different places at one time. McMillan in the USA had discovered the principle and presented it in an article in the September issue of *Physical Review* in 1945. It was a short article, only two pages, but it immediately became world famous. However, Veksler in Moscow had discovered the principle at the same time and already written a long article about it. As if that were not enough, it appeared that Oliphant, an Australian, and his colleagues in England had made the same discovery, or at least part of it, also without knowing about the others. Rolf claimed that he had lodged the patent application at New Year without any sure knowledge of what the others were doing:

> I saw McMillan's article a few months later. Communication and exchange of information among the scientific community was poor during the war.[16]

Several years before, while he was studying in Germany, he had also proposed and patented what he called the lens method. This was a way to co-ordinate or improve the focussing of the particle beams. He had thought about the problem for a while and had come to the conclusion that the new method was simpler to apply, and also better. The first person to develop this idea further was Nicholas Christofilos, a Greek who registered a patent on it in March 1950.[17] According to Rolf, however, that was not known about until February 1956. The Greek had been working at Westinghouse when Rolf was with Norsk Elektrisk Brown Boveri (NEBB) in Oslo, and they had met once at a conference in Russia. The lens method was the precursor of the better known 'strong focussing' that was introduced later.

Courageous Italians

A new and proud chapter was now beginning in Rolf's scientific career. In the 1950s he built a synchrotron for Turin University, that he considered his most important machine since the betatron. As if nomenclature was not already confused enough, he thought that the most suitable description of this machine would be 'beta-synchrotron,' indicating that it was a further development of the betatron. From 1953 onwards he had travelled to Italy several times to discuss the construction of synchrotrons. Two researchers were planning no less than a gigantic 1,000 MeV electron-synchrotron.[18] It was later built in a laboratory outside Rome where one of Rolf's former assistants, Bruno Touschek, was working.[19] Rolf took a different direction, however. He contracted with the researchers in Turin to build a smaller accelerator intended for experiments in nuclear physics. This was a

prestigious project, supported by the FIAT factory and the Italian Research Council, and Rolf had found like-minded collaborators:

> It was clear to me that a betatron was not the best instrument for this task. If instead I used the synchrotron principle, I could achieve better results with much smaller machines of about 100 MeV. But a synchrotron requires an injector, a pre-accelerator to give the particles a starting energy. In this project, the researchers in Turin were willing to follow rather untried methods to produce a compact, reliable and economical machine that could also be used in future in other research institutes. So we worked on a rather original concept, though we owed much to the work that had been done by F.K. Goward and D.E. Barnes in England. (…)
>
> The machine would work as a betatron until the electrons reached 2 MeV. It would then work as a synchrotron to continue increasing the particle energy. For me, this was the long-awaited opportunity to use my ideas and my knowledge of synchrotrons to build a machine myself. Obviously, this new project was based on our earlier positive experiences building betatrons at Brown Boveri.[20]

This takes us to the mid 1950s. Rolf had described the basic principle in his Norwegian patent in January 1946, and in the first phase of operation, when the machine functioned as a betatron, he was applying ideas he had patented in 1948. The machine was required to accelerate electrons in both directions, as some of his earlier betatrons had also done. Several of the physicists at Turin University were actively engaged on the project right from when the machine was ordered until it was ready and installed.[21] They came across many difficulties, however, and by 1956 it was clear that they would need more time than they had originally thought. So Brown Boveri temporarily installed a 31 MeV betatron, which continued in use in Turin until the new beta-synchrotron was delivered. This took a further three years, but Rolf was very proud of the final result, a 105 MeV machine exactly as they had intended. He and a professor who had been closely involved in the project wrote an enthusiastic report along with a colleague from Brown Boveri who had also taken part.[22]

All three of them had worked on the concept, the development and the construction of the machine. Rolf praised the major contribution that the Italian researchers had made to the success of the project. The most important thing had been to demonstrate that it worked in practice, and that it was also easy and inexpensive to build. Since then even simpler and more compact linear accelerators have been developed to work at this level of energy, and these have supplanted both betatrons and small synchrotrons.[23]

Maybe the Answer Is in the Wastepaper Basket

The youngest member of the team working on the Turin synchrotron was a Norwegian engineer, Karsten Drangeid, who was only 29 when he started in Rolf's department.

> You couldn't wish for a better boss,' he says. 'I really didn't notice that he was the boss; he was a member of the group.
>
> *Some people say that he was not a team-player?*
>
> Yes, but he had so many ideas that he became the leader of the team. For me, he was an ideal boss. Encouraging, stimulating, fun to work with. And lively. He took part in what I was doing. I've never had the same contact with other bosses.
>
> *Was he impulsive?*
>
> No.
>
> *But involved?*
>
> Yes, personally interested.
>
> *In the job or in you?*
>
> Both.
>
> *What made him so special?*
>
> A good example is when we were working on the machine for Turin University. We had a fragile, ring-shaped synchrotron tube that I worked on the drawing for. It was expensive, certainly more than 5,000 kroner, and it usually hang on a hook on the wall beside his desk. One day after working on the designs I put the tube back on the hook, when the hook broke and the tube fell down and was smashed. I looked at him. He sat and wrote something. Then, without a word, he handed me a requisition for a new tube. It wasn't a matter of finding a scapegoat, but of finding a solution to the problem that had arisen. It didn't matter who was to blame.
>
> Another example is his optimism. We faced many problems when we were working on the synchrotron. I showed him some design drawings I had done, which must have been wrong. We looked at them together and then he said, 'Perhaps this is exactly what we need to get it to work!' I never heard him say that something was impossible. Or, one day I had forgotten something when I went home and I went back to the office. There he was, rummaging in my wastepaper basket. He looked up and said, "You write interesting things and then throw them away?" He wasn't out to steal my ideas, he just wanted to help to solve the problem.

'The Turin machine was complicated, and he taught me to persist with it,' Drangeid said. He and Rolf never spoke Norwegian at work, but they spoke it when they were alone together. After just two years, Karsten Drangeid

was offered a position where he would take part in the building up of IBM's research laboratory in Switzerland, where he later became a director. This caused consternation in Brown Boveri, who would have preferred to keep him, and in his reference Rolf particularly mentioned that he had played an important part in bringing the Turin synchrotron into being.

I admired Widerøe enormously. We exchanged Christmas cards every year after I left, and my wife and I visited him when he and his family moved into their new house in Nussbaumen.

Arild *(eldest son)*
One autumn holiday I think it was, we went by car to France. What I remember best is that we stayed with a wine merchant. Old Widerøe, Theodor, had a wine agency. Among other things, he had the agency for Martell cognac over the whole of Scandinavia. We were guests there for a couple of days, I think it was autumn 1949. Later, in spring 1950, we went by car to Spain. The whole family. Sometimes with a tent. Father was an outdoor man. He had been on masses of camping trips and ski trips in what we call 'the old days,' in the 1920s. Both with Viggo and with his younger brother Arild. We have loads of photos of that.

Rolf jnr *(youngest son)*
We were on holiday at the place where Martell make their cognac. We were invited to dinner in a chateau with a beautiful, huge park, all symmetrical like the one at Versailles. And we ate outside in lovely weather, I remember. With white tablecloths. It was very formal and very good.

Rolf jnr *(youngest son)*
He could switch off from his surroundings completely, and then he was unaware of almost everything going on round about him. He drove past me once when I was on my bike and I sprinted behind and threw my bag onto the baggage rack at the back. He didn't notice anything and took it all the way home. Or maybe he was just pretending that he hadn't noticed.

Arild *(eldest son)*
My mother's sister Lydia was married to Iens Ludvik Høst who was sales manager at Aschehoug publishing house, and they always sent books as Christmas and birthday presents. Good books. So that was basically how I learned to read and write Norwegian. My first year at school was in the Steiner school in Oslo, where we just made models and so on, there was no writing to begin with. So I didn't learn to write Norwegian until after we moved to Switzerland.

Norbert Lang *(former head archivist at BBC/ABB Switzerland)*
Rolf's dog, a schäfer called 'Rex,' obeyed orders in three languages: Norwegian, German and English.

Martin Hug *(a neighbour's son in Switzerland)*
Rolf Widerøe was an important person in the town where I grew up.

Arild *(eldest son)*
Father often took part in conferences. He was regularly invited to lecture and was a very popular speaker. The lectures were always in English. He wrote them in Norwegian and translated them into English. When I read them now, I see that there were some mistakes in the English. But that didn't really matter, because what he said was so interesting that people listened. And it wasn't just all about technical stuff. There was a lot of nature study in it too.

Aasmund Berner *(nephew, Rolf's sister Grethe's son)*
They were naturally cautious about money and thought it shouldn't be used on unnecessary luxuries.
The old school?
Yes, the old school. You should take the hard way and cope yourself. He didn't live in luxury at all. My cousins said that when they went for a Sunday outing they took very simple food with them, perhaps not as good as their friends had.
There were other things that mattered more to them?
Yes, even though they certainly had the means for it, the children didn't get any extras.

Thor Spandow *(nephew, Rolf's sister Else's son)*
Rolf was good with numbers. Viggo and Else were good with people.

Radiotherapy Machines Worldwide

Commercial work at Brown Boveri's head office was running full ahead, alongside the research and development work. New and better betatrons were being installed in hospitals throughout the world. One of Rolf's engineer colleagues, Christian Gerber, was responsible in the 1960s and 70s for adjusting and calibrating the machines when they were installed on site. He recalls[24]:

> I enjoyed my time working with Widerøe. I was young when I started there and was excited to travel around the world. This seemed to me a fascinating type of accelerator, quite different from what I had known before. Previously, I had worked with Van de Graaff accelerators. Widerøe was amazing, but he did demand a lot.

Gerber was responsible for dose metering. This is a vital part of radiotherapy and consists of adjusting the machine to deliver to the patient the precise dose of radiation that the doctor has prescribed to achieve the desired effect. All betatrons that were sold to the USA went through his hands. In

the 1960s, betatrons were installed at many places, including: Montefiore Hospital in New York (1961); University of Maryland Hospital in Baltimore (1964); Galveston in Texas (1965); Mercy Hospital in Chicago (1967) and Henry Ford Hospital in Detroit (1968). These were all Asklepitron 35 models.

The first hospital he was sent to was in Helsinki. In consultation with Rolf he created his own tactical approach, based to some extent on intuition and on their good understanding of each other:

> When I went to Finland I was newly qualified and newly married, and this was my first job for Widerøe. He told me "You can finish off this machine and deliver it." Yes, right. I decided to involve the hospital personnel from the start; they were my salvation. I thought to myself, "When I deliver the betatron I need to know what I am giving them and they need to know what they are getting." And it worked. The Finns were interested in learning something new and moreover, if something later turned out to be not entirely to specification, as often happened, they understood why, and I think that was what Rolf Widerøe liked, because if the purchaser didn't accept and sign there was no payment.

Helsinki University Hospital bought betatrons both in 1962 and in 1963. When they came back the second time, Rolf said:

> You can do the job in six months.' I said "A year" and explained why. It took a year and everyone was satisfied.

They did struggle with one problem but finally solved it, thanks not least to one of the Finnish physicists who has since become a friend of his, Gerber recounts as he enthuses over his years working under Widerøe:

> He gave me confidence and opportunities. I enjoyed travelling – it didn't really matter where – and meeting other cultures. The social aspect was important to me, and my time in Helsinki was particularly good. We were working together on a commercial contract, but we got on well together. People were very enthusiastic about the new hospital, and we brought together a good team. The physicists and the physicians were all good at their respective jobs and by the time I left they knew the machine as well as I did. That was my secret. I had colleagues at Brown Boveri who wouldn't let anybody from a hospital come near a machine until it was ready, with the result that they got a surprise when the installation was complete but didn't know how the machine had been set up. I continued doing it my way throughout the world. This was possible because of Widerøe's reputation but also because of his leadership style.

In a way, he was the same enthusiastic type as myself. Keep going. You can do it. It wasn't always so easy, but the machines were amazing. I'm sorry to say it, but Widerøe wasn't really a businessman. He was an ideas man, a scientific genius. I remember the senior medical radio-oncology experts I met saying that they bought betatrons because of him – Schumacher in Berlin, Schinz in Zurich, Zuppinger in Bern.[25] All the leading people in cancer treatment. I could name many more. They all knew Widerøe. There was no effective competition. There was still a competitor in the States building betatrons, Allis-Chalmers. And Siemens in Germany. But we were the best. It began to change in the 1970s when people went over to smaller, cheaper machines, but these were also sophisticated, reliable machines.

Did he have a tough leadership style?

Yes, not a bad style but a firm style. He knew what he wanted. When he promised the customers something, he assumed that his promise would be carried out. He didn't ask if you could do it; he just assumed that you would. He gave advice rather than orders. He always said "It can be done!" and he really believed that it could be done. Often that was not the case, at least not without a lot of extra modifications. When that happened I didn't argue with him, but just showed him that it wasn't possible, and he respected that. Often there were things that had hardly ever been tried. When he promised things like that it was a bit of a job afterwards to sort the problem out and find solutions. Such was my life at that time, but it was a good life for me and my family. I was at Brown Boveri for fourteen years and I worked with Widerøe most of that time, including when he retired and continued working. At the end, to be honest, he was slightly forced out of his position as head of department, but not by me.

Why? Who pushed him out?

The person who took over from him, Dr. Max Sempert. Widerøe's mind wasn't on business considerations. He was still highly in demand as a lecturer at conferences throughout the world, because there was nobody better to talk enthusiastically about accelerators. Brown Boveri had to sell machines, and to do that they needed Widerøe. Leading a research and development department just by good salesmanship would be a mistake. Also, he wasn't always fully up to date with the very latest developments, and that can be risky for a company. I told him that. The others were too scared.

Not a Teacher

But what was he like as a person?

Everybody knew Widerøe, but hardly anybody knew him well. At the time of his ninetieth birthday there was a celebration at the technical college in

Zurich where he had taught, a colloquium in his honour with contributions by prominent scientists. I went along just as a member of the audience, but he rushed up to me and said "You must sit beside me!" "No, I'm not invited, I can't do that." "Oh yes you are," he replied, and simply took me to sit beside him in the midst of all these great names. Of course I felt greatly honoured by this, but we weren't close personally even though my wife and I had been invited to his house several times. He didn't let anybody get close to him. I don't know that he had any really close friends, except one. Remember, some of his colleagues were often competitors. That's how it often is in the world of science. People are obsessed about who gets research grants and who doesn't. If you cite me, I'll cite you.

Was he a teacher?

No, no, he was too domineering. Not a teacher. Nor am I for that matter, I'm not patient enough. But he was a personality. I don't think anybody really understands what an amazing man he was. He was a very special person. For example, he would come into the laboratory, stretch out his arm and say "Oh, I've got such a pain here in my elbow. Give me a little radiation." Then he went over to the machine and had his elbow irradiated. He believed in that, and he knew what he was doing. These were different times, obviously. Today you could never go into a radiation room without the necessary procedures.

Gerber recalls that when he was in the USA, Siemens tried to recruit him, but he declined:

I took the job here because it was interesting. It continued to be interesting, not least because of Widerøe. Long after he had retired, he often came to see what I was up to. I can see him yet, walking over the bridge towards the institution where I was working. Yes, he really was "somebody" in radiotherapy circles. He knew all the "big shots" in the world. There was nobody like him. Wherever he went – China, the States – the door was always open to him.

The Last Emperor

Did you go to China with him?

Yes, first to Hong Kong. We installed a betatron at the Queen Elizabeth Hospital there in 1963. A few years later we did the same in Beijing. Widerøe had been there beforehand to negotiate the sale. Then he came to me and asked, "Would you like to go there?" This was during the Cultural Revolution. He sent a team to construct it, and then we both went there. I had a group of twenty people: six or seven physicists, medical personnel, communist party

representatives, the security service – 'everybody' was there. So I did exactly as I had done in Finland and elsewhere. I said, "We'll do this together." We built up a fantastic team. I was there for a couple of months. It was a very interesting stay, and I even managed to learn a little Chinese.

The head of the cancer clinic had studied in England. He was a good bloke, and we have kept in touch since. I wasn't working on my own. Everybody in the group was on the job, some of them quite remarkable people, good people, and we helped each other. When I was leaving, there was one of them whom I knew to be the highest communist official there. I felt I had to say to him, "You are a good communist." – meaning that he was an honourable and honest man. I didn't agree with their politics, but I could talk with them.

Was it unusual for these people to have such contact?

Yes, to be able to speak openly. We worked on the betatron that Widerøe had sold to them, we told them about life here in Switzerland and they showed me their homes and possessions. This was very unusual at that time.

How was it possible to run such a collaborative project during the Cultural Revolution?

I've been asked that many times, how they could do that in the middle of a revolution. I actually asked about that myself, asked one of the official representatives, and he replied to me in English, "One of the big guys got sick." Isn't that typical? It's the same everywhere. Things become possible when the boss is ill. The last Emperor of China was also a patient in the hospital, and I spoke with him once. He died while I was there.

The glass tube in the betatron in Hong Kong was a particular success for Brown Boveri, Gerber recalls. It lasted for over forty years. He knows this because the Chinese head physicist visited him almost every year and kept him updated. In fact, the team stayed in contact for a long time:

You would hardly believe it. Even though they were staunch communists, I stayed in touch with them for a long time afterwards. When I went to China almost twenty years later with my family, they provided a fine car with a driver and guide for us. When I asked "Why are you doing this?" they replied that "We were not always so friendly to you the first time."

Then Gerber says that he saw Chinese colleagues being beaten up, and that he himself was once arrested.

Walking in the street during the Cultural Revolution, I saw professors from the universities in Beijing being beaten on the back with sticks. I saw it for

myself. I was right in the middle of it and nobody harmed me, except that I had to go to prison once. They accused me of something or another, and one morning when I came to the hospital there were placards everywhere and slogans painted on the walls, "Down with Gerber." My people at the hospital had tears in their eyes. They couldn't believe it. One revolutionary group was struggling with another revolutionary group, and I was caught in the middle. But the hospital needed me to finish the job, and I was released after three days.

Celebrities

Taking delivery of a betatron anywhere in the world was a big occasion both for the medics and for the local community, with press and TV invited to the ceremony. There are heaps of hospital magazines and newsletters from these times with reports of amazement at the wonder-machine and pictures of eminent doctors, politicians and donors who have made the purchase possible. Masses of articles about the revolutionary new treatment that could kill cancer cells in a tumour without damaging the surrounding tissue.

In Guildford in England, for example, Princess Alexandra of Kent had set up her own organisation, The Betatron Cancer Appeal Trust, to support the installation of a betatron in St. Luke's Hospital. Christian Gerber had been responsible for calibrating the machine and he was invited to the opening ceremony where the princess was present. Gerber says that the project was sponsored by Bugatti, who was a friend of the director, and the installation was very prestigious. A big feature on the front page of the local newspaper on 5th May 1967 showed the princess taking part in the opening ceremony together with the bishop and the local mayor, and of course, close-up pictures of the betatron, an Asklepitron 35. A machine of the same type was installed in Bristol three years later. This type of betatron, with a rotating lens, was a high status product for Brown Boveri. In the 1960s Rolf had four such projects in France, two in Belgium, one in Italy, two in Austria, two in Switzerland, four in Sweden, three in Denmark, two in Germany and two in Canada, plus a new machine for the Radium Hospital in Oslo which had already had its first betatron for over ten years.

By the 1970s Brown Boveri had developed the Asklepitron 45 as its leading machine in this field. This too had a rotating lens. It delivered slightly higher energy radiation and was no less popular. According to Rolf's meticulously hand-written list, twenty-three of these were sold. These included replacements for hospitals that already had the older model, plus new sales to countries such as Greece, Spain and what was then Czechoslovakia. Sales

to America were now so big that an office was set up and Gerber was stationed there permanently. Shortly before, he had been in Japan to deliver a betatron to Toshiba in Yokohama for materials testing. Brown Boveri made two machines of this type, able to 'see' through 60 cm of steel while the metal was still molten. The other one went to Germany.

So you could detect holes before the material had set?

Yes, very interesting. Obviously it was difficult. The problem was to make fine adjustments on cameras and instruments that were handling red-hot molten metal at 600–800°C.

Despite all the praise, Brown Boveri never made really big profits from the betatron project on its own, Gerber says. It was a question of status and huge prestige. The betatron was very important for their reputation.

100 Betatrons and 200 Patents

In 1986 the betatron's time was over. By then 22 countries had received altogether 93 custom-built machines from Rolf and Brown Boveri: Austria 4; Belgium 4; Canada 3; China 2; Czechoslovakia1; Denmark 5; Finland 4; France 10; Germany 8; Great Britain 4; Greece 1; Hong Kong 1, Israel 2; Italy 6; Japan 1; Norway 3; Soviet Union 1; Spain 2; Sweden 4; Switzerland 12; USA 14; Yugoslavia 1.

Rolf considered that it was difficult to give a precise figure for the number of betatrons built by various companies throughout the world. There were at least 200, and he and Brown Boveri had been responsible for about half of them. Betatrons in the power range of 30–45 MeV were useful in many areas. Most of them were installed in hospitals, some in atomic research institutions and some in industry for materials testing.[26]

Rolf had been head of Brown Boveri's Electrical Accelerator (EA) department since 1954. In 1973 the department's name was changed to Electrical Components for Betatrons (EKB). At the end of his time in Brown Boveri, commercial changes were happening both within and around the company. Important contributions to the development of betatrons were made by Stanford Linear Accelerator Centre, often in collaboration with Varian Medical Systems, the company that took over Rolf's department in Brown Boveri when he retired. Today, Varian Medical is among the world leaders in radiotherapy equipment. Then in 1988 Brown Boveri merged with the Swedish firm ASEA to become ABB.

In the course of his career, Rolf registered over two hundred patents, mostly in Germany but also in Switzerland, USA and Norway.[27] Fifty-three of these were registered on behalf of Brown Boveri. He obviously didn't do all the work himself but was dependent on good assistants and colleagues. Karsten Drangeid was one of these. Another he particularly named was Dr. Nabholz who had helped him with the machine for Turin. He also gave glowing praise to the firm's 'scintillating mechanic,' Gräf, 'who knew exactly how to carry out the delicate work of building the cathodes,' and he added that 'It was mainly thanks to him that our machines lasted so long, as he had taken on the task of making the glass tubes.' Others Rolf considered himself indebted to were his second-in-command Dr. Arnold von Arx, plus Gamper in materials testing, the design engineer von Dechend and the workshop foreman, Jonitz. Among the engineers responsible for mounting and installing the betatrons on site, in addition to Christian Gerber he also mentioned Alfons Fischer and the Norwegian Knut Vikene. He also commended his successor, Dr. Max Sempert, but as there was a degree of competition between them this may have been mostly out of courtesy.

Arild *(eldest son)*
Was there any pressure on you to study engineering and technical subjects?

Not really on Father's part. But there was a pressure to gain university entrance qualifications so that we could study. Myself, I never sat the entrance exams. Me, I was maybe a little difficult at that time and wouldn't always listen to Father. I didn't want to be an engineer, because I felt I was always being plagued by people round about on the streets here in Baden – and Baden was a small town – asking me. My father was already well known then. Lots of people asked me, "But what will you do then?" and "Won't you do something in the same line as your father?" In retrospect I think that bothered me subconsciously, so it might have been a reaction.

Arild *(eldest son)*
What about your sister, didn't she have plans to become an engineer.

Yes, she wanted to go into he same line as my father. She was quite sure of it at the time. So after high school she began to study machine engineering. But that didn't last long, possibly one and a half semesters, and then she fell off a wall in the garden and got concussion. I've always said that that happened very timely for her. She could drop out and say, "No, I can't study any more with this head." Then she trained in ballet and qualified as a dance teacher.

I heard that she married a Yugoslav?

Yes, Dragomir Trifunovic from Beograd, who was on an excursion in Berlin and absconded to West Germany. She met him there, near Mannheim where

she lived for many years. Then they moved – because he didn't have a passport, he only had a Nansen pass, as refugees did at that time. They couldn't go just anywhere with that – then they moved to Norway. Their son Per was born there, and Dragomir was happy in Norway. He learned perfect Norwegian in the course of three or four years and was an important member of the family. But what he didn't like was the long winter. He wanted to go south again, it was too cold in Norway. While they were in Norway, they lived in 8 Melumveien.

So they took over your parents' house then?

Yes, but after a few years they moved back to Mannheim where he got a position in a big architectural firm. By then he had acquired Norwegian citizenship.

***Arild** (eldest son)*

I remember when we moved to Baden in 1949 I joined the Scouts. I was a year too young, but Father thought there was no point in starting as a Wolf Cub. I should start properly in the Scouts right away. I went on a winter camp up in the Alps once, using just the gear that we had already. We went up to St. Gotthard from Andermatt and stayed in a youth hostel. Obviously I was the youngest. We had skins to put on our skis so that we could climb without slipping back down, but I kept losing them. It was bitter cold, and the only gloves I had were hand-knitted mitts that the cold went right through. But I remember that I was well equipped the next year. I needed this, and I must have that.

***Arild** (eldest son)*

We had skied in Norway, obviously. If you lived in Røa you were, so to say, right in the middle of the skiing terrain and there was a field a little below our house where you could also ski at that time. So we did have skis when we came here. But of course what we brought were not Alpine skis but cross-country skis. And I remember going on a Christmas holiday when we were eight or ten years old, to a place called Oberiberg. We were staying in a hotel and we still had Norwegian skis that had been waxed. We managed to go up and we managed to come down, in a fashion. We weren't given any real instruction. It was just "Stay up," for that was what Father always called to us so that we wouldn't fall. When we went skiing with our parents on Sundays Father was very good at finding places where there was a ski lift, but we always just walked up beside it.

So you didn't get to use the ski lift?

Not on the piste there, no.

You had to walk up beside it?

Yes, walk beside it. And now basically I'm glad that we weren't spoiled. Really, my father couldn't afford for us all to use the ski lift in these days.

More Irons in the Fire

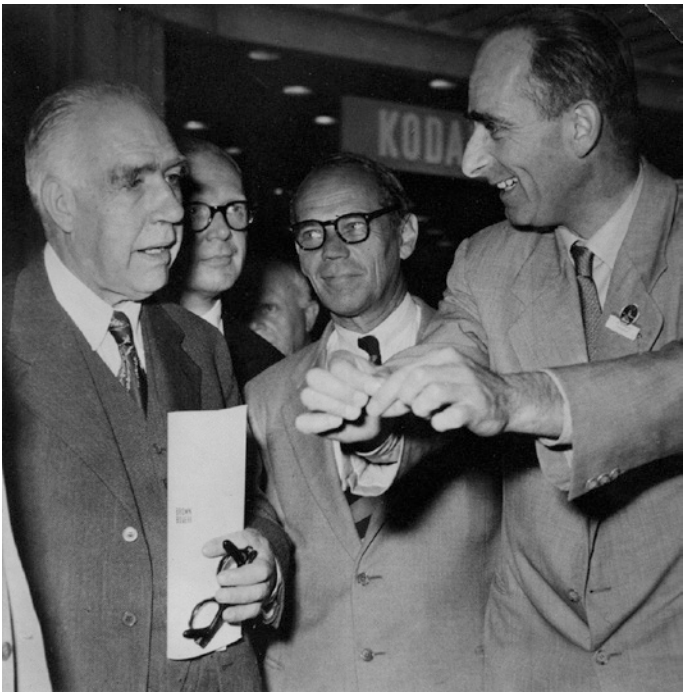
But that wasn't all. Relays and betatrons were only one part of Rolf's career. Already during his first five or six years in Switzerland, while he was trying to keep his head above water economically and professionally, when he had to succeed with the betatron for the hospital in Zurich, while he was hoping that Norway would place an order for a similar one and he was at the same time developing new designs for betatrons and almost as a side issue researching synchrotron technology – while all this was going on he took on another formidable task. He agreed to be a consultant for Europe's most prestigious research project, the CERN (*Conseil Européen pour la Recherche Nucléaire*) project in Geneva. After the war, when Europe was striving to rebuild itself industrially and technologically and to set up a research environment on a level with the USA, people turned to Rolf.

The idea was to set up a research centre with a particle accelerator at its core. The collaborative CERN project would be the world's biggest nuclear physics research laboratory. A huge, doughnut-shaped laboratory. A tunnel going round in a circle, a sort of model train set for physicists, so to speak, with locomotives and wagons smaller than atoms, rushing round to accelerate tiny charged particles to higher and higher energies. Then the controllers would let the particles collide with stationary targets and watch to see what happened when they crashed. Then they drove them round even faster, and then a little more. The question is always, 'What will happen next? How do these tiny particles interact? How do they decay? Are we approaching the very heart of matter? And what will happen if we just increase the velocity a little bit more? What then?'

This was indeed a very welcome and appropriate gift for Rolf. Right in the middle of his field of interest. And huge, in more than one sense. What possibilities! What consequences! Nobody had done anything like this before. His accelerators up to this time had been almost monstrous compared to today's radiotherapy machines, but had found their place in treatment rooms with slightly raised ceilings. This was something else. And not least, he would be enjoying the company of the world's leading nuclear physicists.

The venture had prestigious support both from politicians and from research organisations. Switzerland was chosen as the safe and neutral ground for former enemies to work together on what was regarded as a giant bridge-building exercise. Slogans such as 'Bridging the Atlantic' or 'Science Bringing Nations Together' were indeed apt. Preliminary negotiations had

been taking place ever since the war. Neither the USA nor Europe would be content to watch Europe's leading scientists moving across the Atlantic to spread their wings in America, leaving Europe afflicted with a 'brain drain.' The project was linked to the United Nations and UNESCO. There was support both for a European organisation and for open access to national facilities. Some people, including the Danish physicist Niels Bohr , feared that the whole project would become too bureaucratic and cumbersome. Important meetings were held in Europe and also in America.



Niels Bohr and Rolf Widerøe both took part in an international radiological congress in Copenhagen July 1953. (*Photo* Ritzau/NTB scanpix)

This was the first really collaborative major project in post-war Europe. Norway and what was then West Germany were in it from the start. CERN itself was formally established in 1954. The organisation became a model for what can be achieved when nations combine resources towards a common goal. Since then, other international research institutions have been founded on a similar pattern, including: the European Space Agency (ESA); the European Molecular Biology Laboratory (EMBL); the European Synchrotron Radiation Facility (ESRF); and the world's biggest fusion

reactor, Joint European Torus (JET). Some research can no longer be carried out by scientists isolated and alone in their own country.[28]

Because I Wanted to

However, the aspect of CERN that interested Rolf was physics, not global politics. His involvement in it started in June 1952, at a meeting in Copenhagen where the visions were to be given solid form and some individual projects planned in more detail. 'I was there just because it interested me. It had little to do with my job in Brown Boveri[29],' as he said himself. The European Council for Nuclear Research, known as 'CERN,' had been founded the year before. Now the laboratory was to be built. Rolf was a member of the expert group responsible for the development of the accelerators that were to be constructed there, a synchro-cyclotron and a proton-synchrotron, popularly known in abbreviated form as 'SC' and 'PS.' This was concrete, this was practical science, this was physics. It was also pushing at the frontiers of knowledge, at the limits of what anyone had managed to create or even conceive up to then. Rolf grasped the opportunity. He had taken out a patent on a proton-synchrotron six years before.

He was able to use all his contacts and establish new ones. For example, it was he who recruited the German physics expert Christoph Schmelzer. This rather worried the leader of the planning group, perhaps for slightly different reasons than one might expect:

> We were looking for good high frequency specialists for the PS project. I knew Dr. Christoph Schmelzer and persuaded him to come to CERN. I remember it well because we had agreed to meet near Waldshut in Germany. I came over from Baden and we went together to Höchenschwand in Schwarzwald. We sat looking over a beautiful hillside and I explained the basic principles of the synchrotron to him. He decided that building such a machine would be a very interesting project and he agreed to be a member of the group. But the leader of the group, Odd Dahl, another Norwegian, was worried that there were now two Germans in the group. We already had a German professor, and Dahl was worried that the Germans would feel uneasy.[30]

In his memoirs, Dahl discussed this combination of Norwegians and Germans, mostly from the point of view of how the Germans would see it:

> Obviously, the general attitude to Germans was not entirely positive at that time. So they were worried that they might not be allowed to use their talents

> fully with a Norwegian as director of the group. However, things went very well right from the start and we have maintained friendship and close contact ever since[31].

Dahl was administrator and co-ordinator for the PS project. There was another Norwegian from Bergen in the group. Kjell Johnsen, an accelerator expert and professor of nuclear physics, was also from the Chr. Michelsen Institute. He was not in right from the start, but Rolf got in touch to consult him after the first meeting in Copenhagen and he later joined the group as a permanent member. Unfortunately, Johnsen was too ill to be interviewed when I spoke to him in preparing this book, and he has since died. But many others have written about the huge construction work. Not least, CERN has documented its own history in connection with its 50th jubilee in 2004, consistently describing Rolf as an accelerator pioneer.

It was a meeting with Rolf in summer 1952 that had convinced Dahl of the need to build a proton-synchrotron at CERN. Presumably they already decided this at the first meeting Rolf attended.[32] The group then decided that the particle energy should be 10 GeV. Note that we are no longer talking of MeV. Even without understanding the technology we can recognise that G for giga is more than M for mega, 10^9 is bigger than 10^6.

The deputy leader of the synchrotron group was Frank Goward from England. He and D. E. Barnes had been the first to succeed in testing the synchrotron principle experimentally. Another Brit, a Swiss and a Frenchman were also in the group,[33] plus two Germans whom Rolf knew from before, Professor Wolfgang Gentner andf Dr. Schmelzer. Norway was well represented, three out of nine. Rolf was actually registered as Swiss, and elsewhere in the CERN history he was referred to as German, which he didn't like at all. According to Dahl, it was no accident that Rolf joined as one of the first. He had done a good job as director of research at Brown Boveri, and the pair of them knew each other from earlier. He gave credit to Rolf in his memoirs:

> In the inter-war years he had done work in Germany that pointed ahead towards the big accelerator installations, he just didn't manage at that time to develop his betatron principle fully.[34]

Dahl himself was a man of action, which may have been a large part of the reason why they found each other. A typical Odd Dahl saying was 'You must think the idea through, but without paying attention to everybody because then you'll get nothing done[35].'

American Enthusiasm

The French physicist and UNESCO director Pierre Auger was an important driving force, as was the Italian Edoardo Amaldi. Rolf knew them both. Across the Atlantic, one of the people campaigning enthusiastically for CERN was the Nobel prize-winner Isidor Rabi. During the war he had had a key role at Massachusetts Institute of Technology, MIT. After the war he was a central figure in building up the famous Brookhaven Laboratory in New York State, and he was keen to support the establishment of a similar laboratory in Europe.[36]

Now the story of CERN really takes off, and Rolf is part of the action. A group of three travelled to the USA in August 1952 to study the plans for the giant synchrotron that was being built in Brookhaven, known to the Americans as a cosmotron. The group consisted of the chairman and deputy chairman plus Rolf, who travelled via Australia where he was due to deliver a lecture before meeting up with the other two in the USA. He relates excitedly that 'We spent several days with ….' and then begins to rattle off the names: George Collins, head of the Brookhaven Cosmotron Department plus random big names, the researchers who only weeks before had developed the strong focussing method.[37] He follows this up with a long explanation of the physics. That person and that person thought this and this. His own patents were based on such and such principles. Perhaps they would be better to do it this way. Because. There is no doubt that Rolf was expressing his ideas. The photograph of the three-man group with the head of the American laboratory has since become famous and was published in the jubilee account of CERN's first fifty years as an illustration of the start of something big.

Rolf considered that what they had been talking about at Brookhaven was some of the basic principles underlying modern synchrotrons, and he drew comparisons with the ideas he himself had proposed in his synchrotron patents in the 1940s. For example at one of the meetings Livingston, who had been Lawrence's assistant, spoke about a system for positioning the magnets that Rolf already knew about and that was immediately accepted by all the others.

In 1952 a group from Europe visited Brookhaven National Laboratory in the USA as part of the preparations for setting up CERN. From the left: Frank Goward, Odd Dahl, Rolf Widerøe, Ernest Courant. (*Courtesy* Brookhaven National Laboratory)

The trio from Europe came on the scene just as the American discussions had come to alternating gradient focusing. One of the major problems was that the enormous strength of the magnetic fields required both the

manufacture and the positioning of the magnets to be done with a level of accuracy far greater than had ever been attempted before.[38] The Americans proposed a revolutionary lay-out for future high-energy accelerators. By experimenting with magnets to produce alternating gradient magnetic fields, they hoped to be able to build more powerful accelerators for the same cost.

This proposal immediately became a hot topic of discussion between the European trio and the Americans. Rolf had proposed a different method to improve the focussing, that he had patented in 1943. However, he recognised that the American proposal was simpler and better, and it appeared that the same principle had been suggested quite independently by a Greek two years previously.[39] Yes, it was exciting and Rolf was in his element:

> We spent a whole week on our discussions in 1952, from 4th to 10th August, and every moment of it was interesting. I saw immediately that their proposal for beam focussing was a much better idea than my earlier lens method.[40]

The Brookhaven team had willingly shared their new knowledge. Not only that, they were prepared to help the Europeans with this relatively risky pioneering enterprise, and the CERN group travelled home satisfied with the new idea.[41] When they arrived, however, they met controversy. These were radical ideas. Rolf's enthusiastic support was a great asset at that time, according to Professor Egil Lillestøl who was associated with CERN for many years including a time as Deputy Leader of the Physics Division:

> Rolf gave a lot of personal support to the leader of the group, Odd Dahl, when the three man delegation came back from the USA and "everybody" was against the new proposal for the accelerator.[42]

This Is How We'll Do It

After two months of argument, by October 1952 everybody in the CERN steering group was convinced about the type and size of accelerator that should be built, and that the machine should be the main element in the new laboratory. It was unknown technology with great theoretical and technical challenges, but that was exactly what stimulated Rolf Widerøe and Odd Dahl. The group upgraded its original proposal to the CERN directorate and obtained approval to go ahead. Planning could now begin. Two of the Americans they had met later came over to CERN and took part in the work.[43]

Everything went ahead now at an unusually high tempo. While physicists discussed the technical details of the synchrotron, the administrators, politicians and diplomats were working to set up the formalities to constitute the new entity CERN—an international laboratory in the middle of Europe with American support and collaboration, financed by the member countries and needing to be approved by the parliaments and governments in all twelve participating countries.

The original twelve countries have now become twenty-three. CERN must have no secrets, not sell anything, have nothing to do with atomic power or military interests, not be dependent on any other international organisation. Just carry out pure research. No-one had heard of anything like it before. From today's global perspective it may appear unremarkable but from the perspective of the time, and so soon after a world war, it was extraordinary.

In October the following year the PS group started holding its meetings in Geneva. Up to then they had travelled round between Amsterdam, Paris, Geneva, Bergen, Brussels, Harwell and Oxford. Then when it was confirmed that CERN would be located in Geneva, the group was allocated a regular meeting place in the physics institute there. But it took time for the practical work of development to start. The decision-making process was still a little protracted for Rolf's taste, and he recognises that some of his colleagues considered him impatient:

> I remember that some of the participants thought that I tried to rush things too much. For my part, I thought that we should concentrate more on the technical questions rather than let ourselves be weighed down in administrative problems.[44]

He adds diplomatically that he understands that such a big undertaking does need an organisational structure. There were plenty of scientific problems to contend with too. However after four years, in June 1956, the main preparatory works for the synchrotron were ready. About 140 employees were taken on and all the important industrial agreements for supply of equipment were complete. A forward planning schedule was drawn up—handwritten. According to this the synchrotron would be ready for use in 1959. Rolf's main involvement with CERN was now over, but not his interest.

Early in 1957 the personnel and the laboratory moved into the newly built premises. Parts of the roof were still missing, but the south and the north halls could be put into use for the testing and storage of machine parts

that were being produced round about in the various member countries. Two years later the first of about a hundred magnet parts for the accelerator was installed in the tunnel. In July that year the construction work on the synchrotron was complete. In August an enlarged version of Rolf's linear accelerator could be fitted, a 50 MeV accelerator that would generate the protons that would travel round in the underground 'doughnut.' The first beams started circulating in the tunnel in September. Performance was still not exactly as the constructors wanted, but that would be adjusted gradually.

And in November 1959 it happened. The acceleration generated 24 GeV. The magnets were adjusted a little more and on 8th December the maximum energy level was achieved, 28.3 GeV. An amazing, almost unbelievable achievement by the scientists and even more of a marvel to non-technical people. But what everybody could grasp was that something very small was going round very fast and that this was important for research. The significance of the world record for generation of high energy particles was yet to be understood. As for Rolf, he hadn't been able to abandon CERN before they reached their goal. He had taken part in making major decisions throughout the seven years until CERN's first machine was ready.

America Strikes Back

The proton-synchrotron machine in Geneva held the world record of being the accelerator with the highest energy for seven or eight months. Then the sister machine in Brookhaven was completed, with a higher—only slightly higher—beam energy[45]. Thanks to their visit to Brookhaven, the Europeans had been able to almost treble the energy level from the target they had originally set for themselves; from 10 GeV to almost 30 GeV.

In the 1960s the PS synchrotron was nuclear physics' state of the art research tool, one of the world's most versatile generators of particles and radiation for use in many of the centre's other accelerators and experiments. For CERN this was the start of an amazing success story that just continues to grow. The CERN laboratory's record of producing constantly better and better accelerators throughout sixty-five years is unique, and the backbone of this whole achievement has been the synchrotron. The decision to do what Rolf had advocated paid off.[46] It was 'an almost unbelievable project: a high precision machine with a diameter of 200 metres, that stretched technology to its absolute outer limits and forced into existence new initiatives and new developments in many fields,' as the former CERN director wrote in connection with the fifty years jubilee celebration in 2004.[47]

He gave unreserved praise to Rolf and his colleagues, commenting that as the decision to develop this particular type of accelerator had been made at the important meeting in October 1952, the half-century should really have been celebrated earlier, in 2002. The decision made at that time 'demonstrated not only extraordinary understanding but also foresight and courage. The original designers of CERN took a brave decision when they decided to listen to the experts.' He asserted that history would have come to be written quite differently if they had chosen the old, safe way.[48]

Rolf experienced it as an adventure and was able to see the victory in a wider perspective, for there were others also on the track. Workers at the Dubna Research Centre north of Moscow had built a 10 GeV proton-synchrotron using the traditional method, which came to be known as 'weak focussing.' He could claim proudly that the Soviet machine lost the competition on all important criteria: 'Their machine was ready in 1957, and 36,000 tonnes of iron had been used to build the magnets. This machine had the highest energy anywhere in the world at that time. For our strong focussing machine at CERN, which reached 28 GeV, we used only 3,200 tonnes of iron, less than a tenth of what had been used in Dubna. We not only reached the goal before the Americans (…) but we also seized the world record for particle energy from our Soviet colleagues.'[49]

A Workhorse

The proton-synchrotron machine still plays an important part in the work of CERN. It was their leading workhorse throughout the 1960s and continues in that role as an injector in the chain of larger accelerators. The PS technology is used in all large accelerators and has been central to all further upgrades and development in what has gradually become a whole complex of accelerators. The facility was popular and researchers flocked into use it. A new hall, the East Hall, was built to accommodate new developments. To check that it was both safe and wise to proceed, a special group investigated whether a different method of locating the magnets in the PS tunnel would increase capacity. The result was unambiguous: just as it had been built twenty years before, the machine was still the best to fulfil all the needs.

Parallel with the development of the PS accelerator, another group was working on the development of a proton-synchro-cyclotron, known as 'SC.' New acronyms and abbreviations have continued to proliferate, just as useful for the researchers as they are incomprehensible to amateurs.

The next stage after PS was ISR ('Intersecting Storage Rings'), a double proton ring that would cause high-energy protons from the PS machine to collide. The protons would circulate in opposite directions and collide head to head, releasing much higher energies. The problems were formidable and many people thought them insoluble. The Norwegian Kjell Johnsen, then director of the division responsible for construction of storage rings, led the project to build the world's first proton-proton colliding beam machine, which was put into use in 1971.

This was unique. With this particle physics machine, Europe was well ahead of the competition for the first time. It reached a completely new energy level, and many researchers were curious to see what it could achieve. In particular, many Americans came to CERN. They had helped at the birth of the organisation and followed its growth and development from the start but it was not until the 1970s when the ISR machine was put into operation that there was significant American participation in the laboratory investigations. The opportunity to work with such a machine was irresistible to American particle physicists, and Americans took part in almost half of the experiments using ISR.[50]

Rolf had taken out a patent for a PS as early as 1946. But 'Unstoppable Widerøe,' as Dahl called him, had in fact taken out a patent for its successor, the ISR, three years earlier.[51] though because of the war it was not published until 1953.[52] So the principles set out by Rolf were also the basis for CERN being able to build its first machine to collide beams of protons.

The Rest of the Alphabet

The story repeats. Even before the ISR machine was ready work had started on the next, a 300 GeV super proton synchrotron, or SPS. By now there was so much happening at CERN that a dramatic upgrade of its information technology was needed to keep control of it all. With improved data processing, all the machines and equipment could be driven in parallel. The old PS machine was still in use and could even cope with some new challenges. As an injector of protons and anti-protons for the SPS it played an important part in the experiments when the particles known as w and z were discovered, earning the CERN researchers their first Nobel Prize in 1984.[53] Not only that, but the PS was also useful in combination with the next machine for anti-protons, LEAR, and its successor, AD.[54]

The 1980s and 1990s were the high times for LEP, which was even bigger and stronger than ISR.[55] The PS was used as an injector in these decades too,

in combination with SPS.[56] At that time LEP was the biggest storage ring in the world, and Rolf could say with some satisfaction that this was a result that tallied exactly with the principle in his own patent.[57] The LEP storage ring was 27 km in circumference, buried in a tunnel 100 m underground. When it was first switched on its energy 'only' came up to 50 GeV, but it eventually achieved 100 GeV. Rolf reckoned that this was the last step in the development of this type of storage ring. He thought it unlikely that a ring with higher energy than LEP would ever be built, and so far he has been right.

Then, in 2007, the physicists and scientific historians got yet another acronym to keep track of, LHC.[58] This was a new proton accelerator with two beampipes that bring particles together at collision points. The research centre provides a remarkably simple explanation in its information material: The accelerator installation at CERN consists of a series of eight machines with higher and higher energy. Each machine injects beams of particles into the next, which takes over and increases the particles to even higher energy, and so on in the same way. Now we are no longer talking about mega and giga; it is tera that describes the particle energy, with twelve zeros after the number. In the LHC machine—the latest link in the chain so far—every particle beam is accelerated to a record level of 7 TeV, which is 230 times higher than in ISR. In addition to this, each of the LHC injectors has its own experiment halls where the lower energy beams are used for research.

It was not always so straightforward. The machine also generated internal drama within CERN and media publicity beyond. This was breaking new frontiers: it would 'create miniature black holes; find new dimensions; recreate the Big Bang;' answer the huge cosmic questions by studying the smallest of the smallest particles, those that were so small that they 'didn't exist.' All the spectacular things that the machine could do were not only incomprehensible, but also mystical and thereby even more exciting. The machine is very expensive to run and was out of operation for over a year because of a breakdown. The numbers could make you giddy: over 7.5 billion euros construction costs; 30 storeys underground; minus 271° temperature. The size and potential of the LHC is almost impossible to grasp, even for physicists.[59]

Meeting with the Great and Famous

Rolf did not live long enough to follow the developments as far as this, but he was involved in the second last step, LEP, before he died in 1996. After his official engagement with CERN was over, he 'helped a little from time to

time,' as he himself said.[60] He was invited to the big accelerator congresses in 1956 and 1959, and it was a feather in the cap for Brown Boveri that their own director of research and development was playing such a central role. In the course of the 1950s and 1960s he took part in altogether nineteen major meetings and conferences, but he never entirely let go of CERN. He had never been given any special brief in his work as a consultant, and he liked the freedom that this role gave him. As a freelance he could take part in meetings and gatherings, meet people, exercise influence and receive stimulation. He obviously didn't consider the work associated with this role as a burden, because it gave him so much and he was able to take part in exciting events right from the start:

> For example, on 18th December 1952 I went to Geneva with Professor Gentner and Dr. Citron to see the place where the machine was to be built. We were to decide the direction the protons should follow, so that the farms and villages in the neighbourhood would not be troubled by particles being thrown out. A protective mound was built later, known as "Mount Citron".[61]

Rolf was used to being in the company of the great and famous. He saw it as a natural part of his job. Wolfgang Gentner, for example, had been one of the leading nuclear physicists in Germany during the war. Rolf also worked with the British Frank Goward and the American Hildred Blewett on the calculations for the PS machine. At the congress in 1965 he also met Gerry O'Neill from the USA. They found that they had more in common than they had thought. This led to mutual admiration and mutual advantage. Rolf learned that the American was working on 'a little storage system with colliding beams' and that he 'had apparently not heard of my 1943 patent and had developed the principle from scratch.' The following year he visited him at Stanford, described the patent he had registered during the war and noted that 'He was really impressed.'[62]

It may have been at the same congress that he met Ernest O. Lawrence, the inventor of the cyclotron. He struggled to remember the exact occasion when asked about that later. Perhaps it was at the 'Atoms for Peace' conference that CERN arranged in August 1955. 'This popular conference would obviously have been the most suitable occasion for a friendly embrace,' he pointed out. But he adds that it might not have been until the following year that he met his legendary rival and fellow-player. Anyway, when they did meet they planned for Rolf to come over to visit Lawrence in the USA, but Lawrence died of cancer before anything came of that.[63]

The Big Questions

It is difficult to say how much of the CERN scenario Rolf anticipated. Not that it would become a whole research town with hundreds of buildings and streets named after Einstein and other great scientists. Probably not the Large Hadron Collider. But he did see that it was big and would become bigger and play an important part in shaping the future. He may also have anticipated that it would make sensational headlines in the new century that he hoped he would live to see.

'Europe takes the lead in particle physics' was the front-page headline on the prestigious American magazine *Science* on 23rd March 2007, together with a picture of CERN's latest giant installation. 'Ready for the world's biggest experiment,' wrote the Norwegian newspaper *VG*. 'The hunt for the Big Bang,' wrote *Aftenposten*. 'Preparing the world's biggest experiment to find the universe's smallest particles,' wrote *Apollon*, the University of Oslo's research journal. The academic journal *Gemini*, published in Trondheim, emphasised the huge significance of the project:

> The plan is for the new accelerator to bring protons up towards the speed of light. The collisions will then release much higher energy, which gives a bigger chance of new particles appearing. New and unconfirmed theories can then be proved – or disproved. The physicists also hope to find supersymmetric matter with the new accelerator. The theory of supersymmetry is an attempt to create a common theory for all the fundamental particles and forces, with the exception of the force of gravity. This has not been done before.

It is not easy to explain quantum mechanics in simple terms, but popular science articles can give an impression of speed, dimensions and extreme precision and of the paradox that something very small could cause something very big to happen. As *Science Illustrated* put it: 'The researchers are smashing the smallest particles they can obtain, to see what is inside them. They are looking for the universe's smallest building blocks, in the hope of finding out how it came into being.'[64]

Even though most people don't fully understand reports from CERN, they still make interesting reading. Details such as 600 million particle collisions per second. Wow! The machine expands and contracts one millimetre between low and high tides. The French high-speed train, the TGV, interferes with the experiment. For the particles to follow the bends in the tunnel and not be hurled out onto the neighbouring farmers' fields, 1,232

magnets are built into the machine. Each of these is 15 m long and weighs 35 tonnes.[65] We could go on.

On 30th March 2010, *Dagbladet* wrote that 'The Big Bang Machine set a world record' and described the twenty years of prior planning. People followed the story, and knew that this was about CERN. For a short time in 2012 the world of physics held its breath. The CERN researchers were thought to have got something to travel faster than light. This was quite soon shown to be a mistake, but it led to sensationalist headlines that even Einstein had been wrong. Physics at CERN had become a hot topic in the media. One of the people who contributed to this is Egil Lillestøl who over several years showed people round CERN and spoke with journalists. He stresses that Rolf's input was vital in creating the world's biggest particle physics laboratory:

> You could say that Rolf Widerøe was almost the reason for two Nobel Prizes. There is a direct line from him to the physics prizes in 1939 and 1984 The first was awarded to Lawrence, who never concealed his debt to Widerøe. The second was to the Italian Carlo Rubbia and the Dutchman Simon van der Meer for their contribution to the discovery of particles W and Z.[66]

Another internationally orientated nuclear physicist who has studied Rolf's input to the development of CERN, Jan Sigurd Vaagen, thinks that it says a lot about Rolf that he was called upon to take part in what has since become such a famous visit to the USA to discuss which type of accelerator CERN should decide upon.

> What they brought home became Europe's flying start, when the Europeans took the opportunity to develop a principle that the Americans had discovered but nobody had really proved. What is called 'strong focussing' in modern scientific terminology enabled the laboratory to compete with the USA. Widerøe played a part in this and is credited in the history of science as one of the important players in the early days of CERN.

People associate CERN with physics. Not so many people know that the World Wide Web was invented there—as a spin-off, we could say, simply to handle enormous masses of data. In the 1980s the researchers needed an easier way to update and share information with each other, and the World Wide Web came into being. The world's first website went live on 6th August 1991.[67]

But the day came when neither their own computers nor the Internet were enough for the CERN researchers. When you need to analyse 1,000 particle collisions per second, enormous masses of measurements pile up in unimaginable quantity. A single one of the projects using the newest machine can accumulate huge amounts of raw data per year, and even the super-computers at CERN have difficulty swallowing such bulk[68]. The solution was to use and develop the "Grid' to link together tens of thousands of computers throughout the world to handle the enormous amounts of data. Work could then be sent automatically to wherever there was vacant machine capacity. Then it doesn't matter where on earth you are, or which subject area needs calculations done, from speech technology to medicine. In theory you can sit at any computer in any research institute anywhere in the world to do your work. That is perhaps even beyond what the founders of CERN predicted, with their vision of research that would 'bring the nations together.'

Doris and Petra

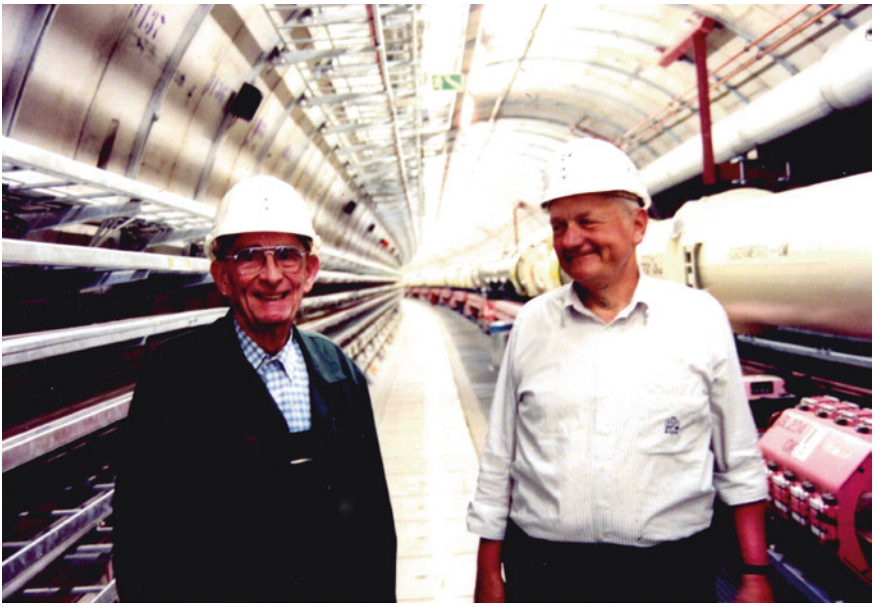
CERN was just the beginning. Similar national accelerator centres were subsequently built in various places, including Hamburg and later Darmstadt. Rolf was a consultant for these too. Over a period of five years while the DESY (*Deutsches Elektronen-Synchrotron*) centre was being planned he travelled there frequently and was there for several days at a time. He worked mostly with a German physicist on technical problems with the electron-synchrotron, which was to have a circumference of 300 metres and reach an energy level of 6.4 GeV.[69]

Start of the DESY synchrotron in 1964. Rolf Widerøe to the far left. (*Photo* DESY)

Stanley Livingston, who had been Lawrence's assistant and whom Rolf had met when the CERN group was in the USA, also visited DESY from time to time. Rolf also worked a lot with the head of the accelerator division and had long technical discussions with the founder and director of the centre on his favourite topic of 'storage rings with colliding beams.'[70]

This centre's first machine for colliding electrons and positrons was called DORIS (***DO****ppel-****Ri****ng-****S****peicher*; '**DO**uble-**RI**ng-**S**torage') and was completed in 1974. The second one, PETRA ('P*ositron-****E****lektron-****T****andem-****R****ing-****A****nlage*') was eight times bigger with a circumference of 2.4 km and was put into use in 1978. Then in 1991 came yet another, HERA ('H*adron-****E****lektron-****R****ing-****A****nlage*'), which was even bigger and which Rolf described as a very special machine.[71] During a visit the following year the then 90 year old former adviser was shown round the centre and was able to hear about all the details. These are obscure to most people but the description he was given can—if nothing else—give anybody an insight into size and high energy:

> Electrons or positrons of up to 30 GeV are stored in one ring and protons of up to 820 GeV in another. Both rings are installed in a 6.4 km long underground tunnel, 2.8 times bigger than PETRA. The protons in HERA need to be held in place by superconductor magnets that produce magnetic fields about three times stronger than ordinary iron magnets.



At the age of 91, Rolf Widerøe made a return visit to the DESY laboratory for which he had been a consultant in the early 1960s. On the right: Professor Gustav-Adolf Voss, director of the accelerator division at Deutsches Elektronen-Synchrotron DESY. (*Photo* Pedro Waloschek)

Rolf could add that a similar type of magnet was used for a proton–antiproton storage ring called the tevatron that was built at Fermilab outside Chicago. The tevatron was about the same size as HERA and was able to store particles with an energy level of 900 GeV.[72]

The person responsible for interpreting the work at DESY to the general public at that time was Professor Pedro Waloschek, who had already started working on his biography of Widerøe. Rolf had long since completed his work as a consultant at DESY, but Waloschek had become curious about him and had visited him in Switzerland.

Twenty Years Teaching

It seems that in the 1950s, long after he had started his work for CERN and DESY, these jobs combined with his directorship in Brown Boveri were not enough for him. He accepted another job, as a lecturer at the technical college in Zurich. This was a third or fourth job, depending on how you see it. How did he cope? His eldest son answered my question thus: 'The

teaching at the college was in the afternoons and evenings.' As if the lecturing had not been any problem. Even if it had been, the children would not have noticed. Mother was there for them.

Rolf himself thought that it was both fun and an honour, a pleasure. The college is still ranked as one of the best in Europe. Einstein had been there, failing the entrance examination at his first attempt but later becoming a professor there. Wilhelm Röntgen had also studied there. In his lectures Rolf was able to talk enthusiastically about the topics he had been working on most of his life. This gave him new ways of expressing himself, and also many new personal contacts. He hadn't worked as a teacher before. 'This was a whole new feeling. I could let my imagination run free without having to think about the interests of an industrial company.'[73] But he hastened to add that Brown Boveri, where he was still an employee, was in no way negative about his work as a lecturer. On the contrary, this was good PR and it helped the sale of betatrons.

Rolf Widerøe liked to have an audience and never tired of explaining his accelerator theory. (*Photo* Pedro Waloschek)

On 12th December 1953 he gave his first lecture at ETH, *Die Eidgnössische Technische Hochschule*. He had prepared carefully, and he kept the original manuscript as long as he lived. The topic was the history of particle accelerators, a historical subject that was not obligatory for the students. So he had relatively few students in the class, but he appreciated the few all the more and he said that he was always glad to have some who

impressed him with their extra industriousness and intelligence. One of these was Christian Gerber whom he later employed to assist him installing betatrons in hospitals throughout the world. For Rolf himself, there was great benefit in preparing his teaching material. At last he got time to go into things more deeply and sort out all the information about accelerators that he had accumulated. He used the opportunity to organise formulae and dig out the theoretical material needed to calculate such things as the size of particle track needed for different types of accelerator, and generally systematise his own contribution to the subject. He may not have been a pedagogue in a narrow sense, but he took to the job with enthusiasm and he loved talking to the students about the betatron.

One of his nephews, Thor Spandow, his sister Else's son, trained as a civil engineer at the college in Zurich and is now head of the Spabo Group. Rolf arranged for him to have three months of practical experience at Brown Boveri, during which time he lived with his uncle in Baden. When I asked him if he really got to know his uncle at that time, he answered as follows:

> You couldn't really get to know Uncle Rolf. Up early, breakfast at Brown Boveri, home at 12 for lunch and a mid-day rest, back to work, home for dinner before he took himself back to his study. He was a scientist through and through.[74]

Engineer Gerber, who also regards Rolf very highly, says the same:

> He was not easy to get to know if he didn't want to talk with you. But if he did want to talk, he could be really charming. At other times he could behave as if he hardly knew you.

The Art of Compromise

At home, Ragnhild was the boss. Nobody doubted that, and everybody was happy with it. She managed everything. She looked after money, house and home, in the midst of many children, a big extended family, frequent visitors and a wide social circle. When Rolf was away travelling, and indeed most of the time, she kept the domestic wheels turning. This was not an unusual pattern of domestic life in that generation, but with a man such as Rolf and with piles of documents sometimes heaped up on the double bed it was especially necessary to have somebody who kept order. For his part, he

tacitly allowed her to make the decisions in the areas that were important for her.

Her sons say that their mother was both caring and well organised. When the children were old enough to look after themselves she volunteered as a Red Cross driver, taking elderly or sick people to the doctor or elsewhere a couple of times each week.

When he was asked if his mother took an interest in her husband's work, Rolf jnr. replied:

> She took an interest, and knew whether he was on the right track or in a blind alley. And of course she was interested in successful sales, for that brought in more money!
>
> *I understand that your mother managed the family finances?*
>
> That's right, my father wouldn't have anything to do with that.

She had a lot to cope with on several levels, and living with Rolf can't have been easy, but they both recognised the need for compromise and their respect was mutual. He acknowledged this himself in his speech at their silver wedding celebration. As he gallantly and diplomatically put it: 'For my part, I couldn't imagine spending time with somebody who didn't have an independent personality.' They had invited many guests to a big party on Saturday 14th November 1959, 25 years to the day after their marriage. Having started his speech in German, '*Liebe Freunde*,' 'Dear Friends,' followed by polite greetings and thanks for gifts, he switched over to addressing his wife in Norwegian. He pointed out that neither of them had been fully clear what they were starting out on but that that had hardly mattered when they married. He confirmed that it had been a happy time that had given him 'much more than I could have imagined,' and he had some thoughts about why this was so:

> I do have certain traits that cannot easily be ignored, and the art of compromise is indeed one of the secrets of a happy marriage. But respect and understanding of the other partner's personality and interests are just as important. I know that this is not an easy task and that you were in a difficult position in the early years when I totally lost interest in everything except other things that were totally unimportant and uninteresting to you.

It sounds both authentic and sober when he ends his speech with some numbers and percentages:

> I thank you for your patience with me during shall we say 90 per cent of your 25 years with me and I wish you happiness and only moderate trouble in the next 25.

What 'trouble' there had been up to then was largely the result of circumstances and events beyond his control. He had been at home in Oslo for 12 of the 25 years and abroad for 13. The war, in the middle of the 25 years, had been a particularly difficult time, and Ragnhild had been the decisive factor in drawing a line under their wartime history and settling abroad. However, the shadow cast over their lives by the war faded with the years.

Between a Rock and a Hard Place

Their son, Arild, reports that Ragnhild's father Alex Christiansen being a Nazi had been difficult for her:

> My father with so many contacts in Germany and her own father a Nazi. That was difficult for the whole Widerøe family.

Ragnhild's father was arrested two days after the liberation and held in detention until 24th November 1945. The case was concluded with a fine for having been a member of the *Nasjonal Samling* ('National Unity') party. Several members of the family, including Rolf's sister Else, have said that Ragnhild was reluctant to go upstairs in her parents' house to see her father, who mostly lived upstairs while her mother lived on the ground floor.

He was a businessman and after the war he tried to whitewash away his Nazi offences. Among other things, he wrote a book that he never succeeded in having published. Apparently his children put a stop to this project. Eventually an abbreviated version was printed as a serial in the NS Party's newspaper *Folk og Land* in summer and autumn 1958, six months after his death.[75] He wrote : 'I don't want to go to my grave before I have cleared up the web of lies that people have tried to strangle me in.'[76] He thought that he had been treated illegally and he continued writing his own defence until he died. He bequeathed much of this documentary material to his loyal secretary, with 5,000 kroner set side to pay for the book to be printed. His secretary continued the struggle on his behalf and submitted the material to the Nazi newspaper. In a postscript, he rebukes Christiansen's family as follows:

> After his death, his closest relatives totally countermanded his last wish and stopped the printing of his book which had already been typeset and proof-read twice. (…) If a deceased's legally valid last wish and his arrangements to have his reminiscences printed and published can be blocked, what is the whole of our western legal system worth?[77]

The intensity of the drama in the extended Widerøe family was maintained by Ragnhild's sister Louise marrying a man who had been captive in six different German concentration camps in the course of the war. Egil Reksten had been captured soon after graduating from the Norwegian Technical College (NTH) in Trondheim in 1941. He had been a student of the resistance fighter and heavy water saboteur, Leif Tronstad and he had been leading 'Skylark B,' the Norwegian intelligence network's Trondheim station for communication with the British, when he was arrested. Reksten's name is recorded in history alongside famous *Nacht-und-Nebel* ('Night and Fog') Directive prisoners such as Kristian Ottosen and Trygve Bratteli. Like them, he earned a reputation as one of those who by their strength of character were an inspiration to their fellow-prisoners. He managed to survive four years in captivity and was eventually freed and sent home in the white buses. Louise was a nurse at the hospital he was sent to, and the story came to a happy ending when they were married two years later.

When members of the family talk about Rolf, most of them say that he was dependent on Ragnhild. When they come to describing his character, their perspective depends on what aspect of him they have known, and more comes to light than meets the eye. Was he social or did he lack social antennae? Was he inclusive of others, or just preoccupied with himself and his family? Introvert or extrovert? A compendium of accounts from a nephew on his wife's side, a nephew on his own side, a brother-in-law and a sister-in-law illustrates the wide range of their perceptions:

My Uncle Wasn't Boring

First, some points of view from Jørgen Holmboe, son of Ragnhild's sister, Margareta:

A little 'different'

> Uncle Rolf was in his fifties when I got to know him. As a teenager I was a little unsure about this slightly eccentric man. Yes, he was an eccentric, that really exciting mixture of – should I say – a world-leading scientist and at the

same time with lots of weird ideas about medicine. My mother and father are also doctors, and it was rather funny to hear what Rolf said about his remarkable ideas of everyday medicine. We used to joke about his strange perceptions of how to take care of one's own health. Yes, he had some odd rituals, bathed in that pool of his and had some brushes to brush himself with and beat himself in various places around the body. In different numbers of times, and they had to be odd numbers. He did that! And carried it out with great bravura. There would be seven or thirteen knocks with this brush on different places. For a cold, you should drop red wine onto a spot of cotton wool and put it into your nose, yes, it was on that level. And at the same time he had honorary doctorates from several medical faculties. When I later became a doctor myself, I thought that was a fascinating combination. I started studying medicine in 1964, and by then he was famous and travelling round giving lectures, and at the same time with such odd performances in his everyday life. That huge gap between the scientist and – yes, I think that today he would have gone in for a whole heap of alternative medicine. And believed in it. I think so.

Mistrust of Conventional Methods

I've heard something about lots of vitamin pills, almost rituals?

Very odd, yes. I don't know whether he was into Linus Pauling's ideas about massive doses of vitamin C, but I could imagine that he might have been. Maybe it was based a little on mistrust of established, conventional medicine. Perhaps it was the scientist in him who saw that lots of what we do in normal medicine is poorly documented. It could be that he thought it was effective for him and that it was at least as good as anything else. Maybe that's how it was. But I couldn't say for sure.

Big ideas and small details

He was obsessed by minor details, while at the same time he had thoughts and ideas in his head that none of us could manage to follow. He brought plant cuttings home from the Far East or somewhere like that, which he had carried on flights round the world to plant in his garden. He had a test-tube in his hand baggage with some unusual plant in it. The garden was a little overgrown, though. The mixture of ideas that small things could be important but that they could be lost among the bigger things in the forest.

How long are you staying?

Did he have social antennae? Was he introvert, detached?

No, he was absolutely an extrovert. But he was perhaps a little, shall we say, self-centred. He needed space. Massively hospitable. But slightly abrupt and

only slightly modest. We would come to visit on a car trip with our baggage and holiday gear. And he would say: "So lovely that you are here! How long are you staying?" From his point of view it was well meant, for then he would set out a programme for us, but it isn't really normal to be met at the door with "How long are you staying?" Yes, that's what he was like. Hospitable and extrovert, but not entirely conventional.

An exciting uncle

Some people say that he was interested only in his research. That doesn't tally with what you are saying now?

No, I don't agree with that. Hiking in the woods. Picking mushrooms. Cultivating friendships. Being proud of his garden and particular plants and his swimming pool. Yes, that's how I experienced him, proud. His interest, it was more of a general interest in everything that was going on in science, not necessarily his own specialty. I hardly ever heard him talk about his research. Not even when I was growing up and studied medicine and would have been capable of understanding a little of what he said. He didn't trouble other people by pushing his thoughts about research. Because his ideas were on a level that we others couldn't attain anyway. He seemed more interested in what he had read in the latest issue of the popular science magazine *Scientific American* or that type of journal. Then he would want to test his thoughts out on us others. Anyway, that's how I remember him.

An exciting uncle to visit …

Yes. Definitely not boring.

A Surprising Uncle

Rolf's nephew Aasmund Berner, his sister Grethe's son, was fond of his uncle and had a lot of contact with him. Aasmund formed his own impressions of Rolf over the years. One of these was of a lack of sense of humour. Sometimes too, he wondered whether his uncle really was interested when they spoke together. On his desk at the Radium Hospital he has a ring binder with Rolf's doctoral thesis and articles by and about him. He shares some memories both of Rolf and of his brother Viggo:

One or two fish

He didn't have much of a sense of humour. We were out on the hills a lot, and he did a lot of fishing. I remember well an episode at Skjæløy, the family's

country property. Uncle Rolf was there. We had been out setting nets and caught a few fish and when we were about to gut the fish he asked, "Have you gutted fish before?" When I replied, "Yes, I've gutted one or two fish," he took it quite literally. Whether I have gutted 100,000 or 10,000 is irrelevant. "One or two" is just what one says so as not to exaggerate. And he believed that I really had gutted only a couple of fish in my whole life.

Did you say party-van!??

Uncle Rolf has a bit of a self-assertive streak, and not just him. The others have it too. I remember well that when I was celebrating graduation from high school I went to see Uncle Viggo to ask if I could get some advertising material for a party-van. But he wouldn't consider having any advertising material on a party-van. What's more, the idea of a party-van was just nonsense. I could take the tram, and Widerøe Airlines certainly wouldn't sponsor any party-van, he would have none of it. Rolf wasn't very interested in communicating with people who weren't like himself. He wasn't really interested in the human aspects. He was more of a technical person, and that is where these self-assertive tendencies come into play in some people who are clever in a particular field.

No reply

When I did my Ph.D., I sent my dissertation to Uncle Rolf. I never got a reply. Then when I started trying to find out if he had received it, all I heard was, "Yes, that there Berner, he is investigating something."

Did you manage to take that calmly?

I didn't fret about it. It wasn't anything to worry about. He was an old man by then. I thought he might have been interested, because he has close connections with this hospital, the Radium Hospital where I work. Betatron Number Two in Europe, which was located here, that is what laid the foundations for the hospital's activity in this field.

A Brother-in Law Who Is Both Social and Antisocial

Ragnhild's sister Louise and her husband Egil Reksten have also kindly shared their many and strong impressions. The pair of them had a lot of contact with Rolf and Ragnhild, visited them in Switzerland and were always with them on summer holidays in Norway. They also took part in

family celebrations, including the golden wedding celebration in Switzerland in 1984. And Rolf and Ragnhild's eldest son came to their own diamond wedding celebration in Oslo a few years ago.[78]

Out walking

Egil: He went out walking a lot …
Louise: … but he liked to have a little following.
Egil: He didn't have a lot of ordinary social chat.
Louise: No, but he did like us to go with him when he went walking.
Egil: Yes, so that we could listen to him.

A hole in the ice

Egil: In later years he was forbidden to go in their swimming pool. At any rate in winter. He just carried on, broke the ice and bathed, even though there was a crust of ice on the water. What he did, he did properly. If he was to bathe, then he would bathe.

He liked an audience

Egil: The first time we were really together with him we made a big blunder. They lived in Switzerland and were here visiting us. At first the whole atmosphere was a little reserved. But on the second last day or sometime like that when we had a big party and a really good time, we saw that we should have done that right away, so that he would come out of his shell and we would have got to know him more quickly.
Was he really shy?
Egil: He was not …
Louise: … not really "with us."

A one-track mind

Egil: Maybe he did have a bit of a one-track mind, yes. I rather think so.
Louise: That seems a nasty way to describe him.
Egil: No, one-track minded! *Somewhat* one-track minded, then.

Domineering

Was Rolf domineering in private life?
Egil: Well, I don't know about that.' (turning to his wife) 'I don't know, was he very domineering at home? You know more about that aspect than I do.
Louise: He was a little domineering.
Egil: Worse than me?
Louise: Perhaps.

Egil: Yes, I think he was maybe a little stubborn. But you'll get a better idea about that from others.

I ask a lot of people, then try to piece the bits together.

Louise: That will be a lot of pieces.

Egil: He certainly wasn't "a man in a grey flannel suit."

Louise: No, he certainly wasn't that.

His brother was more sociable

Egil: If I were to compare the two brothers, I would say Viggo was much more sociable.

Louise: Yes indeed.

Egil: He had more to talk about, you could say.

Louise: Rolf was really happy when we came to visit.

Egil: Yes, he liked having us visit, and I could chat a little about technical things he was busy with.

Stand there!

Egil: Like probably all good researchers, he was fascinated by everything new. Child-like curiosity. I remember once when we were visiting them there in Switzerland. No sooner was I in the door than he said, "Come here! Stand there! Just there, a little further to the left. Yes, there, just stand there." He wanted to demonstrate the first stereo equipment to me. But I didn't like having to stand totally still "just there" to listen to this "wonderful stereophonic effect."

Was he interested in music, or was it the technical aspects that were important?

Egil: I think it was the technical aspects. At any rate, that's how it seems to me. He was always like that. He was very committed. Very fascinated. When he was fascinated, he was totally immersed. He was a lovely guy, but his interest was rather focussed on what he himself was busy with, for example his work in the garden. I've never known anybody so enthusiastic. He was a real researcher. What you are looking at, what you are engaged on, that's what is important and anything outside that is not so important. So I would say he was childish in a way, or rather child-like, to use a better word.

The children

Was he interested in his children?

Egil: Oh yes!

Louise: Oh yes!

Curiosity Takes New Directions

While Rolf was busy delivering lectures and developing, selling and installing new betatrons—and before anybody started worrying that the market for betatrons would one day be saturated—he suddenly shifted the focus of his own interests, from 'How to *create* radiation?' to 'How does radiation *work?* ' What does all this radiation do to the cancer cells in the body? In other words, what is the biological effect of radiation? His curiosity took new directions. He started keeping company with doctors and reading about radiation treatment and its results. As a physicist and an engineer, he took an interest in the medical effect of the equipment he had developed. He described it as a metamorphosis, but for him it was logical. Contact with the hospital environment and meeting patients and seeing how they could be helped, contributed to this change in his interests. Other 60 year olds might begin to think of retired life on a pension, enjoying some overseas travel and a little consultancy work now and again and delivering a few lectures on their life's work with speculations about the future. Nobody who knew Rolf would expect that of him.

Until now, Rolf had been interested almost exclusively in the technology. Medicine had never basically interested him before. The concept of multidisciplinary research had not yet really been invented. Rolf had concentrated on generating radiation, of as high energy as possible. But what happens to the body when the radiation meets the skin and when it passes through the skin and meets other body tissues? What effect does it have on the living cells? Diseased cells or healthy cells? From now on, Rolf spent most of his time on radiation biophysics and radiation biology. He was interested in how radiation interacts with body tissue and malignant tumours and he wanted to contribute to making radiotherapy more effective.

Professor Jan Sigurd Vaagen from Bergen says that Rolf played an important role[79]:

> There was widespread interest in radiotherapy at that time. Widerøe tried to use other types of radiation than X-rays for cancer treatment. He pioneered a type of therapy that is still in use today, albeit with protons whereas he used electrons.
>
> Widerøe had to update himself quite a lot and learn about radiotherapy and its application. That is surely one of the most impressive things about him, that he was never too old to learn something new. He seemed to me to be an eternal student and he maintained his excitement in seeing new things throughout his whole life. There was something of a young folk-tale hero

about him, but instead of having many helpers as "Askeladd" had, Widerøe did much of the job himself.[80]

As a physicist, Rolf realised that when radiation particles penetrate into tissues and cells, they leave trails behind, rather as animals leave tracks in newly fallen snow, as he used to say. Some types of radiation lay dense trails, whereas others have long intervals between each 'footprint.' His idea was to look for a difference in the tissue damage caused when the marks were close together, compared with when the marks were further apart. This information could then be used to tell something about what sort of effect the radiation had and what type of radiation should be used for what type of tumour. The outcome of this research was that he and the others working in this field developed a theory, expressed as a mathematical formula, for the probability of cells surviving a specified dose of radiation. One of the variables in this equation is the closeness of the 'footprints,' what physicists call the 'ionisation density.'

There is disagreement among scientists about the value of what is known as the 'two-component theory.' Rolf's own dosimetry expert, Christian Gerber, says that nobody really believed in it.[81] Tor Brustad at the Radium Hospital in Oslo thinks that the theory was useful for a long time in radiation biophysics research, in radiobiological research and in deciding radiation doses for treatment of patients with cancer. He claims that Rolf has contributed to the advancement of radiotherapy in two ways, both with his development of accelerators and with his formulation of new ideas in radiobiology.

Together with the head of the radiotherapy department in the regional hospital in Zurich, a leading man in this field, Rolf wrote several articles about his findings.[82] The results that had been achieved in treating cancer patients clearly showed that the use of betatrons had been a big leap forward in radiotherapy. Rolf liked to express himself in clear, simple language and at an international radiology congress in Munich in 1959 he used a tabloid style in statements such as 'To use anything other than betatrons in the treatment of deep-seated cancer tumours should be forbidden by law!' He then spoke about X-rays and electron beams of up to 30 MeV.

At the end of his life he still thought that his strong words from that time still applied. However, it was several years before his ideas really spread and were put into use. He regretted that doctors were conservative people who didn't readily switch over to new methods of treating their patients. There obviously always came a point where they had to accept new ideas, but enthusiastic as he was, he thought that this inertia was a problem for medical research. When he first started discussing new methods of treatment at

the Radium Hospital in Oslo, he felt that he wasn't being taken seriously. 'We were considered almost as charlatans at first,' he said. Even though much had changed for the better, he still thought quite brutally that many of the old methods did more harm than good.

At the same conference in Munich he had for the first time spoken officially about the treatment of cancer tumours with 31 MeV electrons. He explained that this gave more accurate delivery of the radiation doses than was possible with X-rays. The irradiation of the diseased tissue was better, and the rest of the body was exposed to less radiation. Gradually, things began to happen. The main theme at a congress in Montreux five years later was radiotherapy using accelerated electrons and the results achieved with such treatment. The conclusions that emerged from this were decisive in opening the way for high-energy radiotherapy.

Two Pretty Dresses

In connection with the marketing of betatrons, Rolf regularly visited institutions and hospitals where Brown Boveri was supplying machines. In addition there were conferences and congresses that enabled him to keep himself updated. Using a ball-point pen and squared paper, he kept a log of his travels with time, date, place, the reason for the visit and the names of the most important people he met. He maintained this from 1947 to 1991, from the age of 45 to the age of 89. Little personal notes also found their way into his travel logs, such as 'Visit to Krüger Safari Park' or the purchase of 'Two pretty dresses' for Ragnhild when he was in Beijing.

He acquired many professional contacts on these journeys. For example, he developed a good relationship with the chief surgeon in the cancer and tumour hospital in Beijing, who bought a betatron early on. Rolf visited China twice to talk about the radiation machine. On his second visit, he discovered that in the meantime the Chinese had built a machine of their own that closely resembled his, and he also noted that it worked quite well.

Another person he got to know in this way was Professor Werner Schumacher, a well-known German specialist in deep-seated lung tumours. Schumacher was one of the many with whom Rolf continued social contact after he retired, and when Schumacher retired in 1986 Rolf was invited to the farewell party and stayed with Schumacher at his house in Berlin. They had first met at a meeting of the German Radiology Association, apparently in 1951, and after that they had met fairly regularly in Berlin, where Schumacher was in charge of radiotherapy research at the Rudolf-Virchow

Hospital. This hospital bought the very first magnetic lens betatron that Rolf developed, which remained in use for eleven years until it was replaced by the moving betatron, the Asklepitron.

Professor Schumacher was more daring than others, which pleased Rolf. He tried out things that other doctors were less willing to try, and he was always looking for new and better ways to deliver radiotherapy. He was particularly interested in Rolf's specialty, high-energy radiation generated by accelerating electrons. Rolf thought that the reluctance of doctors to try anything new was a hindrance to good treatment. He once recommended, for example, that one of the staff at the Norwegian Radium Hospital should visit Schumacher in Berlin, and he went so far as to arrange a meeting.[83] When the date approached, however, the staff member wrote to tell Rolf that his boss had forbidden him to go. The senior doctors were obviously anxious about new methods, as Rolf said.

He was also very enthusiastic about a researcher he met at an international radiological congress in Evian in France, Dr. Lionel Cohen, who was in charge of radiotherapy at a big hospital in Johannesburg in South Africa. Rolf visited him there twice, and they still stayed in touch when Cohen moved to Chicago. Christian Gerber points out that part of the story is that these doctors had a certain self-interest in being associated with Rolf. Widerøe's name was well known, and he allowed himself to be named as a co-author when they wrote scholarly articles. The doctors and their patients needed Rolf's expertise in accelerators, and Rolf for his part needed support in medical circles to progress his own ideas.

> 'He was an opportunist who used people, but only clever people. All parties profited, and he was always ahead in his field,' Gerber says.

Doctor *Honoris Causa*

Yes, Rolf was a pioneer. At that time, nobody knew much about either the basic physical effects of radiation or the biological effects. Rolf was flourishing now. Throughout the 1960s and 1970s, indeed also the 1980s, he was busy travelling to meet medical experts, working with them, gathering new ideas, seeing other points of view. He also travelled to receive prizes and honours. Altogether, he was given more honours for his contributions to radiotherapy than for his original ideas and work in developing particle accelerators. He attributed this to the many lectures he delivered on radiotherapy and the many articles he wrote on the subject.

Rolf Widerøe received three honorary doctorates: from the technical college in Zurich where he taught; from the college in Aachen where he did his original doctorate; and from the Medical Faculty of the University of Zurich. (Archive photo, photographer unknown)

In 1962, after he had been teaching at the college in Zurich for ten years, he experienced a new high point in his career. The college awarded him an honorary doctorate in medicine. He became *Dr. med. Ehrenhalber der ETH Zurich*, or in Latin, *Dr. honoris causa*. Then on 10th July that year, his sixtieth birthday, he was also awarded an honorary doctorate by the technical college in Aachen where he had done his original doctorate. The local newspaper, *Badener Tagblatt*, mentions the event and adds that 'Dr. Wideröe is well known in his professional field.' In April 1964 he became an honorary doctor for the third time. The medical faculty at the University of Zurich didn't want to be out-done by the technical college.

He was awarded more and more honours. There had long been need for a translation of his doctorate thesis, and in the 1960s an English version was printed in a review of the development of accelerators.[84] He had a bit of a struggle with the editor, Lawrence's former assistant Stanley Livingston at Brookhaven National Laboratory in New York State. Livingston only wanted to publish the part of the dissertation that dealt with linear accelerators, the type that Rolf had got to work in practice, and not the betatron, the one with the round track, which at that time he had only worked out in theory. Rolf insisted 'Either you take everything, or there will be nothing.' Livingston took everything. Rolf knew that he was on firm ground. He knew where Lawrence had got the idea for the cyclotron that earned him the Nobel Prize, and he knew that Lawrence knew.

He was honoured in regular order by all the institutions associated with the development of X-rays and radiotherapy. On 3rd May 1969 he was awarded the Röntgen Medal, a very special recognition that the German town where Wilhelm Röntgen was born awards to people who have contributed in his spirit to the further development of radiology. Up to now, eight of the medal-winners have also been Nobel Prize-winners. That same autumn the newspaper *Süddeutsche Zeitung* published a special supplement about Wilhelm Röntgen and X-ray technology, with a large section about Rolf and his contribution. Then it was the turn of the town of Würzburg to honour Rolf. It was at the university there that Wilhelm Röntgen had discovered the radiation known as 'Röntgen rays' or X-rays.' In memory of the discovery, a medal is awarded every twenty-five years.[85] Rolf was the third person to receive it, on 24th January 1971. In the following year, he gave his last lecture at the college in Zurich. But he continued his activity travelling to promote betatrons. He had retired from Brown Boveri three years previously, but he was still 'the boss,' nobody else knew as much about betatrons as he did, and nobody else was as enthusiastic or as skilled in telling people about them as he was.

Come and Sit Down, My Boy

Rolf was aged 70, with three grandsons and one granddaughter, when his family circumstances suddenly changed. He had been admitted to hospital for a routine operation, but suddenly had to switch his attention from his own health to the survival and well-being of another member of the family. His daughter Unn was on her way home from visiting her parents-in-law on holiday with her husband and their two young children. As they were driving out of Yugoslavia they were involved in a full frontal collision. The only survivor was their son, Per. He wakened up in a hospital in Zagreb, having lost his mother, father and little sister. He had a grandmother and grandfather and two uncles in their thirties, all far away in Switzerland.

Lying in hospital in Zurich recovering from his operation, Grandfather Rolf immediately took command of the situation. He worked closely with the doctors both in the hospital where he was a patient and in Zagreb where his grandson was being treated, to organise the boy's treatment from a distance. His first concern was to ensure that the boy's leg wasn't amputated. This was well before the age of mobile telephones, and the practicalities of such long-distance communication were quite demanding.

The boy kept his leg, was discharged from hospital and was sent to Switzerland. But where would he live? Who would look after him? Who would take parental responsibility? One possibility was for him to go to Rolf's younger son and his wife, who already had two boys about Per's age. Another possibility was the grandparents, even though that would be considered less usual as even in Switzerland they were considered elderly.

Just try to imagine the situation. You are a fit seventy year old. Your spouse often accompanies you on lecture tours abroad, to which you usually add in a few days holiday. You are enjoying life as a very active pensioner socialising with an international circle of friends. You have had a satisfying career, earned status, received honours and you are still playing an active part both in your profession and in life in general. Life is good. You are reaping the good seed you have sown and because you are healthy and have unstoppable energy you are still able to keep going and to be stimulated by new ideas. Nevertheless, you are seventy and your colleagues are gradually beginning to become grandparents.

Sometimes the world is turned on its head. In Rolf's case that shouldn't be a surprise to anybody. He and Ragnhild adopt their grandson. An intelligent, orphaned eight year old moves into the house, with his toy cars and noisy friends. A little boy who needs to sit on your knee, be read to and be

helped with his lessons. Who needs to be cared for and supported for many years to come. It is one thing to be seventy when the boy is eight, but what about being eighty when he is eighteen? What was it like at that time for Per, or for Rolf? Rolf obviously didn't know then that he would live to ninety-four and follow the boy through all stages of development until he was a well-educated man of thirty-two.

Per got on well with his Grandfather Rolf and also with his Grandmother Ragnhild. He also got on well with his uncles, who became like big brothers to him even though they were much older and had long since left home and become established. Many years later, Per—who in the meantime has become managing director in a business consultancy with clients throughout the globe—paints a picture of a not altogether usual grandfather and 'father.' We shall present the impressions thick and fast, just as the association of ideas flowed together in our conversation. We spoke in Norwegian; Per is a Norwegian citizen, even though he has lived in Switzerland for most of his life.

Acid rain

I remember when there was talk in the 1980s about trees dying from acid rain. I was seventeen or eighteen then and of course on the side of those who were worried about the environment, but he always said that he didn't believe it was really so dramatic and that the problem would pass over after a time. I think that if he were alive today he would be very sceptical about all the talk of global warming.

Atomic power

He was in favour of using atomic energy to generate electricity, wasn't he?

Yes, absolutely. He was for atomic power. But I think I remember that he only saw that as a transition. For that is just splitting the atomic nucleus, and he thought that nuclear fusion would be the solution to the whole problem.

So he thought that technology would solve the energy problems?

Certainly. Progress has its good sides, that is something my grandfather repeatedly emphasised. So many people are critical of progress and technology. He was firmly on the other side, really optimistic and positive. Perhaps a little too much so. But he was absolutely right in many things.

Detached interest

Was he also really positive as a person, or are you particularly thinking of technical contexts?

I was thinking of technology and progress. He was very positive about that. He was also very positive as a person, but at the same time he was rather distant. It's not that he couldn't laugh, but he was in his own world. For example,

it could be a little difficult for my grandmother always to find something to talk about that really interested him. And in his conversation with me it was usually topics to do with school, such as physics, science or something technical that was easiest to talk about. When I was a student – I studied data technology – he became really interested in that, and he was quite old then. Almost ninety. He was particularly interested in things he had read about in his technical journals, things that were being "hyped" at that time. Yes, he was interested in things like that right to the end.

A party animal

He was a really cheerful person. You saw that best when he was in company. It was as if he opened out then. When the audience was big enough he responded. As a family man, on the other hand, he was a little withdrawn.

He enjoyed company, then?

Very much. He was good at making speeches on festive occasions. That's maybe a little unusual for a scientist.

Impractical

He didn't do anything in the house. He was totally traditional in that. I remember once that when he needed stamps he didn't have the faintest idea where to get hold of them. So all these practical things were organised by my grandmother.

She must really have been amazing?

Yes, absolutely. It certainly wasn't easy to live with a person such as my grandfather.

You all understood that he was special?

Oh yes.

Forgot that it was Sunday

I remember that he could be very absent-minded. For example a friend of mine phoned one day, a Sunday, and asked if I was at home. "No," he replied, "Per is at school." But it was a Sunday, and he had forgotten that. Another time, a friend of mine came to visit and again he said "Per isn't at home." It was as if he was in another world.

Were you scared? Or were you angry, or …?

No, he was a "professor" type.

Forgot that he was married

I've heard a story from when Ragnhild worked in the same place, right at the start of their marriage. Your grandfather is said to have said to her late one evening "You can go home now, Miss Christiansen"[86] He had forgotten that they were married. Is that true, or is it just a good story?

I wasn't born then, but I think it could be true. I think the special thing is that he could be both ways, close and distant. Many people can be distant as he was in this story, but not many of them can change to being effervescent and the epitome of eloquence when in company.

Didn't dare disturb his papers

In my time, he had an office at home. He had thousands of manuscripts and documents round about him.

I assume that you weren't particularly popular when you disturbed his papers?

No, no, no. I never dared do that.

Tennis and science fiction

Did he have any interests or hobbies?

He had played tennis before, but he didn't do so after I came to the house in 1972. His biggest hobby was the garden. He did everything there. That was his domain.

So was Ragnhild not the boss there?

'No, that was his. And then he read a lot. Not just scientific stuff but also novels, especially science fiction.'

Ragnhild and Rolf

Were they like each other? Or was she a sort of opposite?

An opposite, I would say. She was a real family person. That in itself is a big opposite.

You're thinking of the core family?

Yes, she held it all together and made sure that they came to lunch every Saturday, even after they had grown up and left home.

No excuses

'It must have been very difficult – a bit of a challenge – to take me on when mother and father died.'

Surely it was a challenge for you too?

'Yes, naturally, but nor is it easy to bring up an eight year old who suddenly comes into your household. But that's what they did, and I can't go round today making excuses because of a difficult upbringing.'

The architect from Yugoslavia

What did your father work at?

He was an architect, from Yugoslavia. He was a political prisoner there. He was against the communist regime, against Tito. He was able to travel out of the country later, but he didn't have a passport and so he was stateless. Then he met my mother. They got married and moved to Switzerland, but it was

always a problem that he was stateless. Then when I was on the way my mother had to go to Norway so that I would be born there, otherwise I would be stateless too. So then all three of us settled in Oslo.

Non-judgemental

My grandfather Rolf was very tolerant. Like when I had a few problems at school and received several warnings. One day I was told that if I didn't improve I would have to re-sit, and then I caused even more trouble, and so on.

Yes, it's often like that …

He was very understanding, didn't think that it was such a big deal. The important thing was to pull myself together quickly. I was amazed at the time. Some of the things I had done were more serious than others, but he didn't think that it was so bad.

Are you saying that he was good at distinguishing between big and small issues, important and unimportant?

'Hm, yes, and also that it was a question of keeping an open mind and not just thinking dogmatically that "People don't do that, and if somebody in my own family does it I must punish them." What amazes me is that even though I did something really bad – something most fathers would be really angry about and punish their sons for – he wasn't angry. I don't know why, but it seems as if he was tolerant enough to accept that sometimes people do wrong.'

Do you think he was tolerant because he himself needed …?

Perhaps his own history …

Was there an idea that you shouldn't judge people too harshly?

Perhaps. My upbringing was not really his responsibility. My grandmother took this on after my parents died. But when you do something as stupid as I had done you are usually reprimanded, and he didn't do that with me. Yes, I think he was very tolerant. And even though he was so taken up in one thing or another, he accepted that other people could have different opinions. He maybe didn't take as much interest in art and some things as many others do, but he would never say that these were uninteresting – just that they didn't interest him.

Evening prayer

I did have a rather closer relationship with my grandmother than my grandfather. What I remember he did was that he sat on my bed in the evening and we said the evening prayer.

Was he Christian, personally Christian?

I think he was Christian. Not that he said much about that. But he had always been a Christian. I think so.

Norway

Did you have an impression that he sometimes thought of going back to Norway when he retired?

Yes. I think that basically he was always convinced that one day when he was old, really old, he would move back to Norway. But he never really thought that he was old, even when he was ninety. I don 't know for sure, but I think it was my grandmother who said that there was no sense in moving to Norway when the children and grandchildren were here in Switzerland.

Have you had much contact with the family in Norway?

At first I went to Norway every summer. With Rolf of course, and Ragnhild. And with Rolf junior and his family. And Arild. While we were there we always met as many family members as possible, and went to the cabins they had by the sea and in the mountains. It's a pity that I haven't taught my own daughter Norwegian. All the Italians here in Switzerland teach the children their mother-tongue, so maybe I have been too lazy.

How have you managed to speak Norwegian so well?

We spoke Norwegian at home. But I only went to first year in Oslo, so I write it rather badly. Before we moved to Germany, I was at the Steiner School in Oslo for a year. At that time we lived in my grandparents' house in Røa.

Not Swiss German

He must have been stubborn to insist that you should all speak Norwegian at home, half a century after he had emigrated, when everybody round about spoke Swiss German.

Yes, he was really stubborn.

He must have been very deliberate about this.

Yes, absolutely. He refused to understand Swiss German. It's a dialect you almost have to force yourself to understand. When anybody spoke to him in Swiss German, he replied in High German. But I could always hear the Norwegian accent underneath.

Not a diplomat

Did he come into conflict with people because of his strong opinions about such things?

No.

Was he a diplomat?

No, he wasn't really a diplomat. I think he was strong enough just to dominate the situation and the topic there and then, and then there was hardly room for any other opinion, so I don't think he had big discussions. He just said what he thought.

Natural authority

My grandfather was special. His great power was somehow a matter of innate authority. Not everybody who is so opinionated can be tolerated, but you could tolerate him because his personality was such that you just accepted him as he was.

But I have wondered what was the secret? People accepted that that's how he was. You accepted it. Because of your situation, you could have been in real conflict with him. You could have kicked doors and walls. You had lost your mother and father and you had had to come to live with this old man …

'I think he was remarkably broad-minded, but I don't think that explains everything. It's like something you can't put into words. It's just something that **is**, an authority such as that'.

Ragnhild didn't have it, as I understand?

No, she was quite strict, but she didn't have that natural authority. She had to work harder at it.

Feet not always on the ground

He didn't always have both feet on the ground. I remember that when I went into sixth or seventh class he wanted to teach me things that were really at university level. Every time I asked him something, the answer was always so much more …

… than you could understand?

Yes, so I gave up asking him anything special.

But he thought it was good that you studied a technical subject, even though it wasn't his own subject?

Yes, and he was genuinely interested in everything that was happening in data technology and in how computer science was developing in areas that he himself didn't know much about. The furthest he went was to buy an electronic pocket-calculator for 3,000 dollars or thereabout, that would cost 100 dollars today.

Just think if he had had a PC …

Yes, he would have thought it was very exciting if he were alive today.

The brothers Rolf and Viggo

Externally, Rolf and Viggo looked very like each other. But they had quite different life histories. Viggo seemed more to have both feet on the ground.

Even though he was an airman?

Yes, even though he was an airman. Rolf flew too, though.

Did he have a pilot's licence?

Yes. Anyway, he flew. The three brothers all flew. One of them died when flying. Viggo was the entrepreneur who founded the airline. Rolf was totally unpractical in that way. He could never have founded a company.

So didn't he have any talent for organisation?
No, none at all. He just liked to work on his own and not have to think about others.
But what about working in a team?
Yes, if he was leading the team! If he was a "dictator," everything went fine. His sister Else also founded a company. Viggo and Else were both founders who saw to the financing and control of what they started. But not Rolf. He was a founder in a different way. I think he gave all the money to Ragnhild and was then given pocket-money. It seemed quite clear who was boss there.

Pressure?
Was there any pressure on his children and on you to study technology as he had done?
Not on me, anyway. They pushed me to go on to higher education, but after that it was up to me. There may have been pressure on the generation before me. Their youngest son did go in the same direction. And my own mother studied electrical engineering for a couple of years. There was undoubtedly some pressure there, but whether it was indirect or direct, I don 't know. I heard that they had been very strict parents, but they weren't like that with me; just with their own children. I think that grandfather was more involved in my time and thought that my upbringing was part of his duties.

New Triumphs

Rolf's career didn't seem to suffer from having a child in the house again. It carried on as before. In 1973 he was awarded a gold medal at the 13th International Radiology Congress in Madrid. What happened in Norway that same year was even more significant, though. At long last he was elected to membership of The Norwegian Academy of Science and Letters. It's difficult to say how much he knew about the power struggles that had taken place within the Academy. Maybe he knew that influential people within and not least around the Academy did not want him as a member. Maybe he didn't know. A scientific academy is not just a society that you sign up to join. You have to be recommended by someone and accepted.

There was a new high point in 1977, at the prestigious Smithsonian Museum in Washington, half-way along the mall linking Congress and the Lincoln Statue, that tourists pass along on their way to or from seeing the White House. The Smithsonian arranged an exhibition called 'Atom Smashers—50 Years.' 'Atom smashers' is another phrase for high-energy

accelerators, and if we go back 50 years from 1977 we come to 1927, the year Rolf started it all with his doctoral thesis.

Appropriately, right at the entrance, prominent and difficult to miss, was a stand specifically about him: 'Rolf Wideroe, the linear accelerator, 1927.' On display here was the famous notebook with the sketch from his student days, the start of a whole epoch in nuclear physics and cancer treatment. Then the exhibition went on through the whole range of accelerators that followed – the cyclotron, the synchrotron, the betatron, the beta-synchrotron and the others with their various refinements and energy levels. Rolf's portrait was hung here too, alongside other great physicists who had contributed to creating and developing accelerator technology: Wilhelm Röntgen, Henri Becquerel, Marie Curie, Albert Einstein, Niels Bohr, Erwin Schrödinger, Ernest Lawrence, John Cockcroft, Ernest Walton, Ernest Rutherford Robert Van de Graff, Werner Heisenberg, J. Robert Oppenheimer, Wernher von Braun, Otto Hahn and Lise Meitner. A set of copies of the photographs on exhibit was also sent to the Norwegian Academy of Science in Oslo, but nobody there today knows what has become of them.[87]

In 1977 The Smithsonian arranged an exhibition called 'Atom Smashers – 50 Years.' 'Atom smashers' is another phrase for high-energy accelerators, and if we go back 50 years from 1977 we come to 1927, the year Rolf started it all with his doctoral thesis. (*Courtesy* Smithsonian Institute, Washington DC)

Paul Forman, the conservator who was responsible for the exhibition, reports that it was intended to be on display for two years but that it was so popular that it stayed on display for several years more. In 1980 he wrote to Rolf to ask if they could keep his notebooks 'that have a prominent place by the entrance,' for a little longer than agreed. Rolf was obviously proud to agree to this request.

The conservator had established contact with Rolf at an early stage in the planning for the exhibition, and fifty to sixty letters had gone back and forth between them in the course of the next few years. Rolf was asked how he had managed to build the first accelerator, what was special about it and was informed that 'Everything you can remember from your work on it will be very welcome.' Paul Forman received masses of material and wrote back saying that 'Reports like this give life to the objects in our collection and help us to explain the material to students and public.' The museum archive in Washington is storing and preserving scientific papers by Rolf and by Kerst,

the Siemens researchers and others. There is information here about radiation treatment of cancer, information about the differences between various types of particle accelerator, and brochures from Brown Boveri with a picture of the first radiotherapy machine bought by the Radium Hospital in Oslo at the start of the 1950s.

The conservator's involvement was more than the management intended, but his professional skill was never in doubt. His written documentation in labels and explanatory texts is a history book in itself, written after going through the usual discussions between museum staff and scientists about how far one can go in popularising, what to include when a label can only have a certain number of words and whether to present an exhibition that the public understands or just to display things as they are. Museum staff understand that a catalogue is not a scientific paper. So only when all display objects and texts had been evaluated, rejected and reassembled in new arrangements and everything had been checked for outside appearance and evaluated by the experts and at last everybody was satisfied – only then could the exhibition open, six months late.

Everybody agreed that it was a success, though Paul Forman's evaluation may not be entirely impartial:

> It was possibly the best exhibition the Smithsonian has ever had,' he said enthusiastically several decades later. 'It was spectacular, it was educational, and twenty people worked for two months to set it up, in close contact with Rolf Widerøe among others.[88]

Despite the success, there was one thing Forman was not satisfied with. The Smithsonian would really have liked to include Rolf's very first betatron in the exhibition, but it was no longer in existence. The museum had written to his old professor in Aachen and to laboratories and various people in different parts of Europe, but it was nowhere to be found. The museum staff set about trying to have a copy made, but this too was difficult. The Smithsonian does not usually display copies, but on this special occasion they made an exception. As Forman explains, this was a big gamble involving great prestige. Even though the temporary exhibition was over, the Smithsonian wanted to have a Widerøe accelerator in their permanent display.

Rolf was more than agreeable to this. Lawrence, Kerst and the Siemens researchers all had their machines on display. The only questions were how to finance it and how to transport it intact over to the USA. On 4th May 1983 Rolf was able to write joyfully to the museum to say that the building

of a copy had begun. Then, in July two years later he wrote that the manufacture hadn't really got properly going until 1984, but that he reckoned they could send the accelerator in August. He was a little concerned about sending the round glass tube by air and he asked the museum for a little advice, whether it could perhaps be assembled over there.

Almost two more years passed. Then on 2nd March 1987 the Norwegian Radium Hospital wrote a formal letter to four museums, informing them that in collaboration with Rolf they had had four copies of his pioneering machine made and that if the museums wanted they could each have one. The letter was signed by Professor Tor Brustad, who at that time was chair of the hospital management committee. Rolf had kept in contact with the physicist Olav Netteland in the instrument workshop at the Radium Hospital, whom he knew from before. But Netteland had a stroke before the work of building the machine had started. They then tried to have the models made by Brown Boveri in Switzerland, but that was too expensive and in the end it was the workshop in the Radium Hospital in Oslo that did the job; 'Exactly according to my specifications,' as Rolf said.

Paul Forman at the Smithsonian says that Rolf was very determined to get this done. He made the transport arrangements, which were a major issue for him. Nothing must be damaged. It ended with himself and the Radium Hospital paying for the freight and insurance as a gift to the museum in Washington, and then Paul Forman making arrangements for the Smithsonian to cover the additional costs. On 8th November 1987 Rolf was able to write to the Smithsonian with a sense of relief, to thank them for the news that the machine had arrived in Washington safe and sound with the glass tube intact.

The museum curator reports that Rolf himself visited the exhibition with his wife in 1992, when he was ninety years old. Rolf liked what he saw and was able to thank personally the people who had been responsible for the exhibition. Everything has to come to an end, however. Today the accelerator lies dismantled in the cellar of the Smithsonian.

Tor Brustad says that one of the copies is in the Radium Hospital as part of a permanent exhibition of the history of radiotherapy. Another was given to the Norwegian Technical Museum in Oslo, where it is still lying in a remote store and has never been displayed. One was sent to the Röntgen Museum in Remscheid in Germany. A similar model was later built at the apprentice workshop in the DESY research centre in Hamburg and has been on display in the foyer there.

More Prizes and Honours

In Norway too in the early 1980s there was some recognition of Rolf and h*is* achievements. In connection with Rolf's 80th birthday celebrations in 1982 the physicist Olav Aspelund wrote an almost panegyrically positive article in the newspaper *Morgenbladet*. In January the following year Rolf delivered a lecture at the University of Oslo that *Aftenposten* reported on 18th January. He also gave a lecture at an international conference in Geilo. Both of these invitations had been arranged by Aspelund.[89] The most important contribution for posterity, however, was arranged by two up-and-coming young Norwegians, research grant holder Finn Aaserud and Assistant Professor Jan Sigurd Vaagen. They organised a group interview in Oslo, a sort of seminar with Rolf and a group of Norwegian physicists.[90]

The seminar took place on Tuesday 12th July 1983, the day after Rolf's 81st birthday. Up till then, this was the only attempt that had been made to document the range of his work. It was arranged under the auspices of a research institute in Oslo and there were six or seven people taking part.[91] The interview lasted several hours and was recorded on tape. The tape-recording is now in the archive at the technical college in Zurich where most of Rolf's bequeathed papers are preserved.[92] There is a copy of the transcript in the Niels Bohr Archive in Copenhagen and another in the Niels Bohr Library and Archives at The American Institute of Physics.

An easily accessible short version was later compiled by two of the interviewers, Aaserud and Vaagen, in the journal *Nature*. This was the first attempt by Norwegian physicists to bring Rolf's contribution into wider recognition.[93] Aaserud has a doctorate in history of science from Johns Hopkins University in the USA. He has been head of the Niels Bohr Archive in Copenhagen for about twenty years and he is committed to recognising Rolf's place in the big picture. Vaagen is Professor of Nuclear Physics in Bergen and has had connections with several foreign universities including Yale in the USA and the University of St. Petersburg. When asked how he had first become interested in Rolf, Vaagen replied as follows:

> It started after both Finn Aaserud and I had been working abroad in the 1970s. When I came home, after some time first in Denmark and then in America, I found a Norway that hadn't yet fully understood its place in the world. When I was abroad I had heard about people who had been significant but whom Norway seemed to have forgotten about, and I realised that we should be interested in some of these. I heard about Widerøe, and his name

> seemed interesting. Aaserud had studied the connection between biophysics and nuclear physics as part of his doctoral thesis, and he was interested in finding out more about Widerøe from that angle. At the same time, the science of physics had fallen in popularity and some of us found that we needed to consider how to spread the message that physics is important.[94]

Was Rolf satisfied with the interview? Jan Sigurd Vaagen answered this question positively, saying that they clearly got that impression and adding that Rolf spent some time reading the transcript, checking through the wording and supplying more material. Waloschek, who wrote the biography, was not quite so convinced. He thought Rolf was unhappy that he had been presented as an inventor rather than as a full-blooded scientist.[95] Vaagen has also discussed Rolf's role as an inventor in the context of Rolf later receiving an important international physics prize:

> His lack of permanent association with distinct scientific or other academic disciplines suggests that he can best be described as an 'inventor' in a certain sense. Dealing with pure science and working in industry were both natural and compatible elements in Widerøe's career, and M. Stanley Livingston's description of him as 'the first accelerator designer' is a suitably comprehensive expression. He influenced a whole field of development. Widerøe's doctoral thesis (…) inspired Lawrence in the USA in his work on the cyclotron, and also other pioneers such as E.T. Walton in England and Jean Thibaud in France.[96]

Vaagen is convinced that Rolf's doctoral thesis supported the development of what today we call 'big science.' He maintains that this happened without his direct involvement, among his contemporaries in the Lawrence Laboratory in America, and he goes so far as to say that without Widerøe, Lawrence would probably not have been awarded the Nobel Prize.

> He can undoubtedly be characterised as an individualist who never really fitted into our homely little academic milieu. But a series of contributions based on his doctoral thesis led to the principles underlying what we call colliding particle beams. His ideas also led to the synchrotron-accelerator principle. The daring concept of the accelerator that he championed enthusiastically when CERN was being set up, enabled Europe to take part in the big science of particle physics. Since then he has played an important part in other big accelerator centres in Europe, including DESY in Hamburg, which also made use of his ideas about colliding particles.[97]

In Norway, Rolf was in the spectators' stand rather than on the track during the 1930s when nuclear physics was gathering speed. Concepts central to our modern understanding of the universe fell into place, and mankind managed for the first time to contend with nature's own radiations, Vaagen explains. He emphasises that current problems in physics and technology are being shared among researchers in many countries. Rolf had the experience several times of seeing rather similar discoveries made in different places simultaneously, and he also had the experience of seeing others possibly benefiting more from them than he did.

Nevertheless

Even though some physicists had taken an initiative in the 1980s and at least arranged an internal interview with Rolf, his fame in his native land never reached the levels of praise elsewhere. In his 80th year, in 1982, he was invited to a congress in India and Sri Lanka under the auspices of The Association of Medical Physicists of India. In March he delivered a lecture at a radiation symposium in Saudi Arabia.

The college in Zurich where he had taught arranged a big colloquium in his honour in spring 1983 with the ambitious title 'The Development of Particle Accelerators to Date and its Further Development in Future.' This meeting was publicised in Norway beforehand with a notice in *Aftenposten*.[98] That same year, he was also awarded honorary membership of *Die Schweizerische Gesellschaft für Strahlenbiologie und Strahlenphysik*. In February 1984 the European physics journal, 'Europhysics News,' published a long article about him. He travelled to Jerusalem where the newly formed association for radium treatment of cancer, ESTRO, held its meeting that year and elected Rolf to honorary membership.[99] He lectured there and later in France.

There have been many other memberships and honorary memberships over the years, named here in alphabetical order: American Physical Society; American Radium Society; British Institute of Radiology; *Deutsche Röntgengesellschaft* (honorary member); European Society of Physics; *Naturforschende Gesellschaft*, *Zurich*; *Norsk Fysisk Selskap*; *Norsk Radiologisk Forening*; *Schweizerische Physikalische Gesellschaft* (honorary member); *Schweizerische Gesellschaft für Radiobiologie* (honorary member); Scandinavian Society for Medical Physics (honorary member) and Society of Nuclear Medicine.

Around the World

Rolf still kept up his travel log with notes of workshops, lectures, conferences, meetings, seminars, congresses, interviews. Australia, Asia, Africa, America. With or without Ragnhild, but often with her after the children grew up. Always with her in the later years. Regular entry about Skjæløy with the family round about his birthday in July. Plus, every year after they had both retired, a one week visit together in February or March to brother Viggo's place in Spain. Not the usual lifestyle of most pensioners. Not typical charter tours either. 1976—six foreign trips. 1977—among other things, three lectures in Rio de Janeiro. 1978—at least three foreign trips. 1979—at least four. 1980—at least four. 1981—at least three, including Cairo and Jerusalem.

In summer 1985 he extended his summer visit to Norway with a few days at Gausdal Mountain Hotel—a place where he often holidayed—and at Rondane Mountain Hotel. So it goes on in the following years with summer tours around Norway by car. He gives himself a *slightly* easier time, *a few* more holiday trips with Ragnhild. Also, he hopes, an extra visit to Norway each year if he is invited to give a lecture, as for example when the University of Bergen at last invited him to a seminar entitled 'Rolf Widerøe—a pioneer in accelerators and radiotherapy,'[100] and Haukeland Hospital did the same four days later. Jan Sigurd Vaagen, who fetched Rolf from the airport for the two seminars in Bergen, recalls:

> As I remember the story, Widerøe arrived at Flesland Airport in the evening. Ragnhild was with him. I drove them to the Grieg Hotel nearby. But then, almost before we had come into the room, Widerøe said "How is my old friend Odd Dahl, then?" "Yes, he's living out here now," I replied, "at Fana." And then Widerøe said "Can we ring him right away." I think it was about eight o'clock by then. When I got Dahl on the phone, Widerøe said "Could I come to visit you?" "Come right away!" replied Odd Dahl. So then we were right out into the car again. When we came into that fine old Bergen house there stood Odd Dahl, with Dry Martini on the usual silver tray, ready to bid Dr. and Mrs. Widerøe welcome. They sat down and spoke politely, addressing each other formally; they really did this at that time. Then after a while
>
> Widerøe said to Dahl, "Dahl, I read with great excitement and a little surprise your book *Trollmann og rundbrenner*." "Yes," said Dahl, "That was an exciting time." Then Widerøe said "I was especially interested in the canoe trip from the Andes down the Amazon to Manaos." A trip Dahl had done as a young man in the 1920s. "That was an exciting trip, said Dahl" "Yes, I did it a

few years ago," responded 85 year old Widerøe. This story shows a little of the bold style of these two chaps.

The following Easter Rolf and his wife went for a trip on the Orient Express. He was then in his 86th year. In June he flew with a group from Brown Boveri to Stockholm and Västerås to visit ASEA in connection with the merger between the two companies. In July, a trip by car to Norway as usual. Same again the next summer. He wrote in his log: 'Drove 2810 km.' He had cause to be proud. Previous entries included 'Alfaz del Pi, Viggo' in February and 'Roentgen Museum in Remscheid, Germany, 21–22 April;' that was when he received the medal. 'By car to Norway 29th June. Gausdal Mountain Hotel. Arrived Skjæløy 17th July. 20th July Hamburg.' By then, he was 87.

The next year—1990—same procedure. Viggo in March, trip by car to Norway in summer and a trip to Brittany in September. The official engagements abroad had ebbed, but the travelling continued. In 1991 he went to his friend Kåre Backer's diamond wedding in Oslo. To Viggo in Spain in March–April. By car to Norway 24th June to 17th July, returning via Hamburg to visit old friends and colleagues and meet Pedro Waloschek, who at that time had introduced the idea of writing Rolf's biography.

Lacking Only the Nobel Prize

Physicists were beginning to realise that this man's story should be taken notice of before it was too late. One of the physicists who saw this was the Norwegian-American Per F. Dahl, Odd Dahl's son who had settled in the USA. In March 1992 he published a long article about Rolf's historical contribution to physics, in connection with an international industrial symposium in New Orleans. The article was about one of the major topics of that era, superconductors, and even though it is an academic paper, it indicates clearly that Dahl jnr. had heard good things about Rolf from his father. In an introductory summary he links Rolf directly to Lawrence:

> This year, 1992, marks the 65th anniversary of Rolf Widerøe's doctoral thesis. In it he not only describes the operating principles for the betatron, but also a working model of the first linear accelerator, constructed to his design. The linear accelerator, a resonance accelerator, gave Ernest Lawrence the idea for his cyclotron.[101]

The Americans accorded great honour to Rolf that year, and in April the American Physical Society awarded him the Robert Wilson Prize for his contribution to accelerator physics.[102] In June it was Europe's turn. One of the sessions at an international accelerator conference in Hamburg was dedicated to Rolf, and he experienced one of the proudest moments of his career. There, in that prestigious forum, was uttered the phrase that would ensure his memory. From the lectern he was described as the founder of the particle accelerator, '*der Urvater*,' 'the originator.' His reputation was now established as a Nestor in the subject. Proclaimed and confirmed. For Europeans and Americans alike. Said and written. Widerøe was the pioneer, the brain behind the invention that led to the revolution in treatment of cancer and made significant contributions to research in physics. The Norwegian Rolf Widerøe had gained his place in the history of science.

On Rolf's 90th birthday there was an article in *Aftenposten* written by the two men who had taken the leading roles in arranging the interview with the physicists. They wrote about him as 'the man who took part in giving humans the tools to control nature using Einstein's recipe,' and they described his doctoral thesis as having 'an almost immediate triggering effect on the further development of accelerators.'

Vaagen has told me that he sent Rolf a copy of an article he had written about him in connection with the award of the Wilson Prize. Rolf took a copy of the copy and sent the original copy back with a note of thanks and with a message noted in the margin, 'We fly to Washington 14th April where I shall give a lecture on 21st April at an APS meeting. Kind regards, Ragnhild and Rolf.'

> The event was the spring meeting of The American Physical Society, and I think he felt that this was a really big occasion. Not least that he could say something at an international physics conference such as this, within the academic milieu. I think he liked that.

Rolf joked about all these awards and said that the only thing lacking now was the Nobel Prize. Secretly, however, he thought that they were deserved. In July he was at Skjæløy as usual with 90th birthday celebrations at a restaurant in Oslo. His big jubilee year ended in December with a special seminar in his honour at the college in Zurich where he had taught for twenty years. He had obviously not been forgotten there, even though he had been retired for just as long.

Rolf Widerøe (90). (*Photo* Pedro Waloschek)

After that, Rolf stopped keeping a travel log. He didn't stop travelling, but the travels became fewer. He became a little less active and his hearing became a little worse. The regular trips continued, however, to visit his brother in spring and the old country in summer.

Otherwise he sits a lot in his chair by the window. Goes for short walks. Reads. Reads some more. He dies in the autumn, on 11th October 1996.

He is buried in the churchyard at Kirchdorf close to Nussbaumen, the little village near the town of Baden in the very north of Switzerland, the country in which he had lived in since autumn 1946 but never became a citizen.

Just in Time

The following year a Norwegian prize was established in his memory, the Widerøe prize. The instigator of this was Tor Brustad from the Radium Hospital. The prize took the form of a bronze statuette made by Nina Sundbye, the sculptor who had created sculptures of well-known Norwegians such as Henrik Ibsen and Per Aabel. The prize is awarded to researchers who have played an important part in the development of radiotherapy and thereby built further on the foundations that Rolf laid.

The artist has entitled the statuette, 'The Widow in Zarephath.' The symbolism is obvious; scientific results inspire new ideas and further developments again and again without ever running empty, just as the widow in Zarephath's cruse was an endless source of nourishment. Rolf had been able to see a photograph of the first draft of the statuette before he died. He was very weak by then, but his wife raised him up in the bed, showed him the picture and told him that the idea of an exhibition was also being considered. He wasn't able to talk, but his wife said that she saw a tear run down his cheek. He died the following day.[103]

The first recipient of the prize was Professor Anders Brahme from the Karolinska Hospital in Stockholm. It was presented by the then Health Minister Gudmund Hernes who spoke on behalf of the government about Rolf's place in the history of science. The Director of the Radium Hospital, Jan Vincents Johannessen, spoke about the significance Rolf's work had had for the hospital, and the Director of the DESY centre in Germany spoke about Rolf's contribution to accelerator technology.[104]

During the celebrations of the Radium Hospital's 70th anniversary in 2002, a bust of Rolf was unveiled as thanks for his part in the fight against cancer. It was mounted as part of the exhibition that was set up for the jubilee, a 'mini-museum' showing the development of radiotherapy. This too was just in time. Two years later it was decided that the Radium Hospital should be combined with the National Hospital where several other institutions had already been incorporated. Now it was not only the history of radiotherapy that was to be presented to the public. The new major hospital was to be presented as the country's most important highly specialised hospital, with the strongest medical and health-related research milieu in Norway.

So it is unlikely that Norway would have had a memorial to Rolf Widerøe if he had not already been given his place thanks to an enthusiast, the retired professor from the Radium Hospital, Tor Brustad, who had had the authority and the courage to bring about the Widerøe Prize, the exhibition and the bust.

The Same Enthusiasm

In the course of helping Waloschek with the biography, Rolf reviewed and summarised what he had contributed to science. Looking back over what he had done, he saw that there were some highlights. However, while he treasured these, *all* that he had done was important and it had *all* been fun.

> I didn't think much about the relevance or the possible future significance of what I was doing. I was happy in my work and always absorbed in what I was doing at the time. I built relays with the same enthusiasm as I later constructed betatrons. And if it was a question of something new I was especially interested and motivated.[105]

At the very top of his list—not unexpectedly—he put the work for his doctorate. The linear accelerator he had built in connection with his thesis and the design principle for the betatron that he had proposed were still the big things for him. It had been important to him at the age of 25 when he was striving to develop his ideas into formulae, his formulae into designs and his designs into the construction of machines. Now, so long afterwards, it was still important to him, possibly even more so. Then, he saw the possibilities and had faith in his vision. Now, he saw the results and he saw the possibilities waiting there for others to build on top of what he had achieved.

He thought he had been lucky. His success had come not just from his doctoral thesis but from its dissemination, the fact that it had been found and read the world over. Or rather simply put, there was not much point in being the founder of accelerator technology if nobody got to know about it and used it for something. His thesis had become one of the most cited publications on particle accelerators, and for a researcher, then as now, being cited was the most important indication that one's work was significant. Citation indexes are administered now in big, international databases and are an important part of the academic accreditation system.

However, the relative merits of 'patents' versus 'academic publications' continued to worry him, the idea that something either is of practical use in industry or a piece of academic work. It is difficult to get people to accept that something can be both of these at once. He made up a list of what he called 'Published academic works' containing 205 titles in all. Here, he included for example both the article for the Physics Society's magazine on how atomic energy can be used technically, and a lecture on the historical development of accelerator technology. Earlier, as head of department in

Brown Boveri, he had made up the list more from a sales and marketing point of view than from a professorial point of view.

In the biography, Waloschek says right out that it is a misrepresentation to label all the articles as academic publications. He analysed the list and considered that many of the items listed either were not scientific, or were not written articles, or had not been published in an academic context. He characterised sixty of the titles as lectures. In other words, an outright slaughter of the list, not because the content is not valid but because in his opinion much of it does not fulfil the criterion of what can be defined as scientific work. Waloschek, himself a professor with a doctorate in physics, emphasised that this didn't shake his admiration for Rolf's contribution as a scientist. At the same time, he asked himself why Rolf was so concerned to be recognised as a scientist.

> You could count his scientific papers on the fingers of one hand, and they were very good. He was a genius, but I think that Norwegian physicists didn't like that being called science. If he had described himself as an inventor it might have been easier for them to accept that.

Pedro Waloschek then interrupts his own train of thought:

> No, I am being too negative now. That isn't my intention; I don't want to be negative. But he doesn't deserve to be glorified. He deserves to be understood as he was. A really brilliant, very intelligent person who did great things.

It may be more difficult for a foreigner to judge to what extent there were other reasons why Rolf was not popular in his homeland, but after a couple of years work on the biography Waloschek was quite clear that there were various different perceptions of this Norwegian who had decided to settle in Switzerland:

> He still had many enemies, many people who had something against him. I had great respect for him; I wouldn't have used so much energy on him otherwise.[106]

It is difficult to say whether Rolf was partly self-deluded when he drew up his list of scholarly publications or whether he was driven by PR considerations. If he drew it up for academics, he misjudged his readership. If on the other hand he had the general public or potential customers in mind, it served its function well. It is certainly useful to anyone who just wants to

gain an insight into Rolf and his activities, even though he would have been better to omit from prominent first position the analysis of inflation from his student days, which had nothing whatever to do with physics.

'Few people have the distinction of writing a doctoral thesis that has such widespread influence,' wrote Jan Sigurd Vaagen in his article in *Bergens Tidende* on the occasion of Rolf's 90th birthday.[107] You don't have to understand physics to see how each discovery builds on the previous one in a long, continuing line. The significance of each single link in the chain is easier to see in retrospect. Rolf himself commented as follows on the accelerator with the circular track:

> The curved accelerator tube appears first in Lawrence's cyclotron and later in the acceleration chambers in the synchrotron. The latter now seems to me much more important because the synchrotron paved the way for the storage rings. My discovery of the stabilised particle tracks may also have been quite important. But the further development of the drift tube – which happened almost simultaneously with the development of the cyclotron (…) is also very interesting. It all started with the first drift tube in Aachen in 1927.[108]

Self-important? Not hiding his light under a bushel? Bragging? Well, not really. He speaks his mind and says it how it is. Straight out, no shilly-shally. It's an almost childish innocence. Some would call it naive, but it is not naive in the helpless, ignorant sense. It's not as if he didn't know what he was saying. It's just blunt—and pardonable.

The Patent He Didn't Talk About

The achievement Rolf rated in second place was the patent he didn't really talk about until ten years later. A theory he 'saw' when he was on holiday in Norway, lying on his back on the lawn in front of the hotel in Telemark, watching the clouds floating by and colliding. It was to do with what are known as 'storage rings.' His inspiration was 'probably very important,' as he put it with poorly concealed understatement, but he decided to keep it secret for quite a long time and he has explained the reasons for this himself:

> My 1943 patent for the invention of storage rings was in fact very important, but it was kept secret for ten years. As I couldn't see any practical applications for it (because there were still too many unsolved technical problems) I didn't say very much about the invention. The first time I explained my proposal

> publicly was at the accelerator conference in Geneva in 1956, after Gerry O'Neill had rediscovered the principle. Others had then developed the idea further. I was fully occupied building betatrons for BBC. I'm very glad that I had the right idea thirteen years before my colleagues. I can't blame them for sometimes forgetting about me, though, because they had often been working on and developing their projects for years. Many very good storage rings were built while I was busy with other things.[109]

Elsewhere, he writes that the reason all the thirteen patents between 14th July and 4th October 1943 were registered in Germany was that 'Siemens were working strongly in this area and so I wanted to secure the German priority for myself, under any circumstances.'[110]

But whether this is a collection of blessings in disguise or a rationalisation for his own sake or an explaining away for other peoples' sake, or whether it simply was a concatenation of many circumstances, the objective fact is that it was wartime. The invention was subjected to censorship. The patent was formally registered in Germany on 8th September 1943 and issued on 11th May 1953 to Rolf Widerøe, with Brown, Boveri & Co. in parentheses. The subject was *Speicherringe* (storage rings).

In third place on his list were the relays. These too he discusses unemotionally and in few words, but not in any way modestly:

> I think my contribution in this area was quite good, and I also think that my relays were very useful. Even though this is not of great relevance to particle physics or to medicine, these were creative works and I am quite proud of them.[111]

In fourth place, he ranks his work on the effects of radiotherapy on people with cancer:

> The interest in radiotherapy was a logical progression in the war we were fighting against the tumour cells with our new megavolt radiation weapon. The patients needed essential help, and I took part in that with great enthusiasm.

The First Love

Even though he had worked in many fields and taken part as a pioneer in a succession of new areas, he never entirely gave up the particle accelerator. That was his first love and it remained special to him, no matter what happened afterwards. He had always continued reading physics journals and

he tried to keep himself informed about what was going on elsewhere. For example, when he was employed at AEG in Berlin before the war he had already heard about the exciting things that were happening in America.

> During the war the situation was obviously much more difficult, but from the late 1940s a completely new spirit came into the scientific community. Communication between researchers was desired and welcomed. Freedom to travel, reciprocal visits and international conferences meant that people got to know about almost everything that was happening in their field. Moreover, one knew most of the participants personally. (…) Nowadays it is important to keep yourself well updated on many topics to do with your research. All it needs is time to read – and good friends. So even since I retired I haven't been able to keep myself away from studying basic problems to do with particle acceleration. Only through experiments with even higher energy will we be in a position to gather new knowledge that can eventually lead us to a comprehensive theory of the structure of matter.

He maintains that after successful engagements with cyclotrons, synchrotrons and storage rings, we are back where we started, with the linear accelerator. The experts had agreed that the doughnut-shaped rings wouldn't become any bigger, but that from then on straight-line accelerators would be built instead for this research. The reasons for this were both technical and economic, but Rolf had his own perception of the motives and thought that researchers should not allow themselves to be scared off by trivial considerations:

> It is totally different with ideas. Here, the boundaries are set only by human intellect. The theoretical possibilities of using electromagnetism to accelerate particles are nowhere near exhausted, (…) and we are astonished almost daily by technical innovations that start us on the next circuit in the pursuit of new things. Even though many of the ideas that have come from this field in recent decades have since been rejected, it is nevertheless possible that there is still a fundamental breakthrough to be made that will allow us to step up into energy levels that today are still impossible to envisage. We should remember that what we are building today was pure Utopia fifty years ago.[112]

The Impossible

One should never stop having faith in future progress, no matter how unlikely it may seem. That was the message from the ninety year old with seventy years of research experience behind him. As an example that 'the

impossible' can become reality, he cited the Russian Vladimir Veksler who researched on synchrotrons. At a conference in Geneva in 1956, Veksler had presented a remarkable idea about attaining high energy levels using a new method that he called 'coherent acceleration.' This had impressed Rolf, but he thought that there was something in what Veksler said that couldn't be right, and this problem continued to vex him. Twenty years later he put together and wrote down what he had worked out so far, and even though much fell into place he still thought that the calculations seemed unrealistic.

Then, after almost another twenty years—when Rolf was ninety—he was told about the plans for new accelerators that were to be built. His method using storage rings had now reached its limit. Later researchers had discovered what the Russian had overlooked, and higher collision energies were now to be achieved using a new method. Rolf was gratified that he had already explored this when he discovered the principle behind storage rings. The lesson is that if you just believe that something really is possible, then it perhaps will become possible one day. When the science comes to a certain point, you will be able to think of other solutions that you cannot see while absorbed in the present work. He said that we should at any rate not set the boundaries at the start, and he began to wax philosophical on behalf of physics:

> No matter how complicated and Utopian it seems to us now, the possibility of protons attaining energy levels of 1,000 TeV will undoubtedly be of great interest in research physics. Today this sort of energy can only be found in cosmic radiation – and only very, very rarely. (…) One could easily come to the conclusion that accelerator- builders with such fantastic ideas are totally mad, if one hadn't personally kept up with the developments in recent years.[113]

Then he used an example something that he had hailed at the beginning of the 1990s as state-of-the-art, namely the CD, the compact disc with the 'perfect' sound that emerged as the ultimate physical format and put an end to crackling and interference when listening to music. Ground-breaking technology at that time, with its almost 100,000 distinct sounds exceeding what the human ear can distinguish:

> The accuracy that is now being applied in the production of millions of CDs would not have been thought possible a few years ago by any technically qualified person. Therefore: you should never lose courage and should continue to strive for ambitious goals, even when you think they seem absolutely unattainable.

Do the impossible! That is the old man's urgent request, put very simply. A request bordering on banality. Said sincerely and honestly. No reason to doubt that he meant it. Nobody who knew Rolf would doubt that he practised what he preached. Strive for the impossible. Keep on striving. Believe in it. Despite everything.

***

That was what he had done that August day in 1946, when he took his wife and children in the car and set out for a new existence in a new country. When he decided to put the past and the war behind him. That was over now. A new time was to begin, in a new world that was awaiting his contribution.

Notes

1. The interview with the physicists on 12th July 1983.
2. *Some Memories and Dreams from the Childhood of Particle Accelerators*, lecture delivered at the Fifth Nordic Conference for Physicists at Geilo on 12th January 1983. The text was signed on 3rd December and probably submitted beforehand. He also spoke about this in the interview with the Norwegian physicists on 12th July 1983.
3. Conversation during the preparation of the book.
4. Odd Dahl: *Trollmann og rundbrenner*, Gyldendal 1981, p. 153.
5. Odd Dahl, p. 154.
6. Odd Dahl, p. 163.
7. Odd Dahl, p. 16.
8. Interview during the preparation of the book.
9. The biography and the interview with the physicists.
10. *Historical Development of the Betatron*, in *Nature* (London) 157 (1946):90, 1946.
11. 6 and 15 MeV, based on Max Steenbeck's ideas.
12. The biography.
13. The biography.
14. The interview with the physicists in 1983.
15. The interview with the physicists in 1983.
16. The interview with the physicists in 1983.
17. '*das Synchrotron und das starke Fokussierungsprinzip für Beschleuniger*'. ('The Synchrotron and the Strong Focussing Principle for Acceleration') Nicholas Christofilos patented the idea in 1950.
18. Professor Giorgio Salvini and Engineer Fernando Amman.
19. *Laboratori Nazionali di Frascati*, south of Rome.
20. The biography.

21. Rolf's contacts in the Physics Institute at Turin University were the director, Professor Gleb Wataghin who came from Russia and had also worked in Brazil for a long time, and Professor L. Gonella.
22. The Italian L. Gonella and Dr. H. Nabholz from Brown Boveri.
23. The interview with the physicists in 1983.
24. Interview during preparation of the book.
25. Werner Schumacher, Hans Rudolf Schinz, Adolf Zuppinger.
26. The biography. Other sources say c. 300. Between 1949 and 1986 Rolf was responsible for the development and construction of 78 betatrons at Brown Boveri, all custom-made for the client and installed by himself. There were also 15 magnetic lenses. In the period 1949–1986 Brown Boveri sold 11 betatrons rated at 31 MeV for use in industry and research and 6 with energy between 31 and 35 MeV for medical use, including the first one at the Norwegian Radium Hospital. The moveable type of betatron was known as the Asklepitron. Of these, they sold 38 rated at 35 MeV and 23 rated at 45 MeV. In addition, they sold 15 betatrons with magnetic lenses.
27. Copies of these can be found, among other places, in the ETH library in the college at Zurich, in the library in the Deutsches Museum in Munich and in the 'minimuseum' in the Radium Hospital in Oslo.
28. European Space Agency (ESA), European Molecular Biology Laboratory (EBML), European Synchrotron Radiation Facility (ESRF) and Joint European Torus (JET)
29. The biography.
30. The biography.
31. Odd Dahl.
32. Lillestøl, CERN/ Bergen University to *forskning.no.*
33. D. W. Fry, Hannes Alfven and F. Regenstreif.
34. Odd Dahl.
35. *Festschrift* to Roald Dahl in his 70th birthday celebrations on 3rd November 1968, A.S. John Grieg's Printing Works, Bergen, 1968.
36. CERN Courier, 22nd March 2002: 'How US physicists first came to work at CERN.'
37. Among those he names are Ernest Courant, Hartland Snyder and Stanley Livingston.
38. Egil Lillestøl's obituary of Kjell Johnsen, *Aftenposten* 10.8, 2007.
39. Nicholas Christofilos.
40. The biography.
41. Ernest Courant: 'Brookhaven and CERN: the AGS and the PS,' CERN Courier Oct 19, 2007.
42. Interview during preparation of the book, 3rd November 2007.
43. John and Hildred Blewett.
44. The biography.

45. The Alternating Gradient Synchrotron, AGS.
46. To build what was called a 'strong focussing,' alternating gradient synchrotron as the Americans proposed.
47. Günther Plass.
48. CERN Courier Jan 27, 2004: 'CERN's heart beats as strong as ever. 50 years of CERN.'
49. The biography.
50. Gordon Fraser: 'How US physicists first came to work at CERN,' CERN Courier, CERN-US collaboration, article 12 of 20.
51. Odd Dahl.
52. Norbert Lang: '*Rolf Wideröe und das Betatron*,' *Physik Anekdoten (13), Communications de la SSP No. 35, 23–25*.
53. The W and Z particles were discovered by Carlo Rubbia and Simon van der Meer. Egil Lillestøl in his obituary of Kjell Johnsen who had been leader of the ISR Project at CERN. *Aftenposten* 10.8 2007.
54. The PS machine was also useful when it became an antiproton decelerator serving the LEAR (Low Energy Antiproton Ring). It is still supplying LEAR's successor, AD (Antiproton Decelerator) with high-intensity primary proton beams.
55. Large Electron Positron Collider.
56. CERN's heart beats as strong as ever, CERN Courier, Jan 27, 2004.
57. The biography.
58. Large Hadron Collider.
59. *Aftenposten* 3 Oct 2010.
60. The biography.
61. Wolfgang Gentner became director of the synchrocyclotron department at CERN in 1956. He had worked with cyclotrons previously in Heidelberg, with Lawrence at Berkeley and with Joliot in Paris. In 1958 he became director of the new Max Planck Institute for Nuclear Physics in Heidelberg. Anselm Citron was also one of the first physicists at CERN, and he followed Gentner in the directorship at Heidelberg. The quotation is from the biography.
62. The biography.
63. The biography.
64. Science Illustrated no. 3, 2012.
65. *Apollon* no. 3, 2007.
66. Interview during preparation of the book.
67. Created by an Englishman, Tim Berners-Lee.
68. *CERN fyller 50* ('CERN Reaches 50'), www.forskning.no, 6 October 2004.
69. Dr. Werner Hardt.
70. The head of the accelerator division was Professor Gustav-Adolf Voss. The director of the centre was Professor Willibald Jentschke.

71. HERA stands for *Hadron-Elektron-Ring-Anlage.*
72. Gustav-Adolf Voss.
73. The biography.
74. Conversation during the preparation of the book, 10 June 2010.
75. 'Power is not justice. The circumstances facing major industry during the occupation. From director Alex Christiansen's bequeathed work about his struggle for truth and justice.' One of Christiansen's secretaries, Alexander Lange, inherited the material and arranged for it to be printed in the newspaper *Folk og Land* on Saturday 28th June 1958, Saturday 12th July, Saturday 26th July, Saturday 9th August and Saturday15th November.
76. *Folk og Land*, Saturday 12th July 1958.
77. *Folk og Land*, Saturday 15th November 1958.
78. Egil Reksten died before this book was ready. The conversation was recorded on tape and was written out word for word.
79. Interview during preparation of the book.
80. In addition to Tor Brustad's article in the same issue, he refers to the Swedish Anders Brahme: 'Aspects on the Development of Radiation Therapy and Radiation Biology Since the Early Work of Rolf Widerøe,' *Acta oncologica* 1998, Vol. 37, No. 6, Pages 593–602.
81. Interview during preparation of the book.
82. Hans Rudolf Schinz.
83. Dr. Selmer Rennæs.
84. Livingston, M.S.: 'The Development of High-Energy Accelerators,' commented reprints or translations of original papers, (book), Dover Publish. Inc. N.Y. (1966).
85. '*Röntgenpreis der Stadt Würzburg und der Physikalsch-Medizinischen Gesellschaft Würzburg*' ('The Würzburg State and Würzburg Medical Physics Association's Röntgen Prize.').
86. The biography.
87. Professor Tor Brustad in a conversation during the preparation of the book. According to Brustad the photographs from the exhibition show: 'Pictures no. 1, 2 and 3 from left to right: Max Planck, Marie and Pierre Curie, Wilhelm Röntgen, Henri Becquerel, Ernest Rutherford, Rolf Widerøe, Ernest Walton, Joseph Slepian and (under Rutherford) Irene and Frederic Joliot Curie. Picture 4 shows Widerøe's first betatron diagram from1923 (with his notes handwritten in Norwegian). His original notebooks from Aachen in the period 1926–1928 and his doctoral thesis from 1927 were also shown. Picture 5 shows Slepian, Widerøe, Ernst Ising's proposal of the linac principle, Leo Szilard and Walton.'
88. Interview with Dr. Paul Forman, Curator of Modern Physics, The National Museum of History and Technology, Smithsonian Institute, Washington DC in connection with the preparation of the book, 15th June 2007.

89. The lecture 'Some Memories and Dreams from the Childhood of Particle Accelerators' was delivered on 12th January 1983 and subsequently printed in *Europhysics News*, 15, 911 (1984).
90. Both have connections with the University of Bergen. Aaserud is a physicist and writes about the history of science and is now head of the Niels Bohr Archive in Copenhagen. Vaagen is Professor of Physics at the University of Bergen.
91. The interview took place under the auspices of what is now NIFU, the Nordic Institute for Studies in Research, Innovation and Education. The main organiser was the head of the institute, Hans Skoie. In addition to Aaserud and Vaagen who had taken the initiative, the other participants were Olav Netteland from the Radium Hospital, Olav Aspelund, and Senior Conservator Gunnar Thoresen from the Technical Museum.
92. *Die Eidgenossische Technishe Hochschule, ETH.*
93. The magazine *Nature*, nos. 5–6, 1983. The print-out is dated 14th March 1984.
94. Interview during preparation of the book, 19th December 2006.
95. Interview during preparation of the book.
96. Jan Sigurd Vaagen: 'FFV Congratulates,' article in *Fra Fysikkens Verden* ('From the World of Physics') in connection with the award of the Wilson Prize in 1992.
97. Interview during preparation of the book.
98. 26th April 1983.
99. The European Society for Therapeutic Radiation and Oncology.
100. 23rd October 1987. Deputy Principal Ole Didrik Lærum: Introduction; Roald Tangen, University of Oslo: 'A backward glance at earlier Norwegian accelerator installations for nuclear physics and medicine;' Tor Brustad, Radium Hospital: 'Microscopic studies of cancer development in living tissues;' Jan S. Vaagen, University of Bergen: 'Rolf Widerøe – the first accelerator designer;' Helmer Dahl, Chr. Michelsens Institute: 'Reflections on the relationship between technology and pure science;' and Rolf Widerøe, Brown Boveri & Co., Switzerland: 'Perspectives.'
101. Dahl, P.F.: 'Rolf Widerøe, Progenitor of Particle Accelerators,' SSC-Report SSCL-SR-1186, 10 pages (1992).
102. The Robert Wilson Prize for Achievement in the Physics of Particle Accelerators.
103. Tor Brustad arranged for the photograph to be given to Rolf's wife, and she told him afterwards about Rolf's reaction. Brustad spoke about the episode in a conversation about the book, on 10th November 2008.
104. 'The First Scandinavian Symposium on Radiation Oncology. Seminar in memory of Professor Dr. Eng. Rolf Widerøe.' Rosendal Manor-house, 24–28th May 1997. The programme included:

Former Church, Education and Research Minister Gudmund Hernes: 'A Tribute to Rolf Widerøe from the Norwegian Government';
'Presentation of the Rolf Widerøe Award;'
Tor Brustad: 'Rolf Widerøe, a great, but overlooked, scientist';
B. H. Wiik: 'Rolf Widerøe, the founder of the science of accelerator technology';
Jan V. Johanessen: 'Rolf Widerøe and the Norwegian Radium Hospital';
Anders Brahme: 'The Widerøe Lecture.'
Three of the lectures were published in *Acta Oncologica* 1998, p. 37, Scandinavian University Press 1998. ISSN 0284-186X:
Tor Brustad: 'Why is the Originator of The Science of Particle Accelerators so Neglected, Particularly in his Home Country' (shortened version without footnotes);
Anders Brahme: 'Aspects of the Development of Radiation Therapy and Radiation Biology Since the Early Work of Rolf Widerøe;'
B. H. Wiik: 'Rolf Widerøe and the Development of Particle Accelerators.'
105. The biography.
106. Conversation in connection with the book, April 2007.
107. Jan Sigurd Vaagen: 'A short journey in Rolf Widerøe's footsteps,' *Bergens Tidende*, 11th July 1992.
108. The biography.
109. The biography.
110. Letter to Fredrik Møller 20th September 1945.
111. The biography.
112. The biography.
113. The biography.