

Saskatchewan's Cobalt-60 Beam Therapy Unit Inaugurates a New Era in Cancer Treatment

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Prepared for
Winning the Prairie Gamble

5 September 2002

Introduction

Saskatchewan has always been a crusader in the fight against disease. When the province took on the burden of dealing with tuberculosis in the early 20th century, it was a costly and long-term responsibility, a commitment which was maintained even through the desperate times of the Great Depression. The advances made in that long battle created precedents for dealing with other chronic diseases that demanded attention as tuberculosis came under control, notably cancer and heart disease. With groundbreaking achievements in research and vaccination programs, province-wide health surveys, and North America's first free tuberculosis care, Saskatchewan did not rest on its laurels. On the contrary, commitment to innovative research and development in health care strengthened. Saskatchewan's aggressive and co-operative response to the cancer threat gained international attention in the 1930s, and became a source of provincial pride.

Within another decade, the world was watching again, as Saskatchewan produced another rabbit out of its hat, one which would bring in a new era in the international fight against cancer. In the midst of the Cold War, Canada led the world in the peaceful application of nuclear power. While other countries were developing the cobalt bomb, Canada was working on the "cobalt bomb" radiation unit for cancer therapy, producing two similar units almost simultaneously, something no other country was even close to achieving. The first of these was created here in Saskatchewan.

Cancer on the Rise- Saskatchewan Doctors Appeal to the Government

Radium was discovered by Pierre and Marie Curie in 1898. After its radioactivity was demonstrated by Madam Curie in 1903, a long process of intensive research began into the uses of nuclear radiation for medical diagnosis and treatment of disease. The out-of-control growth of cancer cells was finally seen to be stoppable, as these cells seemed to be more sensitive to radiation than were normal cells. Unfortunately, as it took 4.5 tonnes of ore to produce 1 gram of radium, it was extremely expensive and few doctors or patients could afford it.

Cancer cases were on the rise across Canada even during the early 20th century. The use in Canada of radiation in cancer therapy began in 1922 with the founding by the Quebec government of the *Institut du Radium*. In Saskatchewan, cancer death rates were also rising, from 8.8 per 100,000 population in 1905 to 32 in 1919. Encouraged by the developments in Quebec, the Saskatchewan Medical Association (SMA) passed a resolution in 1922 endorsing state purchase of radium and the establishment of a Saskatchewan radium institute. However, government attention was taken up with tuberculosis and the proposal was rejected. Cancer, needless to say, did not go away. In 1924, for the first time cancer deaths, at a rate of 40.9, were higher than tuberculosis by one case. And, despite Saskatchewan's best efforts, by 1941 the rate would surge to 90.9 per 100,000 persons.

The Saskatchewan Medical Association and Canada's First Cancer Committee

Although some diseases were coming under control in Saskatchewan during the late 1920s, cancer cases were still increasing steadily and doctors were concerned that people were getting treatment too late for it to be successful. Also concerned, the Department of Public Health (DPH) conducted surveys and the resulting cancer statistics were frightening. Spurred by this, the DPH consulted experts in the field about other cancer organizations and radium therapy. The

Saskatchewan Minister of Health, Dr. Frederick Dennis Monroe, gave a radio address to warn the public about cancer and the need for immediate treatment, asking for the “hearty and sincere co-operation of all citizens”. At the same time, in 1929, the SMA formed a Cancer Committee to study cancer, radiotherapy and the possibility of government purchase of radium for treatment. An important voice was that of Dr. E. Shepley, an experienced Saskatoon radiotherapist. Within weeks, the Committee had presented seven recommendations to the government emphasizing centralization, co-ordination and education, and these became the foundation of Saskatchewan’s cancer program.

The Saskatchewan Cancer Commission, Canada’s First

In quick, aggressive response, and with the endorsement of the Canadian Medical Association, the *Saskatchewan Cancer Commission Act* was passed in March 1930 giving the Commission the power to create cancer clinics, buy radium for treatment and obtain equipment. This was Canada’s first province-wide program for the control and treatment of cancer. New York was the only State in the America to have a similar program. The same year, to keep current with developments around the world, the Commission affiliated itself with the British Empire Cancer Campaign, a world-wide association of cancer experts. Another important step was to set up an emanation plant¹, to produce radon gas locally at a reasonable cost. To ensure the co-operation of private physicians, it was emphasized that free treatment was not being offered. There would be a schedule of fees for those who could pay. As well, cancer services at the clinics would not include surgery. Maintaining good relations with doctors who feared government interference in private practice was essential, and Saskatchewan’s efforts were envied in eastern Canada. Several well-respected doctors were appointed members of the Commission and the Minister of Health was appointed Chairman. The co-operative involvement of private physicians in public programs was, of course, a hallmark of Saskatchewan’s approach to health care from before 1905, that culminated in Canada’s first universal health insurance plan in 1962. Amazingly, since there were no Canadian models for the program, cancer diagnostic and treatment clinics opened within 18 months in Regina and Saskatoon. The fee for the consultative diagnosis was ten dollars. The treatment fee was \$20, \$25, or \$50, depending on the type of cancer, payable in advance. Indigents were provided for by their municipalities and no cases were denied any of the facilities because of inability to pay. Each clinic was staffed with experienced members of already existing hospital personnel and was equipped with an x-ray machine and radium in various-sized needles to be inserted close to tumours. A co-operative arrangement between the Saskatchewan Cancer Commission and the existing hospitals allowed the clinics to provide deep x-ray therapy to all patients at close to cost. The government owned the radium which was used only in clinics by clinic radiotherapists. When surgery was needed, the patient and his doctor chose the surgeon. The SMA approved. It was soon seen that the cancer situation was even worse than was previously estimated. Of the first 500 cases in 1932, 26.9 % were too far advanced and only palliative treatment was possible; 17.7% were so far

¹The University of Saskatchewan semi-automatic radon emanation plant was built under the supervision of Professor E.L. Harrington of the physics department. A supply of radium was brought in, including a bulk supply for the plant and a selection of needles, tubes and plaques for immediate use. The plant began operations in 1931 and produced more than enough radon for Saskatchewan’s two clinics. The surplus could be bought by governments, universities, recognized cancer organizations or certified radiotherapists outside Saskatchewan. Dr. Harrington was instrumental in fostering the career of Harold Johns and the cobalt therapy unit in the late 1940s.

advanced that there was nothing that could be done for them.

Medical personnel kept excellent records and statistics, including records of the all-important follow-ups on former patients. In 1933, cancer was made a notifiable disease, an essential step in understanding the true incidence of the disease. This was the beginning of the Saskatchewan Tumour Registry, the first cancer registry system in Canada. Education was also an important part of the program and several films, such as “Ray of Hope” (1935), were shown at theatres and public meetings. Also that year, Canada’s Governor General, Lord Tweedsmuir, initiated the King George V Silver Jubilee Cancer Fund, to which Canadians contributed almost \$500,000 by the end of the year.

In the ten year period from 1 January 1932 to 1 May 1942, 8,897 patients passed through the clinics. However, there was much work to be done. In 1935, it was found that only 50% of the patients in cases from 1932 were still alive. Many victims were still seeking treatment too late. Dr. R. O. Davison conducted a survey and found that people delayed seeing their doctors because of fear of the disease itself, fear of surgery, not taking symptoms seriously, simple procrastination and inability to pay for treatment. Education efforts were stepped up, for both the public and medical professionals, emphasizing the importance of recognizing and treating cancer early.

With doctors becoming reluctant to send their patients away to be treated and cancer doctors not wanting to treat patients for other conditions, the authority of the Commission began to wane. New blood was needed. In 1939, Regina’s Dr. Allan Blair left his position as Associate Director of the Toronto Institute of Radiotherapy at the Toronto General Hospital, and returned to Saskatchewan to become the Director of Cancer Services and Director of the Cancer Clinic in Regina, now at Grey Nuns’ Hospital. His leadership² was important in ensuring new cancer cases were referred to the clinics by local doctors and keeping the goodwill of doctors.

Effects of the Depression: Tommy Douglas’ CCF Government Invests in Health Care

The difficulties of the Depression had huge effects on the provision of health care in Saskatchewan in the 1940s. As municipalities ran out of money due to fewer and fewer people paying their taxes, RMs could not contribute to hospitals. Both the cancer clinics and hospitals were overfull of relief patients. RMs were reluctant to send more cancer victims in to the clinics and this created a great deal of suffering among patients, their families and their physicians. And cancer cases were still increasing. Between 1932 and 1944, 11,545 patients were examined. Of those, 6,608 were diagnosed as having cases of cancer or pre-cancer.

During the war years, in 1944, the Co-operative Commonwealth Federation, (CCF), came to power in Saskatchewan and, with the terrible experiences of the Depression in mind, wasted no time in attacking cancer. Almost immediately, Minister of Health Dr. J.M. Uhrich introduced the *Cancer Control Act*, providing for free diagnosis, treatment and care for all Saskatchewan residents of at least six months standing.

²In 1947, the National Cancer Institute of Canada, the research body of the Canadian Cancer Society, was begun through an agreement between the CCS and the federal Department of Health and Welfare. Its mandate was to co-ordinate and correlate the efforts of individuals and organized bodies to reduce the morbidity and mortality from cancer. Regina’s Dr. Blair was invited to conduct a national survey of cancer facilities. Although he died before the final report was written, the important survey results are still known as the “Blair Report” and his contribution to the fight against cancer memorialized in the name of the Allan Blair Clinic in Regina.

The Limitations of Elemental Radium and Radon Gas in Cancer Therapy

Radium, a natural radioactive substance refined from uranium ore, was easy to use but worked best when placed close to the cancer tumour. Steel or glass “seeds” containing radon gas, and radium formed into thin needles and implanted near tumours, were used commonly, but were very expensive and could only destroy surface tumours. In the 1950s, deep tumours killed 80% of cancer victims. Teletherapy aimed the radiation at deep-seated tumours through a long tube placed above a tumour, but radium was not strong enough to be very effective. High-energy radiation equipment like x-ray machines were also used, but they were expensive, required experienced technicians to operate and maintain them, and often burned the skin.

The War at Home- Excitement Grows as Canada Invests in Nuclear Research

During the Second World War, both Canada and the United States built nuclear reactors. Canada took its first steps into nuclear research with the establishment of the National Research Council’s (NRC) Montreal Laboratory in 1942, a program begun by scientists who were refugees from Hitler’s Europe. In 1944, at the NRC facility at Chalk River, Ontario, construction began on ZEEP (Zero Energy Experimental Pile). In September of 1945, the 10 Watt ZEEP achieved the first self-sustained nuclear reaction outside the United States, launching Canada into the forefront of nuclear energy research. But, where the United States used graphite to moderate³ the atomic reaction, Canadian reactors used “heavy water” (D₂O)⁴ to slow and control the explosive chain reactions. Building on data and experience gained from ZEEP, further reactors were constructed and produced radioisotopes for research purposes, one of which was cobalt-60, used for radiation therapy.

At Chalk River, the NRC built the NRX (National Research Experimental) reactor which went into service in 1947. When the scientists first put cobalt⁵ into the reactor, they found it adopted another neutron and became cobalt-60, an unstable atom which gave off much more radiation as it decayed⁶ than did radium.⁷ This was just what was needed for radiation cancer therapy. The

³Moderators are used to lower the speed of the neutrons emitted during the splitting of atoms to increase the probability of their hitting more atoms to cause further splitting. Heavy water is a very efficient moderator.

⁴Heavy water, or D₂O, is similar to water, but contains stable, naturally occurring deuterium atoms instead of hydrogen atoms. Both elements have relatively simple nuclei, but where hydrogen consists of one proton, deuterium’s nucleus comprises a proton and a neutron. Heavy water is about 10% heavier than normal water.

⁵Cobalt, discovered in about 1735, is a brittle, hard metal, resembling iron and nickel, often used in magnets and other alloys. Cobalt salts have been used for centuries to produce brilliant and permanent blue colours in ceramics, glass and enamels. At present, cobalt-60 costs about \$1 to \$10 per curie.

⁶Cobalt-60 is unstable, emitting gamma radiation as the nuclei are transformed back into a stable state. Every 5.27 years, cobalt-60 loses 50% of its radioactivity, on its way to becoming stable nickel, atom by atom. This period is called its half-life.

⁷ The radio-active isotope cobalt-60 is a variant form of the cobalt element. It has 60 neutrons in its nucleus instead of the normal fifty-nine. Cobalt-60 was a new Canadian resource, produced economically and in large quantities at the NRC’s Chalk River nuclear research facility. Cobalt-60 is 6,000 times cheaper and much safer than radium, and 300 times more powerful. To match cobalt radiation, 2,000 grams of radium would have been necessary, at a cost of \$40 million. It was used to produce a concentrated beam of high-energy x-rays and gamma rays capable of destroying deep-seated tumours without harming the surface skin layers.

NRX, with its unique heavy water design, could produce cobalt-60 about 100 times stronger than radium and faster and in greater amounts than any other reactor⁸.

The University of Saskatchewan Gets Canada's First Betatron in 1948

In 1948 there were 203 new cancer cases per 100,000 population. Dr. Harold E. Johns, directing radium and x-ray therapy for the Saskatchewan Cancer Commission at the University of Saskatchewan, already a leading centre for radiation therapy, jumped at the opportunity to develop this technology into a really effective therapy for cancer victims. And Premier Tommy Douglas supported him all the way. He was very receptive to the idea that the university should develop a high energy x-ray beam for cancer treatment. To this end, he bypassed his cabinet and the Provincial treasury and approved the purchase of radioactive cobalt-60 from the Chalk River Laboratories in the spring of 1949.

In 1948 after considerable lobbying, University of Saskatchewan physicists Leon Katz, Harold Johns and Ertle Harrington were able to obtain Canada's first betatron accelerator⁹. This 25 million volt piece of equipment was essential to furthering research into atomic nuclear physics and cancer therapy in medicine.

Actually two were ordered at the same time. One for Michael Reese Hospital [Chicago] and one for Saskatchewan. Their winters were too severe and they couldn't put up the building to house it. We put up our building at 40 below and we could house ours! So we started treating patients six months before [the Reese Hospital]. (WDM: Katz interview 2001, clip 12)

With the betatron, the world's first to be used in the treatment of cancer, the physics department developed into a first-class facility for research into radiation treatment, sub-atomic physics research, deep-seated cancer therapy, radiation biology, and created a national reputation for the university.¹⁰ With a background in radar and x-ray testing of aircraft structural integrity, Johns developed a program at the university in medical physics that focussed on x-ray radiation and radioactive isotopes for cancer treatment.

The Development of the World's First Cobalt-60 Beam Therapy Unit

In the fall of 1949, scientists at the Chalk River research facility put two packages of cobalt-59 into the NRX reactor: one for Dr. Johns and one for Roy Errington, head of radium sales for Eldorado Mining and Refining Ltd, the Crown corporation controlling Canadian uranium mining and refining. Errington was interested in the sales potential of cobalt-60 which would be tremendous with the advent of a cobalt-60 radiation therapy unit, as well as the medical benefits to Canadians of the therapy. Now there was a race to be the first to develop a machine to deliver the radiation.

⁸What happens in the reactor? Before it is put into the reactor, stable cobalt-59 metal is nickel plated and welded into metal capsules. In the reactor, it enters an intense neutron radiation field where it stays for up to five years. During this time it is transformed into radio-active cobalt-60 as each nucleus of cobalt-59 absorbs an extra neutron.

⁹A betatron is a compact circular electron accelerator. The magnetic field used to make the electrons move in a circle is also the one used to accelerate them, producing a high energy directional x-ray beam

¹⁰This reputation was largely attributable to Dr. Harrington's stewardship. Dr. Harrington was responsible for recruiting Harold Johns to the university.

Dr. Johns recruited graduate student Lloyd Bates at the University of Saskatchewan to help him design his machine, which was manufactured by John MacKay, head of ACME Machine and Electric Company of Saskatoon. There were new dangers associated with using cobalt-60. Radiation leaks had to be prevented. The radiation was so strong that only a few minutes of direct exposure to the source was lethal. Also, some way of turning the machine on and off had to be devised. While Errington used a liquid mercury switch to block off the radiation exit port, Dr. Johns' mounted his cobalt-60 on a wheel in the centre of the treatment head to allow the source to be turned away from the hole. There were five members on Dr. Johns' team, including Canada's only woman medical physicist, Assistant Physicist Sylvia Fedoruk. Mr Errington's machine was ready by early 1951, as was Dr. Johns'. However, Errington's treatment facility, to be run by Dr. Ivan Smith, was under construction in London, Ontario, and was not nearly ready. In Saskatoon, Dr. Johns was also awaiting completion of his special lead-lined room, Room 167, in the basement of the Cancer Clinic wing at the new university hospital. The concrete wall opposite the machine had to be forty inches thick to block the radiation coming at it. The ceiling and other walls were to be eight inches thick to absorb any scattered radiation.

The First Cobalt Arrives

On 30 July 1951 the first cobalt-60 arrived in Saskatoon. The 3 x 5.5 cm. cylinder of metal was transported in a thick-walled radiation-absorbing lead container which weighed one ton. It radiated 1,500 curies, the equivalent of a 2,000,000 volt x-ray machine. On 17 August, the Saskatoon therapy unit was installed and the treatment head mounted on its overhead carriage, though the walls were still wet and the concrete floor had not yet been poured. The next day, Dr. Johns and his team carefully loaded the cobalt-60. He had to wait for the room to be finished before he could test his machine. It went into service officially on 23 October 1951. Racing to the finish-line right behind Dr. Johns, Errington and Smith in London were the first to treat a patient, on 27 October. The quintessential salesman, Errington garnered international headlines for the Eldorado A unit at its official inauguration two weeks later. Dr. Johns, having conducted rigorous calibration tests on his machine and having treated his first patient on 8 November 1951, was in attendance along with other scientists and politicians.

How the Unit Worked

The unit comprised a patient bed, a large treatment head which ran on a track above the bed, and the machine control units. The cobalt source, located inside the lead shielded treatment head, was mounted on a wheel which could be turned to align it with an opening in the shield. The radiation escaped through the port and bombarded the tumour with x-rays and gamma rays. Saskatoon's new cobalt-60 unit was much simpler and easier to operate and maintain than the huge now-obsolete 400,000-volt x-ray machine housed next door. Dr. Johns and his team also worked to develop proper doses of radiation and ways to control the radiation during treatment. His radiation dosage tables are still in use today. As Assistant Physicist with the Saskatchewan Cancer Commission, Dr. Sylvia Fedoruk conducted further radiation and cancer research during the 1950s.

The Impact of the Cobalt-60 Beam Therapy Unit

The cobalt-60 beam therapy unit was more compact and easily manoeuvrable than the previous radium units. It also caused less damage to skin surface and had greater penetration. While

Errington concentrated on marketing his unit to midsized cancer facilities around the world, Dr. Johns focussed on research, selling the rights of his machine to Picker X-Ray of the United States, who would go head-to-head against Errington in the marketplace. Meanwhile, after treating 6,728 patients in its 21 years of service, the Johns prototype was replaced in 1972 with a commercial machine built by Errington's organization, MDS Nordion. The prototype is currently on display at the Saskatoon Cancer Centre. The descendants of Eldorado A, still being made in Canada and exported around the world, continue to repay our government's investment in atomic research. Since 1951, Canada has manufactured more than half the world's cobalt-60 therapy units, exporting them to more than 80 countries. Independent of electrical power, they are particularly useful in developing countries where electrical sources are not always available.

The development of the cobalt-60 therapy unit greatly improved the chances of survival for people suffering from many types of cancer previously untreatable, including cancers of the bladder, prostate, and cervix. Dr. Johns' first patient was cured of her cancer and lived into her 90s. Cervical cancer cure rates soon rose to 75% from 25%. By 1981, more than 2500 units were providing treatments around the world. An estimated seven million people in communities all over the world have now been helped by cobalt-60 therapy since Dr. Johns created his prototype. It revolutionized cancer radiation therapy worldwide. The unit also made possible other types of research, into radiological physics, radiation chemistry, and the effects of high radiation on animals and plants.

By 1962 Saskatchewan's cancer program was the best in the world, diagnosing and treating at least 90% of all cancer patients in the province. Cancer statistics, unusually complete and accurate at this time, indicated that 1.3% of Saskatchewan males over 35 years of age and 1% of women over 35 had some sort of cancer. In the mid-1960s, a new concern arose about lung cancer and its relationship to tobacco smoking, as the connection between the two was not clearly understood at the time. Education, particularly of young people, was a major plank in the Canadian Cancer Society program, and one in which the Saskatchewan division participated fully. Cancer death rates would only fall when cancer victims got treatment early in the course of their disease. Saskatchewan researchers, physicians and technicians were internationally recognized at major cancer conferences around the world. Much of this research was supported by funds raised by the Canadian Cancer Society.

In 1963, the linear accelerator (linac) built by Dr. Leon Katz at the University of Saskatchewan was Canada's first and one of fewer than a dozen such accelerators worldwide. The 80 foot electron accelerator tube would create energy six times that of the betatron. The laboratory was a direct continuation of the preceding physics work at the university and was to become a training ground for the physicists who would work on the Canadian Light Source accelerator. In 1983, the Electron Ring of Saskatchewan, or EROS, was begun by Dr. Katz and Dr. Servranckx. This was an electron storage ring that could stretch electron impulses from the linac to produce a continuous electron stream. This was the highest energy electron machine of its kind in the world and made possible a new era of sub-atomic physics experiments. Most recently in the long line of achievements, the Canadian Light Source (CLS) accelerator was built at the University of Saskatchewan. Canada's biggest scientific project in a generation, the CLS can accelerate electrons to nearly the speed of light, producing intense light beams for probing the structure of matter. This could lead to new drugs, more powerful computer microchips, better

engine lubricants, new materials for safer medical implants and a host of other applications. Owned and operated by the U of S, the facility serves the research needs of Canadian universities, industry, scientific institutions and governments.

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