Focal Point

Stanford Linear Accelerator Center

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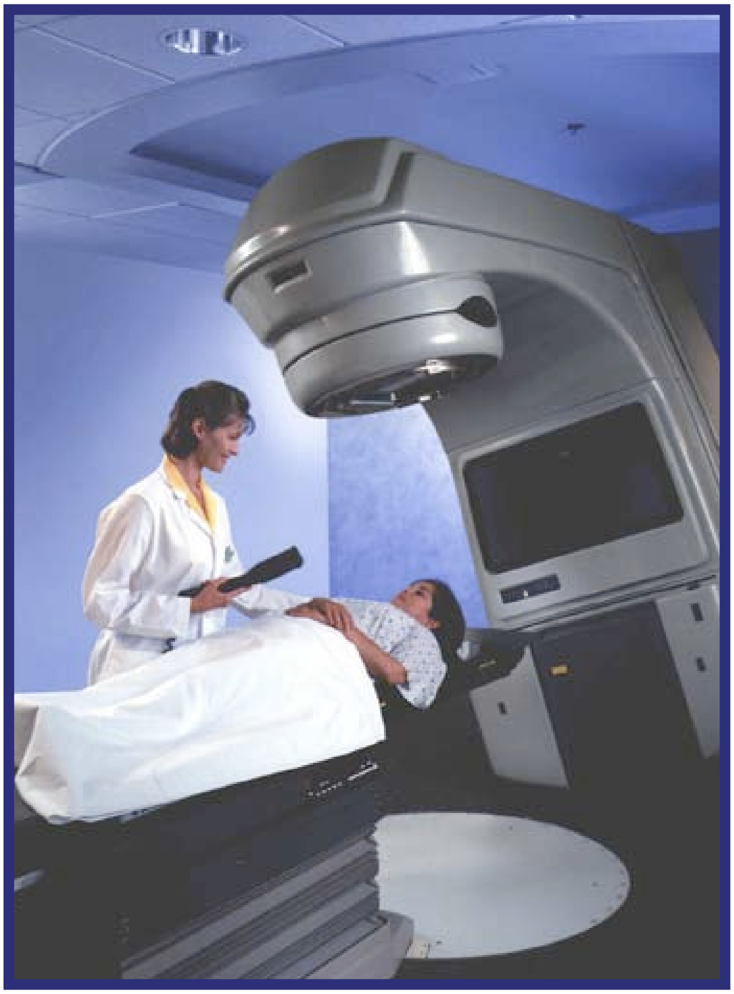
Particle Accelerators Help to Advance Cancer Therapy

Barring a miracle cure for cancer, one in six Americans will eventually come face-to-face with a particle accelerator during their lifetimes. For the primary means of cancer radiotherapy now uses linear accelerators to generate the precise, energetic beams of electrons and X-rays (high-energy photons) needed to attack and kill malignant tumors in over a million patients annually. The world's leading producer of these radiation treatment systems is Varian Medical Systems, Inc., a multibillion-dollar corporation in Palo Alto, California. For over five decades, Varian has been working closely with physicians, scientists and engineers at Stanford University and Stanford Linear Accelerator Center to perfect this very successful approach to cancer therapy.



Varian's Clinac® radiotherapy systems treat over a million cancer patients annually. These machines can quickly rotate about the patient to deliver a series of radiation doses from a wide variety of angles.

Incorporated in 1948 as Varian Associates, Inc., the company has deep roots in the Stanford physics and electrical engineering departments. Its original goal was to take scientific and technological advances at the university and develop them into marketable products. At the time, Stanford physicists began building linear electron accelerators for particle-physics research based on microwave power sources called "klystrons" that Russell and Sigurd Varian had invented in 1937. One day in 1950, Dr. Henry Kaplan, a physician at the Stanford Hospital, shared lunch with physicist Edward L. Ginzton, head of the microwave laboratory and a Varian cofounder. Out of that meeting came the novel idea that linear accelerators, or "linacs," might also be adapted for cancer therapy. Enthralled by the possibility, Ginzton pursued this goal for the rest of his professional life.

By the mid-1950s, Stanford physicists were planning an enormous, two-mile long electron accelerator eventually named the Stanford Linear Accelerator Center (SLAC), with Ginzton as project leader. But before its construction began in 1961, he stepped in as President of Varian Associates and resigned as SLAC director. Under his leadership, Varian developed its first two medical accelerators, the Clinac-6 in 1962 and the Clinac-4 in 1968.

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Edward L. Ginzton during the mid-1950s, standing by the linear electron accelerator in Stanford University's High Energy Physics Laboratory.

Artist's cut-away view of the internal elements of a Clinac radiotherapy system. Just over a meter long, a copper waveguide accelerates the electron beam (blue line) from right to left. After this beam exits the waveguide with multimillion-volt energies, a sophisticated magnet system (upper left) bends it downwards to strike a tungsten target and generate a cone of high-energy X-rays (orange). Several elements, including a set of 120 adjustable tungsten slats, precisely shape this radiation so that it is concentrated as much as possible on the tumor under attack.

During the 1960s and 1970s, these and later Clinac® radiotherapy systems slowly displaced cobalt-60 machines as the preferred method of cancer radiotherapy in U.S. hospitals. The much higher-energy X-rays from these systems penetrate deeper into the patient's body; their much more accurate, intense beams can be focused better on a tumor while limiting ancillary damage to healthy tissues surrounding it. As their designs evolved, these compact, versatile devices increasingly allowed oncologists to treat patients from many different angles with precisely sculpted radiation doses calculated to provide maximum possible benefit.

Over the years since Ginzton left Stanford, SLAC and Varian have enjoyed a close relationship, sharing ideas, technologies, and expertise in microwave sources and linear accelerators. While SLAC built a National Engineering Landmark that pushed electrons to multibillion-volt energies, enabling physicists to peer deep into protons and neutrons (and discover quarks inside!), Varian focused on accelerators and energies that are a thousand times smaller but far more useful in treating cancer. Especially important were bilateral exchanges of scientists and engineers—as both employees and consultants—who brought with them unique expertise that helped in Varian's case to steadily improve the capabilities of its radiotherapy systems.

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Take for instance Karl Brown, a physicist from Ginzton's Stanford group who had been an early SLAC employee. He became an internationally recognized expert on how to divert and transport particle beams using magnetic fields. He brought this expertise with him

Aerial view of SLAC, with the two-mile accelerator running diagonally from the upper right and passing beneath Interstate 280.

to Varian in the late 1960s, and it proved crucial in developing the compact accelerators required for hospital settings. Brown designed the intricate magnet systems that allow electron beams to execute a delicate right-angle downward turn—much like a springboard diver executing a back flip—after being accelerated but before they strike tungsten targets to generate the curative X-rays. He continued to consult for Varian after returning to SLAC in the 1970s.

Another excellent example is Ralph Nelson, a SLAC health physicist who began consulting for Varian in the late 1960s. At SLAC he had pioneered a series of increasingly sophisticated computer programs to simulate what occurs when high-energy electrons strike solid matter and generate showers of subatomic particles. At Varian he used these programs to calculate the X-ray energies and intensities produced when the electron beam hits the target—as well as to estimate the thermal and mechanical stresses it experiences. And with Nelson consulting, the National Research Council of Canada developed a version of this program to model how the radiation passes through various human tissues. This program has been employed in hundreds of hospitals around the globe for planning patient-specific radiotherapy treatments. It has also been adapted by Varian for use in the sophisticated software systems that accompany its medical accelerators, allowing therapists to calculate, adjust and monitor radiation dosages received by a tumor and the adjacent healthy tissues.

In these and other ways, SLAC scientists and engineers have helped Varian to make a long, continuing series of pioneering innovations in its radiotherapy systems and maintain its competitive edge in this market. One recent major advance, known as "image-guided radiation therapy" allows the systems to monitor tumor motion due to the patient's breathing or heartbeat and to adjust the beam accordingly. Devices to implement this advanced treatment strategy have been incorporated in Varian's highly versatile Trilogy™ system, which allows the therapist to do a quick X-ray scan of a patient and precisely determine the tumor size and position just before treatment begins. A set of 120 adjustable tungsten slats then shapes the beam of radiation to concentrate its energy on the tumor and avoid the surrounding healthy tissues as much as possible. So accurate is this system that it has begun to be employed in a promising new therapy called radiosurgery, in which high doses of radiation are applied to eliminate well-defined tumors in a single treatment.

Although Varian's competition has included such multi-national giants of the electronics industry as General Electric, Philips, and Siemens, the smaller Palo Alto firm has prospered—recently grabbing about 70 percent of the U.S. market for radiotherapy systems and 60 percent

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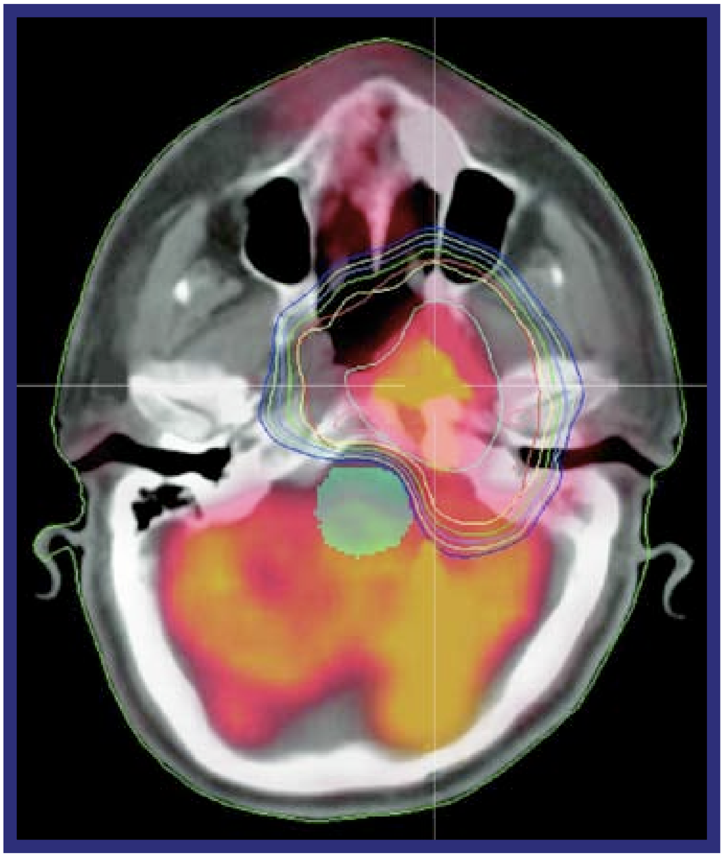
SLAC R&D Horizons

SLAC has recently begun converting its two-mile linear accelerator, now 40 years old, into a pioneering X-ray laser facility called the Linac Coherent Light Source (LCLS). Scheduled for completion in 2009, it will produce ultrafast, ultrashort pulses of X-rays a billion times brighter than available anywhere else in the world. Because the pulses will last less than a nanosecond, they will enable scientists to glimpse atoms and molecules in motion and to examine physical and biological processes in what was previously unimaginable detail. This research facility will enable them to image the chemical and structural properties of materials at the nanoscale—as well as to view important biological molecules with atomic-scale resolution. Research on the LCLS will likely have many applications to California's biotech, semiconductor and other high-tech industries.

worldwide. There are more than 4,700 Varian systems now installed in hospitals and cancer treatment centers around the globe, and annual sales of them exceed a billion dollars.

Linear accelerators are also being used for other applications, such as cargo screening and industrial radiography, and Varian has been gaining an important share of these markets. Here again, a compact, versatile—even portable—device is needed, and the company's technology is well suited to these uses. Thus SLAC and Varian are working together once again to push the technology to its limits. After September 11, SLAC scientists and engineers including Nelson began developing a portable accelerator using advanced microwave sources they had been promoting for a next-generation atom smasher. Varian representatives have been meeting regularly with this group, assessing whether the company can take on the device and bring it to market.

The long, close relationship between SLAC and Varian well illustrates how basic research at a national laboratory, intended principally to understand how energy and matter behave, can contribute to public welfare in unanticipated ways. In this case, the results have also had a substantial impact on the California economy and livelihood.



Blended image from a Clinac treatment plan, showing the cross-section of a patient's head through the nasal cavity. The white cross hairs meet at the tumor, around which colored contour lines indicate that the highest radiation dose will be concentrated in the tumor, with the dosage falling off rapidly in the healthy tissues around it—and entirely avoiding the patient's brain stem (green circle).