SLAC BEAM LINE

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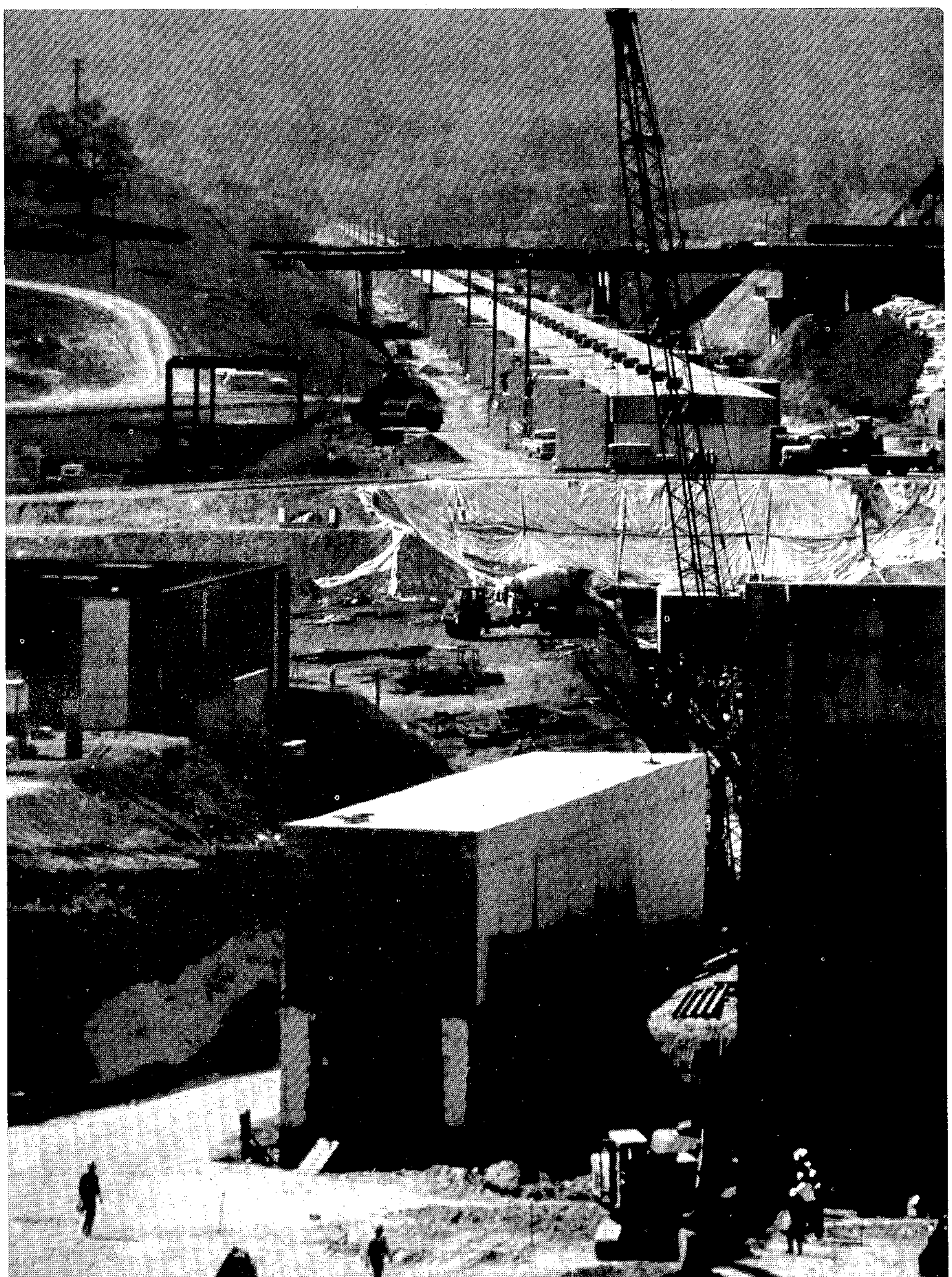
—AN INFORMAL HISTORY OF SLAC—

PART TWO: THE EVOLUTION OF SLAC AND ITS PROGRAM

by W.K.H. Panofsky



THE CONSTRUCTION OF SLAC—MARCH 1965

THE EVOLUTION OF SLAC AND ITS PROGRAM

W.K.H. Panofsky

The history of electron accelerators at Stanford University started with the brilliant contributions of W.W. Hansen. There has rarely been a physicist like Hansen who combined physical insight with superb analytical power and mechanical skills. The resulting sequence of early accelerators made great contributions to physics; in particular the work of Hofstadter and collaborators established the electromagnetic dimensions of the proton and the neutron and also of heavier nuclei. Moreover, inelastic electron scattering and various tests of the electromagnetic behavior of muons and pions set the stage for things to come. In consequence the proposal to construct the 'Monster' was well received and eventually led to approval in 1962 to proceed with the construction of SLAC at Stanford University under the auspices of the Atomic Energy Commission.

The new machine was very much larger than any one previous undertaking of Stanford, and in fact it was a project larger than any which had then been carried out under the aegis of a single university. The Mark III accelerator, constructed under the leadership of Edward L. Ginzton, was 300 feet in length—30 times smaller than the SLAC linac. Thus the actual creation of SLAC was a very large leap and required the answers to many problems—human, administrative, technical and, above all, questions in physics.

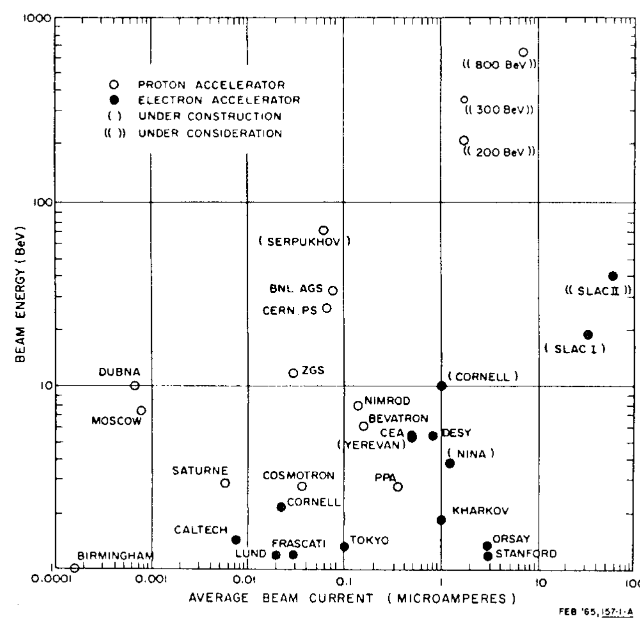
Organizing

All prior projects of Stanford University, including the construction of the earlier electron linear accelerators, were carried out within the framework of the regular departmental structure of the Unversity. Although the W.W. Hansen Laboratories of Physics formed the umbrella laboratory under which the Mark II and Mark III electron accelerators were built, the individuals responsible were members of the regular departmental faculties of Stanford. Also, the Mark II and Mark III accelerators were designed to be research tools intended for use of Stanford faculty, staff, and students; the participation of outside visiting scientists was incidental. It became clear from the outset that a machine costing above 100 million dollars (at a time when a million dollars really was a million dollars!) would have to be a national facility; that is, it should be accessible to any scientist on the basis of the quality of the proposed research, without preference for Stanford people.

At the same time we were also fully aware of the fact that the SLAC machine was a maverick in the then prevalent pattern of US high-energy physics . At the time of the SLAC proposal in 1957, and even at the time of groundbreaking in 1962, the main thrust of American high-energy physics depended on proton accelerators, primarily the Bevatron at Berkeley and the Cosmotron and the Alternating Gradient Synchrotron at Brookhaven. Only a small number of physicists within the international community shared Stanford's enthusiasm for electron machines. At that time, however, competition for funds was not extremely intense. Therefore, although few physicists intended to use SLAC at that time, there was general acquiescence, even if not outright support, by the entire scientific community for the construction of the Stanford accelerator.

One can speculate whether SLAC would ever have been built had the current financial climate prevailed in the 1960's. Had SLAC not been approved, one can only surmise what insights in physics would have been lost, or at least greatly delayed. Since initially it was doubtful that many non-Stanford physicists would be willing to commit large fractions of their scientific careers in planning for physics use of the new machine, we had to take the initial responsibility for planning for physics research with the machine when it was completed, and then make it nationally accessible.

There was another important difference in the research planning for SLAC and the national pattern



Accelerators available or planned in 1965. SLAC stands out here as the highest intensity electron machine, a distinction it enjoys to this day.

centered around proton machines: the technical nature of doing physics with a high-intensity, low duty-cycle electron accelerator required that most of the experimental program be facility-centered. Elaborate devices would have to be constructed for a succession of scientific experiments. In contrast, a large number of excellent experiments then being done with proton accelerators were more of the building block type. The participating physicists constructed experiments with relatively small components such as counters with associated electronics, shielding blocks, and small magnets. A central elaborate facility was not needed.

There are two technical reasons for this difference. First, the poor duty cycle of the linac (the small fraction of the time in which the beam is concentrated) makes it very difficult to do experiments where time coincidence is a primary signature identifying the event. When many counters look directly at a target exposed to an intense but low duty-cycle beam, almost all events appear to be in coincidence as seen by the different counters; some presorting of the events is necessary. The second problem comes from the nature of electromagnetic interactions. The cross sections for producing the particles of interest are small while at the same time an intense 'shower' of electrons, positrons, and x-rays is produced in a narrow cone in the forward direction. This very intense cone must be isolated from the devices which detect the particles of interest.

Translated into human terms, it soon appeared that the SLAC linac could only become a tool for excellent particle physics immediately after turnon if we created a very strong in-house research staff. This group would have to put a large part of its scientific skills and careers on the line to design the major facilities which were needed to exploit the electron beam once it became a reality. In turn, this required that the leaders of this research staff be regular members of the Stanford University faculty because attracting the necessary talent would only be possible if the leadership was composed of 'first class citizens' on campus. This new faculty was set up as a separate structure in order not to produce a major imbalance in the professorial mix within the Stanford Physics Department. At the same time we assured the outside physics community of full and equitable access to the SLAC facilities, and we set up the necessary advisory committees and other administrative machinery to make sure that this assurance corresponded to reality.

A further problem which had to be faced was to convince the Stanford community that the 'Monster' was not a threat to traditional academic values. We designed the link between SLAC and the balance of the Stanford community to be *intellectually* tight; but *administratively* SLAC would be entirely separate and would thus not drown the existing administrative machinery of the University. SLAC would operate under general policy set by the University, but its actual operation would be almost autonomous. This method has worked out well.

We then negotiated a contract between Stanford University and the Atomic Energy Commission (now the US Department of Energy). This negotiation resulted in a contract which fully preserved academic values and policies and which totally delegated to the University the responsibility for managing the SLAC program.

Building the Linac

The most essential step in building the SLAC laboratory was, of course, the construction of the two-mile linear accelerator itself. The job was directed by Professor Richard B. Neal and he deserves the primary credit for the construction being finished on schedule, within budget, and to performance standards exceeding the original goals set by the proposal. The detailed story of the construction of the two-mile machine is documented in the well-known 'Blue Book'* in which the many contributors to the subsystems of the machine describe the technical characteristics and history in their respective areas.

Dick Neal established a systematic method of charting the progress in design and construction of the accelerator using critical-path networks. He met regularly with each of the individuals responsible for the various subsystems so that progress and costs of everything could be charted and no surprises would occur later in the game. Interestingly enough, the contingency which was contained in the budget for the unexpected was not used on the basic two-mile machine at all, but was almost entirely spent on the target area and the beam switchyard which distributed the beam to the various users. The construction of the accelerator did not turn up many surprises and went pretty much according to plan.

Since the extrapolation by a factor of 30 above existing machines appeared large, assurance was needed that technical problems would be tractable. Nevertheless, one of the first decisions made during the construction project was that building a separate prototype for the basic accelerator was not necessary. We used the fact that a linear accelerator is in fact linear—a small section of it can function while the larger part of it is still under construction. We therefore awarded contracts for the

* *The Stanford Two-Mile Accelerator*, R.B. Neal, editor, W.A. Benjamin, New York (1968).

first 800 feet of the machine separately and managed to obtain a beam from this section while the rest of the machine (and in particular the experimental target areas) was far from completed. This saved the money which a separate prototype would have cost and it also raised our confidence that no fundamental design errors had been made.

From the point of view of the electron the extrapolation by a factor of 30 in energy and accelerator length is actually minor: the relativistically contracted length as observed in the electron's rest frame is only 3.4 times longer for the SLAC linac than for the 100 meter Mark III machine. The focusing required to confine the beam is thus moderate and alignment standards are not severe.

In spite of these comforting facts, the matter of stability of the machine—in earthquake country in particular—received a great deal of internal and external attention. Thanks to the effort of many seismic experts, in particular Dr. John Blume, this matter was analyzed in great detail since the chosen site placed the injector only one-half mile east of the San Andreas Fault. The consensus was that with careful construction practices the earthquake risk could be held to standards which assured the safety of people and which minimized the potential damage to the facilities.

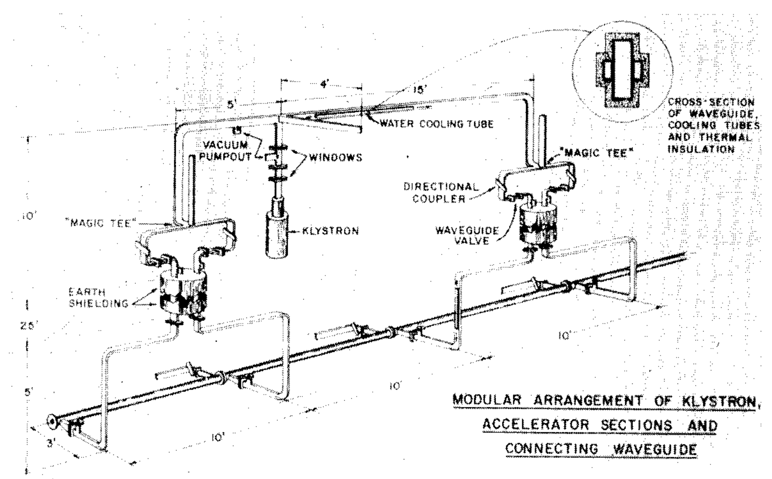
Outside Industry and In-House Talent

Construction of the accelerator was accomplished partially with in-house talent and partially through industry. The principal civil engineering for the accelerator was handled by an exceedingly capable outside Architect-Engineering-Management firm managed by John Blume whose help had been crucial with early seismic studies. They were responsible for the design of all accelerator housing, the beam switchyard, and the target areas in addition to managing the construction itself. The photograph on the front cover was taken in the midst of this activity.

The actual construction work was done by a variety of individual contractors. We were, of course, obligated under government rules to award each item of construction to the lowest bidder, unless we were able to *prove* that the bidder was unable to do the work!

Let me illustrate this problem with just one example. We had received bids for a major electrical job. Our construction manager, a 75-year-old gentleman working with our management firm said "Don't award the job to the lowest bidder." I asked why and he said "Because he's a son-of-a-bitch." The AEC manager, the late Larry Mohr, replied "That doesn't disqualify him in the eyes of the AEC." So the job was awarded to the low bidder, and indeed our 75-year-old construction manager turned out to be correct.

The accelerator itself, of course, involved an enormous amount of engineering and construction of prototypes for separate components and subsystems. Feeding power from the klystrons to the accelerator required very complex waveguide plumbing. We decided to mock up a prototype consisting of a single klystron feeding an accelerator section through the actual waveguide system. To provide for adequate shielding from the linac, the klystrons must be 25 feet above the machine in the actual installation. Therefore, this mockup had to be constructed as a tower which contained the klystron and its supplies while the accelerator section was placed at ground level. The easiest way to install the waveguide feeds from the upper story of the tower down to the accelerator was by helicopter (a method later used in the actual accelerator construction). As it happened, this mockup tower was next to the Stanford football stadium, and it also happened that the lowering of the waveguide by helicopter was made on the Friday before a critical game. The Stanford football coach was practicing some very secret formations in the stadium at the time and thought the helicopter was part of a spy operation by Saturday's opponent! He cancelled the practice, and when informed of the actual situation sent a strong letter of protest to SLAC.



The klystrons must stand 25 feet above the accelerator to allow earth shielding. This caused more difficulty during tests on campus than in the actual construction.

Building an accelerator on a university campus has its singular difficulties.

Our experience with industry was mixed, ranging from absolutely superb performance to some disappointments, not only in connection with civil construction but also with the highly technical items. For example, we placed a contract for research and development on a prototype for the modulator which supplies pulsed power to the klystrons. Half a million dollars later we were left with a very unsatisfactory and poorly performing design. We then built our own prototypes for the modulator at SLAC under the direction of Carl Olsen, and procured the 245 modulators as a straight fabrication job with the industry simply following our design. This saved a great deal of money and resulted in modulators which gave excellent performance.

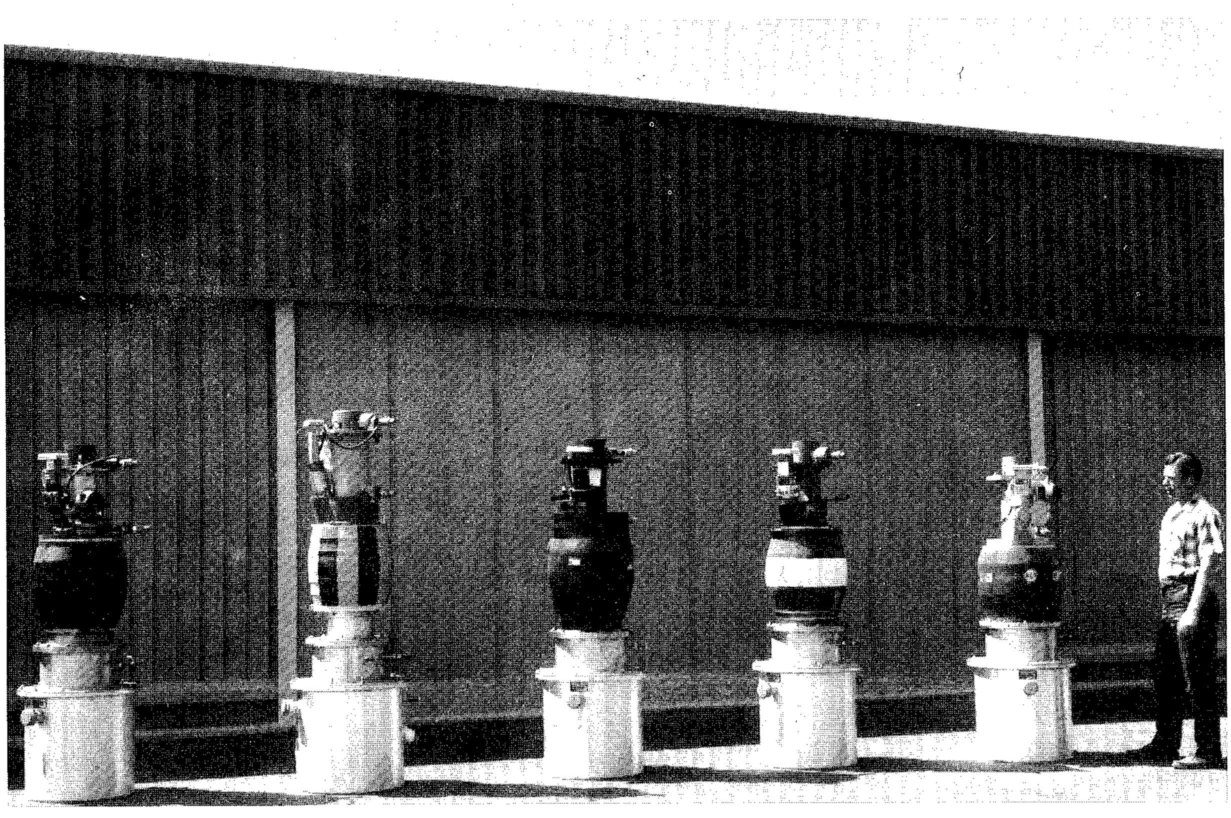
Klystrons

The performance of the klystrons is absolutely crucial to the success of the SLAC accelerator. Our early experience with making our own klystrons at the Mark III accelerator was mixed. At times our tubes performed well, but there were periods when the yield of in-house tubes slumped and the physics program almost came to a halt while we studied the problem.

We decided to play it safe and build up both an internal capacity to produce klystrons (under the direction of Dr. John Lebacqz) and also to contract with two different industrial firms. The first two outside contractors were unable to perform to the required standards, and two new contractors bid for the job. As a result, our initial inventory of klystron tubes was varied.

Having an in-house capacity for klystron production turned out to be a wise move for a number of reasons. During the early days when the first contractors had difficulties, one of them apparently let his problems be known to Congress. I was asked as a witness during Congressional testimony whether it was true the klystron specifications which we required industry to meet were physically impossible. I replied that we met these specifications with our own tubes, and that ended the dialogue. Having a 'yardstick' operation in-house was the most powerful lever we had to assure good performance.

As time went on the mean lifetime of the tubes grew to over 20,000 hours and the total replacement rate dropped to only 5 tubes per month. This was insufficient to be economically attractive to industry, so by mutual agreement we phased out the industrial suppliers. All klystron tubes at SLAC are now homemade. The in-house capacity has also served us since in supplying the lower power klystrons in the drive chain and the large



The first SLAC klystrons were made both by industry and within the lab. The photo shows four outside versions and one made by SLAC. Eventually all tubes were produced in-house.

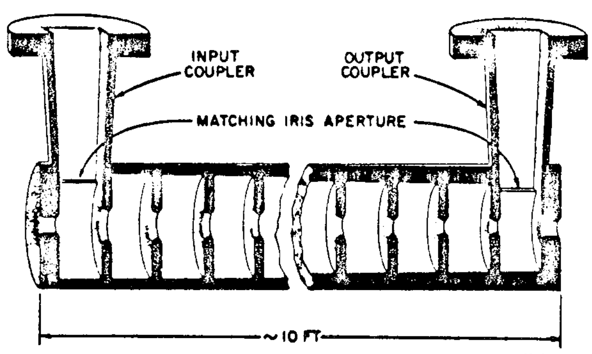
tubes used in the storage rings.

As this example shows, an essential element in building up SLAC was a balance between internal and industrial support. In our case the balance turned out to be somewhat further in the direction of building up an in-house capability than in customary at other US laboratories. This applied not only to the case of klystrons and modulators but also to such diverse items as magnets, detectors , and electronic components. This continues to be a delicate issue, but SLAC history clearly indicates that this laboratory would have been in very serious trouble indeed, and may not have survived at all, if we had not had the opportunity to pitch in with our own forces to construct vital components when necessary.

The Linac Structure

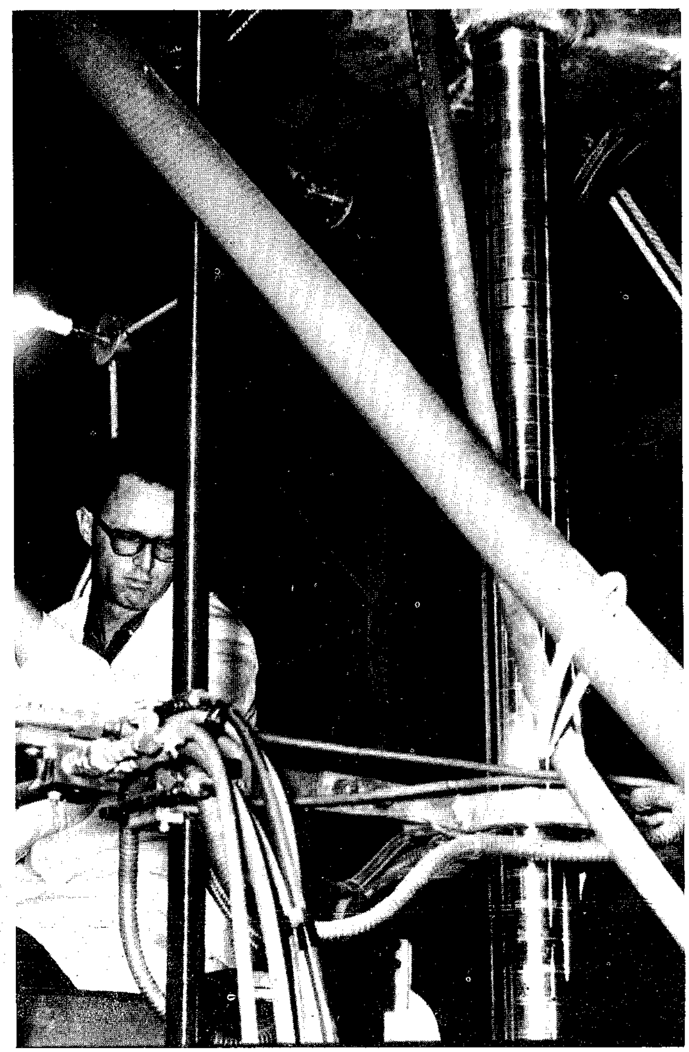
The linear accelerator itself is the two-mile evacuated tube in which the electrons gain energy from the microwave power provided by the klystrons. This required both choosing a design for the accelerating structure itself and then deciding how to build it.

The basic design consists of a long series of connected cavities as shown in the figure.



Such a cylindrical disk-loaded waveguide permits acceleration of the electrons by the electromagnetic wave traveling down the guide. Clearly the linac construction is much easier if all the sections can be made identical. Unfortunately, there is a problem with such a 'constant-impedance' structure since the accelerating field decreases along the length as the power is absorbed in the walls. This leads to poorer acceleration and electrical breakdown properties. If, however, the dimensions of the successive cavities are chosen so that the group velocity progressively decreases, then the electric field can be held to a constant value. This 'constant gradient' structure was the method chosen although it was a major departure from previous practice. As it turned out, the choice was fortunate not only because it permits larger overall acceleration (greater than 20 MeV per meter) but also because it leads to greater stability at high beam intensities.

The choice of fabrication method was the second critical item. The technique used in the Mark III was a shrinking method originally developed by Bill Hansen. This caused some trouble over the years as cold flow gradually loosened the disks. New approaches were necessary and we developed two different techniques and kept both going for over a year as candidates for the full-scale production. In the electroforming method, the copper disks were separated by aluminum spacers while a thick layer of copper was electroplated on the



Brazing the assembly of disks which form the linear accelerator itself required a special hydrogen furnace.

outside. The aluminum spacers were then dissolved with lye. The other technique was to braze disks and rings together in a special vertical hydrogen furnace. Both methods worked, but the time between discovering possible defects and correcting the production process was too long in the electroforming process, and it was dropped.

The brazing process was a novel undertaking. It was a repetitive job which had to be done with extremely high precision as mistakes could be very damaging. We started with about two million pounds of oxygen-free high-conductivity copper. The rings and spacers were machined, annealed, finish-machined, stacked, and finally brazed together in a hydrogen atmosphere using the primitive-looking furnace shown in the photograph. The work was largely done by housewives responding to this special opportunity for steady part-time employment for several years. It speaks well for the quality of that operation that not a single one of the 200,000 brazed joints of the accelerator has developed a vacuum leak in more than 15 years of steady operation.

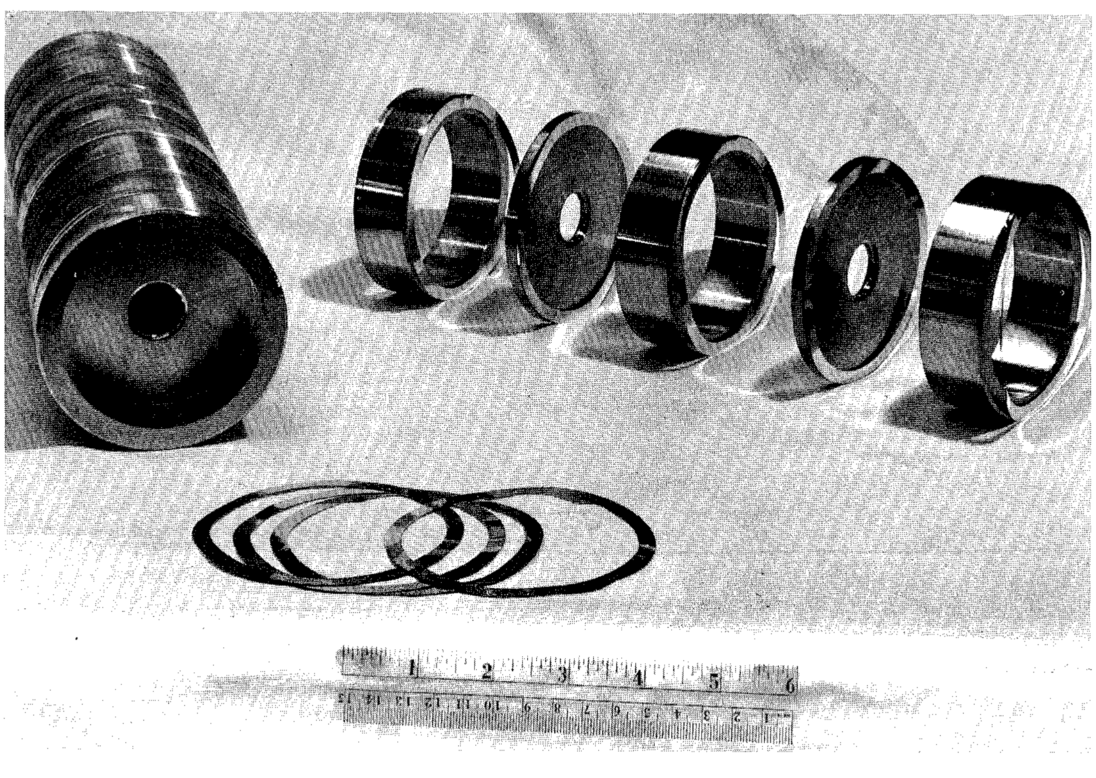
The First Beams

Commissioning the two-mile accelerator was generally less difficult than anticipated. In fact, obtaining a beam in the two-mile structure was not significantly more difficult than in the 300-foot Mark III. There was one unanticipated difficulty, however: the beam intensity was limited by a 'beam breakup' phenomenon. Beams of the design intensity could not be accelerated the full length of the linac without colliding with the walls or collimators.

We had anticipated one process which would limit current. The electron beam produces a secondary wave as it travels through an accelerator section. This wave travels backward to the front of the section and disrupts the beam. The observed effect occurred at much lower currents, however, and was due to something else.

The basic physical process responsible was soon diagnosed: if an electron bunch within the beam travels somewhat off-axis, it produces electromagnetic fields in the structure which deflect the following bunches even more. This results in an instability which grows both in time and in distance along the axis. Happily, the choice of the non-uniform constant-gradient structure greatly mitigates this effect since only a small portion of each section matches another. Nevertheless, initially we were limited to about one-third of the design beam intensity. The cure of small deformation of the structure and increased magnetic focusing was carried out in small steps which eventually brought the beam up to the predicted value.

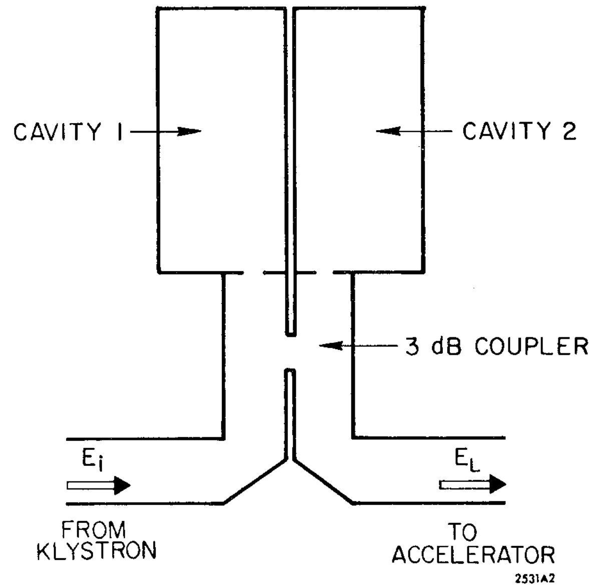
In the original proposal we had conservatively



A view of the rings, disks, and brazing material together with a partial assembly of a section of the linac. About 200,000 such pieces went into the machine.

predicted the energy of the machine to be between 10 and 20 GeV. This caution was prompted mainly by concern about klystron performance. In fact, 20 GeV was exceeded early in 1967, and the energy continued several GeV past this as klystron power grew.

The SLAC Energy Doubler program (SLED) began much later and has raised the beam energy to over 30 GeV. In this scheme a small cavity is coupled to the waveguide which connects the klystron to the accelerator as shown in the figure. Microwave power from the klystron begins to accumulate in this cavity instead of the accelerator when the klystron is turned on. Partway through the pulse a slight adjustment in the klystron allows the power already stored in the cavity to flow out and add to the power from the klystron on its way to the accelerator. Thus, we have nearly twice the power in exchange for a shorter pulse time.



A schematic of the SLED cavity which gives substantial increase in beam energy with the same klystrons.

Using the Beams

In some ways the original 1957 proposal was a more far-seeing document in respect to the construction methods and the human and administrative problems than it was in respect to the technical arrangements needed for physics research. Perhaps this is not surprising, considering the fast pace of high-energy physics research and the decentralized initiatives guiding the research program. SLAC research was to be facility-oriented and these facilities were designed on the basis of proposals generated largely by the laboratory staff. The proposals were reviewed extensively and publicly; the green light was then given by SLAC and the AEC provided a one-shot infusion of funds to support the first generation of research facilities.

These initial facilities turned out to be quite different than those envisaged in the 1957 proposal. The electron-scattering area, for example, was to consist of two large spectrometers each sweeping out 180 degrees. During the actual design we recognized that there was little need for having a single detector sweep all the way from the forward to backward region, since particles scattered in the backward direction are of much lower energy and are produced much less copiously. Accordingly, a better match would be two kinds of instruments: spectrometers designed for high energy and relatively small acceptance in the forward regions and different spectrometers for low-energy particles but with large acceptance in the backward angles. We built three spectrometers, in fact, to cover the forward, intermediate, and backward angles in a very large shielded building called End Station A. These instruments, shown in the photograph, were the work horses which led to establishing the pointlike substructure of the neutron and proton.

The 1957 proposal also envisaged that SLAC might copiously produce secondary particles such as the π and K mesons in addition to its role of studying the primary interactions of the electron and photon beams. Historically, such secondary beams had been the sole province of the proton accelerators; electron accelerators had generally lower intensities and faced much lower basic production cross sections. SLAC succeeded in revising this tradition for two reasons. First, the intensities of the SLAC beam are ten to a hundred times larger than those previously available at electron machines. Second, although the total production cross sections for secondary particles are indeed lower in electron beams than in proton beams, the particles that are produced are thrown forward into a very narrow cone. This phenomenon of forward concentration was predicted theoretically by Sidney Drell and was confirmed by a team of SLAC physicists led by Joe Ballam in early experiments at the Cambridge Electron Accelerator.

Thus, we could anticipate that SLAC would not only be preeminent in high-energy electron and photon physics, but would also be competitive in the exploitation of secondary beams of unstable particles. Accordingly, the research area of SLAC was segregated into a complex dedicated to studies of primary (that is, electron and photon) interactions and another area for secondary beams.

Not only were the secondary beams produced at SLAC competitive in terms of particle flux, but some of the beams could also be designed with characteristics not found at proton machines. A high-intensity x-ray beam with photons of only one energy was possible, for example. This contrasts favorably with the photon beams at proton machines which are produced by the decay of neutral pions and consequently have a smeared-out energy spectrum.

Initially, such a monochromatic photon beam was produced by annihilation of positrons on atomic electrons in hydrogen. In another technique near-monochromatic x-rays were produced by electromagnetic radiation from high-energy electrons striking targets composed of a single crystal.

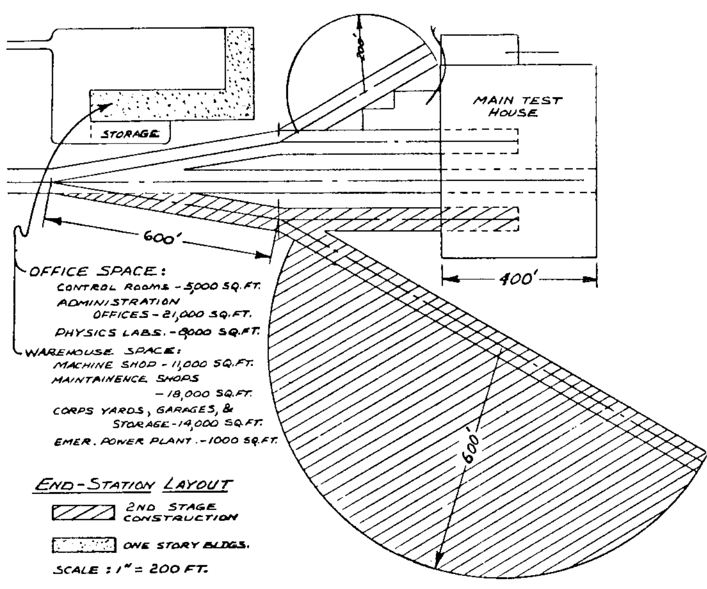
In the present method the beam is produced by scattering ultraviolet-light (low energy) photons from a laser on the high-energy electron beam itself. These collide head-on with 30 GeV electrons and are scattered back as 20 GeV photons. This monochromatic and polarizable beam is now used in experiments.

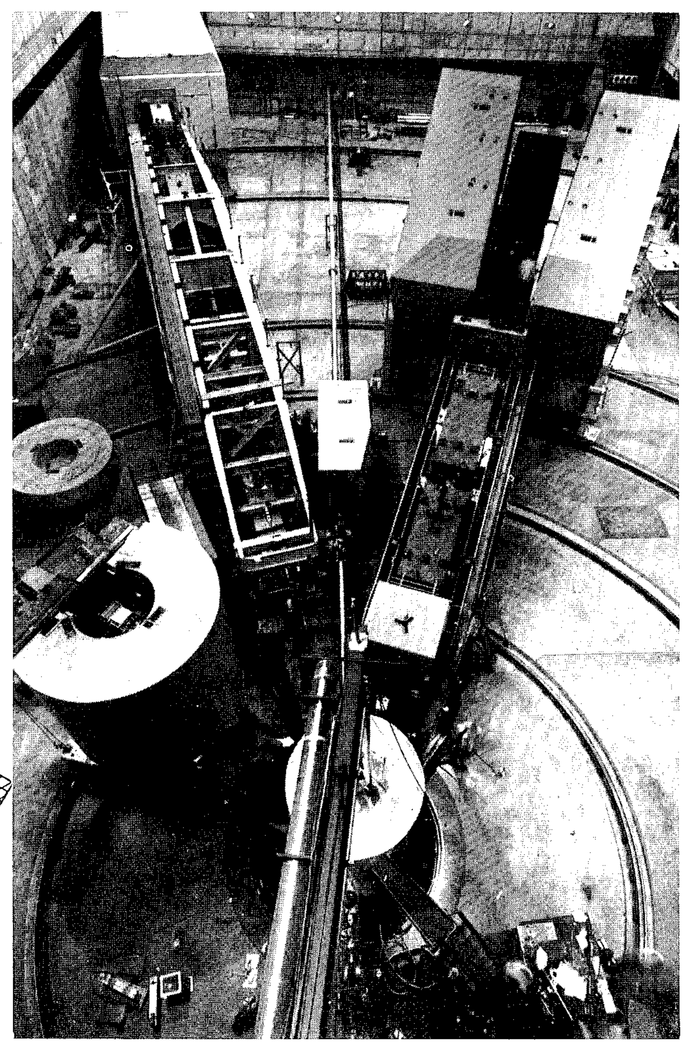
It also turned out that secondary beams produced by photons rather than heavy particles had other desirable characteristics. For instance, beams of neutral K mesons had become very popular in many laboratories for studying some very fundamental properties of the weak interaction. Such studies are particularly valuable for determining quantitatively the parameters which define the precise level to which certain symmetries are violated in the weak interaction. The main bugaboo with proton machines for these purposes is the contamination of neutral kaon beams by neutrons which are, of course, difficult to separate from neutral kaons. The nature of the production mechanism of neutral kaons by electrons and photons reduces this neutron contamination so that the kaon beams can be used directly in many particle detectors, including bubble chambers. Thus SLAC in its early days became a major contributor to the worldwide activity in furnishing quantitative values of the weak interaction decay parameters of the neutral kaon.

The Beam Switchyard

The applications of the SLAC beams proved much larger than anticipated in the 1957 proposal, and a complete re-engineering of the distribution of beams to experimenters was required. This was solved by the design of a 'beam switchyard' (BSY) carried out under the direction of Dick Taylor.

The BSY is much more than a tool to direct beams to a variety of experiments. It is also a 'purgatory'





A comparison of the electron-scattering facilities envisioned in the 1957 proposal and the actual instruments of End Station A.

to assure that each experimenter receives electrons of known energy and energy spread, and that the primary and secondary beams have known and stable optical properties. The requirements set by the different experimental facilities for pulse delivery rate and intensity can be very different. Bubble chambers, for example, cannot handle more than a few pulses per second to match the chamber's expansion rate; spectrometers, on the other hand, can take all the pulses available. All these needs were met by the BSY design.

The beam first entered a pulsed magnet which could deflect the beam right or left on a programmed pattern. The energy of the beam could also be predetermined on a pulse-by-pulse basis by activating the required number of klystrons along the length of the accelerator at the correct pulse time while deliberately mistiming the rest. As a result, each beam pulse could enter one of three magnetic channels set at a fixed momentum band. Two of these channels used elaborate magnetic transport lines. The energy was dispersed halfway along the path to the switchyard to permit energy selection by successive cooled slits. The beam was then refocused and directed to each experimental area. Targeting provisions within the BSY were made for the production of secondary beams, including hadron beams and specialized x-ray sources. In general these secondary beams could be transported to experimenters outside the BSY by transport channels similar to those of proton machines.

The average beam power could be as high as a megawatt, a value unheard of in high-energy machines. As a result, the shielding and remote maintenance requirements were severe. Slits, collimators and beam stoppers required novel design not only to withstand the high average power but to handle the shock stresses due to the pulsed delivery. Radioactivity in the cooling water had to be dealt with.

The result of all these needs was a system much more complex than envisaged in the original proposal. Fortunately, we could control the costs of the construction of the basic accelerator and of the 'conventional facilities' (the beam housing, buildings, site development, and utilities) to within the original estimates. Thus, almost all the budget contingency could be dedicated to the beam switchyard.

Each experimenter established downstream from the switchyard can in essence control his own accelerator, receiving beams of preselected composition, time structure, energy, and resolution. Thus the technical design of the BSY was the primary factor in making the SLAC beams available to a substantial number of simultaneous (or, more accurately, interlaced) experiments.

Bubble Chambers at SLAC

This entire story documents the fact that the research program at SLAC became very much broader than was foreseen in the original proposal. Not only did this increased activity lead to more experimental results, but at the same time it widened the horizons of detector technology. In particular, it turned out that the use of bubble chambers at SLAC , which was not at all considered in the proposal, was highly productive. Proton machines produce a pulse only every few seconds, while the linear accelerator can pulse hundreds of times per second. Generally bubble chambers register in a single picture all charged particles produced during a pulse, and therefore only a few particles per pulse would be handled by the chamber. Note that for proton accelerators a bubble chamber can pulse more rapidly than can the accelerator, while the SLAC linear accelerator can pulse more rapidly than a bubble chamber. Thus the data production rate for bubble chambers can be greatly enhanced if they are used at SLAC. The exploitation of these facts resulted in excellent data from the early work in the monoenergetic photon beam.

Luis Alvarez at Berkeley also recognized that his famed 72-inch bubble chamber would become very much more productive if it were moved across the bay to SLAC. This increase would stem from two sources. First, the data rate would increase because of the more efficient use of pulses as discussed above. Second, SLAC could produce higher energy secondary beams than could the Bevatron at Berkeley. As is frequently the case, however, a great deal more was involved than simply moving the chamber from one place to another. It was decided to make extensive modifications, including a totally different expansion system. The chamber body was revised and the instrument changed from the '72-inch' to the '82-inch' bubble chamber.

The 82-inch chamber turned out to be the world's most prolific producer of bubble chamber photographs for the large community of high-energy physicists interested in analyzing the results of bubble chamber exposures. In fact the entry of the bubble chamber into the SLAC program caused a major increase in the number of outside users here. Since both interest and facilities connected with bubble chamber analysis were worldwide, the outside user participation in bubble chamber physics has always exceeded that of in-house physicists by a large factor. As many as six million bubble chamber photographs were generated at SLAC during one year. In fact, the production of the 82-inch bubble chamber was so prolific that in a relatively small number of years the market for bubble chamber photographs became saturated. Exposures at all reasonable particle energies and with all available particle types were made and the number of pictures was so large that the limiting factor was the ability of the world to analyze data rather than the rate at which it could be produced.

The fact that secondary particles with electron machines are produced according to a well-understood theoretical model means that searches for new unstable particles become particularly useful. If no new particles are found, one can conclude that within the limits of available energy none exist. Such a search for new long-lived particles was carried out by Martin Perl in the early days of SLAC with negative results. It is interesting to note that Professor Perl and his collaborators discovered a third member of the lepton family of elementary particles at a later date using an electron-positron storage ring. The secondary beam fluxes were also used extensively with other detectors. In particular, a very large streamer chamber was built and other, more traditional, detector arrangements were put in place. All these devices generated important physics data complementary to those generated by the proton machines.

Thus the total coverage of SLAC research became much broader than that envisaged in the original proposal. On top of this increased and unforeseen scope came another addition—the development of electron-

The 82-inch hydrogen bubble chamber with (from bottom) Luis Alvarez, Bob Watt, Joe Ballam, and Pief Panofsky.

positron storage rings. This is a separate and exciting story described by Burt Richter.

Conclusion

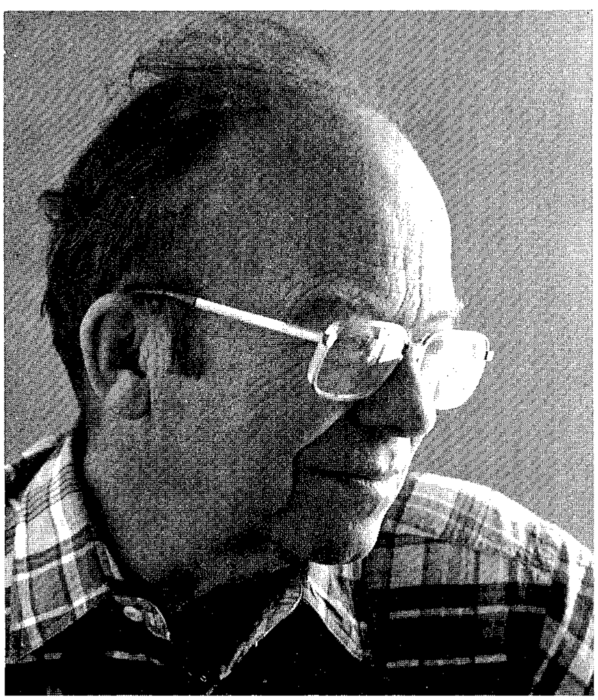
One vexing question which was raised at the time SLAC was started and which continues to be asked today is "How long will SLAC live?" The answer was then, and still is today, "About 10 to 15 years, *unless somebody has a good idea.*"

It is now indeed 20 years after beginning of construction and we are again looking a decade or more ahead. As it turns out, someone always has had a good idea which was exploited and which has led to a new lease on life for the laboratory. It is indeed true that full research exploitation of most, if not all, large accelerators and colliders takes about 10 or 15 years and thus the motto relating to such machines has always been "Innovate or Die!"

Happily, new ideas have not been lacking in the environment of Stanford University. We have moved from the original proposal for the SLAC linac dedicated to electron and photon physics to the exploitation of secondary hadron beams, to electron-positron storage rings, and SLAC is now on its way to developing the SLAC Linear Collider—a device aimed at bringing 50 GeV electrons and positrons into annihilating collisions.

Worldwide we have seen a life and death cycle of various accelerators as the frontier of particle energy has advanced and as the type of accelerators and colliders to achieve these energies has changed. The life and death cycle of *machines* need not correspond to the life and death cycle of *institutions* unless the size of machines required to remain at the frontier becomes so large that they cannot be accommodated within the boundaries of the laboratory. It is fortunate that Stanford University could accommodate a two-mile accelerator on its own lands; thus far the additions to that accelerator, in particular the SPEAR and PEP storage rings and the proposed SLC collider project, also fit within the boundaries provided by Stanford to the government under a 50-year lease. What may come after is an open question.

The evolution of SLAC and its program has indeed demonstrated again that the principal contributions to physics of a new accelerator are rarely those envisioned in the original proposal Although those goals have been met, the actual program turned out to be much richer and more exciting. Let us hope that the future will be equally unpredictable in the same manner.



W.K.H. PANOFSKY

This article was based on a talk given by W.K.H. Panofsky at SLAC's Multi-Anniversary Celebration held on August 14 and 15, 1982. Bill Ash, Editor

W.K.H. PANOFSKY

In a talk at the SLAC Anniversary Celebration Stanford University President Donald Kennedy noted, "The institution is the shadow of the man; in the case of Pief Panofsky, that shadow is two miles long." Since 1961 the biography of Panofsky is very much a history of SLAC.

He received his A.B. degree in physics at Princeton in 1938 and his Ph.D. from the California Institute of Technology in 1942. From 1942 to 1943 he was Director of the Office of Scientific Research and Development Project at Caltech, and from 1943 to 1945 was consultant to the Manhattan District at Los Alamos.

He served on the faculty of the University of California at Berkeley from 1945 to 1951, when he came to Stanford University as Professor of Physics. He was Director of the High Energy Physics Laboratory at Stanford from 1953 to 1961, and has been Director and Professor at SLAC since that time.

Panofsky's extensive research has been in x-rays and natural constants, accelerator design, nuclear research, and high-energy particle physics. His interest in international arms control is reflected as a Consultant to the Arms Control and Disarmament Agency since 1959 and as a member of the Committee on International Security and Arms Control of the National Academy of Sciences since 1981.

His many honors include the National Medal of Science in 1969 and the Enrico Fermi Award in 1979.