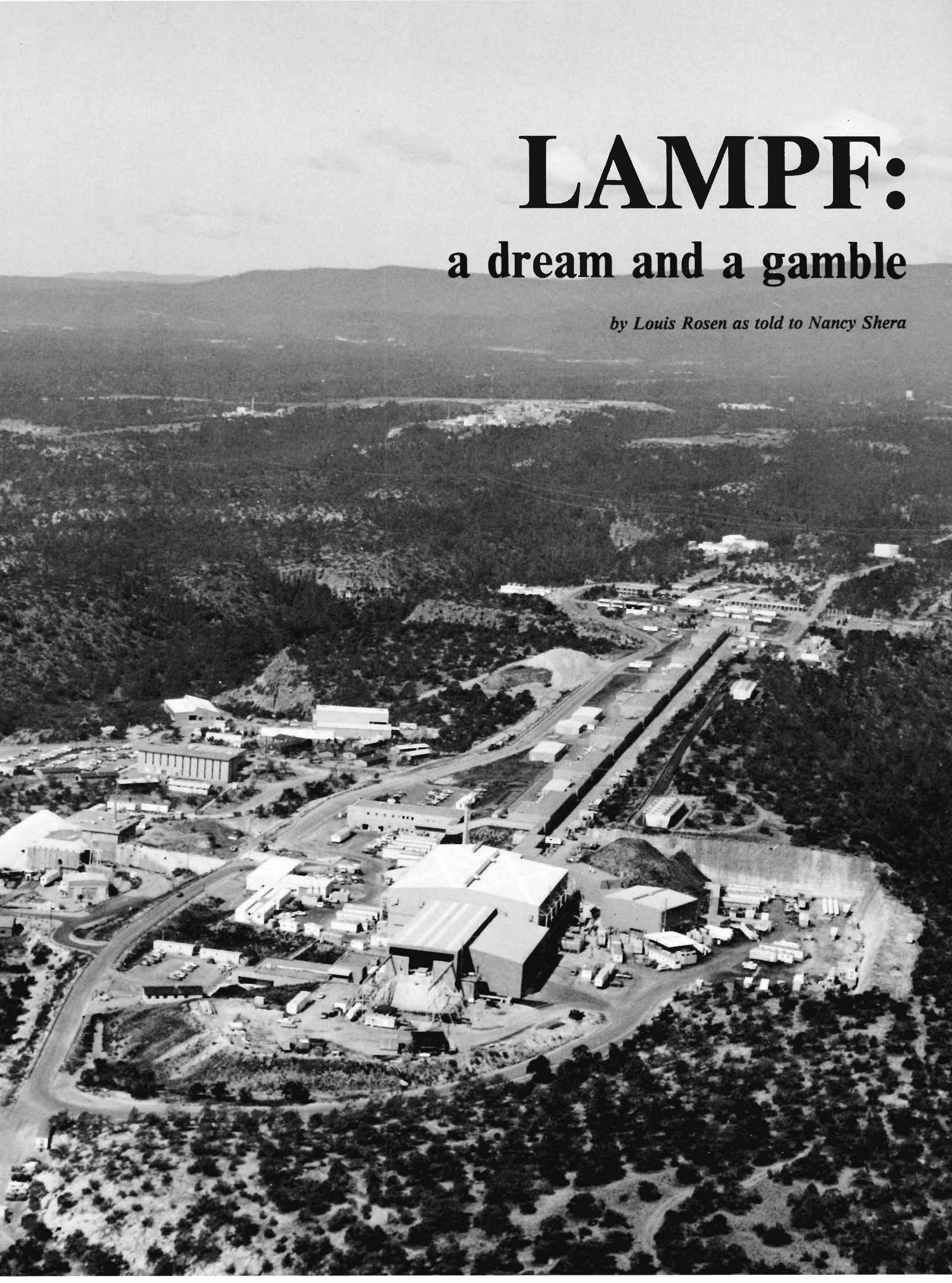
LAMPF:
a dream and a gamble

by Louis Rosen as told to Nancy Shera



The Clinton P. Anderson Meson Physics Facility, familiarly known as LAMPF, is a striking example of the Laboratory's transition from an institution primarily involved in weapons-related research to one aggressively engaged in a diverse range of basic and applied research. At the heart of LAMPF is a half-mile-long linear accelerator that produces a beam of protons with a maximum energy of 800 million electron volts. That in itself is not particularly remarkable: other accelerators exceed this energy by a wide margin. But no other proton accelerator in the world even approaches the combination of energy and average beam intensity—1 milliampere—that can be supplied by LAMPF.

A primary purpose of the proton beam, in its own right a valuable scientific tool, is production of secondary beams of pi mesons (hence LAMPF is often called a meson factory). The pions are produced as the protons strike light-element targets. Decay of the pions creates muons, and decay of the muons yields muon and electron neutrinos. In addition, interaction of the protons with heavy-element targets produces neutrons. These particles—the protons, pions, muons, neutrinos, and neutrons—are used as probes for obtaining information about the structure and properties of nuclei and the nature of the nuclear forces. This information, in turn, is used to test the success of quantum electrodynamics and theories unifying the forces of nature.

First proposed in 1962 and ready for use in 1973, the facility is host to hundreds of scientists from all over the United States and many foreign countries. LAMPF's usefulness to these scientists has been enhanced by many additions, including facilities for treatment of cancer with pions, for research with neutrons and neutrinos, and for production of isotopes. Under construction at present is a proton storage ring that will permit generation of short-duration, extremely high-intensity neutron pulses. Hopes for the future include a high-intensity neutrino facility in conjunction with the proton storage ring and LAMP II, a kaon (K meson) factory using the present accelerator as an injector.

How did this extraordinary research facility come into being on a mesa dotted with prehistoric Indian ruins? Louis Rosen, a foremost advocate of LAMPF since its conception, here reminisces on its origins and talks about its present and future.

In the early 1950s Los Alamos was still probably the most renowned nuclear science laboratory in the world. Our renown was based on a capability built up in a very short time during the war. Expertise in nuclear science was absolutely essential to the tasks that Los Alamos had to do. After the war we continued to work on a great many remaining uncertainties, many of which involved nuclear properties, such as neutron cross sections and spontaneous fission rates.

Its geometry matching the architecture of the mesa on which it lies, the Clinton P. Anderson Meson Physics Facility (LAMPF) is the world's foremost producer of pi mesons. Hidden within the structures are impressive arrays of equipment—and scientists who respond happily to the news that the beam is on and despondently to the news that the beam is off.

Anyway, we were in the early 1950s the world's foremost nuclear science laboratory, but the world was catching up with us. By the end of the decade, we no longer were ahead. Although we had some nice equipment and quite a few outstanding people, other laboratories, not only in this country but in Europe as well, had either caught up with us or surpassed us. This situation caused us some concern and frustration.

It was also in the late 1950s that Dr. Bradbury, among others, started to address the fact that since Los Alamos was going to be a national security laboratory with prime responsibility for nuclear weapons, we had to have a broad base, not only in nuclear science but in other areas as well. He encouraged efforts on the part of the staff to think of ways to diversify the Laboratory. However, he assumed that we wouldn't diversify in a promiscuous way—I feel we eventually did just that, but not during Bradbury's tenure. We were careful then to undertake activities that were pertinent or necessary to carrying out our responsibilities in the weapons area. For example, many scientists are interested in finding ways to solve nonlinear equations, but here we *had* to find ways to solve them.

We diversified into areas that were vital to support of our basic mission and into other areas only if they had the earmark of being important national goals and of being incapable of pursuit by either industry or universities. One of those areas was nuclear rocketry. It didn't materialize—it fell flat—but it was the kind of thing that could only be done in a multidisciplinary national laboratory. Another area we entered was high-temperature gas-cooled reactors, which may yet turn out to be the safest, most efficient, most appropriate way to generate nuclear power. But funding in this area was cut off. I think that was a terrible mistake—the government really blew it when they abandoned that technology. General Atomic is trying to revitalize it, but it should have been pursued here. We could have developed it much faster and more economically.

Toward the end of the 1950s we made major improvements in the cyclotron here and we built a vertical Van de Graaff, and so we could hope to keep pace with other nuclear science laboratories. Then, about 1959, my wife told me she just had to get away from Los Alamos. I applied for a Guggenheim Fellowship and, despite my application's being way past the deadline, received one. The Fellowship was a marvelous thing. Not only was it quite a lot of money for those days, five thousand dollars, but it was tax free. I let Mary choose where to go. Since she had stuck with me at Los Alamos, I figured it was now her turn. She chose Paris.

What does one do in Paris other than look at pretty girls? There was then, and still is now, a major laboratory, Centre d'Etudes Nucléaires, located just outside Paris at Saclay. It has always been the foremost basic nuclear science laboratory in France. We lived in Paris, and Mary reveled in its art and language schools and its beautiful shops while I commuted through its kamikaze traffic every day to Saclay.

That year at Saclay was great because it gave me a chance to think about where Los Alamos should be going. Also, I wrote more papers that year than in any year before or since, and I even did a little research. As regards Los Alamos, I convinced myself that we had to do something really major in nuclear science if we were, on the one hand, to fulfill our obligations to support a strong nuclear weapons program and, on the other hand, to maintain the prestige and credentials that would permit us to attract the very highest caliber of scientific people. A laboratory is, in first approximation, made up not of hardware and computers and buildings but of people—dedicated, competent people, well educated in the activities that you want to pursue but, more important, inspired by the magnitude of their ignorance.

So in France I convinced myself that something dramatic had to be done. Back in Los Alamos I continued in my research—with polarized beams—and started talking with others about what that something should be. One group of people thought it should be solar sailing, propelling enormous vehicles just by the sunlight bouncing off them. But that seemed to have little relevance to anything. Another group wanted to have a large astrophysics program, which made more sense because astrophysical phenomena are not all that far removed from nuclear weapons phenomenology. And a group led by Jim Tuck was pushing very hard in the direction of controlled thermonuclear energy. I tried to help Jim and succeeded in providing him with neutron spectra demonstrating that he had achieved true thermonuclear reactions in one of his devices. Energy from nuclear fusion seemed then, and still now, a good thing for the Laboratory to pursue, because the payoff is too far down the road for industry to be interested.

However, although I had never taken a formal course in nuclear physics, my own leanings were toward nuclear science. I felt, and some others agreed, that we should think in terms of a great nuclear science facility centered around what we dreamed of as the world's most powerful meson factory. No point in thinking small: if you are going to do something, you may as well go all the way. Well, the arguments for such a facility had to be very compelling because it obviously involved lots and lots of money—upward of a hundred million dollars for development and construction. We finally worked out what seemed an honest and very persuasive rationale for requesting of Congress the resources to build LAMPF.

The most fundamental reason we advanced stemmed from a belief, still held today, that eventually this country and the entire industrialized world will be forced, whether they like it or not, to a nuclear-energy economy. Safety is not going to have much to do with it. We are simply running out of conventional organic sources of energy, and there is the much more fundamental problem of the effect of carbon dioxide on the earth's climate. Every scientific investigation of this problem points to the conclusion that there is a limit on how much carbon dioxide we can spew into the atmosphere without causing quite catastrophic climatic changes. Now that is a natural limit, not a human-made limit. So what can we do? We can stop using so much energy and go back to a primitive economy, but nobody is going to agree to that. The other possibility is to find another energy source. Fusion energy would be great, but it's not at all clear that it will happen in the next fifty years, not at all. And solar energy cannot serve for really large-scale production of electricity, ever. The big source of energy required by industrialized societies is going to have to come, very soon, from nuclear fission and later, maybe, from nuclear fusion.

If a nuclear-energy economy is inevitable, how can we make it as efficient and safe as possible? With advanced nuclear technology. The reason we are doing so badly now with power reactors is that we didn't start with enough technology. And because technology is the child of science, we need a strong science base. Without that, technology cannot advance and will soon dry up. We felt that the need for science as the basis of technology was the most compelling reason for Los Alamos to engage, at a very high level, in basic nuclear science. However, there were other reasons.

One was that many senators were seeking some kind of national facility for this part of the country, which was very poor in that respect. But we had to convince people that, in contrast to the rest of the Laboratory, the facility would be open to all interested users. People feared that after capitalizing on their support to get LAMPF built we would put a fence around it, and they would be outside looking in. Fortunately, I was reasonably well known in the scientific community, and I think people believed me when I told them we would do no such thing. And the Users Group charter, which was adopted long before construction was complete, backed up our intent in this regard. It states that the users, the hundreds of them, will be involved in the governance of LAMPF. The entire scientific community can participate. We don't say, "Look, come and use whatever we have if you can use it, but don't tell us what you need or what we should do." Users are involved in determining policy for upgrading the facility, for new beam lines, and for experimental programs, and, of course, they are primarily and heavily involved in advising on the allocation of beam time. Although the users do not make the final decisions, they advise us on what scientific priorities should be assigned to various proposals. Incidentally, Los Alamos people compete with everybody else. They get no preference in allocation of beam time, with one minor exception—the beam to the Weapons Neutron Research Facility.

This exception is another reason for LAMPF. While the accelerator was being built, I told the Congress that we should include a facility for doing research with a high-intensity neutron beam because eventually the question of a nuclear test ban would arise. In the presence of a ban, maintaining the cadre of very bright people needed for nuclear weapons design would be very difficult unless they had something interesting to do related to their primary tasks. Lo and behold, Congress understood completely and with minimal debate authorized the funds for WNR. The facility is now operating, and its capabilities will soon be dramatically increased by the proton storage ring now under construction.

It is interesting that the version of LAMPF being built by the Russians, which will provide a lower current of somewhat lower energy protons, has included a proton storage ring from the start. I believe their facility is being built primarily for use in the event of a test ban. They may or may not use the mesons, but they will certainly use the neutrons.

Getting back to the reasons for building the facility, a final but very important reason was education. LAMPF provides a great arena where faculty and students can together teach and practice the art and science of solving interdisciplinary problems. The very large number of publications and doctoral theses based on research at LAMPF attests to its excellence as an educational tool and, in a larger sense, as an educational environment.

Speaking of education, I was disheartened by what I heard at last summer's AAAS Symposium on Research and the FY 83 Budgets. The many speakers from the Congress, from the Office of Science and Technology Policy, and from the Office of Management and Budget left me with the impression that, although this administration is going to support basic research perhaps better than any other, it does not recognize that federal support for education is of prime importance to a first-class research endeavor. I believe that education in this country, in the primary schools, the secondary schools, and, in most cases, the universities, is not producing the number and quality of people that are needed to maintain a high-technology society. But the administration, as nearly as I can tell, does not feel that it is a federal responsibility to improve the situation. To agree that the government should fund research and yet to deny that the government should actively promote good science education seems a contradiction.

But let's be grateful for the good news. This administration clearly recognizes that research is important and is going to provide money for it, no question. I have never felt more comfortable about LAMPF's funding. Ten years ago the situation was quite different. I had the feeling then that people in Washington were hiding from me. Once Johnny Abadessa, the comptroller for the AEC, gave a colloquium here. Halfway through he spotted me in the audience, and said, "Ah, Louis Rosen is here. Every time I talk to him, it costs me a million dollars." Now it is a pleasure to go to Washington; people are even glad to see me.

But I am getting ahead of the story. Having convinced ourselves, at least, that LAMPF was a great idea, the next step was to approach the AEC. We worked out a proposal, and in January of '63 I presented an outline of it to the General Advisory Committee and the President's Scientific Advisory Committee. Later in the year we forwarded a Schedule 44—a Construction Project Data Sheet—to the AEC. The Commission didn't respond immediately by any means. They not only had to convince themselves of the wisdom of spending so much money in the then no man's land of medium-energy physics, but also to choose among four proposals for a meson factory—by Yale, Oak Ridge, UCLA, and us. They sought advice, and our proposal was helped by committee reports, especially that of the Bethe Panel, that favored the idea of a meson factory and of a national facility in this part of the country.

The Commission decided that our proposal was the best one and in 1964 gave us half a million dollars for design work. We used part of it to dig the tunnel for the machine—not exactly the kosher thing to do. But we were not home free yet. For several years we faced almost constant uncertainty about whether Congress would continue support of the design effort, let alone fund full construction. But design money did continue to flow and was put to good use. We developed a new and very advantageous cavity scheme for the accelerator, contracted for architectural and engineering work on the buildings, constructed a home for prototype systems, and made considerable progress on the rf system.

Finally, the AEC included in its fiscal year 1968 budget the full remaining amount of construction money. But Congress, which has been tremendously supportive of LAMPF, followed the procedure of doling the money out in installments to permit annual reviews of cost and progress. Over the years this funding procedure caused uncertainty and some frustration.

The official groundbreaking took place in the auditorium of the Administration Building in February of '68—the weather didn't cooperate—and only a little more than four years later the first trickle of 800-MeV protons came down the line. Then in August of '73 we saw our first mesons. Not only had the original proposal been realized, on time and only very slightly over budget, but we had also already begun to upgrade the facility. We had received additional funding for the high-resolution proton spectrometer and had provided for the beam lines for research with neutrons and neutrinos and for treatment of cancer with pions.

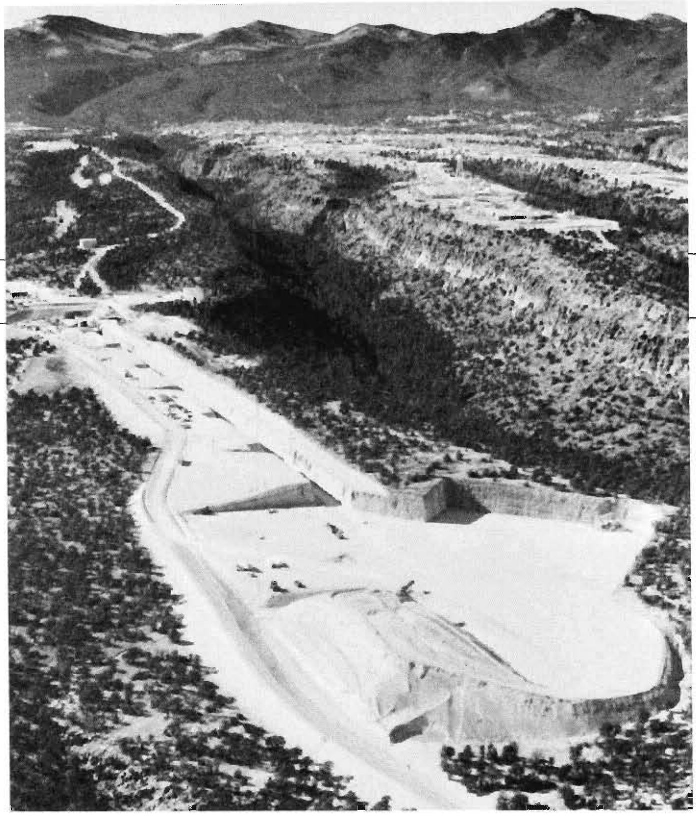
Since 1973 an impressive amount of basic research has been carried out at LAMPF. Let me tell you a little about some of the current experiments and the scientific motivation behind them. Of fundamental importance are the studies of the interactions between nucleons—protons and neutrons. The measured properties of these interactions are clues to the nature of the strong nuclear force. To sort out the spin dependence of the strong force, the interactions are studied at various relative alignments of the nucleon spins by using polarized proton or neutron beams and polarized targets.

Once the strong force is understood, it may be possible to develop a theory that can predict in very fine detail the structure and dynamic behavior of a collection of nucleons—a nucleus. In the meantime these properties are being measured. For both the ground and excited states, the distribution of nuclear matter is investigated with protons, charge distributions and magnetic moments are studied with muons, and the proton and neutron distributions can be separated, to some extent, with positive and negative pions. In the field of nuclear dynamics, a recent experiment has demonstrated for the first time the existence of the so-called isovector giant monopole resonance. In this simple mode of motion, which had been predicted many years ago, the neutron and proton distributions expand and contract separately along the nuclear radius, giving rise to nuclear density oscillations. This resonance has now been observed in tin-120. The energy and width of the resonance tell us something about the compressibility of nuclear matter. This parameter is important in astrophysics as well as in nuclear physics.

February 14, 1968. At the LAMPF construction site the podium and bleachers erected for the groundbreaking ceremony stood deserted and snow-covered. Meanwhile, in the Laboratory's Administration Building, New Mexico Senator Clinton P. Anderson (left), AEC Chairman Glenn Seaborg (center), and Louis Rosen attacked a box of sand hastily substituted for the hard ground of the site. Appreciation for Senator Anderson's great help in making LAMPF a reality was acknowledged by formally naming the facility in his honor in 1972.

LAMPF is also the site of numerous experiments in particle physics that deal mainly with the weak nuclear force. Under way now is an experiment to measure the properties of the scattering between electrons and electron neutrinos. This information will help pin down the mathematical structure of the theory unifying the electromagnetic and weak forces. Coming soon is a search for decays of the muon in which muon number or lepton number is not conserved. The unified electroweak theory predicts that these conservation laws are not absolute, and so does the most credible of the theories unifying the electromagnetic, the weak, and the strong forces. The measured probability of these decays, or at least better limits on their absence, will be of considerable interest to theoreticians.

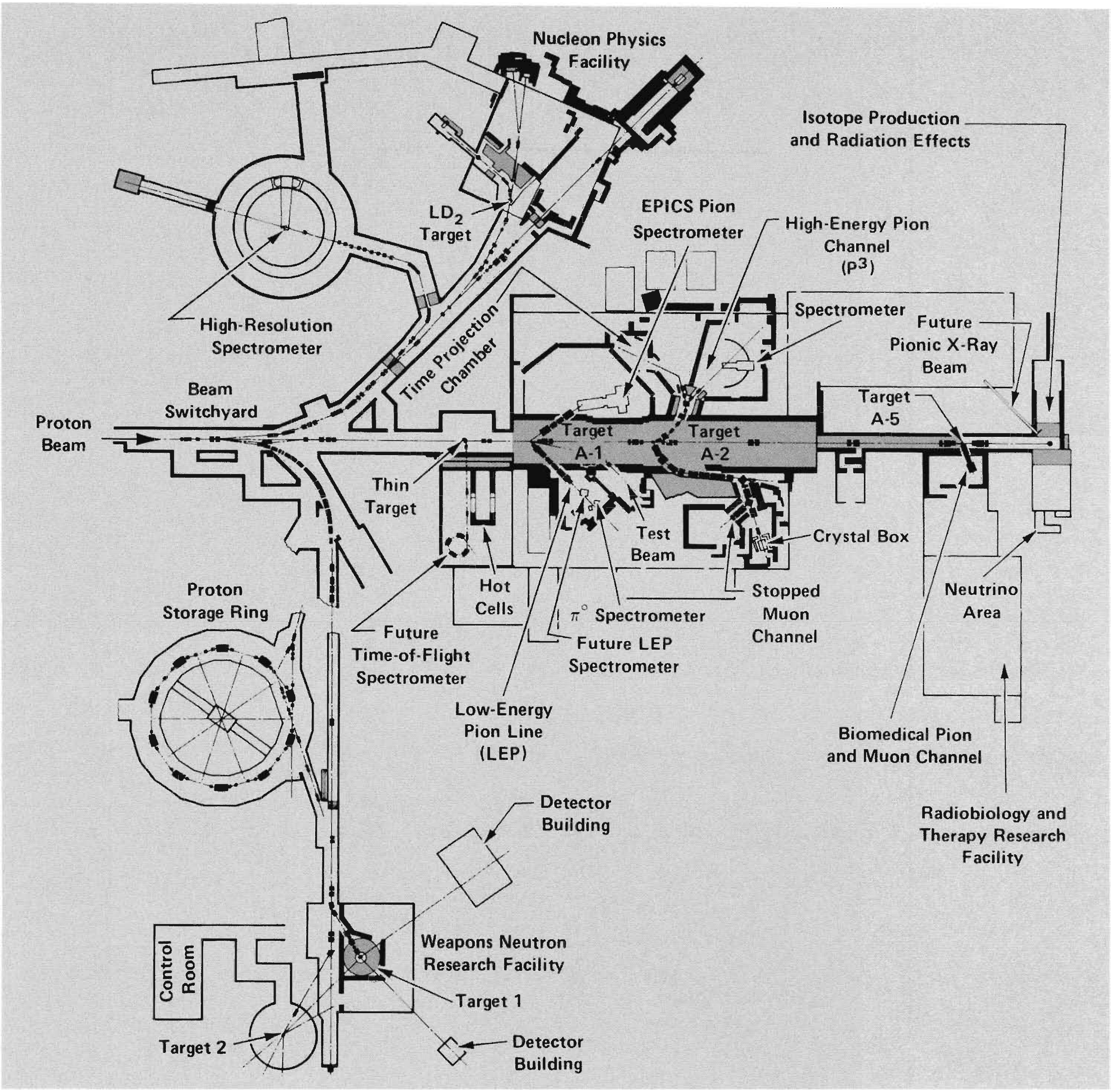
To conclude this brief and incomplete sketch of basic research at LAMPF, let me



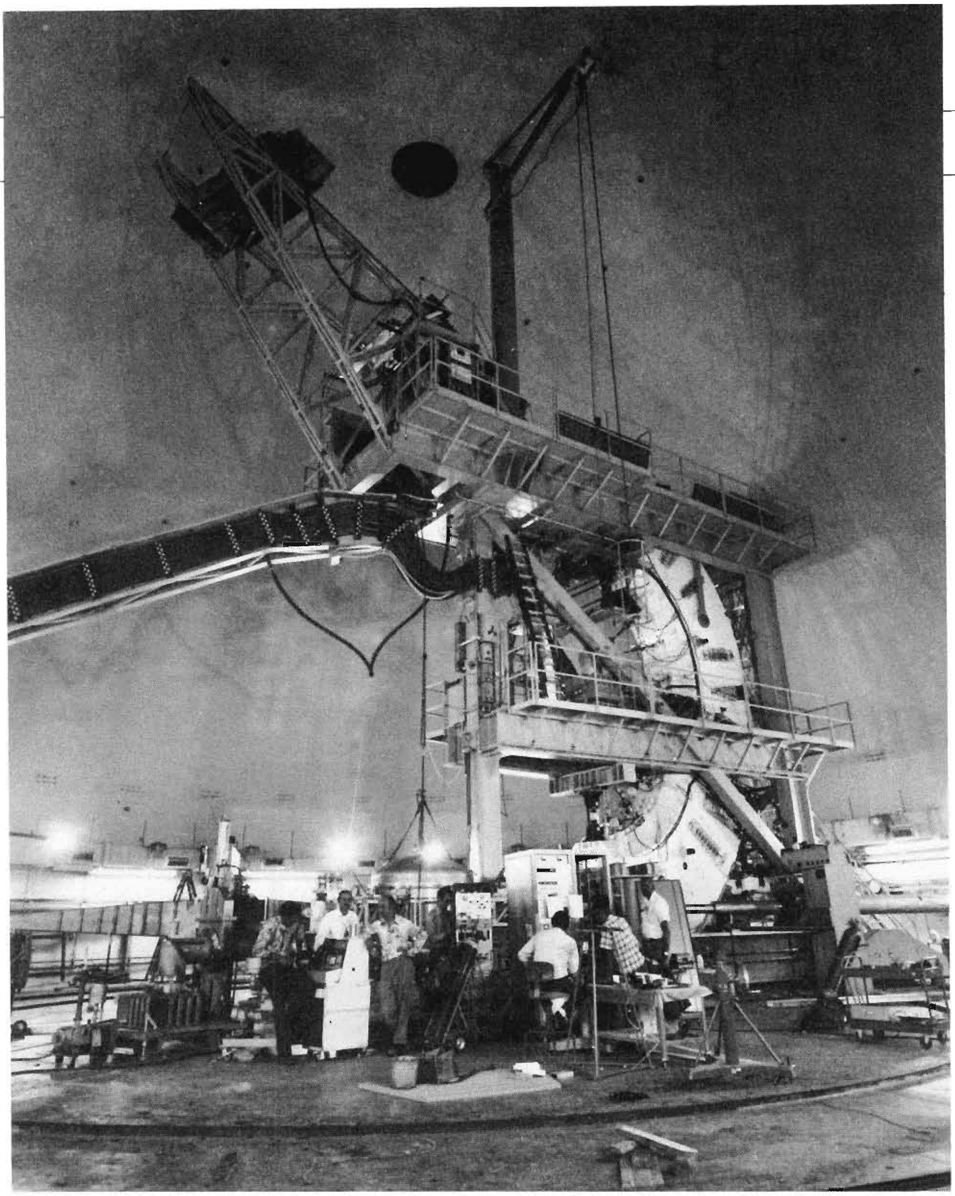
The location chosen for LAMPF, Mesita de Los Alamos, was one of the finger-like mesas extending eastward from the main Laboratory and town sites. Scattered on most of these mesas are ruins of pre-Columbian Indian settlements. Information about the ruins on Mesita de Los Alamos was preserved by archeological studies conducted before construction began. This aerial photograph of 1969 shows the mesa when excavation for the facility was nearly complete. Clearly visible in the center is the tunnel for the accelerator. West of the tunnel, toward the Jemez Mountains, are sites for laboratory and office structures and the injector system. East of the tunnel is the site of the main experimental area.

No one can mistake the delight and satisfaction on the faces of those watching the instruments that told in June 1972 of achieving the design beam energy. News of the event was quickly proclaimed in monumental style along the road to LAMPF.

The LAMPF accelerator consists of three consecutive accelerators: a Cockcroft-Walton preaccelerator that provides a beam of 0.75 MeV protons; a drift-tube (Alvarez) linac that increases the proton energy to 100 MeV; and, shown here being tuned, a side-coupled cavity linac that increases the proton energy to a maximum of 800 MeV. The side-coupled cavity linac was conceived and developed by Los Alamos scientists. Compared to earlier designs, the side-coupled cavity scheme reduces the length of a linear accelerator by a factor of 2.



The beam of energetic protons produced by LAMPF's half-mile-long linear accelerator is routed to many targets and experimental areas. The particles created by interaction of the protons with the targets, and the protons themselves, are used as probes to investigate the world on a nuclear scale.



The high-resolution proton spectrometer, perhaps the physically most impressive scientific tool at LAMPF, is shown here near completion in 1975. The instrument is housed within a 46-foot-radius hemispherical dome, which is covered by a minimum of 12 feet of earth for radiation containment. A specially tailored proton beam enters the target chamber (center) from the left. After interacting with the target, the scattered protons (or other particles that may be formed) are guided magnetically in a vertical plane to detectors positioned at the upper level of the superstructure. For protons with energies in the vicinity of 800 million electron volts, the spectrometer can resolve an energy difference as small as 60 thousand electron volts. To investigate the angular dependence of the proton-target interaction, the spectrometer can be rotated as a whole about the target chamber. A wide variety of research in nuclear and particle physics is performed with the spectrometer, including studies of elastic and inelastic scattering between protons and nuclei, of particle-pickup reactions such as (p,d) *and* (p,t)*, of pion-production reactions leading to discrete final states in the residual nucleus, and of the fundamental nucleon-nucleon interaction.*

mention the Weapons Neutron Research Facility. Its high-intensity neutron pulses are used, of course, for weapons-related research and also for investigating the macrostructure of matter. Neutrons are a marvelous supplement to x rays in solid-state physics because they make it possible to "see" the arrangement of hydrogen atoms.

The particles produced at LAMPF have more practical applications as well. An outstanding example is the pion therapy program carried out at the Biomedical Facility in cooperation with the University of New Mexico Medical School. To date about 250 patients have received therapy. We are not treating patients at the moment, however, because UNM does not have an eminent therapist to run the program. This has been a great disappointment to me. UNM is hard at work trying to attract an appropriate principal investigator, and we are helping them as much as we can. If they determine that they can't restart the program, we will try other ways.

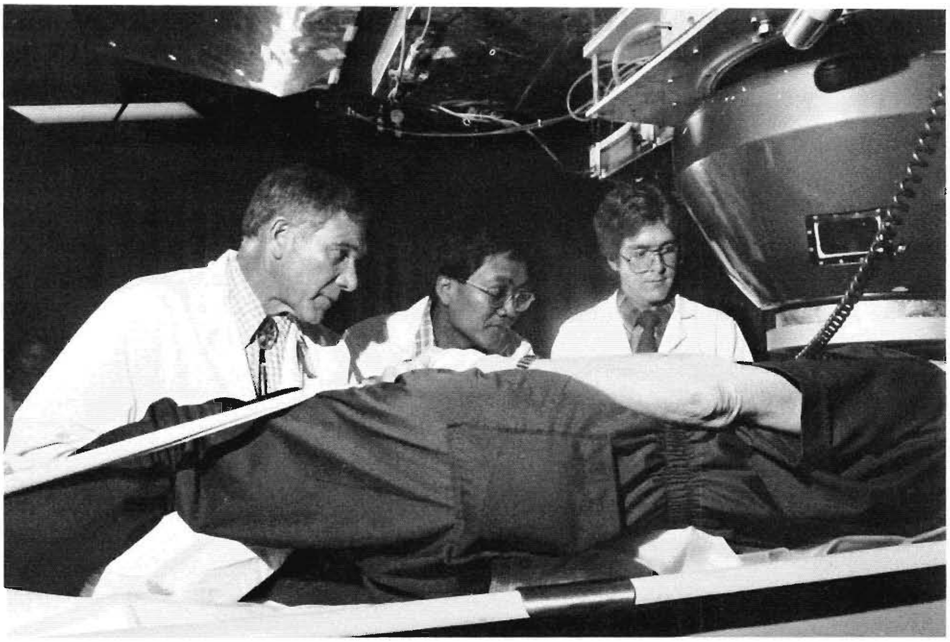
Another practical application is the production of radioactive isotopes with the residual proton beam. The isotopes, most of which decay by positron emission or electron capture, are being used as tracers in a variety of medical and biological studies. During the past year radioisotopes were shipped to about fifty research groups.

We have also been successful in transferring technology to the private sector. Let me point out first that all megavoltage radiation-therapy machines built in the United States use the accelerator structure developed here for LAMPF. Another example is a device for treating superficial tumors, such as cancer eye in cattle, by inducing hyperthermia with radio-frequency energy. One of our radio-frequency experts developed the device after the accelerator was completed. A number of companies in this country are manufacturing units for sale here and abroad, and similar technology is being investigated at a number of eye institutes as a means for changing the curvature of the eye. The Chinese are experimenting with the device on human tumors, particularly certain types of brain tumor for which surgery is not feasible. I received a report about this application during Mary's and my visit to China in 1981. A Chinese scientist told us, "We have received your device in Shanghai, and I want to thank you for this collaboration." I was quite impressed by this example of LAMPF's international impact, which promises soon to be even greater because the Department of Energy has recently decided to allow two Chinese scientists to spend a year at LAMPF. Here they will interact with people from many nations. What better way is there to foster international cooperation and understanding?

It must be fairly obvious that I have the same pride and joy in LAMPF that parents do in their children. I have watched it grow into its position of pre-eminence and do not want to see it grow old and uninteresting before its time. I believe that the projects now under way, such as the proton storage ring, the time-of-flight magnetic spectrometer, and the low-energy pion spectrometer, should maintain LAMPF's stature through this decade. We are planning now for a major upgrade—LAMPF II, the kaon factory—that, if it comes to pass, should take care of the next decade. Then we must start thinking about 2001.

Before relinquishing my soapbox, I want to emphasize one thing very strongly. LAMPF was a very great technological gamble. There was a good possibility that what we had proposed wouldn't work. Were it not for the fact that we were able, partly by design and partly by accident, to assemble here one of the most competent and dedicated groups of people I have ever seen anywhere in the world, the idea would have ended in failure. We had set ourselves a very difficult goal: accelerating a proton beam—actually two beams simultaneously—at intensities never before achieved. The intensities are so high that if more than

For most LAMPF users a trailer is home away from home while an experiment is in progress. This recent aerial photo shows many such trailers clustered around LAMPF's main experimental area. The trailers house equipment for collecting and analyzing data during the precious hours of allotted beam time.



In a pilot experimental program at LAMPF's Biomedical Facility, about 250 patients were treated with negative pions for a variety of advanced deep-seated tumors. Compared to conventional x-ray therapy, pion therapy is expected to provide improved dose localization and biological effectiveness. Shown positioning a patient under the pion radiotherapy beam are (left to right) Dr. Morton Kligerman, former Director of the University of New Mexico's Cancer Research and Treatment Center, a visiting radiotherapist from Japan, and Dr. Steven Bush, formerly of the University of New Mexico. The hardware at the upper right includes a beam collimator, a dose monitor, and a device for changing the penetration depth of the pions.

Because the targets and other objects struck by the proton beam become extremely radioactive, maintenance, repair, or replacement of these items must be carried out by remote control. LAMPF's remote handling system includes a slave unit shown here near a target cell (hidden within the shielding at the right). The crane positions the manipulator near the work area. Also visible are television cameras that provide the only view of the manipulator in operation. A master manipulator controls the slave unit from a nearby trailer, which also houses the television monitors and various camera and crane controls.

1 per cent of the beam goes astray, you make the structures along the beam line so radioactive that they can't be maintained or repaired. It's no trick to accelerate charged particles, but accelerating them with such small loss is very tricky indeed. No one could guarantee it could be done, and, in fact, people who really knew the game were betting we would fail. No one had achieved a transmission of 99 per cent through a half-mile-long machine because charged particles repel each other. They don't want to go all in a straight line, they want to separate, to diverge, and then they will interact with the structures. We had to devise, from very first principles, focusing and beam diagnostic techniques to control the stability of the beam. Now it seems so easy—we start a beam at the injector, and a half mile down it can be one millimeter in diameter. *One millimeter.* We had to develop a most basic understanding of beam dynamics to achieve this, and there are some interactions, some couplings between radial and longitudinal oscillations, that are hellishly hard to predict, even today.

That was the biggest problem, getting the beam out of the machine with such a small loss. Once we solved that problem, we faced another. A main purpose of the beam was to make pions. To do that, you put a target in front of the beam. When the beam interacts with the target, all kinds of particles and radiations break loose. The volume around the target becomes so radioactive that human access to the area is forbidden for a very long time. Even with the machine off, the radiation level in the target is tens of thousands of roentgens per hour. We knew then, and we know even better now, that no matter how perfectly something is made, it is going to break sometime and will have to be fixed. How do you fix it if you can't get to it and work on it? With remote maintenance. But nobody had ever tried to do remote maintenance on systems so delicate and so intricate as the water and vacuum and electrical and magnetic systems in a target cell. And it was fairly certain that these systems would need repair sooner or later. The target rotates on bearings—to distribute dissipation of the beam power—and is exposed to enormous radiation and extreme heat cycling. We didn't know, and there was no way to find out, whether we would start up the machine, run it at high intensity for a month, two months, three months, only to have something in the target break. What would happen if we couldn't fix it? We would have had to bury it; that was in the cards.

But you have to have faith and you have to have courage—this game is not for the faint of heart. You have to realize that if things go badly, your name is going to be mud, and you may have to go some place and live out your life without ever seeing your colleagues again. It takes people of extraordinary courage to stake their scientific future, their professional careers, on something that is really very risky. But people do it all the time; they take the gamble and they may lose. But unless you take these gambles, you can never win. I think we have won our gamble. ■