The LANSCE National User Facility

Thomas Wangler and Paul W. Lisowski

Particle accelerators have played an important role at Los Alamos ever since the Manhattan Project, when beams from two Van de Graaff accelerators and a cyclotron were used to answer experimentally important nuclear-physics questions. The data obtained from those machines helped ensure success of the "gadget" and its descendents.

Today, an 800-million-electron-volt (MeV) proton linear accelerator, or linac, forms the backbone of the Laboratory's national user facility, the Los Alamos Neutron Science Center (LANSCE), shown in Figure 1. Protons from the linac, travelling at 84 percent the speed of light, smash into a heavy-metal target and, through a process known as spallation, produce copious numbers of neutrons. The neutrons are used in experiments that support the weapons program and advance basic research. The linac's proton beam can simultaneously be used in a capability known as proton radiography, or pRad, to make high-speed "movies" of dynamic systems. (See the article "The Development of Flash Radiography" on page 76.)

A Brief History of the LANSCE Complex

The proton linac used by LANSCE was originally built in the late 1960s to produce pi-mesons, also known as pions, for the Los Alamos Meson Physics Facility (LAMPF). The pions and their decay products (muons, electron, and muon neutrinos) were used to conduct fundamental studies in nuclear, atomic, and particle physics.

The idea for a pion factory was first mentioned in a memo by Louis Rosen, dated May 16, 1962. As Rosen described the situation, this was a critical time in the history of what was then known as Los Alamos Scientific Laboratory. The Cold War was at its height, and the Laboratory had successfully developed our nuclear deterrent—the fission and thermonuclear weapons now in the stockpile. New challenges and new facilities in the field of nuclear science would be needed to maintain and advance the Laboratory's world-class capabilities. The meson factory would benefit the Laboratory and the nation by providing the experimental capabilities that would support the Laboratory's programmatic needs for the weapons program. In addition, the facility would foster opportunities in basic research, and be the catalyst for a scientific user program that would bring leading scientists and students to Los Alamos from all over the world.

However, it was a tremendous technical challenge to produce protons with enough energy to support pion production. The protons had to have more than 290 MeV of kinetic energy in the laboratory just to create the pion rest mass, but at that time, proton linac energies had not exceeded 100 MeV. After two years of design studies, a bold proposal was made in September 1964 for an 800-MeV high-current (1-milliampere average current) proton linac for medium-energy physics research. The innovative development that made this energy scale feasible was the side-coupled linac accelerating structure (see Figure 2).

The Medium-Energy Physics Division was formed in July 1965 (with Rosen as division leader) to continue with the design and development of the meson facility. Construction funds were authorized by Congress in the fiscal year 1968 budget, and physical construction began with a groundbreaking ceremony on February 15, 1968. Only four years later, on June 8, 1972, this new linac delivered its first beam. The machine builders can take great pride that LAMPF was completed on schedule and within budget ($57 million). LAMPF also achieved all its major goals. In September 1972, the facility was dedicated to U.S. Senator Clinton P. Anderson of New Mexico, who was instrumental in turning the project into reality.

An interesting footnote to the LAMPF story is that the side-coupled linac was later widely adopted by industry. As a result, thousands of side-coupled linacs were eventually produced around the world for radiation therapy. Thus, Los Alamos research and development resulted in one of the most beneficial uses of nuclear-physics technology for mankind.

It was clear even before LAMPF was built that, with a neutron-rich, heavy-element target, rather than the light-element target that was suitable for pion production, neutrons would be produced by spallation and that such a source would compete very favorably with nuclear reactor-based neutron sources. Based on that premise, the Weapons Neutron Research (WNR) facility, consisting of a proton-beam transport system and a spallation-neutron target, was built in the LAMPF complex to support the Laboratory's materials-science and nuclear-physics programmatic needs. The WNR facility produced neutrons for the first time in May 1977 and gave the Laboratory an intense neutron source that could be used to study the behavior of matter at extreme temperatures and densities, as well as to study radiation effects and obtain nuclear data needed for weapons design.

The LAMPF complex expanded again in the early 1980s with the addition of a unique 30-meter-diameter Proton Storage Ring (PSR), which accumulates the proton beam injected from the linac and compresses the relatively long 625-microsecond pulses into short 125-nanosecond pulses. These short bursts of protons are then directed to the heavy-element target to produce very short bursts of spallation neutrons. The short pulses allow time-of-flight measurements for a more precise determination of the energy and wavelength of the neutrons. Construction of the PSR began in May 1982 and was completed in April 1985. The first beam was circulated in the ring on April 26, 1985.

In 1986, construction was started on a new experimental area (adjacent to the existing WNR facility) that was summarily filled with a suite of world-class instruments. The new area was named the Manuel Lujan Jr. Neutron Scattering Center (the Lujan Center) in honor of a popular congressman from New Mexico. Scientists use the low-energy neutrons at the Lujan Center to perform novel studies of materials. The old WNR facility was also rebuilt during this construction project to provide another spallation source that concentrated on producing beams of higher-energy neutrons for nuclear science. Both new sources came into operation in the early 1990s, just before the medium-energy program of pion and nuclear physics at LAMPF came to an end.

With the closeout of the nuclear physics user program and an increased national need for neutrons, the mission of the LAMPF accelerator complex was changed from nuclear physics to neutron research. In October 1995, the complex was renamed as LANSCE.

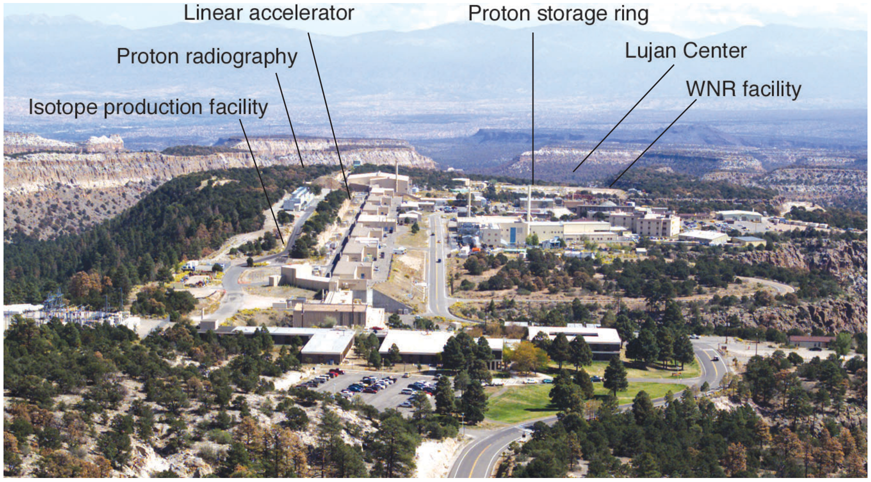


Figure 1. The LANSCE Complex
The half-mile-long 800-MeV proton linac is the backbone of the complex.

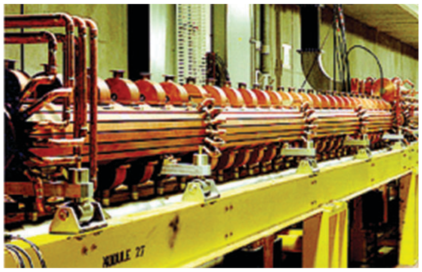


Figure 2. From 100 to 800 MeV
The side-coupled linac accelerating structure (100 to 800 MeV) was invented by Los Alamos accelerator scientists during the design of LAMPF.

The LANSCE Complex Today

The combination of the Lujan Center and the WNR facility gives researchers access to high-intensity neutron beams covering 16 orders of magnitude in energy, and the LANSCE complex has evolved into a major international resource; a record 750 user visits by scientists from around the world occurred during the last operating period. Because so many students and professors visit each year, LANSCE is one of the Laboratory's most important "windows" into the academic community and a source of many of our brightest early-career scientists. It is estimated that LANSCE and its predecessor, LAMPF, have served as a gateway to 10 percent of the Laboratory staff.

Within the past year, users have achieved many significant accomplishments in materials science, nuclear science, and technology. A few highlights are described below.

Research at the WNR Facility.

The WNR facility is the only remaining broad-spectrum neutron source available to conduct the kinds of precise nuclear science measurements needed to develop predictive capability in the weapons program. As an example of this need, a problem that has been around since the early days of nuclear weapons was recently solved through accurate measurements of the plutonium (n,2n) cross section, which is needed to quantify the production of plutonium-238 from plutonium-239. Knowledge of the plutonium-238 production rate over a range of incident neutron energies is essential for understanding past Nevada Test Site (NTS) data. This

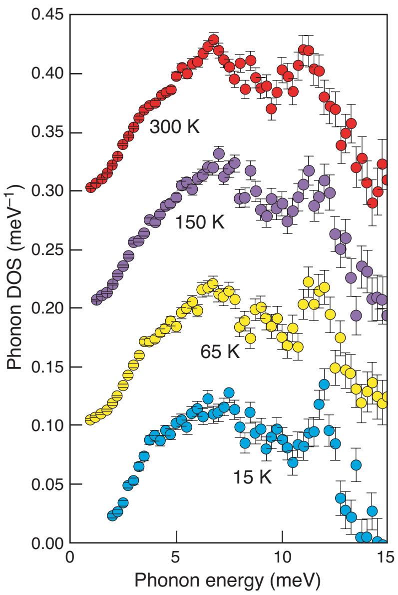


Figure 3. EOS Measurements
Shown here is the phonon density of states of a δ-phase plutonium-aluminum alloy at different temperatures. The peaks in the data give the distribution of phonon-mode frequencies in the alloy.

definitive measurement has allowed us to significantly improve our predictive capabilities and resolve complicated physics issues in the performance of our weapons that were previously not understood.

Another use of WNR neutrons arises because electronic assemblies, particularly those used in high-altitude aircraft, are subject to neutron-induced "upsets" at the altitudes at which they operate. The neutron-beam energy spectrum from WNR mimics neutrons seen by aircraft electronics in flight, but with an intensity one million times stronger. WNR is now the standard facility for testing neutron-induced upsets in electronics. Thirteen major companies used the facility in 2002 to validate the operation of selected electronics. Similarly, Los Alamos researchers must address whether neutron-induced upsets could affect the ASCI Q machine, one of the most powerful supercomputers in the world and a pillar of the Stockpile Stewardship Program. The intense neutron source at LANSCE was used to conduct a study of the impact of cosmic-ray-produced neutrons on the Q machine's reliability.

Research at the Lujan Center. Neutron-scattering experiments at LANSCE have provided a new method for characterizing the basic material properties of plutonium, and we now have the ability to compare plutonium parts that were produced by different manufacturing processes. The original parts were made at the Rocky Flats facility, which is now closed, and newly manufactured parts are made by a different process. The new characterization method allows us to address the question of whether the change will affect weapons performance or safety, two critical issues for the enduring nuclear-weapons stockpile.

Stockpile stewardship also requires that weapons modelers have an accurate, well-understood equation of state (EOS) of plutonium. Otherwise, it is impossible to construct a dependable model of weapons performance. Inelastic neutron scattering from a plutonium-gallium alloy allowed the first-ever determination of phonon density of states, which is an integral component in understanding the EOS (see Figure 3).

The high-pressure preferred orientation (referred to as HIPPO) diffractometer at the Lujan Center can make in situ neutron-diffraction measurements of samples that are at high temperature. Recent experiments revealed texture changes in quartzite that establish this rock as a shape-memory system. In such a system, the orientation of grains is controlled by internal stresses. Shape memory is a desirable attribute for many applications. For example, if an eyeglass frame made from a shape-memory alloy were to become bent, only modest heating would be required to return the frame to its original condition. The revelation that Earth materials have a similar attribute could have profound implications about the plasticity of Earth's crust.

Another research avenue involved helium, which is the decay product of the tritium used in nuclear weapons. The partial pressure of helium in a weapon's neutron generator is a lifetime-limiting factor for components of the stockpile. Working with Sandia National Laboratories, scientists at the Lujan Center investigated helium retention, providing information that has significantly influenced the design.

The Lujan Center has completed construction of a major new instrument called Asterix, which provides a polarized neutron beam for studies of magnetic materials and spin polarization. Asterix made it possible to analyze the structure of crystalline and polycrystalline materials through the use of neutron scattering while the materials are located in a magnetic field that is 100,000 times stronger than Earth's magnetic field.

The Lujan Center is also home to the protein crystallography station, the only neutron-scattering instrument in the world designed specifically to investigate the properties of proteins. It performed the first studies of electric-field-induced structural changes in an organic single crystal (see Figure 4).

Finally, LANSCE has completed construction of a major new detector system that will enable, for the first time, measurements of the nuclear properties of radioactive targets using as little as 1 microgram of material. These measurements will affect such diverse areas as the analysis of radiochemical information from past underground nuclear tests, models of astrophysical processes, and technical issues in homeland defense.

pRad. Protons that are used to produce neutrons for the Lujan Center and the WNR facility can instead be used directly. Similar to the way an ordinary photon source is used to take

Figure 4. Protein Crystallography
Paul Langan of the Bioscience Division points out the single-crystal α-glycine sample used in the protein crystallography station.

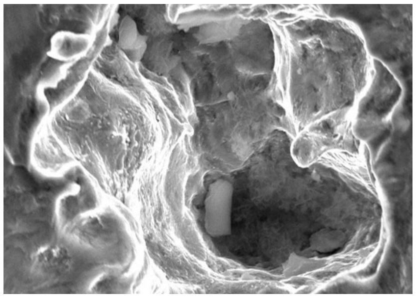


Figure 5. Target Investigation
A scanning-electron-microscope image of a large pit produced in a steel container. The pit resulted when a bubble of mercury collapsed. The bubble had been generated by an intense proton pulse during a test of SNS target technology at LANSCE.

a picture, in pRad the properties of the protons are exploited to create a radiographic "motion picture" with a frame speed of 50 billionths of a second. The pRad capability has allowed us to understand better the aging and performance of weapons systems components and to observe the properties of materials shocked by high explosives. During the 2002 run cycle, 42 dynamic pRad experiments were performed at LANSCE in support of weapons-physics research efforts at Sandia and, Lawrence Livermore National Laboratories and at the Aldermaston Weapons Establishment. A unique permanent-magnet proton "microscope" system, designed by LANSCE and fielded by the Physics Division, has produced radiographs with up to 15-micrometer resolution, opening an entirely new realm for studying material features under extremes of pressure and speed.

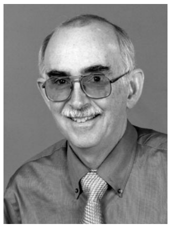
New Facilities. There are two new areas under construction to further enhance the versatility of LANSCE. In 2003, a medical radioisotope facility, called the Isotope Production Facility (IPF), will begin operations. The IPF will allow LANSCE to provide the research community with medical radioisotopes, many of which are not otherwise available in the United States. In a separate area that reuses one of the old experimental areas from LAMPF, researchers have demonstrated the ability to produce the most intense source of ultracold neutrons (UCNs) in the world. UCNs move at speeds not much higher than those at which humans can run, and they have unique properties that allow them to be "bottled" and used for research. Work funded by the Department of Energy is under way to complete a facility for precision studies of forefront problems in physics and cosmology using UCNs.

The Future

The LANSCE spallation neutron source of 2003 owes its existence to the accelerator work done more than 30 years ago to design and build the original LAMPF complex. Today, major progress in accelerator technology continues. Los Alamos is doing work important for the Spallation Neutron Source (SNS) under construction at Oak Ridge National Laboratory in Tennessee. The $1.4 billion project—expected to deliver first beam in 2006—uses a particle accelerator that operates at an average power 10 times that of the Lujan Center. Mercury containers were irradiated at LANSCE to help scientists develop techniques to increase the lifetime of the SNS target (see Figure 5).

Although the future of neutron science is shifting to the SNS, LANSCE will still play an important role. With its low-repetition rate, high peak-intensity pulse from the PSR, and innovative neutron-production source, the Lujan Center will be a powerful force in neutron scattering and fundamental physics research for many years. The WNR facility will remain the only neutron source in the world that can perform basic and applied neutron science over the range needed for defense and advanced nuclear applications. In addition, the pRad facility will continue to be invaluable for defense and, possibly, for other research.■

Paul W. Lisowski became the director of LANSCE in 2001. In his many years at Los Alamos, he has served in a broad range of technical and management positions. These include group leader for neutron and nuclear science, project leader and project director for the National Accelerator Production of Tritium (APT) Project, and director of the Laboratory's Advanced Hydrotest Facility (AHF) project. His technical interests include basic and applied science with neutrons and protons, applications of spallation source technology, and particle accelerator design and operation. Paul received his doctorate in nuclear physics from Duke University.



Thomas P. Wangler received his Ph.D. in physics from the University of Wisconsin in 1964. He worked in experimental high-energy physics at Brookhaven and Argonne National Laboratories and has worked in the particle accelerator field at Argonne and Los Alamos for 28 years. Thomas is a technical staff member in LANSCE Division, as well as a Los Alamos fellow. His main areas of interest in the accelerator field are the physics of high-intensity beams, proton linear-accelerators, and superconducting linacs. Thomas is author of the book *Principles of RF Linear Accelerators* published in 1998.