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# MINI REVIEW

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*Before an experimental run, Susan Seestrom of the neutron and nuclear science group checks connections to the superconducting magnet used to polarize the protons in the neutron-spin filter. Current flowing in the copper-colored wires of the split coil magnet provides the magnetic field in which the protons are polarized by microwave pumping. The neutron beam passes through the center of the magnet, which will be cooled to 1 degree kelvin in a bath of pumped helium-4. The magnet assembly and helium bath together are placed in the vacuum vessel (foreground).*

# *The Weapons Neutron Research Facility: Providing Unique Opportunities in Nuclear Science*

*Grace Y. Hollen*

If a powerful enough microscope existed, we could see the nucleus of an atom as a collection of protons and neutrons, collectively known as nucleons. Around this nucleus is a cloud of electrons that extends about ten-thousand times the diameter of the nucleus. These electrons control most chemical processes. On the other hand, nuclei are the basis of all nuclear energy technologies, including nuclear weapons, peaceful uses of nuclear energy, medical radioisotopes, and nuclear geological probes. Unfortunately, microscopes cannot "see" this deep into the atom. Scientists have had to devise other methods by which they could probe the nucleus and unravel its mysteries.

Particle accelerators, first introduced by Ernest Rutherford in 1919, are designed to supply enough energy to break apart, or at least modify, the tightly bound nucleus. In a sense, these accelerators are the microscopes through which we can "see" the nucleus. But instead of seeing as we do with our eyes, we must deduce what is going on inside the nucleus from what we observe when it is struck by a particle. Is the particle scattered? If so, at what angle? Does the particle lose energy? If so, how much? Are other types of particles emitted? If so, with what energy, intensity, and angular distribution? What are the residual products? Are these products useful?

As accelerator technology advanced since Rutherford's time, more powerful and higher-energy machines were built. As a result, many more reactions can be initiated with higher beam energy, and rarer events can therefore be studied. Increasingly sophisticated detectors allow scientists to construct much sharper views of the structure of nuclei and the reactions that can alter this structure.

## Reaching unmatched neutron intensities

Los Alamos National Laboratory's Weapons Neutron Research (WNR) Facility, first conceived in the early 1970s, has become a premier facility for both condensed-matter and nuclear-physics research worldwide. The half-mile-long accelerator at the Los Alamos Meson Physics Facility (LAMPF) produces a beam of protons with an energy of 800 mega-electron volts and a beam power of about 800 kilowatts—enough to power 800 homes. The neutron and nuclear science group of the Physics Division uses a part of this beam to fulfill the Laboratory's nuclear-physics programmatic needs.

We operate an external proton beam (Target 2), a high-energy neutron source (Target 4), and three beamlines at the Manuel Lujan, Jr. Neutron Scattering Center (LANSCE), all of which make up the WNR program. The two "white" neutron sources at LANSCE and WNR cover a range of energies from small fractions of an electron volt to 800 mega-electron volts. This energy span, which is truly unique, allows us to study the effects of an unmatched range of neutron energies, often simultaneously in one experiment. The neutron intensities achieved over most of the energy range exceed those available at any other "white" neutron source facility or at any other facility of this type. Furthermore, for energy ranges below 1 kilo-electron volt and above 3 mega-electron volts, these sources have an intensity advantage of more than 10 times that of any other source used in nuclear-physics research.

## Creating a neutron source

Neutrons, unlike protons or electrons, can only be produced for research purposes through reactions that cause them to be ejected from the nuclei of a target. When the powerful LAMPF proton beam bombards a dense target, such as tungsten, an extremely high flux of neutrons, as well as a host of charged particles and various forms of radiation, is produced through a process known as "spallation." At LANSCE, for example, approximately 20 neutrons are emitted for every proton that strikes the production target. Accelerated protons from LAMPF are fired at the initial target in bursts, subsequently producing "pulses" of neutrons that travel in a flight path to secondary targets situated at various detector stations.

In a single pulse, the faster, more energetic neutrons "race" down the flight path and arrive at the detector stations before the slower, lower-energy neutrons. A sufficient time interval must exist between pulses from the accelerator so that the fast neutrons from one pulse do not overtake the slow neutrons from the preceding pulse. In the low-energy range used at LANSCE, extremely intense pulses occur at a rate of 20 times per second. At the WNR Facility—Target 2 and Target 4—where high-energy neutrons are used, less intense pulses arrive at rates of up to 32,000 times per second. The longer the flight path, the greater is the time difference between fast and slow neutrons. (Longer flight paths generally produce the best energy resolution.) Using very fast electronic "stopwatches," we determine a neutron's energy from its speed by measuring the time between when the neutron left the initial target and when it arrived at the detector station for a known flight path.

Target 2 is a very flexible experimental area that can be arranged to examine spallation-source reactions or to directly irradiate samples with the proton beam from LAMPF. Experiments operating in Target 2 can exploit the variable-energy feature of LAMPF using proton beams from 256 to 800 mega-electron volts. When we run experiments on Target 4, the LAMPF proton beam is simply transported through Target 2 into a magnet that bends the beam up to a cylindrical neutron production target of water-cooled tungsten (3 centimeters in diameter and 7.5 centimeters long). This target is suspended at the center of a vacuum chamber and surrounded by a massive shield. Target 4 currently has six flight paths that can operate simultaneously.

The neutron beams are used in different experimental areas at flight paths of up to 90 meters from the production target. In the detector stations, sophisticated systems detect neutrons or their reaction products to probe nuclear level densities; to measure the production cross sections of charged particles, pions, and gamma rays and of radioactive isotopes; to investigate collective-motion phenomena in compound nuclei; and to study phenomena important to understanding fission and fusion processes.

At LANSCE, moderators are placed adjacent to the production target to slow down the energetic neutrons produced by the intense proton beam from LAMPF. A proton storage ring, commissioned in 1985, alters the intensity, time structure, and repetition rate of the pulses. With these unique capabilities, we can measure properties never before possible, and by applying the techniques used in nuclear-physics work to condensed matter, we can explore the dynamics of material structures.

## What goes on in a nuclear reaction?

When a neutron hits a nucleus, several types of nuclear reactions can be initiated. The neutron may be captured to form a hot, unstable compound nucleus; it may simply scatter; or it may knock out a proton or some collection of protons and neutrons. Moreover, neutrons can initiate fission—a common reaction that produces nuclear energy for nuclear power and nuclear weapons. Fission occurs when nuclei split in two and release a large amount of energy. At the WNR Facility, we are exploring neutron-induced fission in compound nuclei by bombarding a uranium target with a wide range of fast-moving neutrons to study various temperature-dependent reactions never before observed experimentally.

Although a number of models for nuclear reactions already exist, we either determine which one of these models is appropriate for describing a certain reaction or we develop a better model. The Physics and Theoretical Divisions at Los Alamos work together to test these reaction models by analyzing experimental data. Because the data needed for applied calculations are not easily measured in the laboratory, we often rely on well-tested and verified models. In a very real sense, we are developing improved tools for use in laboratory programs.

## From defense research to applications in health and environment, energy, and space exploration

In support of the defense program, we are studying the interactions of neutrons with very small quantities of radioactive isotopes to improve radiochemical tracers used as diagnostics in underground nuclear tests. The radioactive elements are produced in a nuclear device through neutron interactions with suitably chosen materials. After a device has been fired, samples of the radioactive debris are recovered and sent to Los Alamos for analysis. Interpreting the results requires knowledge of both the production and destruction of these isotopes. For example, beryllium-7, a short-lived isotope formed in a thermonuclear explosion, provides us with information about how the nuclear device performed. Unfortunately, most of this isotope is destroyed by neutrons released during the explosion. Earlier interpretations of the results relied entirely on unverified theoretical calculations and inaccurate data. Our unique capability allowed us, for the first time, to measure the actual "burn-up" rate of beryllium-7 for energies ranging from thermal to 13 kilo-electron volts, therefore freeing us from doubt cast on earlier measurements and allowing us to

Photo by Robert Pena CN90 3258

*Dr. Wini Parker and Chris Zoller developed a novel triple-coincidence apparatus to measure the spectrum of neutrons produced in coincidence with fission fragments emitted when uranium-238 is struck by energetic neutrons. The neutron beam enters from the right and exits to the left through the blue pipe. The six detectors used to measure the outgoing neutrons are the black components surrounding the chamber. Inside the chamber is an array of 38 solid-state, fission-fragment detectors.*

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reliably use beryllium-7 in weapons diagnostics.

Our experiments support the Laboratory's weapons programmatic needs; however, we also perform basic scientific research parallel to, and often as a spin-off from, research for the weapons program. As such, recent efforts, which began in the neutron and nuclear science group, led to new discoveries of physical phenomena that may solve one of our country's most pressing and controversial problems—the buildup of radioactive waste from industry and research. Furthermore, if this research proves practical, it could possibly be applied to the safe production of electrical energy from fission using an accelerator.

The long-term effects of radiation on humans have traditionally had an impact on nuclear research and industry. Much of our knowledge of these effects has come from studies involving the survivors of Hiroshima and Nagasaki. We are re-evaluating the information needed to calculate how energetic neutrons are converted into gamma rays when they interact with nitrogen—the most abundant element in air. From these experimental results, we should obtain more accurate calculations on how much of a dose an individual receives from gamma rays and neutrons. We are also investigating the effects of space radiation on human tissue and on sensitive electronic components needed for space explorations. Furthermore, neutron irradiation as a treatment of certain types of tumors depends on our understanding of how neutrons interact with tissue elements, particularly carbon and oxygen. We are measuring nuclear reactions at Target 4 to learn more about these interactions to provide a reliable data base for biomedical research and therapy.

The impact of neutron research conducted at the WNR Facility will extend to other planets when, in 1992, a mission will be launched to "map out" the elemental composition of Mars. A neutron and gamma-ray detector, carried onboard the spacecraft slated for the Mars Observer Mission, will be part of an experiment designed to measure the neutrons produced by the interaction of cosmic rays with the surface materials on Mars. At Target 2, we filled a container with a mixture of simulated "Martian sand." We then bombarded it with the proton beam from LAMPF to measure the energy spectra of the emitted neutrons. These experiments

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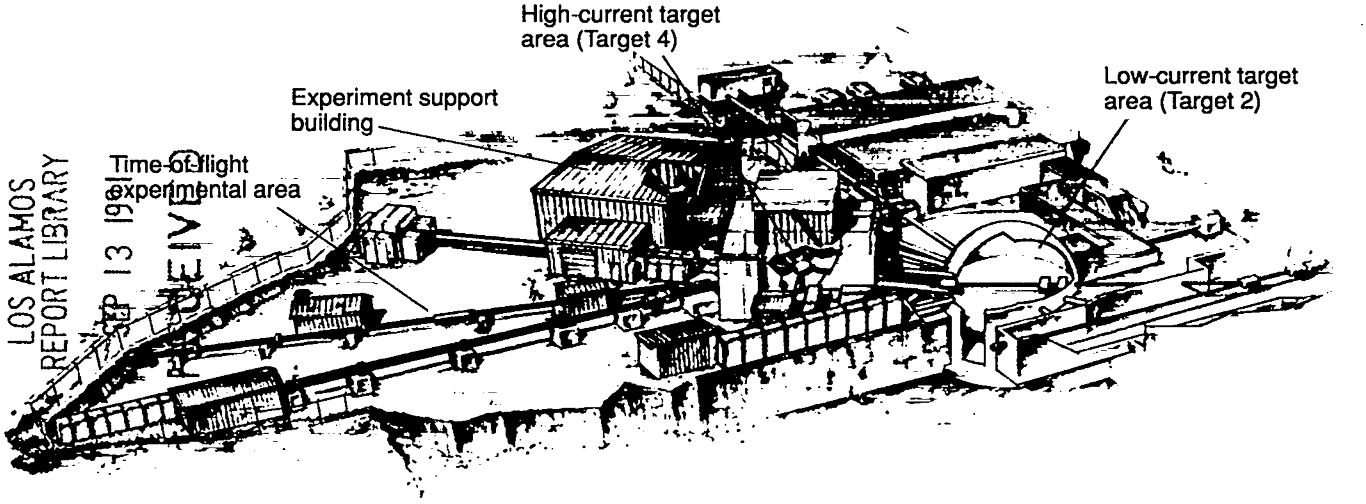

*The Weapons Neutron Research Facility. The beam from LAMPF enters from the right inside the proton beam line (red). It makes a 30-degree bend before entering the dome-shaped, low-current area—Target 2. For most experiments, the beam is delivered through Target 2 into Target 4, a high-current area. Neutrons then pass out of Target 4 through iron and polyethylene collimators and are used in the time-of-flight experimental area shown in the left portion of the illustration. The olive-colored buildings are for experiments located along neutron time-of-flight paths. Those above grade from Target 4 are shown in red; those below grade from Target 2 are shown in silver. LANSCE, not shown here but discussed in the text, is located in the bottom right-hand corner.*

offered us a unique preview of what we should see from the Martian surface before the actual mission is launched. Our results confirm that the sensors onboard the spacecraft will give us important information about the planet's geochemistry and evolution.

By studying nuclear physics with neutrons, we can test the effects of two of the four known forces in nature—the weak and strong—without interference from the other two. The weak and strong forces are of special interest because they exist at deep levels within the nucleus. We are performing the most sensitive experiments in the world to study the effects of the weak force within the nucleus. (The weak force is ten-million times weaker than the strong force, which binds the nucleus together.) To accomplish this task, we are using an intense polarized beam at LANSCE to measure processes that violate the symmetry of parity conservation—that is, we can observe processes that are different from those that would occur in a "mirror" world. In most of our experience with physical phenomena, anything that happens in the "real" world is indistinguishable from what would happen in a world that is its mirror image. LANSCE will also be used to study time symmetry (or time reversal invariance) with unprecedented accuracy. Time reversal invariance implies that reactions should be the same whether they occur forwards or backwards in time. A measurement of a violation of this hypothesis could possibly be the single most important scientific accomplishment at Los Alamos in the past forty years.

We are currently working at the interface of nuclear-physics and condensed-matter research. Strong transient conditions (applying stress or pressure to material or varying its temperature or velocity over a short time period) change the properties of materials. A wealth of information on the density and unit-cell structure of the atoms of different materials can be gathered from diffraction patterns produced when neutrons pass through the material. Because individual LANSCE pulses are spaced 50 milliseconds apart, we were able to develop a "snapshot" technique that produces a sequence (much like a motion picture) of diffraction spectra. This technique allows us to watch the material move through a variety of phase transitions, such as solid to liquid. These dynamic studies can be used to examine problem areas in welds or to measure the buildup of strain in rapidly rotating machinery to try to predict beforehand where the point of failure will occur. Dynamic studies can also be applied to annealing processes by which material is heated and then cooled to remove internal stresses and to make it less brittle. This information may be extremely important for developing new or improved materials used, for instance, in the design of automobiles, spacecraft, power reactors, and weapons.

## Where do we go from here?

Despite an ongoing effort to understand nuclear forces and reactions and the composite structure of the nucleus, much of what goes on inside the nucleus remains a mystery. Unlike the well-understood electromagnetic interaction, which governs processes at the atomic level, the weak and strong forces are very complex as they govern interactions at the subatomic level. Progress in nuclear science over the next few decades will depend on how well we can probe the nucleus. The WNR Facility, with its high intensity and very broad range of energies, will, in one sense, become the "microscope" through which we can penetrate the complexity of nuclear processes, gain a better understanding of the fundamental workings of the nucleus, and investigate exciting applications.

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