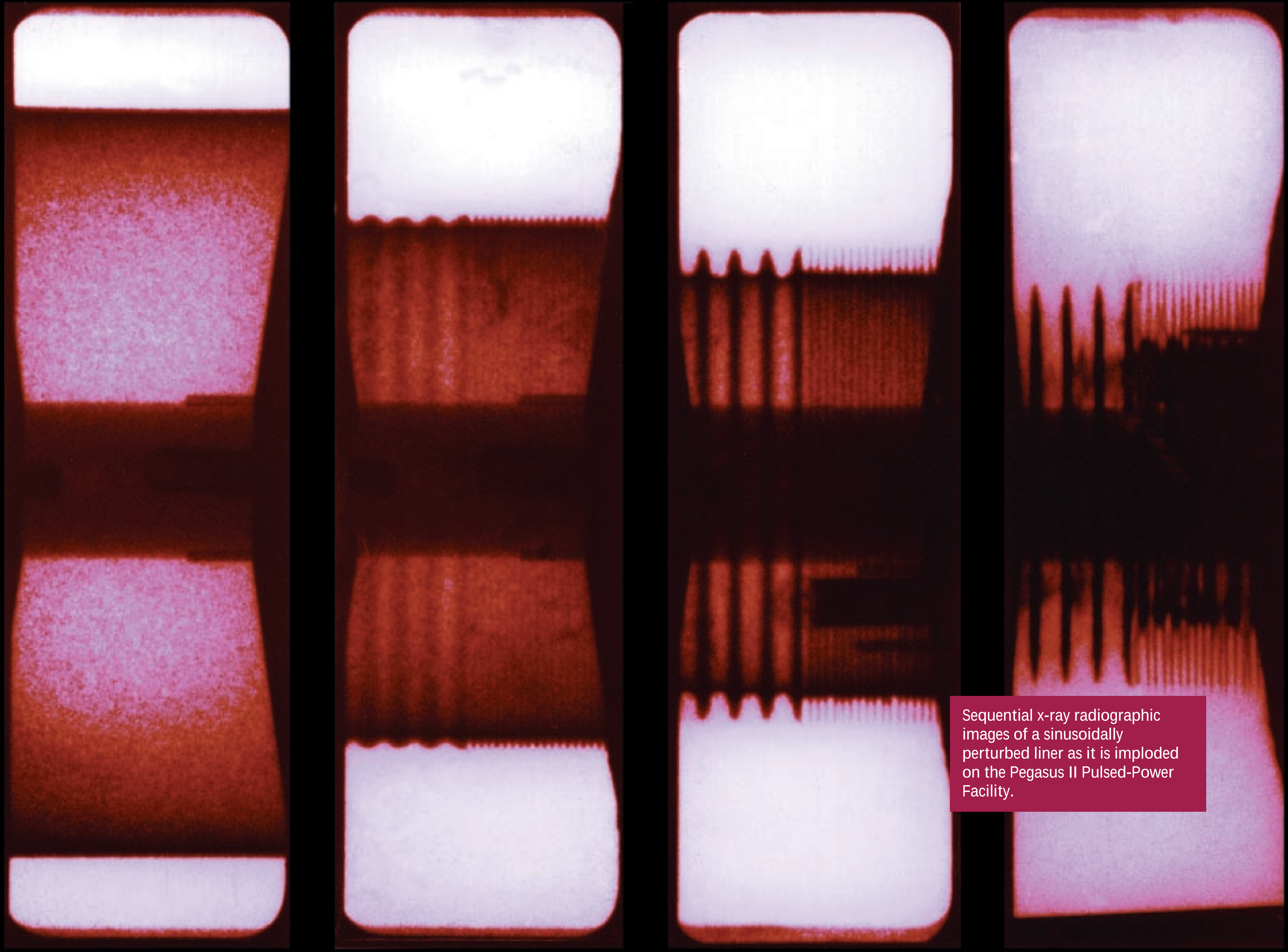

Sequential x-ray radiographic images of a sinusoidally perturbed liner as it is imploded on the Pegasus II Pulsed-Power Facility.

III. Project Descriptions

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P-21: Biophysics

Neuromagnetic Mapping of Multiple Visual Areas in Humans

C. J. Aine [(505) 665-2551], H.-W. Chen, J. S. George, M. Huang, J. C. Mosher (P-21), D. Ranken, E. Best (CIC-12)

This NIH (National Institutes of Health) project includes a series of experiments aimed at identifying and characterizing multiple visual areas in the human brain. These studies employ stimulus manipulations that have been shown in nonhuman primates to differentially activate specific cortical regions (e.g., regions with color or motion processing). Magnetoencephalography (MEG), in conjunction with magnetic resonance imaging (MRI), is used to determine the locations and arrangement of multiple visual areas in the human cortex and to probe their functional significance. In addition to suggesting human parallels to the nonhuman primate results, the proposed experiments provide an opportunity to discover new properties of the human visual system that may not exactly parallel those in nonhuman primates or expectations from other data in humans. For example, results obtained during the preceding project period on the retinotopic organization (point-to-point projection of the visual field onto areas of the brain) of the human visual cortex suggest that although the functional anatomy of the human occipital cortex corresponds in general terms to the "cruciform model" derived from lesion and human event-related potential (ERP) data, there are important differences revealed by the combination of magnetic measurements and anatomical MRI (Aine et al., "Unexpected Features of Retinotopic Organization in Human Visual Cortex Revealed by Neuromagnetic Mapping," in "Physics Division Progress Report, January 1, 1994–December 31, 1994," G. Y. Hollen and G. T. Schappert, Eds., Los Alamos National Laboratory report LA-13048-PR [November 1995], p. 36). We have also made a new and unexpected finding: the cingulate cortex in the central/frontal regions is not only responsive to visual stimulation but also appears to have some crude retinotopy. Because this region shows evidence of retinotopy, it should be classified as a visual area. This result has not been shown in invasive monkey studies because this region is too difficult to access in monkeys.

Identification of Two Streams of Visual Processing Using Magnetoencephalography, Functional Magnetic Resonance Imaging, and Positron Emission Tomography

C. J. Aine [(505) 665-2551], J. S. George (P-21), H. Schlitt, J. B. Shah, J. B. Krause (Institute for Medicine, Research Centre Juelich [KFA] 52425 Juelich, Germany), D. Ranken, E. Best (CIC-12)

Recent studies in nonhuman primates and noninvasive functional imaging studies in humans suggest the existence of two streams of processing visual information, labeled the "dorsal" and "ventral" streams, that represent two different paths of activation along the cortex. The dorsal stream progresses from the occipital to the superior parietal cortex and is associated with processing spatial location and motion. The ventral stream (arrayed along the inferior occipital and temporal cortex) is associated with the processing of color and form. Anatomical and physiological studies indicate that these two streams differ in terms of their sensitivities to stimulus parameters such as luminance, spatial frequency, temporal frequency, and chromatic cues. In collaboration with the German National Laboratory in Juelich, we acquired positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and magnetoencephalographic (MEG) data in the same six subjects in order to separate the streams of processing in the visual cortex. Responses to a stimulus containing a combination of features that preferentially excite the dorsal stream are being compared with responses to a stimulus containing features that should preferentially excite the ventral stream. Two different stimuli (circular with radially symmetric sinusoidal variation in either color contrast or luminance, using a black background and the highest possible contrast) were presented in the lower right visual field. The stimulus designed to activate the ventral stream was 3.5-deg in diameter, isoluminant, placed foveally, with a spatial frequency of 4.5 cycles/deg, and alternated at 2 Hz. The luminance of the red and green bands was adjusted to be equal for each subject. The larger (7.3-deg-diameter) isochromatic stimulus with luminance cues was placed as peripherally as possible, within the limitations of the hardware. The spatial frequency of the yellow bands was 3.5 cycles/deg, and alternated at 4 Hz. In all subjects, the activation evident in the primary visual cortex, for both fMRI and MEG measures, was found to be more anterior when the stimulus was presented more peripherally. Activations evoked when the stimulus was located more foveally were more posterior. This result reveals retinotopic organization. As predicted, more regions of activation were evident in the ventral slices for the foveal stimulus (of isoluminant color) than for the more peripheral stimulus containing luminance cues. Activity associated with the more peripheral stimulus was more medial and dorsal, in general.

Ultrasensitive Genetic Analysis

Alonso Castro [(505) 665-8044] (P-21)

Our research group focuses on the development of laser-based techniques for the ultrasensitive detection and analysis of biological molecules and the application of these techniques to molecular biology and medical diagnosis. We have recently developed a procedure for the rapid, direct detection of specific nucleic-acid sequences in biological samples. This method is based on a two-color, single-fluorescent-molecule detection technique. The basis of our approach is to monitor for the presence of a specific nucleic-acid sequence of bacterial, human, plant, or other origin. The nucleic-acid sequence may be a DNA or RNA sequence and may be characteristic of a specific taxonomic group, a specific physiological function, or a specific genetic trait. The detection scheme involves the use of two nucleic-acid probes that have sequences that are complementary to the nucleic-acid target. The two probes are labeled with two different fluorescent dyes. If the target is present when the probes are mixed in the sample under investigation, both probes bind to the target. The sample is then analyzed by a laser-based ultrasensitive fluorescence system capable of simultaneously detecting single fluorescent molecules at two different wavelengths. Since the probes bind to the same nucleic-acid target fragment, their signals will appear at the same time. Thus, the simultaneous detection of the two probes signifies the presence of a target molecule. When there is no target present, the probes will emit signals after illumination that are not coincident in time.

Studies of the Human Visual System Using m-Sequences and Sparse-Stimulation Techniques

H.-W. Chen [(505) 667-0825], C. J. Aine, E. Flynn, C. C. Wood (P-21), E. Best, D. Ranken (CIC-12)

The m-sequence pseudorandom signal has shown itself to be a more effective probing signal for studying nonlinear biological systems using cross-correlation techniques than the traditional Gaussian white noise. However, anomalies occurring in the measurements of second- and higher-order cross-correlations become obstacles to the m-sequence being more widely used in studying nonlinear systems. In these studies, a new approach using a short m-sequence as a probing signal together with the “padded sparse-stimulation” method is proposed. Simulation results showed that when using the sparse-stimulation method the estimation errors caused by anomalies will be greatly alleviated even for a short m-sequence. Another advantage of the padded sparse-stimulation method is that it can obtain all the information of the second- and higher-order kernels, whereas the traditional “inserted sparse-stimulation” method could not obtain all of the information of a nonlinear system. The new approach has been applied to neuromagnetic studies of the human brain. The weak neuromagnetic responses were stimulated by light modulated by short m-sequences

(1023 in length for binary and 728 in length for ternary) and measured by highly sensitive SQUID (superconducting quantum interference device) sensors located on the scalp of the human head. Cross-correlations with high signal-to-noise ratios were obtained, which show that the proposed methods in these studies are well applicable to the study of practical systems. These methods will be useful for both basic research and clinical applications.

Automatic Source Localization Procedures for MEG

M. Huang [(505) 665-6133], C. J. Aine, J. C. Mosher (P-21), E. Best (CIC-12), S. Supek (Department of Physics, Faculty of Science, Bijenická c. 32, 10 000 Zagreb, Croatia)

Cortical brain activity encountered in magnetoencephalography (MEG) studies can usually be modeled as electric current dipoles, if the regions of activation are relatively focused. The dipole location, orientation, and moment parameters are determined by fitting the measured data with a nonlinear minimization procedure. Due to the existence of many local minima and the properties of various minimization techniques, such minimization in a high-dimensional search space is usually very sensitive to the initial guesses when the number of modeled dipoles is greater than one. Manually selecting initial guesses is a time-consuming procedure, and if the initial guesses are not close enough to the global minimum, the calculation may fail to find the global minimum and become trapped in the local minima. Therefore, it is necessary to find an automated procedure to effectively handle the multiplicity of local minima. In this project, the performance of a number of global-minimization techniques applied to MEG is studied. These techniques include: (1) Multi-Start Downhill Simplex, (2) Genetic Algorithm, and (3) Simulated Annealing. These algorithms are tested for different simulated noise conditions (different noise levels and white noise versus color noise) and head models (a spherical head model and a real-shape head model). In addition to the simulated conditions, we will examine the algorithms using empirical MEG data collected with 122 channels from the whole-head Neuromag system.

Spatio-Temporal Magnetoencephalography and Electroencephalography Source Estimation

J. C. Mosher [(505) 665-2175], M. Huang, C. C. Wood (P-21), R. Leahy, J. Phillips, M. Spencer (University of Southern California Signal and Image Processing Institute, Los Angeles, California)

MEG and electroencephalography (EEG) provide unique views of the dynamic behavior of the human brain because they are able to follow changes in neural activity on a millisecond time scale. There is a clear need both for the development of new algorithms that exploit the most recent advances in sensor design, signal processing theory, and other functional and anatomical imaging modalities, and for a detailed study of the limitations of these and existing inverse procedures. LANL is a subcontractor to the University of Southern California on a three-year National Institute of Mental Health grant to develop such algorithms and to distribute the software and phantom data generated by this research. In addition to providing a suite of thoroughly tested inverse procedures, we anticipate that this work will provide insight into the fundamental limitations of EEG- and MEG-based source estimation.

Nuclear Magnetic Resonance Imaging with Hyperpolarized Noble Gases

D. M. Schmidt [(505) 665-3584], J. George (P-21), S. I. Penttila (P-23), A. Caprihan, E. Fukushima (The Lovelace Institutes, Albuquerque, New Mexico)

Several novel aspects of nuclear magnetic resonance (NMR) or MRI with hyperpolarized noble gases have recently been demonstrated, including the ability to easily image gas-filled spaces and to transfer part of the polarization to other nuclei. Using these new techniques, we have been investigating diffusion. We hyperpolarized ^{3}He by applying laser-optical pumping in the presence of rubidium molecules. We obtained one-dimensional images of ^{3}He gas diffusing in a slice that was tagged by inverting its magnetization, a technique previously used for observing the diffusion of thermally polarized ^{129}Xe gas. Also, a one-dimensional diffusion image of the gas was made with and without a temperature gradient present. Our results show that temperature changes can be monitored by diffusion images of ^{3}He gas.

Biomorphic Walking Machines for Unattended UXO (Unexploded Ordinance) Detection

M. W. Tilden [(505) 667-2902] (P-21)

The purpose of this project was to demonstrate the feasibility of building an automatic system for locating and, eventually, destroying UXO on military test ranges. The system would consist of three parts: sensors, legged robot platforms to carry the sensors, and an interface to connect the sensors and robots to implement a search strategy. In this first year, it was decided to concentrate on the development of robots capable of surviving harsh (Yuma desert) environments while carrying minimal sensor payloads. The robots are distinguished by the nervous-net (Nv) analog design, which is very inexpensive and is based on biological organism control. This design avoids the complexity and cost of computer-based systems and allows the use of inexpensive, off-the-shelf components. In September 1996 the most successful of the legged-walker prototypes was tested on a Yuma range, and, using a prototype Nv magnetic gradiometer sensor, found its footing, True North, and a mock magnetic mine during repeated trials. It was the first such device in the history of the range to perform these actions with complete autonomy and under full desert conditions (ground temperature ≅ 140°F). Work is proceeding now on a solar-powered version with a weeks-long survival potential and on more sophisticated magnetic sensors for true UXO detection.

Biomorphic Control of Autonomous Spacecraft

M. W. Tilden [(505) 667-2902] (P-21), J. R. Frigo, K. R. Moore (NIS-1)

The objective of this project is to define a mission to continuously monitor the characteristics of a major portion of the terrestrial magnetopause. This would be accomplished using one hundred or more biomorphically controlled, autonomous microsatellites with simple sensors. The mission would capitalize on highly innovative and radically smaller and cheaper satellite and sensor technologies that are currently under development by NASA, the Department of Defense (DoD), and DOE. This is a first step toward defining a useful, minimal microsatellite design for the future and is relevant to all areas that use spacecraft platforms. Toward this, we presented an application of a technology that seems, in experiment, to overcome most of the problems normally present in space missions: complexity, reliability, redundancy, and cost. Although the nervous-net (Nv) control method could be adapted to most types of machine control, we have applied it to autonomous satellite control because of the difficulty that conventional control systems have in solving the seemingly simple task of negotiating complex magnetic gradients. Over a dozen "nanosat" magnetic gradiometer prototypes were built and studied in a range of magnetic fields; analyses were performed, papers published, and a prototype presented at NASA and JPL workshops. The conclusions are that Nv systems could trivialize the cost of small-scale (20-g) satellite systems, and work is progressing toward a larger (200-g) prototype to assess payload control and handling requirements for commercial platforms.

Nonlinear Analysis of Nervous-Net (Nv) Designs

M. W. Tilden [(505) 667-2902] (P-21), B. Hasslacher (T-13)

Three years of studying experimental Nv control devices has resulted in various successes and several amusing failures that have implied some general principles on the nature of capable control systems for autonomous machines and, perhaps, biological organisms. These systems are minimal, elegant, and, depending upon their implementation in a "creature" structure, astonishingly robust. Their only problem seems to be that since they are collections of nonlinear asynchronous elements, only a very complex analysis can adequately extract and explain the emergent competency of their operation. The implications are that so long as Nv nonlinear topologies can retain some measure of subcritically coupled planar stability, the Piexito theorem will guarantee a form of plastic mode-locking necessary for broad-behavior competency. Further experimental evidence also suggests that if Nv topologies are kept in subchaotically stable regimes, they can be implemented at any scale and still automatically fall into effective survival strategies in unstructured environments. The conclusion is that Nv controllers have the power to scale, both physically and dimensionally, into any range of tasks that would otherwise require sophisticated programming. Research continues into understanding how such devices can converge their skills to evolve retentive abilities similar to neural-net structures, resulting in capable learning machines that have a trivial setup cost.

Autonomous Self-Assembling Robotic Mechanisms

M. W. Tilden [(505) 667-2902], M. S. Moses (P-21)

This research is aimed at the study, development, and integration of minimal nervous-net (Nv) artificial agents and the principles that allow for their elegant design, operation, organization, and self-assembly. Previous work along these lines (by Hasslacher and Tilden) has hinted that the field of nonlinear dynamics may provide important, broad principles with which we can promote the survival of active, robust devices in unstructured environments. Advances in this area will allow for the design of devices that are "smart enough" for a task without the usual cost-intense complexity that accompanies traditional robotic construction. Since the start of the project, 18 self-contained "assembler bots" have been built and studied in our robot "Jurassic Park." New control systems have been devised to allow these devices to power-mine their environment—exploiting the available light-energy sources—without having to resort to internal batteries. Future work will examine and promote the development of these mobile machine components so that they may act as coordinating organs in sophisticated robots for application-specific tasks, creating a form of "living Lego" with inherent self-repair and self-optimization characteristics.

P-22: Hydrodynamic and X-Ray Physics

Subcritical Experiments: Data Recording

G. Allred [(505) 667-2497], D. Bartram, T. Petersen (P-22)

The JTO-1 trailer at the Nevada Test Site (NTS) provides much of the high-speed data-recording capability for the P-22 activities in the U1a underground complex. Amplitude calibration and absolute timing of approximately 200 data-recording channels have been performed, using simulated signals generated in the downhole "zero" room that are transmitted in some cases over fiber-optic links. While preparation continued on the first subcritical event (Rebound), dry runs were performed on a routine basis to confirm system reliability.

Radiation Science

R. Bartlett [(505) 667-5923], J. Benage, G. Idzorek (P-22)

P-22 is collaborating with other Los Alamos groups and with Sandia National Laboratories (SNL) personnel on several pulsed-power radiation-driven campaigns on PBFA-Z (the Z-pinch radiation driver at SNL). The two most active efforts at this time are the Integrated Compression Experiment and the Dynamic Hohlraum Experiment. In the former experiment, several aspects relevant to weapons physics are addressed simultaneously, with the result that designs and codes can be tested in an integrated manner. In the Dynamic Hohlraum Experiment, the goal is to create high-temperature hohlraums and to drive inertial confinement fusion (ICF) capsules by using the pinch itself to form the hohlraum. By using the pinch or the end-on radiation to drive the experiment, more energy will be available than would be possible through the more conventional approach of radially coupling the radiation from the pinch to a secondary hohlraum.

P-22 is involved in the definition of the experiments and in fielding diagnostics on the shots. We also analyze and interpret the results. In the past we have fielded filtered silicon diode arrays, pinhole cameras, and a transmission-grating spectrometer. We have also been involved in the calibration of these instruments at the National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory (BNL), where Los Alamos owns and maintains three synchrotron beamlines. Calibration of these instruments is very important to the interpretation of the results.

High-Explosive Pulsed Power

D. Bartram [(505) 667-2501], G. Allred, O. Garcia, T. Petersen, J. Stokes, L. Tabaka (P-22)

P-22 is working with DX Division, preparing for a series of upcoming tests at the Lawrence Livermore National Laboratory (LLNL) facility in Area 4 at NTS known as BEEF (Big Experimental Explosive Facility). These tests, Ranchito, Ranchero, and Caballero are part of the High-Explosive Pulsed-Power (HEPP) program.

P-22 is performing the diagnostic recording for all of these experiments. These will include Faraday rotation, Rogowski loops, B-dots, and voltage probes. The first shot, Ranchito III, will be recorded by the LLNL bunker personnel under the guidance of P-22 and DX-3. Subsequent experiments are planned to be recorded in a P-22 trailer that will be moved into a recently completed protective enclosure. Current plans and support funding (from Bechtel Nevada) suggest that there will be two experiments in FY97 and some preliminary work for a third.

The facility is currently completing two years of development and certification. The first official experiment to be performed will be the LANL Ranchito III shot, which is currently scheduled for the first week in March 1997.

Radiation Source/Switch Development

J. Benage [(505) 667-8900], R. Newton (P-22), F. Wysocki, T. Ortiz (P-24)

The radiation-source project has been focused on the development of a plasma flow switch for use on the Atlas pulsed-power facility when it becomes operational in FY 2000. This switch consists of two components: an aluminum wire array and a plastic barrier film. The switch works by carrying an electric current for a few microseconds, during which the switch moves down a coaxial transmission line driven by the magnetic force from the current. It then transfers the current to another area, called the load region, as it passes by. This allows the machine to provide electric current to the load region on a time scale much shorter than the natural time scale of the machine, which is necessary if the Atlas facility is to be used to produce a radiation source for weapons-physics experiments.

The effort in this past year has been focused on the initial conditions produced in the switch plasma and on how to manipulate these conditions. We have done a series of experiments on the P-24 Colt facility and the P-22 Pegasus II facility. These experiments indicate that our past designs have not produced the right conditions in the switch. The plasma does not assemble as a single switch but seems to come together in two pieces, creating a thick plasma sheath and not producing in the coaxial conductor the current rise times that are needed. We believe the reason for this is that the machine parameters are not well matched to the requirements for this initial formation. We are planning another set of experiments on Colt in the near future to investigate this discrepancy between parameters and requirements in more detail and to attempt to design a slightly different switch to compensate for the machine parameters available to us. The overall goal is to understand this initial formation process and to determine what is required to get the best performance. Once we have reached this goal, we are planning more experiments to investigate the interaction of the switch with whatever is in the load region. This effort will move us a long way toward a working switch for Atlas.

Dense-Plasma Equation-of-State Project

J. Benage [(505) 667-8900], J. Workman (P-22), G. Kyrala, S. Evans, P. J. Walsh (P-24)

The purpose of the dense-plasma equation-of-state (EOS) project is to measure the EOS of aluminum under dense-plasma conditions. By "dense plasma" we mean material that is 0.1–1.0 times the solid density of aluminum and has a temperature of tens of electronvolts. These conditions are such that the material is ionized and in the plasma state, but interactions between particles in the plasma are very strong and the linear theories used to describe the properties of the plasma are no longer valid. It is under just such conditions that the thermodynamic properties of materials are least well known and where there are no data available to compare to theory.

We have designed a novel way of producing a dense plasma and will use a standard technique for determining the EOS of this plasma. The standard technique, which has been mainly used on solids, is to produce a shock and then measure the velocity of the shock and the density of the material in front of and behind the shock. Using these measurements and the conservation equations across the shock front, one can determine the density, pressure, and internal energy of the material and thus the EOS of the material under those conditions. We produce our plasma by using a small capacitor bank to electrically heat an aluminum wire to a temperature of ~2 eV. This aluminum plasma is allowed to expand into a vacuum through a rectangular slit, producing a uniform plasma that is used as a target for a powerful laser. The laser is focused onto this plasma, producing a shock that propagates through it. We then use an x-ray backlighter to image this plasma and measure its density and the velocity of the shock.

We have begun preliminary measurements of the x-ray backlighter source and have nearly completed construction of the new capacitor bank that will be used to produce these plasmas. We will soon be testing this bank and using the backlighter to make preliminary measurements of the target plasma we produce. We have also begun construction of the laser needed for producing the shocks in the plasma, and we expect this laser to be completed by August 1997, at which time we expect to begin measurements of the EOS of the plasma. We are also in the process of designing and constructing an x-ray microscope for imaging the shock propagation through the plasma. This diagnostic should also be ready for operation in August.

Optical Constants Research on LANL Synchrotron Beamlines

R. L. Blake [(505) 667-7369] (P-22)

A program of measuring atomic constants has been active on LANL beamlines for seven years. Our experience and precision x-ray spectrometer/reflectometer, combined with existing LANL beamlines at NSLS at BNL, place us in a unique position to contribute high-accuracy (~0.1%–1% 3σ-error) measurements of both the real and imaginary parts of the complex dielectric constants of elements and materials. We are able to make these measurements over a wide energy range, from 50 eV to 15 keV, including all of the edge structure that is largely nonexistent in literature compilations for most of the energy range. The hardware and computer software is transportable between LANL beamlines.

From combined reflectivity and transmission measurements, we have provided new or improved optical constants of gold, iridium, molybdenum, palladium, and platinum over the energy range 2–15 keV. Iridium and the polymer polyimide ($C_{22}H_{10}O_4N_2$) have also been measured from 50 to 1000 eV. Measurement precision has varied from 0.1 to 1.0 percent, depending on the beamline and the circumstances. Present accuracy of a few percent will soon be improved to better than one percent by using multiple techniques to refine the sample thicknesses and smoothness. Detailed measurements through the M-edges of gold, platinum, and iridium have provided new values of the x-ray absorption edge energies that differ by 30 to 40 eV from photoelectron spectroscopy binding energies. These differences have been explained with atomic modeling for gold; they are due to the slow onset of the 3*d* * *f* transition. Further band structure modeling confirms this explanation and confirms the observed x-ray absorption fine structure as well.

Self-Directing Elastic-Backscatter Lidar

D. A. Clark [(505) 667-5054] (P-22), collaborators from NIS and Bechtel Nevada

Lidar (light detection and ranging) has many applications in the fields of atmospheric research and environmental monitoring. Elastic-backscatter lidar, also called Mie lidar, can “see” aerosols in the air, even if the concentration is very slight and the aerosol cloud is not visible to the eye. Elastic-backscatter lidar systems have been used to detect aerosol emissions from industrial stacks and debris clouds from transient events such as above-ground explosions. However, they have not been used to track the path of debris clouds or to map cloud evolution.

A new adaptive, scanning, self-directing, elastic-backscatter lidar that automatically tracks and maps isolated clouds has been developed at Los Alamos. It has been used to gather cloud data from two above-ground explosive tests. Accurate cloud volume, density distribution, and track information was obtained from small, fast-moving, low-density, invisible debris clouds. The new lidar control system utilizes the backscatter signal itself to direct the lidar toward the cloud and minimize the scan dimensions. As the cloud evolves, both spatially and temporally, the system dynamically readjusts the scan to cover the entire volume of the cloud. Confinement of the scan region to the immediate vicinity of the cloud allows more scans in a given time, producing high-resolution information during the cloud evolution.

Cloud-tracking lidar can be used as part of an environmental monitoring program to assess the migration of emissions from transient events. It can also direct other remote-sensing devices for species identification.

High-Energy Liner Experiment

D. A. Clark [(505) 667-5054], T. Petersen, L. Tabaka, B. Anderson (P-22), collaborators from the NWT Program office, DX, and X Divisions

Magnetically driven, imploding liner systems can be used as a source of shock energy for materials EOS studies; implosion-driven, magnetized-plasma fusion experiments; and similar applications. Such systems can play an important role in support of nuclear-weapons stockpile stewardship by allowing us to verify our abilities to perform accurate calculations. The imploding liner is a cylinder of conducting material through which a very high current is passed in the longitudinal direction. Interaction of the current with its own magnetic field causes the liner to implode at high velocity. Experiments requiring high-velocity impact or volume reduction are placed at the center of the liner. In order to be effective, the liner must remain in a condensed state (not vaporized), retain its cylindrical shape (liner stability), and attain a high velocity during the implosion. In order to meet these requirements, liners must be thick and of large diameter, be manufactured to precise tolerances, and have high convergence ratios. High energy is required to move these heavy liners. Robust and accurate diagnostics are needed to measure the liner performance and target responses.

In August 1996, a collaboration of scientists from LANL and the All-Russian Scientific Institute of Experimental Physics (VNIIEF) of Sarov, Russia, conducted a high-energy liner experiment in Sarov. It was the highest-energy and largest liner experiment ever performed. The purpose of the experiment was to measure performance of the explosive pulsed-power generator and the heavy imploding liner, to test the capabilities of various diagnostics under extreme conditions, and to obtain data for comparison with performance calculations. A 5-tier, 1-m-diameter explosive disk generator provided electrical energy to drive a 48-cm-outside-diameter, 4-mm-thick aluminum-alloy liner having a mass of about 1 kg onto an 11-cm-diameter diagnostic package.

The experiment was a great success. Peak current was greater than 100 million amperes and the liner kinetic energy was more than 20 megajoules. Results of this American-Russian collaborative effort will provide needed information for improved performance in future high-energy liner systems.

Nuclear Weapons Archiving Project (NWAP) in P-22

K. Croasdell [(505) 667-2483], D. Bartram, G. Idzorek, J. Lamkin, D. Mills, J. Pelzer, D. Thayer, B. Wright, C. Young, L. Zongker (P-22)

Several objectives and priorities for Science-Based Stockpile Stewardship (SBSS) have been established by LANL and the nation as a whole. Weapon-design competence is presently viewed as the cornerstone of this stewardship. In the absence of any new nuclear testing, designing nonnuclear physics experiments and applying new computational skills to past NTS data will be important steps in the development of our predictive capability and in the improvement of our ability to solve unanticipated nuclear-weapons problems.

P Division is the steward of much of the data recorded in past NTS tests. Collecting the data, putting it into a usable format, and maintaining the expertise required for interpretation of the data are crucial tasks for the present group of weapons-physics scientists in P Division.

In P-22, NWAP has grown from a funding base of $100 K in FY94 to $1.21 M in FY97. We are addressing four major tasks in this project.

Collection/analysis of reaction-history experiments. We completed our review and reanalysis of the reaction-history data from the W76 weapon system in FY95. The actual data files and metadata were placed on the Common Event Data System (COEDS) and have been transferred to LLNL to satisfy requirements of the Dual Revalidation Program. COEDS is a weapons-information database that resides in XCM for the use of the LANL weapons community. In FY96, we concentrated on the W87 and B61 systems. In FY97, we continued to work on the B61 data. New analysis requirements for FY97 include reanalyzing events related to the W80 system and events related to tests that are unusual and not related to a specific weapon system.

Experimental procedure documentation and training. We are using weapons-test data and our staff expertise to document experimental procedures and build a foundation for training future scientists. In FY97 one of our primary tasks is to describe how to perform a reaction-history measurement. We are also updating and expanding a glossary on COEDS of terms that relate to weapons testing. We are writing a general electro-magnetic-pulse (EMP) report, addressing the technical basis for EMP experiments and writing physics reports for several NTS events dating back to the early 1980s. We are working with Bechtel to develop 1990s hardware and software platforms for converting and working with the historical data; this task will occupy us well into FY98.

Collection and analysis of advanced diagnostic experiments. P-22 is learning what advanced diagnostic experiments were fielded and is planning to suggest appropriate reprioritizations of the list of tasks that we are pursuing. Many of these advanced diagnostic experiments were unclassified, resulting in inconsistent organization of the initial archiving of the event. In several instances this deficiency makes it very difficult to locate pertinent data for reanalysis. We are interpreting and documenting shot-physicist notebook quotations to obtain more details of these NTS experiments.

Completion of physics reports on the most recent NTS events. Only two of the six experimentalists involved in the original NTS events still work as full-time staff members for P-22, so completion of this task becomes ever more important. Divider, Whiteface A, Whiteface B, Sundown A, Sundown B, and Junction are the first shots we are examining. Victoria, Lubbock, and Houston will need extensive work. The archiving-project members have contributed information for the P-Division Internal Weapons-Physics Report and to the Nuclear Weapon Technology "Green Book," which describes the procedures for stockpile stewardship.

P-22 will continue to address requests as needed to support the weapons program. Reaction-history data about the W76 were given to LLNL to use in the Dual Revalidation Program, and W87 reaction-history data were collected from LLNL for the X-Division weapons designers to use in the Life Cycle Program. Data archived for the B61 were instrumental in the certification process for the B61 mod 11. We have participated in the interlaboratory information group (NWIG) to establish data-transfer standards between the three nuclear laboratories, the production plants, and the U.K. Atomic Weapons Establishment (AWE). We may perform analyses of U.K. shots if funding becomes available.

High-Speed Multiwavelength Infrared Pyrometer

D. Holtkamp [(505) 667-8082], P. Rodriguez, J. Studebaker (P-22), G. Schmitt (DX-1)

P-22 has assembled a high-speed, multiwavelength infrared (IR) pyrometer for use in Pegasus II and high-explosive (HE) experiments. We expect to be able to measure temperatures between 500 and 1300 K. The unit uses four liquid-nitrogen-cooled detectors (HgMgTe) operating over various wavelength bands between 1 and 5 μm. These detectors are coupled via four 1-mm-diameter IR fibers to a position that views the surface of interest. The instrument has been repackaged by Bechtel Nevada into an electromagnetic-interference- (EMI-) and debris-shielded box for use in pulsed-power and HE environments. The bandwidth of the system is approximately 10 MHz. Improvements are planned that will extend the measurements to colder temperatures and higher bandwidths. Calibrations are currently in progress, and we expect to field the instrument at Pegasus and in HE shots in early 1997.

Radial Radiography at Pegasus II

D. V. Morgan [(505) 665-6679], D. Platts, D. Martinez (P-22), B. Carpenter (P-24)

At Pegasus II, electromagnetically driven implosions in a cylindrical geometry are observed using three radially oriented, flash x-ray sources. Our three x-ray sources backlight the target with tungsten line and bremsstrahlung x-rays with an endpoint energy of approximately 270 keV. The x-ray pulse duration for each source is approximately 20 ns, which is quite short compared to the time scale of the implosion. The radiographs are recorded on film and deliver quantitative information about the position and density of the imploding material. Recent improvements to the three radial x-ray imaging systems include reduced x-ray scattering, improved source collimation, blur reduction, and an improved signal-to-noise ratio. We have developed a computer code that can generate a simulated radial radiograph of both static and dynamic Pegasus targets. Radial radiography was an important diagnostic for Liner Stability, Megabar, Ejecta, and Liner Gap experiments at Pegasus in 1995 and 1996. We expect that radial radiography will continue to provide quality data for future Pegasus and Atlas experiments.

Fiber-Optic Data-Link System

T. Petersen [(505) 665-2786], D. Bartram, G. Allred (P-22), collaborators from Bechtel Nevada

A new fiber-optic link system has been produced in association with Bechtel Nevada to deliver experimental data from hazardous areas to data-recording areas. The hazards that were thus circumvented include both severe electrical and high-explosive hazards. The transmitters are enclosed in an EMI-shielded enclosure that is battery powered for electrical isolation and has fiber-optic-coupled calibration and monitor functions. The optical receivers also have monitor functions. Two different fiber-link modules are interchangeable in this system, a 200-Hz to 75-MHz light-emitting-diode (LED) link and a 2-kHz to 450-MHz laser link. They have a linear signal level of 0.5 V and a signal-to-noise ratio of better than 40 dB. There are about 100 channels available of each fiber link. At present this system is in use on Pegasus II, the Atlas Test Bay, BEEF (at NTS), Ancho Canyon, and the Integrated Test Stand.

Ejecta Experiments at the Pegasus II Pulsed-Power Facility

D. S. Sorenson [(505) 665-2860] (P-23), R. E. Reinovsky (DX-DO), L. D. Smith (DX-5), R. A. Gore, M. G. Sheppard (XNH), G. D. Allred, B. G. Anderson, D. E. Bartram, R. R. Bartsch, D. A. Clark, J. C. Cochrane, W. L. Coulter, F. Garcia, K. Hosack, D. L. Martinez, D. Morgan, D. Ortega, D. Platts, P. Rodriquez, P. Roybal, J. L. Stokes, L. J. Tabaka, L. R. Veeser (P-22), K. Alrick, F. Cverna, N. Gray, M. Hockaday, V. Holmes, S. Jaramillo, N. King, A. Obst, M. L. Stelts (P-23), B. Carpenter (P-24), W. L. Atchison, R. L. Bowers, W. R. Shanahan (XPA), W. E. Anderson, E. V. Armijo, J. J. Bartos, F. P. Garcia, V. M. Gomez, J. E. Moore, L. J. Salzer (MST-7), J. P. Roberts, A. Taylor (MST-11), collaborators from Bechtel Nevada

When a shock wave reaches a solid/gas (or liquid/gas) interface, pieces of the solid or liquid can be emitted into the gas region. This material can range in size from submicron to hundreds of microns and is referred to as ejecta. The amount, size, and velocity of ejecta will depend on material properties such as grain size, surface finish, and the state of the shock wave in the material. Ejecta occur in a nuclear weapon when a shock wave interacts at interfaces between weapon materials and gases. At these interfaces, materials can be injected into the gas, contributing to the mix of weapon materials and gas, which in turn has an effect on the performance of the nuclear device. In order to characterize the ejecta, P Division has developed an in-line Fraunhofer holography technique to make measurements of ejecta in a dynamic system. This diagnostic has been developed and implemented on numerous experiments based at the Pegasus II Pulsed-Power Facility. This facility has the capability of driving many megaamperes of current through an aluminum cylinder (liner) that is 400 μm thick, 10 cm in diameter, and 2 cm high. Physics experiments are performed inside the cylinder, making use of its cylindrical geometry. For the ejecta experiments, a 3.0-cm-diameter target cylinder is placed inside the liner cylinder. When the liner impacts the target cylinder, a shock wave is set up in the target. The shock wave then propagates through the 400-μm-thick target, and at the target/vacuum interface, ejecta are emitted. An additional 1.6-cm-diameter cylindrical collimator with various slit openings is used to control the amount of ejecta that passes through to the axial center. This target assembly consists of three cylinders with the same axis. To make the ejecta holographic measurement, a 60-mJ, 100-ps, 1.5-cm-diameter laser pulse is transported along the collimator axis. The laser beam then interacts with the ejecta, which passed through the collimator slits some time after the liner cylinder impacted the target cylinder. The actual hologram is made when the scattered light from the ejecta interferes with the unscattered laser light (reference beam) at the plane of the film. In order to measure particles a few microns in size, the holographic film should be placed a few centimeters from the ejecta. However, at this distance the film would be destroyed in the experiment. To address this problem, an optical transfer system was developed, which relays the interference pattern 93 cm from the ejecta to the holographic film. The hologram contains information about particles ranging in size from a few microns to a hundred microns in diameter, over a volume of 1 cm^3. In addition to the holography diagnostic, a visible shadowgraphy and dark-field imaging technique has also been developed. This diagnostic does not provide three-dimensional information like holography, but it provides time- and spatially resolved data about the ejecta front as it moves through space. This diagnostic makes use of a long-pulsed ruby laser (with a 450-μs pulse), in which the laser beam passes through the ejecta and a framing camera is used to make time-dependent, spatially resolved shadowgrams of the ejecta. This technique has been applied to many experiments successfully. Ejecta data have been obtained for both aluminum and tin targets for which the target surface finish and shock strength have been varied.

Liner Gap 7

J. L. Stokes [(505) 667-4900] (P-22), P. Brown, M. Fell, P. Jones (Atomic Weapons Establishment, Aldermaston, England), R. D. Fulton, D. Platts, D. L. Martinez, D. M. Oró (P-22), A. W. Obst, N. S. P. King (P-23), B. Carpenter (P-24), P. J. Adams, J. A. Guzik, (XTA), H. Oona (DX-3)

Liner Gap 7 was successfully fired on April 11, 1996, at 2:35 p.m. This was the first test fielded in collaboration with the Atomic Weapons Establishment (AWE) in the U.K. The classified target was designed by Peter Brown and Michael Fell (AWE) and was built by LANL in MST-7 by Wally Anderson and his crew. The process from concept to actualization was completed in a very short period of time: the definition occurred March 9, and the shot was fired April 11.

The normal gap diagnostics were fielded by LANL. These included axial x-ray images at two different times, radial x-ray images at three different times, framing cameras looking at a backlighter for shock position, radial visible imaging at three different times, as well as the normal machine diagnostics. All systems returned good data, and the axial imaging data were the best to date. They showed shock structure that we did not expect to see, but having seen it, we reexamined the calculations and found that it had been calculated before the shot.

We were extremely pleased with the results, as was AWE. As a result of the good-quality data from Gap 7, AWE expects to continue our collaboration on future tests. The next joint test will be in the second quarter of FY97.

In June 1996 we reviewed the Gap 7 data with B-Division members at Livermore, and they were very interested. They have proposed to do tests with us on Pegasus, and we are looking forward to this collaboration as well.

Peter Adams and Joyce Guzik (XTA) are designing Gap targets for the Gap tests in FY97.

Liner Gap Experiments

J. L. Stokes [(505) 667-4900], R. D. Fulton, D. Platts, D. L. Martinez, D. M. Oró (P-22), A. W. Obst, N. S. P. King (P-23), B. Carpenter (P-24), P. J. Adams, J. A. Guzik (XTA), H. Oona (DX-3), E. Chandler, P. Egan (LLNL), collaborators from Bechtel Nevada

We are planning three Gap shots for FY97. The first two shots are planned as a campaign. We have chosen designs for the first two shots from a list of ideas for future shots. Some calculations were done on several of the ideas and one of the more interesting was chosen to be the first shot, in February 1997. The second shot is already designed and will follow a week later.

We are improving the axial x-ray imaging system for the first campaign of Gap shots. The new system will be a single optical path that will be split in the screen room. This will solve the vignetting problem. We also hope to have new cameras for this new system. One small disadvantage will be that there will be only two cameras on this system, which means no redundancy for either image capture. One advantage is that this is a simpler system and should be fielded more easily. This updated system is expected to be in place by the second campaign, which is scheduled for the summer of 1997.

The Dirac Series of Experiments at Multimegagauss Magnetic Fields

L. R. Veeser [(505) 667-7741], P. J. Rodriguez, D. E. Bartram, D. A. Clark (P-22), collaborators from DX, T, and X Divisions, All-Russian Scientific Institute of Experimental Physics, Bechtel Special Technologies Laboratory, and Bechtel Nevada

In May 1996 we began a series of experiments using explosive-driven flux compression generators that produce microsecond-time-scale, megagauss magnetic fields at Firing Point 88 in Ancho Canyon. The series was named for P. A. M. Dirac, whose contributions to quantum theory are basic to all of the physics in the series. The experiments attracted scientists from Japan, Australia, Russia, and several U.S. laboratories, including Louisiana State and Florida State Universities and the National High Magnetic Field Laboratory. We used two types of generators, inexpensive Los Alamos–designed strip generators, capable of 130-T fields, and more elaborate Russian MC1 generators, which can produce over 1000 T (10 MG). In addition to recording the data for all of the experiments, P Division participated in several of the research efforts, including improved-geometry glass crystals to optically monitor high magnetic fields, a technique of particular interest to us because we will be producing very high fields on the Atlas Pulsed-Power Facility when it comes on line in 1999. We measured the Faraday rotation of polarized laser light in the diluted magnetic semiconductor CdMnTe, in which the spin exchange between magnetic ions (Mn^{2+} in this case) and the band electrons produces a large splitting of the band and consequently a giant Faraday effect. We took some interesting data, which we are now trying to interpret, and we will make further measurements. We also fielded a first attempt to determine a measurement standard for ultrahigh magnetic fields using samarium or europium. The ions Eu^{3+} and Sm^{3+} encounter jumps in Faraday rotation when the Zeeman-split excited states cross the ground states in energy. The critical fields at which these jumps occur are determined only by atomic constants and are unaffected by the environment in which the ions find themselves. This last experiment was unsuccessful because of a lack of light in our sample, so we will repeat it. All of the experiments, and perhaps some new ones, will be continued when the series resumes in the summer of 1997.

Equation of State (EOS) of Plutonium

L. R. Veeser [(505) 667-7741], P. J. Rodriguez, D. A. Clark, D. M. Oró, G. D. Allred, R. D. Fulton, O. F. Garcia (P-22), F. H. Cverna, N. S. P. King (P-23), collaborators from DX, X, and ESA Divisions, Sandia and Lawrence Livermore National Laboratories, and Bechtel Nevada

Following the decision by DOE to use NTS for experiments involving plutonium and uranium isotopes that are hazards to the environment, we are preparing a measurement of the EOS of delta-phase plutonium to increase our understanding of the physics of nuclear weapons. The first of these experiments, Rebound, is being fielded jointly by P Division, DX Division, and the rest of the support groups formerly responsible for experiments on underground nuclear tests (UGTs). We will have three experimental assemblies contained underground in a way similar to UGTs. In each assembly we will accelerate a steel flyer plate with high explosives, and the plate will impact several flat plutonium samples. By measuring the plate velocity and the velocity of the shock waves induced in the plutonium for each explosive configuration, we will obtain three EOS data points for plutonium at pressures between 80 and 230 GPa. Each impact will produce a shock that travels back through the flyer plate, unloads into the vacuum, and returns toward the plutonium as a rarefaction. For each assembly we will determine the sound speed in the shock-heated plutonium from the position where the rarefaction overtakes the shock in a heavy glass sample on the back of the plutonium. The sound speed results will be used to determine the shock pressures at which phase changes occur in plutonium. Jointly with experimenters from Livermore, we will measure a point on the plutonium release adiabat by placing a low-density foam on one of the samples and measuring the shock velocity in the foam that is induced by the unloading of the plutonium shock. Finally, DX and Sandia will measure the spall strength of shocked plutonium using a VISAR interferometer to follow the velocity of the back surface of one of the samples. The role of P Division is similar to its UGT role: participating in the experiment design, fielding the diagnostics and recording equipment, and working on the data interpretation. We have carried out seven local experiments substituting copper for the plutonium to test out the diagnostics and procedures, and we will execute Rebound in 1997.

Isentropic Compression of Argon

L. R. Veeser [(505) 667-7741], P. J. Rodriguez (P-22), H. Oona (DX-3), J. C. Solem (DDT-DO), S.M. Younger, C. E. Ekdahl (NWT), W. Lewis, W. D. Turley (Bechtel Nevada), A.I. Bykov, V.V. Aseeva, G. V. Boriskov, M. I. Dolotenko, N. I. Egorov, N. P. Kolokol'chikov, Y.P. Kuropatkin, V.D. Mironenko, V. N. Pavlov, A. A. Volkov (All-Russian Scientific Institute of Experimental Physics, Sarov, Russia)

Los Alamos National Laboratory and the All-Russian Scientific Institute of Experimental Physics are performing a set of experiments to explore the conductivity and possible metalization of argon when it is compressed to more than five times its normal density. The experiments use a magnetic field of several megagauss generated by a Russian MC1 explosive-driven flux-compression generator. The field compresses a small metallic tube (~14 mm in diameter by 180 mm long) containing solidified argon. A probe in the center of the tube measures the electrical conductivity to the walls, and a 60-MeV betatron serves as a source for a radiographic measurement of the compression at a point near its maximum. For a compression of ~4.9 times (at a calculated pressure of about 7 Mbar and temperature of 2000 K), we measured a conductivity of 8 $\Omega^{-1}\bullet\text{cm}^{-1}$, more characteristic of electron hopping than incipient metalization. Upon increasing the compression to about 5.1 and improving the probe design, we saw a conductivity of 75 $\Omega^{-1}\bullet\text{cm}^{-1}$, still far from a metal. The radiographically measured compression of 5.1 is theoretically above metalization for body-centered cubic (bcc) lattice structure, but below metalization for face-centered cubic (fcc) and hexagonal close pack. A transition from fcc to bcc is predicted to occur at a compression of 3.91. Because of the temperature, substantial fractions of each lattice structure are expected. Calculations of the lattice indicate that we are in a region where the highest point in the valence band is above the lowest point in the conduction band, but the two points occur at different places in the crystal structure. As a result, indirect transitions are needed for an electron to move from one atom to another. In view of the surprisingly small conductivity and its variation with compression, we are planning substantial improvements in the experiment, including a repeat of the low-compression measurement with the new conductivity probe and a measurement with a Teflon insulator inside the tube wall to verify that the observed conductivity was due to the argon and that the insulators in the experiment remained nonconducting at the high pressures obtained. The compression remains at its maximum for a very short time, at most a few hundred nanoseconds, so we intend to measure the compression curve with time to confirm the timing of the radiograph relative to peak compression. For this, the betatron has been modified to produce a series of three pulses per event. We will use a thin scintillator—to convert to visible light the x-rays transmitted through the tube—and an electronic camera that will record the images. We will also begin to measure the conductivity of krypton, which has a similar lattice structure but is expected to metalize more easily than argon, to determine the compression at which full metalization of krypton occurs.

Beam Diagnostics for the Dual-Axis Radiographic Hydrodynamic Test (DARHT) Accelerator

B. Wright [(505) 665-6450], D. Oró, D. Fulton, J. Studebaker (P-22)

Microwave diagnostics are being developed by P-22 to monitor the diameter of the electron beam of the DARHT linear accelerator. Nonintrusive diameter measurements are needed in the DARHT beam-transport sections to ensure proper focusing of the beam on the x-ray-generating target. A two-pass microwave interferometer at 24 GHz has been assembled for this purpose. It is currently undergoing trials on the Integrated Test Stand (~4 MeV, ~4 kA). Looking ahead to the more stringent requirements of DARHT itself (~20 MeV), a microwave resonator concept has been examined in detail. The latter approach, at 8 GHz, offers increased sensitivity and better control of geometrical factors.

P-23: Neutron Science and Technology

Sudbury Neutrino Observatory Experiment

T. J.Bowles [(505) 667-3937], S.Brice, E.I.Esch, M.M.Fowler, A.Goldschmidt, A.Hime, F.McGirt, P.Thornewell (P-23), J.B.Wilhelmy, J.M.Wouters (CST-11), collaborators from Lawrence Berkeley National Laboratory, Queen's University (Kingston, Ontario, Canada), Chalk River Laboratories (Ontario, Canada), Centre for Research in Particle Physics (Ottawa, Ontario, Canada), Carleton University (Ottawa, Ontario, Canada), University of Guelph, Laurentian University (Sudbury, Ontario, Canada), University of British Columbia (Vancouver, Canada), University of Pennsylvania, University of Washington, and Oxford University (United Kingdom)

In order to make a model-independent test of the origin of the solar-neutrino problem, we have joined the Sudbury Neutrino Observatory (SNO) experiment. The SNO detector (which will soon to be operational) is a water Cerenkov detector with 1,000 tonnes of heavy water contained in an acrylic vessel. The acrylic vessel is surrounded by another vessel with 8,000 tonnes of light (regular) water in which 9500 8-in. photomultipliers view the Cerenkov events in the heavy water. Solar neutrinos produced from the decay of ^{8}B in the sun may interact with the deuterium in the heavy water either to produce an electron (which is observed from its Cherenkov radiation) or to break up the deuteron into a proton and a neutron. The first (charged current) reaction can be initiated only by electron-type neutrinos, whereas the latter (neutral current) reaction can be produced by any of the three flavors of neutrinos (electron, muon, or tau). Our group at Los Alamos National Laboratory (LANL) originated and developed the use of extremely low background ^{3}He counters to be installed in the SNO detector as a means of detecting the neutrons produced by solar neutrinos. (As a spin-off, the semiconductor industry is very interested in using the very sensitive, low-background detectors to screen high-density microelectronics for trace radioactive contaminants that can cause computer errors by "flipping" bit patterns.) The SNO detector will carry out two model-independent tests of the origin of the solar-neutrino problem. In the first method, we will accurately measure the shape of the ^{8}B neutrino spectrum and see if the distortion characteristic of neutrino oscillations is occurring. In the second, we will observe if the rates of the charged and neutral current interactions are equal. If they differ, this would also indicate that neutrino oscillations are occurring.

GaAs Detector Development

T.J.Bowles [(505) 667-3937], S.Brice, A.Goldschmidt, A. Hime (P-23), M.Fowler, J.Wilhelmy (CST-11), collaborators from the Institute for Nuclear Research (Moscow, Russia), and Ioffe Institute of Physical Sciences

A GaAs detector can offer substantial advantages over other technologies in searches for weakly interacting massive-particle (WIMP) dark matter and high-resolution measurements of the solar-neutrino spectrum. GaAs offers the prospect of providing lower backgrounds than possible in other detectors along with a low energy threshold and very good energy resolution at room temperature. The physics that can be addressed is at the forefront of modern physics. In the short term, our efforts will be directed at searching for the cold dark matter that apparently makes up 90% of the mass in the universe. In the long term, it may prove feasible to address the question of neutrino mass using a large GaAs solar-neutrino detector. This could provide the possibility of making a very precise determination of the neutrino-oscillation parameters (if neutrino oscillations are shown to be the source of the solar-neutrino problem), a model-independent test for the existence of sterile neutrinos, and a model-independent measurement of the central temperature of the sun.

We have formed a collaboration with the Institute for Nuclear Research in Moscow to develop small GaAs detectors and to construct a prototype dark-matter detector. If successful, we then plan to propose a full-scale dark-matter detector that would be capable of covering most of the predicted range for the existence of WIMPs. This research would also allow us to determine the technical feasibility of pursuing a large-scale GaAs solar-neutrino detector.

EMIT

T. J. Bowles [(505) 667-3937] (P-23), G. L. Greene (LANSCE-DO), collaborators from the University of Michigan, National Institute of Standards and Technology (NIST), University of California at Berkeley, University of Washington, and Notre Dame University

The discovery of charge-parity violation by Cronin and Fitch, coupled with the CPT theorem (one of the basic tenets of modern physics), necessarily implies the existence of time violation. However, unlike parity violation, time-reversal invariance violation (TRIV) has been observed only in the kaon system, and presently several alternative theoretical explanations are possible. Untangling this interesting puzzle requires a variety of experiments that have unique sensitivities to the many models that predict possible TRIV effects.

Los Alamos initiated the EMIT ("TIME" reversed) collaboration to pursue a search for TRIV in the beta decay of the free neutron. A nonzero triple correlation between neutron spin, electron momentum, and proton recoil violates T symmetry. The experimental technique is to record the betas and proton recoils from the in-flight decay of polarized, cold neutrons. The TRIV signal consists of a nonvanishing difference when the neutron spin is flipped. A Monte Carlo study to model experimental sensitivity, verified by a test measurement, has revealed an optimized detector geometry seven times more sensitive than geometries employed in previous experiments. An octagonal detector geometry (4 proton- and 4 electron-detector assemblies) has been constructed, and we are now beginning to exploit this sensitivity and take data using the cold-neutron beam at the NIST reactor. We expect to improve the sensitivity of the previous measurements (which were at the 3×10^{-3} level) by an order of magnitude.

SAGE

T.J.Bowles [(505) 667-3937], J.S.Nico, W.A.Teasdale, D.L.Wark (P-23), collaborators from the Institute for Nuclear Research of the Russian Academy of Sciences, University of Washington, University of Pennsylvania, and Louisiana State University

The number and spectrum of neutrinos from the sun continues to challenge our understanding of solar physics and neutrino properties. Los Alamos has been the lead U.S. laboratory in the SAGE (Soviet-American gallium solar-neutrino experiment) collaboration since it began in 1985. SAGE is a radiochemical experiment located at the Baksan Neutrino Observatory in southern Russia.

Solar neutrinos produce ^{71}Ge atoms by inverse beta decay on ^{71}Ga. The ^{71}Ge atoms are chemically extracted from the 60 tons of metallic liquid gallium, and their decay is measured in miniature ultralow-background proportional counters. SAGE is sensitive to all of the fusion reactions occurring in the sun. Beginning in 1990, we have carried out measurements of the flux of solar neutrinos and have found that the flux of neutrinos detected is about half of that predicted by the Standard Solar Model. We have also confirmed the correct overall operation of the experiment using an intense (0.5 MCi) ^{51}Cr artificial neutrino source. Combined with results from other solar-neutrino experiments that measure only the higher-energy solar neutrinos produced from ^{7}Be and ^{8}B reactions in the sun, it appears that the most plausible explanation of the observed deficit is neutrino oscillations. If this proves to be true, it will be the first evidence for physics beyond the Standard Electroweak Model, as predicted by the Grand Unified Field Theories.

Ultracold Neutrons

T.J.Bowles [(505) 667-3937], S.J.Seestrom, R.Hill (P-23), C.Morris, G. Hogan (P-25), T.Brun (LANSCE), collaborators from the University of Rhode Island, University of California at Berkeley, and Petersburg Nuclear Physics Institute

Ultracold neutrons (UCNs) are neutrons whose wavelengths are sufficiently long that they can undergo total internal reflection from a variety of materials. This makes it possible to confine UCNs in a bottle for more than 100 seconds, providing a compact source for use in fundamental physics research.

At LANSCE, ultracold neutrons were first produced in 1996 by Bragg-scattering cold neutrons (having a velocity of 400 m/s) from a moving mica-crystal package so that the cold neutrons were Doppler shifted into the ultracold regime (<7 m/s). We are continuing to develop this source with improved diagnostics, a mica-crystal package with higher reflectivity, and better control of the matching of the source to the MLNSC cold moderator. We are also developing the use of cryogenic moderators for UCN production at the proposed Long-Pulse Spallation Source. This source promises densities 100–1000 times higher than presently available. Such an intense source of UCNs may make it possible to pursue materials-science applications with UCNs.

A fundamental-physics research program with UCNs is now being started with plans for measurement of angular correlations in polarized UCN beta decay and the electric dipole moment of the neutron. These experiments aim at detecting physics beyond the Standard Model of strong and electroweak interactions.

Neutron Total Cross Sections

F.S.Dietrich (Lawrence Livermore National Laboratory), W.P.Abfalterer [(505) 667-3632], R.C.Haight (P-23), R.W.Finlay (Ohio University)

This joint project of Lawrence Livermore National Laboratory (LLNL), Ohio University, and LANL is making precise measurements of the neutron total cross sections over a wide neutron energy range for a comprehensive set of materials for the Accelerator Production of Tritium (APT) program. These data are necessary in the calculations of neutron transport in APT systems, and they are essential input to model calculations of neutron scattering and reactions. In 1996, we investigated over 30 samples in the energy range 4–550 MeV and obtained data accurate to approximately 1%. The WNR fast-neutron spallation source at LANSCE is ideal for this work. We are continuing this work in 1997 with additional materials, including isotopes of tungsten and iron.

Nuclear Level Densities

R.C.Haight [(505) 667-2829], F.B.Bateman (P-23), S.M.Grimes (Ohio University), H.Vonach (University of Vienna)

At low excitation energies, a given nucleus has a sequence of energy levels that can be described by their quantum numbers and spectroscopic properties. At higher excitation, the number of levels rises very quickly, so that the properties of the individual levels cannot be determined individually but must be understood as statistical averages such as the “nuclear level density.” It is generally believed that there is a transition from the ordered set of states at low energy to a Fermi gas (a gas-like collection of protons and neutrons) at much higher energies. The characterization of the transition between the two regimes is the subject of many theories. We test these models by measuring, with the WNR/LANSCE spallation neutron source, neutron-induced, charged-particle-producing reactions over the range from threshold to 50 MeV. Three independent approaches are possible with these reactions: the shape of the emission (evaporation) spectra gives information on the nuclear level density in the residual nucleus; the cross section as a function of energy indicates level densities for excited states in the target nucleus; and very-high-resolution measurements with respect to incident neutron energy reflect overlapping states in the compound nucleus. The quantification of nuclear level densities is essential for nuclear-reaction models of reactions that cannot be measured, such as reactions on unstable species that are formed in stellar nucleosynthesis and in the explosion of nuclear weapons.

Milagro Gamma-Ray Observatory at Fenton Hill

T. J. Haines [(505) 667-3638], R. Miller, C. Sinnis (P-23), C. M. Hoffman (P-DO), G. Gisler (NIS-2), collaborators from the University Autonoma de Barcelona, University of California at Irvine, University of California at Riverside, University of California at Santa Barbara, University of California at Santa Cruz, University of Maryland, George Mason University, University of New Hampshire, New York University, and University of Utah

The Milagro Gamma-Ray Observatory at Fenton Hill in the Jemez Mountains uses hundreds of sensitive, light-detecting photomultiplier tubes submerged in a five-million-gallon artificial pond to record signals from high-energy cosmic emissions. Milagro—the Spanish word for “miracle”—is a collaboration involving researchers from LANL; University of California (UC) campuses at Irvine, Riverside, and Santa Cruz; the University of Maryland; George Mason University; the University of New Hampshire; and New York University. The $2.5-million project is funded by the National Science Foundation, DOE, and UC. The 25-ft-deep pond was emptied and covered with durable, waterproof plastic. The water in the pond is circulated, filtered, and treated to maintain its clarity in a support building next to the pond, which also holds the computers and electronics that process the signals recorded by Milagro. The pond was refilled with water after the first 225 light detectors in the bottom array were installed. In the summer of 1998, project members will drain the pond and expand the array to its full size.

Milagro is sensitive to a range of gamma rays, high-energy photons with energies above 500 GeV. These gamma rays, generated by black holes, active galaxies, supernovae, or "gamma-ray bursters," strike air molecules in the upper atmosphere before they reach Earth. These initial collisions produce showers of subatomic particles and lower-energy photons that avalanche groundward in a cone. Each air shower either dissipates in the atmosphere or, at high elevations, intercepts the ground. Milagro's pool acts as a camera larger than a football field and stares at the sky around the clock. A light-tight cover on the pool keeps the inside of the observatory absolutely dark but is easily penetrated by the energetic particles in the air shower. When a gamma-ray-generated air shower strikes the pool, electrons and positrons in the shower create Cerenkov radiation as they move through the water. Milagro's light detectors sense this light and record information for reconstructing the point on the sky from which the original gamma ray came. Milagro observes hundreds of events each second. Computers automatically sift the arriving data, discarding the many background events generated by cosmic rays and recording the gamma-ray signals.

Gamma-ray bursters, which flash briefly into view and then disappear, have puzzled astronomers since they were discovered by Los Alamos scientists in the 1960s. Currently, astronomers are debating whether gamma-ray bursters originate in our own galaxy or reach us from the most remote reaches of the universe. The latter explanation would require exotic new physics to explain such powerful bursts of energy. Milagro can help to answer the question of whether or not the gamma-ray bursters are located at cosmological distances; researchers are eager to combine its data with those from the Gamma Ray Observer satellite, which observes less-energetic gamma rays from its vantage point in space. Milagro builds on the success of the CYGNUS experiment, which ran at Los Alamos for 10 years. CYGNUS, begun by Darragh Nagle of Los Alamos and collaborators at the University of Maryland, used only scintillation detectors and was sensitive only to gamma rays at the upper end of Milagro's range of detection. Data from the CYGNUS experiment have to date produced 10 doctoral dissertations. Milagro's flood of data will support many more graduate students studying high-energy physics and astrophysics; the project currently employs 7 graduate students, including 4 doctoral candidates.

Fundamental Symmetry Measurements with Trapped Atoms

A.Hime [(505) 667-0191], T.J.Bowles, S.J.Brice, A.Goldschmidt, R.Guckert (P-23), E. I.Esch, D.Tupa (P-25), M.M.Fowler, D.J.Vieira, J.B.Wilhelmy, X.Zhao (CST-11), C.Weiman (NIST)

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments has arisen that would exploit point-like, massless samples of essentially fully polarized nuclei. At Los Alamos we are pursuing a measurement of the beta-spin correlation function in the beta decay of ^{82}Rb confined to a time orbiting potential (TOP) magnetic trap as a means to probe the origin of parity violation in the weak interaction. A new generation of atomic-parity nonconservation experiments that test the neutral current part of the weak interaction is also envisioned, wherein measurements with a series of radioactive isotopes of cesium and/or francium could eliminate atomic structure uncertainties that presently limit the ultimate precision of such experiments.

Our near-term goals are to demonstrate the high-efficiency optical trapping of rubidium and cesium radioisotopes, to polarize and transfer these cold atoms to a pure magnetic trap that confines only one polarized state, and then to measure the beta-asymmetry using a symmetric array of beta-telescopes surrounding the trap. Initial trapping and cooling of rubidium and cesium isotopes have been carried out, and we are now working to complete the design of the transfer and the second magnetic trap, where ^{82}Rb atoms will be polarized and placed in a magnetic TOP trap for high-precision beta-asymmetry measurements. Our initial studies will concentrate on the pure Gamow-Teller transition in ^{82}Rb; our goal is to measure the parity-violating beta-spin asymmetry correlation with a precision one order of magnitude greater than any previous experiment.

Quantum Cryptography for Secure Communications to Low-Earth-Orbit Satellites

R.J.Hughes [(505) 667-3876], W.T.Buttler, G.G.Luther, G.L.Morgan, C.G.Peterson, C.Simmons (P-23), J.E.Nordholt (NIS-1)

Cryptanalysis techniques and algorithms are advancing rapidly and by the start of the twenty-first century will necessitate the development and use of new encryption technologies to ensure secure communications to satellites. The aim of our project is to develop quantum cryptography so that it may provide absolutely secure encryption of communications to low-earth-orbiting satellites. We will develop and demonstrate the cryptographic technology to a stage where it can be feasibly incorporated into new satellites. During the past year, we have designed, constructed, and tested a quantum-cryptography system that creates and transmits—using single-photon transmissions—cryptographic random numbers between sending and receiving instruments separated by more than 200 m within our laboratory. The system is based on the propagation and detection of nonorthogonal polarization states of single photons in free space at a wavelength (771 nm) for which the atmosphere has a very low attenuation.

Quantum Computation Using Cold, Trapped Ions

R.J.Hughes [(505) 667-3876], M.H.Holzscheiter, P.G.Kwiat, S. K. Lamoreaux, C.G.Peterson, C.Simmons (P-23), M.Schauer (P-24), M.Gulley, V.Sandberg, D.Tupa (P-25)

Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows computing with quantum-mechanical superpositions of many numbers at once. In a quantum computer, binary numbers will be represented by quantum-mechanical states ("qubits"). We are developing a quantum-computational device in which the qubits will be two electronic states of calcium ions that have been cooled with a laser to rest in an ion trap. We will then perform quantum logical operations with a laser beam that is resonant with the qubit transition frequency and is directed at individual ions. We have recently succeeded in trapping and imaging a cloud of calcium ions using two titanium-sapphire lasers: one, frequency doubled to 397 nm; the other at 866 nm.

Quantum Cryptographic Key Distribution over Optical Fibers

R.J.Hughes [(505) 667-3876], G.G.Luther, G.L.Morgan, C.G.Peterson, C.Simmons (P-23)

The secure distribution of secret random-bit sequences, known as "key" material, is an essential precursor to the use of that key material for the encryption and decryption of confidential communications. Quantum cryptography is an emerging technology for secure key distribution with single-photon transmissions. Heisenberg's uncertainty principle ensures that an adversary can neither successfully tap the key transmissions nor evade detection, because eavesdropping raises the key error rate above a threshold value. We are performing quantum cryptography over 48 km of underground optical fiber using nonorthogonal single-photon interference states to generate shared key material. Key material is built up by transmitting a single photon per bit of an initial secret random sequence. A quantum-mechanically random subset of this sequence is identified and becomes the key material after a data-reconciliation stage with the sender. The nonorthogonal nature of the quantum states ensures that an eavesdropper cannot identify the bit values in the key sequence. Our experiment demonstrates that secure, real-time key generation over "open," multikilometer node-to-node, optical-fiber communications links is possible.

Diode Laser Development for Quantum Computation

R.J.Hughes [(505) 667-3876], P.G.Kwiat, C.G.Peterson (P-23), J.Gomez, V.Sandberg, C.Simmons, D.Tupa (P-25)

Titanium-sapphire lasers are a proven technology for our quantum-computation application, but they are expensive, require a laser expert, use over 40 kW of power, and fill an entire laser table. The objective of this project is to develop diode lasers for this application because diode lasers are easy to use, low in cost, and compact. This year, we have developed diode lasers at the 866-nm and 794-nm wavelengths that are required for cooling calcium ions, and in the next few months, we will double the frequency of the 794-nm light to obtain 397-nm light. We have assembled external-cavity diode-laser systems and, with a prototype, demonstrated locking to an existing frequency standard. We have developed frequency-offset techniques using modulators and/or ultrastable cavities to reference the 866- and 397-nm wavelengths to stable atomic lines. Typically, the wavelength of the light emitted by the laser must be controlled with respect to a reference wavelength, which is near the desired wavelength. For our diode lasers, we can reference light wavelengths to an absolute atomic standard or to a very stable optical cavity that resonates at a very well defined frequency.

"Interaction-Free" Measurements

P.Kwiat [(505) 667-6173], A.White, J.Mitchell (P-23), collaborators from the University of Innsbruck (Austria)

Using the complementary wave- and particle-like nature of light, it is possible to determine the presence of an object without any photons being absorbed or scattered by it. The maximum efficiency of the simplest schemes (wherein the object, if placed in one arm of an interferometer, prevents interference) is only 50%. However, by incorporating a repeated interrogation scheme—an application of the Quantum Zeno effect—one can, in principle, achieve efficiencies arbitrarily close to 100%, with an arbitrarily small chance that any photons are absorbed. So far, an 85%-interaction-free measurement has been achieved (in collaboration with researchers at the University of Innsbruck), and this is the current world record. A fast switching system that should allow efficiencies in excess of 95% is currently under development. Also, we have begun investigating the practical implementation of interaction-free imaging, in which these techniques are used to obtain a pixelated image of an object, again with the goal of negligible absorption or scattering. To date, a resolution of less than 10 μm has been achieved, and we hope to improve this even further. Finally, we are beginning research on coupling our measurement system to a quantum object in a superposition state. This would allow the production of macroscopic entangled states of light and Schrödinger-cat states.

Development of a Cold-Neutron Radiography Capability at the Manuel Lujan Neutron Scattering Center (MLNSC)

T.E.McDonald, Jr.[(505) 667-7294]) (P-23), T.N.Claytor, M.J.Schwab(ESA-MT), E.H.Farnum (MST-4), G.L.Greene (LANSCE-DO), A. Michaudon (LANSCE-3)

Neutron radiography is an attractive technique for nondestructive testing and evaluation due to the strong variation of neutron cross sections from element to element. Cold-neutron radiography (CNR), which uses neutron energies in the millielectronvolt (meV) regime, has been employed for the most part with reactors in which a steady-state source of cold neutrons can be obtained. Spatial resolutions of a few tens of microns can be obtained in radiographs from such sources. An important behavior of the cross sections of crystalline materials for cold neutrons is that below an energy of a few meV (the exact energy depends on the material), there is an abrupt drop in the cross section when the wavelength reaches twice the largest d-spacing of the material. The energy at which this abrupt drop occurs is referred to as the Bragg cutoff. This behavior is generally not exploited in a reactor environment because the steady-state nature of the neutron source does not facilitate the separation of neutrons of different energies. However, a pulsed neutron source using a time-of-flight capability can easily differentiate neutron energies and thus has the capability to obtain radiography at various neutron energies. By recording image data at different times during a neutron pulse, it is possible to obtain neutron images below and above the abrupt drop (or threshold) in the cross section for a given component of the sample.

We recently demonstrated this phenomenon at the MLNSC on Flight Path 11a. A beam guide was installed to achieve a flight path of approximately 19 m. A lithium zinc sulfide scintillator was used as a neutron-to-light converter, and a set of mirrors and lenses relayed the image from the scintillator to a gated image intensifier, the output of which was recorded by a cooled charge-coupled device (CCD) camera. We have demonstrated the Bragg cutoff at 6 meV on a block of beryllium that is approximately 73 mm thick. Imaging at energies above about 7 meV shows the beryllium to be dark, and items being shadowed by the beryllium cannot be seen. However, imaging at energies below approximately 5 meV shows the beryllium to be almost clear, and items previously shadowed by the beryllium can be clearly seen. These images are our first proof-of-concept experiment, and we expect to achieve increased resolution and image quality in subsequent work.

Neutron-Based Land-Mine Detection System Development

T.E.McDonald, Jr.[(505) 667-7294] (P-23), H.A.Davis (P-24), R.A.Nebel (T-15), M.M.Pickrell (NIS-5)

Determining the location of land mines is important both militarily and in peace time. Even in today's absence of large conflicts, more than 26,000 people are killed or wounded yearly by land mines that were deployed previously. The goal of this project is to examine the feasibility of developing a buried-land-mine detection system using the detection and analysis of prompt gamma rays that are induced by neutron interrogation. This technique is a mature concept and has been used in a variety of explosives-detection applications. However, it has not successfully been applied to the buried-mine detection problem because of lack of both a suitable neutron source (that is, one having sufficient intensity) and a detection system having a sufficiently high signal-to-noise ratio. The basic concept is to interrogate a suspected area with neutrons. The explosives in any mines that may be present would have an elevated presence of nitrogen, whereas the surrounding earth generally would have little or no nitrogen. Some of the neutrons would react with the nitrogen in the explosive, and gamma rays that have specific and unique energies would be emitted as a result of the reaction. Most previous attempts to use this neutron-based (NB) technology for mine detection have relied on spontaneous fission sources, which can be used only at low intensity, in the range of 10^6–10^7 neutrons per second (n/s), together with heavy shielding, because of personnel safety considerations. A system using such low-intensity sources is slow (requiring several minutes) and requires close proximity (within a few centimeters) to the explosive being detected. Most studies indicate that a source strength in the range of 10^9–10^{11} n/s would be necessary to achieve a relatively high signal-to-noise ratio in an interrogation time of a few seconds. In this project, we consider two alternative neutron sources that have the potential of producing neutron fluxes in the neighborhood of 10^{11} n/s: the Intense Ion-Beam Source and the Inertial Electrostatic-Confinement Source. The advantage of these sources is that they can be turned off when not in use and can be operated over a wide range, from steady state to pulsed. We also review alternative detection techniques and have carried out preliminary measurements using mock high-explosive (HE) material.

Advanced Technology Imaging Sensor Development (Fast CCD Sensors)

T.E.McDonald, Jr. [(505) 667-7294], G.G.Yates, R.A.Gallegos, N.S.P.King (P-23), B.T.Turko (Lawrence Berkeley Laboratory), F.J.Zutavern (Sandia National Laboratories), M.C.Thomas (Bechtel Nevada)

The goal of the Advanced Technology Imaging Sensor Development (Fast CCD Sensors) project is to develop an advanced, gated, intensified imaging system for use over a broad range of applications in the Department of Defense (DoD) and Department of Energy (DOE). Our focus is on increased frame rate, extended spectral range sensitivity into the near infrared (including the "eye-safe" spectrum in the neighborhood of 1.54 μm), reduced gate width, increased resolution, and increased quantum efficiency. Such an advanced imager would be used in the DoD in lidar; range gating; imaging through scattering media such as fog, clouds, and turbid water; long-distance target acquisition and ranging; underwater imaging; and laser detection and ranging (LADAR) imaging, including eye-safe LADAR. Applications in the DOE include shock-wave-breakout characterization, neutron and proton radiography of dynamic systems, imaging of high-speed assembly and associated reactions, and diagnostics of accelerator beam pulses. The high-speed imaging technology developed by Los Alamos and the other DOE national laboratories for use in the underground testing program at the Nevada Test Site (NTS) serves as the technology foundation for this project. Starting with this base, we are advancing the technology along several fronts. We are designing a high-speed camera around a new 512 × 512 pixel, 16-port CCD. The camera is designed to operate continuously at up to 4000 frames per second. We are working on the design of microchannel plate intensifier configurations that will gate in the few-hundred-picosecond regime, and we are working with manufacturers on the fabrication of such intensifiers. We are also working with intensifier manufacturers on extending the sensitivity of the photocathode to cover the near infrared up to the eye-safe spectrum range. In addition, we are pursuing a quantum improvement in intensifier technology by using a back-thinned, electron-bombarded CCD (EBCCD) that will be placed directly in the intensifier envelope and replace the microchannel plate, phosphor, and intensifier-camera coupling. If the EBCCD development is successful, we expect close to an order-of-magnitude improvement in sensitivity and resolution.

Basic Physics with Spallation-Neutron Sources

A.Michaudon [(505) 665-2883] (LANSCE-3)

Progress in basic physics with neutrons strongly depends on the availability of intense neutron sources. High-flux reactors are at the limit of their technical possibilities, with no substantial progress in performance in the last twenty years. Spallation-neutron sources (SNSs) that use intense proton beams (of about 1 GeV) already have demonstrated both interesting capabilities that complement those of reactors and great potential for future development. Although neutron sources are mainly used for condensed-matter studies, they also present attractive possibilities for studies in other fields, including nuclear physics, fundamental physics, and particle physics.

The interest and future potential of SNSs, which can produce neutrons with an energy range spanning 16 orders of magnitude, and their possible use in scientific disciplines outside that of condensed matter have been reviewed in detail in a major 3-volume report[1] written by more than 30 scientists from inside and outside LANL. This report forms a comprehensive base in support of the launching of LANSCE as a truly multidisciplinary national user facility.

1. "Basic Physics with Spallation-Neutron Sources," A. Michaudon, Ed., Los Alamos National Laboratory document LA-UR-94-1320 (1994).

Use of Ultracold Neutrons for Condensed-Matter Studies

A. Michaudon [(505) 665-2883] (LANSCE-3)

Ultracold neutrons (UCNs) have played a very important role in fundamental-physics research but can also be used in condensed-matter studies. Because of their small penetration depth into matter, UCNs are well suited for surface studies. High-resolution UCN spectrometers can also be built, using gravity as a strongly dispersive medium for low-energy neutrons. With such excellent resolution, UCN quasielastic scattering can give insight into slow dynamics over long distances in macromolecules such as polymers or biopolymers. All these studies were recently reconsidered with the possible advent of new, more-intense UCN sources, which are now envisaged. This reassessment, now available as a Los Alamos report, includes a broad review of UCN properties (including their reflectivity by different types of samples), UCN spectrometers and their comparison with other high-resolution instruments, experimental results obtained with all these instruments, and neutron microscopes.

Infrared Pyrometry for Temperature Measurements of Shocked Surfaces

A.W.Obst [(505) 667-1330], N.S.P.King, M.L.Stelts (P-23), collaborators from Bechtel Nevada and DOE Los Alamos Area Office

Measurements of the time-dependent absolute temperature of surfaces shocked by high explosives (HE) provide valuable constraints on the equation of state of materials and on the state of ejecta from those shocked surfaces. A pyrometer system has been designed and built for studying these temperatures, which typically lie in the range 0.04–0.2 eV, corresponding to shock heating of surfaces to temperatures from about 400 K to about 2000 K. These temperatures are equivalent to infrared (IR) wavelengths in the range of 1 to 10 μm. Blackbody IR spot pyrometry, utilizing the color ratio technique, permits a measurement of these surface temperatures. An a priori knowledge of the behavior of the surface emissivity with wavelength is required, but the absolute values of the emissivity are not. This detector system will be applied to experiments in the above-ground experiments (AGEX) program.

The detector system uses IR lenses to image a spot (whose diameter is determined by the optics) onto a mixing rod. The mixing rod allows spatially homogenized samples of the IR emission to be transferred to three 3-m-long IR fibers. The other ends of the fibers go to a detector box, which can be protected from the HE shock. The IR radiation from each of the three fibers is focused through a doublet lens system onto quad metal (HgCdZnTe) IR detectors. Filters are placed between the doublets to transmit IR radiation only from moderately narrow bands. The three bands are centered about 3, 6, and 8 μm to optimize the color ratios for the temperature range of interest. The system is being characterized and will be tested on flyer plate configurations driving polished copper plates, for which the temperature has been well characterized.

Ejecta Measurements Using In-Line Fraunhofer Holography

D.S.Sorenson [(505) 665-2860], N.S.P.King, A.Obst, M.Stelts, N.Gray, V.Holmes, S.Jarimillo (P-23), collaborators from Bechtel Nevada

When a shock wave interacts at the interface between a solid (or liquid) and a gas, pieces of the material can be emitted into the gas region. This material can range in size from submicron to hundreds of microns and is referred to as ejecta. Ejecta can occur in a nuclear weapon when a shock wave interacts at such an interface. The amount, size, and velocity of ejecta will depend on material properties such as grain size, surface finish, and the state of the shock wave in the material. In order to characterize ejecta, P-23 has played a major role in developing an in-line Fraunhofer holography technique to make measurements of ejecta in a dynamic system. This diagnostic has been developed and implemented on numerous experiments based at the Pegasus II Pulsed-Power Facility and is currently being developed for HE experiments. At Pegasus, an aluminum cylinder is imploded and then impacts a smaller-diameter target cylinder, which sets up a shock wave in the target. When the shock wave interacts at the target/vacuum interface, ejecta are emitted. To make the ejecta holographic measurement, a laser pulse is transported through the ejecta, where part of the laser light scatters and part is unscattered. These two beams interfere at the film plane where the hologram is formed. The hologram contains information about particles ranging in size from a few microns to a hundred microns in diameter over a volume of 1 cm^3. Ejecta data have been obtained for both aluminum and tin targets over a range of surface finishes and shock strengths.

X-Ray Imaging Experiments Using Pulsed-Power and High-Explosive Facilities

D.S.Sorenson [(505) 665-2860], N.S.P.King, A.Obst, M.Stelts, N.Gray, V.Holmes, S.Jarimillo (P-23), D.Morgan, D.Platts (P-22), collaborators from Bechtel Nevada

Many weapons-physics issues deal with instabilities and shock waves interacting in materials and gases. In order to investigate these issues associated with dynamic systems, groups P-23 and P-22 are developing a spatially resolved, time-dependent x-ray imaging system. Providing time-dependent information is critical in understanding the physics involved and in comparing experimental data with predictions given by the hydrodynamic weapon codes. The system makes use of 600-keV x-ray sources developed in P-22, which provide roughly 100 mrad at a distance of one foot in a 10-ns full-width-at-half-maximum (FWHM) pulse. P-23 has developed scintillator packages for forming the image, an optical transfer system for relaying the image, and gated-intensifier camera systems for recording the image. Depending on the type of experiment, the scintillator type and thickness are optimized to maximize image contrast. The optical-transfer system is designed to relay the image far enough from the experiment that the camera systems are protected, while still providing high resolution and good light collection. Many experiments have been successfully completed at the Pegasus II Pulsed-Power Facility, where images at two different times were obtained. For the Icebound and local HE experiments, a time-dependent x-ray imaging system is being developed. With this system we are making images over an 18-mm-diameter area that allow us to measure ejecta mass with an accuracy of 10%.

P-23 Weapons-Physics Experimental Team

M.L.Stelts [(505) 667-1507], K.R.Alrick, N.T.Gray, V.T.Holmes, P.Liu, A.W.Obst, D.S.Sorenson (P-23), collaborators from Bechtel Nevada

This team performs experiments that expand our understanding of the physical processes that take place in the detonation of nuclear devices. Some issues that are being studied include the development of instabilities that form in imploding systems, the formation of ejecta from shocked surfaces, interaction of shock waves with materials, and equation-of-state (EOS) measurements in materials and pressure regimes of interest to weapons physics. The experiments are performed using liners imploded with pulsed power at the Pegasus II facility and on explosively driven systems both at LANL and in the U1a facility at the Nevada Test Site (NTS).

We apply a variety of diagnostics to measure the physical phenomena that occur in these experiments. Holograms, taken with a pulsed laser, measure the distribution of particle size in ejecta. We have developed a system to take a sequence of gated x-ray images to provide information on the evolution of instabilities and the mass distributions in surface ejecta. Visible imaging experiments, which either use framing cameras to capture the emitted light from shocks or use lasers or argon candles to backlight the experiments, provide information on the evolution of the phenomena being investigated. We are developing pyrometers to measure time-dependent temperatures and IR imaging techniques to study spatial distributions of temperatures for shocked systems. Various techniques, including the use of streak cameras, are employed to measure shock arrival times in EOS experiments.

P-23 NTS Prompt Diagnostic Archival Team

M.L.Stelts [(505) 667-1507], P.Liu, K.B.Morley (P-23), collaborators from Sumner Associates and Bechtel Nevada

The laboratory is now required to certify our nuclear-weapons stockpile without being able to test the weapons. This will require the development of better physics models and better computer codes that, ultimately, should be able to compute the performance of the weapons, including effects of aging, defects, and remanufacture. To have confidence in the ability of these codes to provide realistic predictions, we must be able to use them to successfully model the performance of devices tested at NTS. Thus, the NTS data will be a crucial link in attaining this goal.

P-23 and its predecessor groups have been responsible for experiments that involve precision neutron output measurements from these devices (NUEX and THREX) and for the imaging of sources of radiation in the devices (PINEX), as well as many other experiments that have been performed to investigate weapons-physics issues. The responsibility of P-23 is two-fold. We are documenting the experimental techniques that were used in the NTS shots so that future users of the NTS data will understand how an experiment is designed, what information can be derived on the weapons-physics issues, and how to field the experiment if we are required to return to testing. We are also systematically saving the data, frequently having to reanalyze experiments, and providing the necessary additional information that will allow comparison of the experimental results with the calculations of device performance. These data are being electronically archived on the P-23 classified computer system in a form that facilitates access and use by other experimentalists, weapon designers, and code developers. To aid in this process, we have installed a World Wide Web–type page on our classified network (behind a firewall computer that limits access to those with a "need to know") to allow easier access to the data through a web browser.

The task of saving and documenting the data taken over decades of testing is formidable. It is necessary to recover data not only on stockpile systems, but on events designed to investigate weapons-physics issues and on those interesting failures, where the results were not what were anticipated.

Neutron Measurements to Support the Optimization of Treatment of Cancer Patients with Fast Neutrons

J. L. Ullmann [(505) 667-2517], R. C. Haight (P-23)

Over 15,000 people with cancer have received radiation treatment with fast neutrons. This clinical experience has shown that 10%–15% of all cancer patients would benefit from this neutron therapy. Accurate dosimetry depends on the knowledge of neutron interactions with elements of tissue such as carbon, nitrogen, and oxygen. In particular, neutron reactions that produce charged particles are of interest because these reactions deposit energy, and hence radiation dose, locally at the point of the interaction. Although there have been measurements in the energy range of importance, from 20 to above 70 MeV, the data base is sparse (we have measurements at only a few selected energies), and there are significant discrepancies among literature values. We are beginning a program to supply accurate data on neutron reactions that produce protons, deuterons, tritons, ^{3}He, and ^{4}He from 0–150 MeV, thereby covering the full range used in neutron therapy. The WNR/LANSCE neutron source covers this range continuously, and the specific neutron energy for a particular reaction can be determined by time-of-flight techniques. Applications of these data extend also to radiation protection at high-energy and medium-energy accelerators and to radiation effects from neutrons produced by cosmic rays.

Molten-Metal-Target Test Loop

S.A.Wender [(505) 667-1344] (LANSCE-3), F.Venneri, N.Li, M.A.Williamson, B.E.Newnam, G.D.Doolen (LANSCE/ADTT)

The development of molten heavy-metal-target technology for spallation neutron sources has recently become recognized as an important objective for several programs at Los Alamos. It is generally believed that the only way to take advantage of the accelerator-beam power levels now possible for compact neutron-spallation targets is to use molten metal as the target material. Molten-metal targets are called for in the National Spallation Neutron Source (NSNS) being designed by Oak Ridge National Laboratory, the European Spallation Source (ESS), and the SINQ project at the Paul Scherrer Institute (PSI). The accelerator-driven transmutation technology (ADTT) program at Los Alamos is proposing systems that depend heavily on molten lead or lead-bismuth eutectic (LBE) fluids for neutron production and for cooling. In addition, molten lead or LBE targets have been suggested as advanced concepts for use in the accelerator production of tritium (APT).

As a first step toward developing this technology at Los Alamos, we are constructing a simple LBE test loop. This test loop will allow us to address many issues, such as material compatibility and corrosion, and to gain experience with LBE. We will be working in close collaboration with scientists from the Institute of Physics and Power Engineering at Obninsk, Russia, who have considerable experience with LBE from their naval propulsion program. We expect the loop to be operational in late 1997.

P-24: Plasma Physics

Development of Methods for Obtaining On- and Off-Hugoniot Equation-of-State Data Using Laser-Driven Shocks

G.R.Bennett [(505) 667-9318], R.E.Chrien (P-24), J.M.Wallace (XPA)

This project investigates advanced equation-of-state (EOS) experimental techniques relevant to measurements such as those suggested for the proposed Trident-Upgrade laser facility at Los Alamos. Experiments, which recently began at the Nova laser facility of Lawrence Livermore National Laboratory (LLNL), are focused toward simultaneous measurements of the direct-laser-drive principal Hugoniot (PH) and zero-pressure-release isentropes of beryllium. Beryllium was chosen as the EOS sample because it is an important inertial confinement fusion (ICF) material with particular relevance to National Ignition Facility (NIF) capsule designs. Furthermore, its low x-ray opacity and high shock and particle speed—in comparison with denser metals—make beryllium an ideal material with which to develop these advanced techniques. Direct drive with side-on x-ray radiography is believed to be the optimum approach toward obtaining a high-accuracy, laser-based EOS. To this end, a novel, one-dimensional, state-of-the-art x-ray microscope, designed by P-24 researchers, has been conceived and is currently under fabrication. Upon completion of this x-ray device, experimental work will be transferred to the Omega laser facility at the University of Rochester. The completion of an active shock-breakout diagnostic in the future will extend this project to include the novel addition of "sound speed" to the PH and isentrope measurements.

Design of Weapons-Physics Experiments Driven by X-Rays from the PBFA-Z Pulsed-Power Facility at Sandia and the Nova Laser at Livermore

R.E.Chrien [(505) 667-1674] (P-24), G.R.Magelssen, F.J.Swenson, B.H.Wilde, D.C.Wilson (XTA)

We are evaluating the PBFA-Z pulsed-power facility at Sandia National Laboratories in Albuquerque (SNL) as an x-ray source for weapons-physics experiments. PBFA-II, originally constructed as a set of 36 light-ion-beam accelerators for ICF experiments, has been reconfigured as PBFA-Z to drive z-pinch implosions using wire-array loads. The implosion efficiently converts the electrical energy in the pulsed-power system into x-rays when the imploding wire plasma stagnates on the cylindrical axis. The initial operation of this reconfigured facility has been very encouraging. X-ray yields of ~2 MJ and peak powers of ~200 TW in 25-cm^3 hohlraums have been produced in early experiments, corresponding to peak black-body temperatures of 100 eV. We are planning to reduce the hohlraum volume to ~5 cm^3 in an effort to raise the peak temperature to 120 eV or more. These hohlraums will be used for studies of foam-filled tubes with diameters in the range of 2.4–5 mm. Similar x-ray drive conditions can also be produced in laser-driven hohlraums on the Nova laser at LLNL but are limited to smaller-diameter tubes. The smaller size of the laser-driven targets is partially offset by the superior imaging diagnostics at the Nova facility. In both the pulsed-power and laser facilities, development of improved x-radiographic capabilities will be important for our above-ground studies.

Fusion Neutrons from the Gas/Pusher Interface in Deuterated-Shell ICF Implosions

R.E.Chrien [(505) 667-1674] (P-24), N.M.Hoffman, J.D.Colvin (XTA), collaborators from Lawrence Livermore National Laboratory

In this project we have performed the first measurements and numerical simulations of fusion neutrons from the gas/pusher interface of indirectly driven ICF implosions using hydrogen-filled capsules made with a deuterated inner layer. Contrary to the case of conventional capsules with D-T (deuterium-tritium) or D-D (deuterium-deuterium) gas fills, neutron yields in these capsules are due mostly to undesirable mix at the pusher/gas interface. We varied the nonlinear saturation of the growth of hydrodynamic perturbations in implosions with high linear growth factors (~325) by adjusting the initial surface roughness of the capsule. The neutron yields are in quantitative agreement with the direct simulations of perturbation growth, and they also agree with a linear-mode superposition and saturation model, including enhanced thermal loss in the mixed region. Neutron spectra from these capsules are broader than expected for the calculated ion temperatures, suggesting the presence of nonthermal broadening from mass motion during the fusion burn.

Instability-Coupling Experiments on the Nova Laser

R.E.Chrien [(505) 667-1674] (P-24), N.M.Hoffman, G.R.Magelssen, D.P.Smitherman (XTA)

Our research team is studying the coupling of Richtmyer-Meshkov (RM) and ablative Rayleigh-Taylor (ART) instabilities with indirectly driven, planar foil experiments on the Nova laser at Livermore. The foil is attached to a 1.6-mm-diameter, 2.75-mm-long gold hohlraum driven by a shaped laser pulse that is 2.2 ns long with a contrast ratio of 1:5. A shock is generated in 35-μm- or 86-μm-thick aluminum foils with a sinusoidal perturbation (with a wavelength of 50 μm and an amplitude of 4 μm) on its rear surface. In some experiments the perturbation is applied to a 10-μm beryllium layer on the aluminum. An RM instability develops when the shock encounters the perturbed surface. The flow field of the RM instability can “feed out” to the ablation surface of the foil and provide the seed for ART perturbation growth. This is an important problem for ICF, in which the nonuniformity in the D-T ice surface inside the capsule can feed ART growth in the capsule exterior. We use face-on and side-on x-radiography to observe areal density perturbations in the foil. For the 86-μm foil, the perturbation arrives at the ablation surface while the hohlraum drive is dropping, and the data are consistent with RM instability alone. For the 35-μm foil, the perturbation feeds out while the hohlraum drive is close to its peak, and the data appear to show strong ART perturbation growth. The data are in generally good agreement with LASNEX simulations (simulations performed with the Los Alamos version of the ICF design code first developed at Livermore) except that the simulations do not reproduce the strong development of a second harmonic in the thin aluminum samples.

High-Intensity Illumination of an Exploding Foil

J.A.Cobble [(505) 667-8290], R.P.Johnson (P-24), R.J.Mason (XPA)

Successful ICF involves the compression of a D-T fuel to sufficiently high density, ignition in a hohlraum hot spot within the fuel, and a propagating fusion burn within the fuel. Conventional ICF relies on carefully timed, converging shocks driven by the compression beams. A promising alternate concept, the "fast-ignitor," relies on a high-intensity laser to light the hot spot on the preassembled fuel. In order to achieve that, the beam must propagate through the underdense plasma surrounding the capsule, where laser-plasma instability could break up the beam.

During the first year of research, we employed the short-pulse capability of the Trident laser at Los Alamos to measure the penetration of a high-intensity beam through a 1-mm-scale-length, underdense, C-H plasma. The highest laser irradiance was 7×10^{18} W/cm^2. The plasma density is controlled via the delay between the low-intensity plasma-formation beam and the high-intensity probe beam. Our experiment used plasmas of several percent of the critical electron density (above this critical density the laser cannot propagate). The probe beam was focused with an *f*/2.5 parabola. We found that the beam *f* number was increased after the beam had passed through the plasma; i.e., it was more collimated on account of its interaction with the plasma. In order to measure this effect, we allowed the transmitted beam to strike a diffuser plate behind the target. The scattered light from the plate was imaged by a camera to produce the data shown in Fig. III-1. We also measured the reflected and transmitted light for different delays (different plasma densities). Even at the low plasma densities used, the transmission was less than we had expected. Theoretical studies that attempt to model the behavior of the beam in the plasma are under way. Work from our first year of research will be published in *Physics of Plasmas*. More experiments, in which the plasma density and laser wavelength will be varied, are planned for 1997.

(a)

(b)

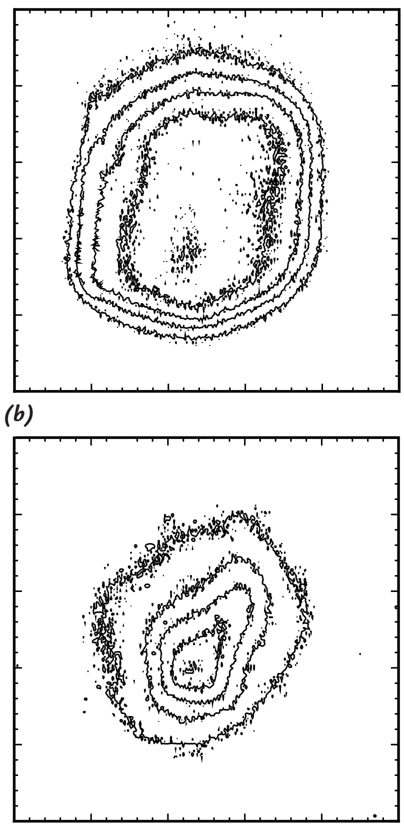

Fig. III-1. The f number of the probe beam is approximately doubled on passage through a 3% critical-density plasma. The case with no plasma is shown in (a); the case with a plasma is shown in (b). Each frame is an array of 250 × 250 pixels.

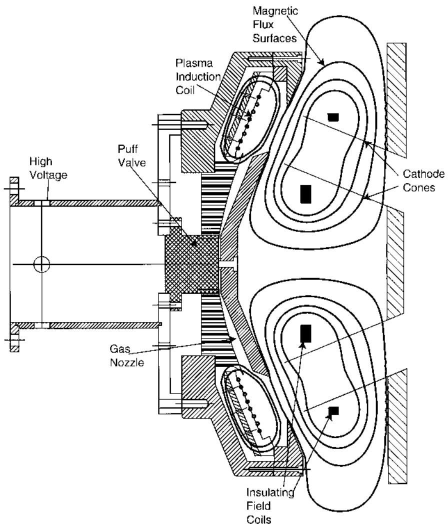

Fig. III-2. Design of the intense-ion-beam source.

Microsecond-Duration, Repetitive, Intense-Ion-Beam Accelerator

H.A.Davis [(505) 667-8373], L.Bitteker, M.D.Monroe, W.A.Reass (P-24), D.M.Coates (P-DO/DuPont Central Research), H.M.Schleinitz (P-24/DuPont Central Research)

A number of intense-ion-beam applications are emerging that require repetitive, high-average-power beams. These applications include ablative deposition of thin films, rapid melt and resolidification for surface-property enhancement, advanced diagnostic neutral beams for the next generation of tokamaks, and intense pulsed-neutron sources. We are developing an intense-ion-beam accelerator called CHAMP (continuous high-average-power microsecond pulser) with a beam energy of 250 keV, a beam current of 15 kA, a pulse length of 1 ms, and a pulse frequency of 1–30 Hz. The accelerator will use a magnetically insulated extraction diode in a ballistically focused geometry (see Fig. III-2). The 450-cm^2 active plasma anode (MAP diode) can utilize any gaseous species. Gas is supplied from a puff valve located on the system axis and is ducted through a radial flow channel. The anode plasma is formed by currents induced in the gas by a fast-rising, two-turn, flat, spiral-wound coil with four parallel sets of windings. The insulating transverse magnetic field will be generated by two magnetic-field coils on the grounded cathode focusing cones. We will use a set of parallel, lumped-element, Blumlein circuits and a step-up pulse transformer to supply the diode acceleration voltage. Our current work is centered on testing and optimizing the plasma-generation system.

Laser-Plasma Instability Research in Fusion-Ignition-Relevant Plasmas

J.C.Fernández [(505) 667-6575], B.S.Bauer, J.A.Cobble, G.A.Kyrala, D.S.Montgomery, R.G.Watt, M.D.Wilke (P-24), W.M.Wood (P-22), D.F.DuBois, H.A.Rose (T-13), H.X.Vu (XPA), B.H.Wilde (XTA), collaborators from Lawrence Livermore National Laboratory and Physics International

Laser-plasma instability could pose a threat to success in ICF either by scattering light outside of the target or spoiling the symmetric illumination of the fusion capsule. The speckled nature of laser beams used in ICF is an important factor in laser-plasma instability processes. Models that account for the laser speckles successfully predict the observed onsets of backscattering due to stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS). Linear convective theory predicts very large levels of SRS backscattering from the long-scale plasmas expected in ignition hohlraums. Our observations of SRS saturation are inconsistent with linear theory scaling, but are qualitatively understood in terms of other processes. In particular, we have shown direct evidence for the dependence on acoustic damping of the SRS reflectivity of a 351-nm, random-phase-plate laser beam from a long-scale hohlraum plasma. Because SRS itself is unrelated to acoustic waves, this is evidence of other parametric processes determining the nonlinear saturation of Raman backscatter. We have great expectations from optical imaging diagnostics recently deployed at Nova. They could help elucidate important outstanding questions relating to SBS and SRS nonlinear saturation, and they could also prove to be valuable electron-density diagnostics.

Effort in Support of the Core Science and Technology Plan for Indirect-Drive ICF Ignition

N.A.Kurnit [(505) 667-6002], T.Shimada, M.S.Sorem, R.F.Harrison (P-24), A.J.Taylor, T.S.Clement, G.Rodriguez (MST-11), D.F.V.James, P.W.Milonni (T-4), collaborators from University of New Mexico and California State University at Fullerton

In conjunction with other researchers in MST and T Divisions, we have carried out a number of theoretical and experimental studies of nonlinear optical phenomena important to the design of the National Ignition Facility (NIF) laser. These studies include measurements of nonlinear refractive index coefficients (n_2), Raman scattering in atmospheric oxygen, and theoretical studies primarily of harmonic conversion. Our motivations for measuring n_2 were the relatively large scatter in the data that had been obtained for fused silica by different techniques at 355 nm and the importance of this effect in setting the size of optics at NIF in order to avoid damage due to self-focusing. Our results were consistent with the lower range of previously reported measurements and indicated that the chosen size for the NIF final optics assembly would not have to be increased; a larger optics assembly would have cost significantly more. We made our measurements by a modified Z-scan technique in which the intensity distribution of an initially flat top beam that is relay-imaged onto a charge-coupled device (CCD) camera is recorded when a sample is scanned through the focus. These measurements were also confirmed by MST-Division researchers using the recently developed ultrashort-pulse characterization technique of frequency-resolved optical gating, with which they determine phase shifts induced by propagation through a sample. The Raman-scattering studies were prompted by some earlier calculations, which indicated that the method that had been suggested to avoid rotational Raman scattering by nitrogen in long air paths at NIF would not be adequate. This suggested method—to place part of the propagation path in a breathable oxygen/argon atmosphere—would be inadequate because the Raman gain in the atmospheric concentration of oxygen is approximately 77% of the nitrogen gain. Experiments to measure the relative gains validated this calculation to within a few percent. The NIF design has since been altered to incorporate inert-gas beam tubes. Work in T Division on efficient, multiple-crystal, harmonic-conversion geometries for NIF has been extended to look at the effect of such geometries as a means of possibly mitigating phase perturbations that result from the baseline design, which are a major contributor to damage in downstream optics. We have observed some improvements with such designs, but we are still seeking an ideal case that maintains high conversion efficiencies. Ongoing work also includes the examination of multiphoton absorption effects in potassium dihydrogen phosphate (KDP) harmonic-conversion crystals and the pursuit of designs for spatial-filter pinholes that do not close because of rapid plasma production.

Plasma-Based Removal of Transuranic Contaminants from Surfaces

C. Munson [(505) 667-7509] (P-24), E.P.Chamberlin, J.M.Veilleux (CST-11), J.R.FitzPatrick (CST-7), J.C.Martz (NMT-5)

The primary goal of this project is to develop and demonstrate the utility of plasma-based processes for the removal of transuranic (TRU) contamination from targets of interest to the DOE complex. The first stage of the process has been to design, fabricate, and perform initial tests of a small prototype plasma-decontamination system, using both uranium and nonradioactive surrogate contaminant materials. We have designed, fabricated, and integrated a small system (~0.5 m^3) with a two-stage cryogenic trapping and recovery system. Examination of the etching characteristics of various gases (including CF_4, NF_3, and SF_6) led to the selection of NF_3 as the plasma precursor gas because of its reduced potential for particulate formation and for nonvolatile material deposition. We have conducted experiments to examine the removal of various contaminant materials in a number of different target geometries. These geometries have included the removal of uranium contamination from the shielding material used in explosives tests as well as from the inside of relatively small diameter pipes (with an inside diameter of 1.25 cm and a length of 20 cm). We have also conducted a very large scale test (~3-m^2 target area) in another available facility. This test examined the removal of a very hard, chemically resistant, amorphous carbon material from the surface of an extremely complex aluminum target. We used an oxygen plasma in this case as an analogue for the fluorine-based plasma that would be used to volitalize and remove plutonium or uranium from contaminated surfaces. Experiments with NF_3 and tungsten (as the TRU surrogate) have demonstrated material-removal rates in a mild, reactive-ion-etching (RIE) mode. These rates are nearly an order of magnitude faster than the material-removal rates we observed in the plasma-immersion mode. Tests using uranium have demonstrated >99% removal of the original contaminant, based on surface alpha-count techniques. Experimental work is now moving in the direction of direct demonstrations using plutonium-contaminated surfaces.

Plasma-Source Ion Implantation and Plasma-Immersion Ion Processing

C.Munson [(505) 667-7509], J.T.Scheuer, B.P.Wood (P-24)

Plasma-source ion implantation (PSII) and plasma-immersion ion processing (PIIP) can be used to provide economical surface modification in order to satisfy industrial and DOE needs. These technologies promise low-cost methods with widespread application for the manufacture and utilization of high-strength, low-friction, corrosion-resistant, or biocompatible materials. R&D is focused on recipe development and materials characterization, pulsed-power equipment development, advanced inductive plasma sources and plasma diagnostics, and manufacturing process controls. Important applications include the following:

Advanced manufacturing. Work in this project includes demonstration implants on industrial components and high-temperature implantation experiments. In addition, we have developed a process to deposit adherent diamond-like carbon films on steels, and we have designed and fabricated a solid-state, insulated-gate, bipolar transistor modulator.

Automotive and other industries. This program, supported by DOE and NIST, involves a vertically integrated consortium of approximately more than a dozen industrial partners directed toward the commercialization of PSII techniques for these industries.

Gun barrels on tanks. In this project we are developing highly adherent coatings for wear- and corrosion-resistant gun barrels. This project supports Army work and involves ion implantation and deposition with plasmas inside 120-mm gun barrels on tanks.

Liquid-metal containment. This area includes containment associated with metal-casting of actinides (for Advanced Design and Production Technology) and of aluminum and magnesium (for industry).

Machine tools. The goal of this project is to commercialize PSII in order to extend the life of machine tools. Los Alamos, the site of the world's largest PSII facility, has teamed with Empire Hard Chrome (EHC) of Chicago, Illinois, to construct the world's first commercial PSII facility. To make this venture a success, Los Alamos will provide hands-on training of EHC equipment operators as well as the plasma and materials expertise that EHC requires to develop recipes, optimize conditions, and qualify applications.

Pistons and automotive tooling. We have successfully completed our major technical goals in this CRADA between Los Alamos and General Motors.

Pits. We are supporting the Nuclear Weapons Technology weapons-surety program by using PSII to develop fire-resistant erbia coatings for pits. In addition, we are developing molten-plutonium-resistant coatings for near-net-shape casting molds, a project that supports the pit-rebuild program.

Penning Fusion Experiment
M.M.Schauer [(505) 665-6014], T.B.Mitchell (P-24), D.C.Barnes (XCM)

The Los Alamos Penning Fusion Experiment seeks to confine high-density, nonneutral plasmas in a Penning trap. These traps combine static electric and magnetic fields to confine charged particles for up to several hours. However, because the traps can hold only a single charge, we are restricted to nonneutral plasmas, and the resulting space charge limits the ultimate density we can attain. The limiting value is known as the Brillouin density. In these experiments we have demonstrated the feasibility of forming a high-density core plasma in a volume-averaged, sub-Brillouin-density electron plasma through spherical focusing of the plasma. This is achieved by tuning the electric and magnetic fields of the trap so that the effective well seen by the electrons is spherical. Hence, the electrons are reflected by the well toward the center of the trap and form a high-density focus. We have seen conclusive evidence of the existence of such a focus in the form of scattering resonances in the trap parameter space. Electron-density distributions inferred from collected data indicate a peak density 35 times the limiting Brillouin value. In addition, we have documented an interesting hysteresis in the onset of the focus as a function of pumping current. Our future plans include an experiment that will confine ions in the virtual cathode provided by the confined-electron space charge.

Particle Removal in a High-Pressure Plasma
G.S.Selwyn [(505) 665-7359] (P-24), collaborators from Beta-Squared, Inc.

Plasma processes are used in 35% of the process steps needed to fabricate a semiconductor device. Particle contamination is a serious problem encountered during fabrication of devices and is a problem exacerbated by the formation of particulate contamination during plasma processing. Also, cleaning steps required to prepare semiconductor surfaces for processing consume several million gallons of water each day for a large foundry, and the use of solvents also required for surface cleaning produces chemical waste and ground-water pollution. Plasma processes may be used to clean wafer surfaces and materials of interest to DOE. The development of this technology offers an approach that is pollution-free because it uses harmless, inert gases; that may be done *in situ* prior to processing steps inside a plasma tool; that rapidly cleans the entire wafer while it is under vacuum; and that avoids redeposition of removed particulate matter back onto the wafer.

The first phase of this technology development was the demonstration of particle removal from wafer surfaces by plasma processes. In this collaboration, LANL applied its knowledge and skills in the development of technology for particle detection and removal from surfaces; Beta Squared, Inc., applied its capabilities in the design of a plasma tool suitable for use with this technology. This program proved highly successful: the Laboratory and Beta Squared, Inc., collaborated to build a prototype tool and successfully demonstrated that particulate contamination could be removed from wafers using plasma processes. The technology is suitable for immediate use on processing tools; a patent is currently in preparation. The same technology can now be applied for the development of a nonpolluting and nonhazardous method for removal of radioactive dust from surfaces. This can offer substantial benefits in cost-effectiveness and safety for decontamination and cleanup of contaminated areas.

Pollution-Free Plasma Cleaning of Materials

G.S.Selwyn [(505) 665-7359], I. Henins, J. Velarde, J. Park, (P-24), R.F.Hicks (University of California at Los Angeles), K. Wilson (Atmoplaz)

A new plasma process is being developed at LANL and at the University of California at Los Angeles (UCLA) for the pollution-free cleaning of materials. In addition to the R&D 100 Award–winning PLASMAX cleaning process, which uses a novel plasma/mechanical process for removal of particulate contamination, we have recently invented an Atmospheric-Pressure Plasma Jet (APPJ) that is capable of removing organic, metallic, and oxide contaminants from materials at rates between 1 and 15 μm/h. These rates are up to ten times faster than can be achieved with conventional, low-pressure plasmas. The APPJ does not require a process chamber; thus, it can decontaminate materials of any size and shape, and it can be used out in the field if necessary. The jet is not like a plasma torch, which ionizes gas through excessive heating. Instead, the APPJ produces a stream of electronically excited metastable and radical species at about 450 K. This makes it safe for use on a wide variety of materials.

We are pursuing several applications for the plasma jet, including the decontamination of nuclear wastes and the cleaning of silicon wafers during integrated-circuit manufacturing. In the former case, the APPJ will etch away plutonium deposits on objects so that they may be reclassified from transuranic to low-level radioactive waste. We have won a $1.2-million DOE Environmental Management Science Program award to develop the science and technology of plasma-jet decontamination of nuclear wastes. The APPJ may also be used to clean semiconductor substrates. Currently, silicon wafers are cleaned with large quantities of deionized water, acid, and organic solvents. The industry wants to replace these wet-chemical methods because they are expensive, are hazardous to workers' health, and can pollute the environment. The APPJ is a promising alternative for wafer cleaning that uses no toxic chemicals and will not pollute the environment. In FY98 we will investigate the physics and chemistry of APPJ etching of tungsten and tantalum films (surrogate metals for plutonium) and of photoresists from silicon wafers. The plasma-source physics and gas chemistry will be investigated at LANL, and the surface chemistry of etching materials will be studied at UCLA. We are hopeful that this research will lead to a new, pollution-free technology for the cleaning and decontamination of materials.

Ion Sources for Etching and Deposition

M.Tuszewski [(505) 667-3566], J.T.Scheuer, J.A.Tobin (P-24)

Inductively coupled plasmas (ICPs) are used increasingly by the semiconductor and other industries as an important class of relatively high density (10^{11}–10^{12} ions/cm^3), low-pressure (1–10 mtorr) plasma sources for etching and deposition processes. Such high-density plasma sources can meet the industrial requirements of submicron feature size, low contamination, and high throughput. We have developed several novel ICP plasma sources for new applications: (1) ICPs powered by continuous radio frequency (0.4–13.56 MHz) in hemispherical, planar, and cylindrical geometries; (2) high-power, pulsed ICPs for plasma-based ion implantation; and (3) inverted ICPs (with a coil inside a dielectric tube) for vacuum chambers with difficult access. We have also studied inductive heating physics with various plasma diagnostics and with theoretical analysis. In particular, the large influence of the induced radio-frequency magnetic fields on low-frequency ICPs has been uncovered for the first time. Finally, we have developed a comprehensive set of plasma and gas diagnostics to gain understanding of how ICPs work and of how to achieve uniform plasmas of the desired composition over increasingly large areas. The above research is performed in part as a collaboration with industries such as Novellus Systems, Inc., Dow Chemical, and North Star Research Corporation.

Alcator C-Mod Tokamak Imaging Diagnostics

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Massachusetts Institute of Technology

A collaboration between Los Alamos and the Massachusetts Institute of Technology (MIT), this project is designed to provide specialized imaging diagnostics to the Alcator C-Mod tokamak. A new digital infrared (IR) camera system and IR periscope, intended to view the heat loads on the inner wall and divertor structures, has been designed, and construction will begin in FY97. Los Alamos delivered a full set of engineering drawings, optical design, and parts lists to MIT. Los Alamos systems at MIT include two fast visible cameras and a neutral-particle, time-of-flight diagnostic.

Columbia HBT-EP Magnetohydrodynamic Feedback Stabilization

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Columbia University

This project is a collaboration between Los Alamos and Columbia University that will provide a high-power, fast-feedback module to the HBT-EP (High-Beta Tokamak—Extended Performance) at Columbia University for the purpose of controlling plasma instabilities in real time. The unit will be used to study the effects of mode locking by using external coils to study driven plasma rotation and disruption prevention. It is the second of a set of two 10-MW, 0- to 30-kHz, 1000-A amplifiers. Although this collaboration was primarily an engineering effort in FY96, in future years we intend to study the underlying physical processes of these instabilities.

Diagnostic Development Relevant to the International Thermonuclear Experimental Reactor

G.A.Wurden [(505) 667-5633], C.W.Barnes, H.A.Davis, R.J.Maqueda, J.C.Olson, W.A.Reass (P-24), R.R.Bartsch (P-22), P.Staples (P-25), S.Han, R.S.Wagner (MST-11), collaborators from Cornell University, DuPont, and University of California at San Diego

Los Alamos is participating in a number of diagnostic-development activities that support the International Thermonuclear Experimental Reactor (ITER). We are supporting ongoing US/Japan collaborations with two advanced diagnostic systems under development and testing; this effort was also used to enhance our collaboration with the Tokamak Fusion Test Reactor (TFTR) at Princeton. First, our studies of diamond neutron detectors were concluded at the LAMPF neutron source at Los Alamos. Ongoing efforts with scintillating-fiber, 14-MeV-neutron detectors at the large JT-60U tokamak at the Japanese Atomic Energy Research Institute in Naka, Japan, continued with demonstration of remote diagnostic control over the Internet and of virtual presence at off-site experiments using integrated services digital network (ISDN) video conferencing. We are also designing a new diagnostic that could be applied directly to ITER for eventual prototyping on the new Large Helical Device in Nagoya, Japan. This diagnostic is a state-of-the-art imaging bolometer that will be able to measure the entire spectrum of energies emitted by a hot steady-state plasma. Los Alamos is also conducting scoping studies and doing diagnostic design to support the ITER Engineering Design Activity (EDA). This includes work on some physics R&D issues deemed important by the U.S. home team. In FY96 we worked on Phase I and II designs for several neutron-detector diagnostics (including neutron-activation and source-strength monitors). We also studied the prospects for an intense diagnostic neutral beam to be used for a variety of plasma measurements, especially for active spectroscopy.

Tokamak Fusion Test Reactor Experiment

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Princeton University

This project is an on-going collaboration between Los Alamos and Princeton University on the TFTR experiment at Princeton. Los Alamos fielded a new digital imaging system on an existing periscope to view plasma disruptions, plasma instabilities, and lithium-pellet injection during deuterium-tritium experiments. Los Alamos personnel are studying the sudden and violent demise of the plasma current and the formation of runaway electron tails, circumstances in which several megajoules of energy can be suddenly deposited on the vessel structures. Irradiation studies of Hall-probe magnetic-field sensors also continued in the realistic neutron environment of the TFTR.

A Target Plasma Experiment for Magnetized Target Fusion

F.J.Wysocki [(505) 667-6543], R.E.Chrien, T.A.Ortiz, D.Whiteson (P-24), G.Idzorek, R.R.Newton (P-22), H.Oona (DX-3), P.T.Sheehey (XNH), R.Kirkpatrick (NIS-9), I.R.Lindemuth (XPA)

Achieving controlled fusion is a scientific “grand challenge” that has been pursued for over 40 years. Fusion energy would help satisfy the long-term energy needs of the growing population on Earth. Magnetized target fusion (MTF) is an approach to controlled fusion in which a premagnetized, preheated target plasma is near-adiabatically compressed to fusion conditions. The objective of this project is to develop the ability to generate suitable target plasmas for MTF, the first critical milestone in the development path for achieving fusion with the MTF concept. Our approach involves driving a fast-rising electrical current reaching 1–2 MA through a fiber of cryogenically frozen deuterium on the order of 200 mm in diameter. The fiber rapidly turns to plasma, heats, and expands to fill a plasma-containment chamber, thus becoming confined by the walls of the chamber.

This project relies heavily on existing facilities and equipment at the Laboratory that are adapted to our needs. This year, we designed and constructed a power-flow-channel and plasma-chamber system, and we incorporated this system into the Laboratory’s Colt capacitor-bank facility. The capacitor bank has a maximum stored energy of 0.25 MJ, and it delivers a maximum of 3 MA of current with a rise time of 2–3 ms. We have performed initial plasma-formation experiments using a static fill of hydrogen gas. The diagnostics that we have fielded include an array of 12 B-dot probes used to determine plasma current; a 1.3-mm laser interferometer to determine plasma density; an optical framing camera; a gated, optical, multichannel analyzer for visible spectroscopy; a visible/near-ultraviolet monochromator with time resolution for spectral time history; photodiodes to measure light emission; and the usual capacitor-bank monitors. The data show that we are generating a plasma that lasts 10–20 ms with no obvious signs of impurities. Further analysis of the data is ongoing. The results from the 1.3-mm interferometer show that we need to go to a shorter-wavelength laser interferometer to reduce beam deflection caused by density gradients in the plasma and to reduce the overall sensitivity of the system. In accordance, we have borrowed a HeCd laser, purchased the supporting optics, and assembled and bench-tested the new interferometer. We will install the new interferometer on the actual plasma chamber in the near future. We are also refurbishing the cryostat used for making the cryogenically frozen deuterium fibers and will be installing it on the plasma chamber.

P-25: Subatomic Physics

Measurement of the Electric Dipole Moment of the Neutron

M. D. Cooper [(505) 667-2929], L. J. Marek, D. Tupa (P-25), M. A. Espy (P-21), S. K. Lamoreaux, S. I. Penttila, J. S. Sandoval (P-23), G. L. Greene (LANSCE-DO)

The Electric Dipole Moment (EDM) project is a new project in which we will develop an experiment to measure the EDM of the neutron. A nonzero value of the neutron's EDM would imply that a fundamental symmetry of space-time reversal has been violated. The only example of such a violation is in the neutral kaon system, although the violation is expected to be a general, but small, phenomenon. A measurement of the neutron's EDM is important for understanding the baryon-antibaryon asymmetry of the universe and for searching for physics beyond the standard model of electroweak interactions, especially grand-unified supersymmetry. We propose to take advantage of the construction of the Long Pulse Spallation Source at LANSCE to build a special superthermal source of ultracold neutrons that will allow us to measure the EDM to a level of 10^{-28} e•cm, an improvement of three orders of magnitude over past measurements. The international collaboration for this complicated experiment is just beginning to form, and development work is commencing in preparation for submitting a funding proposal to DOE at the end of 1998.

MEGA

M. D. Cooper [(505) 667-2929], M. Brooks, A. V. Chernyshev, G. W. Hart, G. E. Hogan, M. A. Kroupa, V. D. Laptev, D. M. Lee, G. B. Mills, R. E. Mischke (P-25), F. J. Naivar, C. Pillai, J. C. Sturrock (LANSCE-6), collaborators from Fermi National Accelerator Laboratory, University of Houston, Indiana University, Texas A&M University, Valparaiso University, University of Virginia, and Virginia Polytechnic Institute and State University

The apparent conservation of muon number remains a central problem of weak-interaction physics. Searching for processes that violate muon-number conservation will give insight into the possible extensions of the minimal standard model of weak interactions. MEGA (muon decays into an electron and a gamma ray) is designed to make such a search at LAMPF, now known as LANSCE. This past year was the final year of acquiring production data. The combined data from the summers of 1993–1995 should yield a sensitivity of roughly 7×10^{-13}, an improvement by a factor of 70 in the current world sensitivity to this process. The MEGA collaboration made substantial strides in developing algorithms to extract the results. The three major components of the analysis include reconstructing the kinematic properties of the photon and of the positron and determining their relative timing. The photon analysis is nearly complete, and the other two components have reached an advanced stage.

Theory

M. B. Johnson [(505) 667-6942], D. Ahluwalia (P-25), J. D. Bowman (P-23), collaborators from institutions in the United States, Canada, France, Israel, Kazakhstan, Russia, and Taiwan

The Subatomic Physics group has a small theory component. We are currently developing a theory for connecting hadron properties in free space, and we have also explored phenomenological approaches that use data to determine masses and coupling constants for higher-mass resonances in nuclei. In addition, we are developing a theory for connecting mean-square matrix elements of the parity-violating interaction (measured by TRIPLE in compound-nuclear resonances) to the underlying parity-violating force. This theory exploits the chaotic properties of the compound nucleus. Another project involves the reaction theory of pion scattering from nuclei. In this project we are simplifying the description of specific reactions so that these reactions can more easily be used for specific purposes, such as evaluating hadron transport in nuclear collisions and interpreting results of dibaryon resonance searches. One group member investigated the phenomenon of neutrino oscillations within a three-state mixing model and found that all reported neutrino-oscillation data are consistent with a mass mixing-angle analysis in terms of three neutrinos. His "Gravitationally Induced Neutrino-Oscillation Phases" is the Gravity Research Foundation's First Award Essay for 1996. Participants at a relativistic heavy-ion meeting held during the summer of 1995 determined that essentially all relativistic heavy-ion transport event generators are incapable of reproducing pion production data taken at LANSCE. We are investigating why the data are irreproducible; the answer could have a significant impact on our heavy-ion and PHENIX experimental programs.

Experiments E866, E789, and E772: Quark-Gluon Physics at FNAL

M. J. Leitch [(505) 667-5481], M. Brooks, T. A. Carey, G. T. Garvey, D. M. Lee, P. McGaughey, J. M. Moss, J.-C. Peng, P. E. Reimer, W. E. Sondheim, T. N. Thompson (P-25), B. K. Park (NIS-6), collaborators from Abilene Christian University, Argonne National Laboratory, Fermi National Accelerator Laboratory, Georgia State University, Illinois Institute of Technology, Louisiana State University, New Mexico State University, Oak Ridge National Laboratory, Texas A&M University, and Valparaiso University

This program at the Fermi National Accelerator Laboratory (FNAL) has been highly visible and productive. Our group was the first to exploit high-energy hadronic processes for exploring the quark structure of nuclei. We are investigating the nuclear dependence of lepton-pair production with proton beams to understand how the quark and gluon structure in nuclei differs from that in free nucleons. During the past year we made substantial progress in the construction and refurbishing of the

FNAL Meson-East spectrometer, where E866 began taking data in July 1996. In that experiment we are searching for deviations in the distributions of anti-up and anti-down quarks in the proton to provide insight into hadronic and partonic descriptions of the nucleonic sea. We also continued major analysis efforts on past experiments E772 and E789. We developed Monte Carlo and analysis software that will enable us to extract cross sections from 1.5 million Drell-Yan and Upsilon production events from the copper beam dump of E772. In addition, we finished analyzing and published the first *B*-meson cross-section data for 800-GeV proton-nucleus interactions and published the nuclear dependence of J/Ψ production in the negative *x*-Feynman region.

Electroweak Physics at the Liquid Scintillator Neutrino Detector

W. C. Louis [(505) 667-6723], R. L. Burman, F. J. Federspiel, G. T. Garvey, G. B. Mills, V. Sandberg, R. Tayloe, D. H. White (P-25), J. B. Donahue (LANSCE-7), collaborators from the University of California at Riverside, University of California at San Diego, University of California at Santa Barbara, Embry-Riddle Aeronautical University, University of California Intercampus Institute for Research at Particle Accelerators, Linfield College, Louisiana State University, Louisiana Tech University, University of New Mexico, Southern University, and Temple University

With the Liquid Scintillator Neutrino Detector (LSND) at LANSCE, we are searching for evidence of neutrino oscillations, in which neutrinos transform from one flavor into another. These oscillations would imply that neutrinos have mass, an implication that contradicts the standard model of particle physics. If neutrinos have mass, they may profoundly affect cosmology and the evolution of the universe. The LSND collaboration has published papers describing the detector and the analysis of the full decay-at-rest data sample through December 1995. The LSND paper "Evidence for Neutrino Oscillations from Muon Decay at Rest" was published in the November 1996 issue of *Physical Review C*. We have also analyzed our decay-in-flight data and have observed an excess of events that is consistent with neutrino oscillations and with our decay-at-rest data. Because the decay-at-rest and decay-in-flight searches have completely different backgrounds and systematics, this decay-in-flight analysis provides strong additional evidence that we are indeed observing neutrino oscillations.

Applied Programs: The Role of Proton Radiography in Stockpile Stewardship

J. B. McClelland [(505) 667-7291], J. F. Amann, J. G. Boissevain, C. J. Espinoza, J. Gomez, G. W. Hart, G. E. Hogan, C. Morris, H. A. Thiessen, H.-J. Ziock, J. D. Zumbro (P-25), collaborators from P-23, DX Division, LANSCE Division, T Division, X Division, ESA Division, Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, Indiana University Cyclotron Facility, and Bechtel

The decisions to forgo underground nuclear testing and to restrict the nuclear stockpile to an increasingly smaller number of weapons have forced DOE and its laboratories to rethink their role in stockpile stewardship. Much of this reassessment has been embodied in the philosophy of science-based rather than test-based stockpile stewardship. Proton radiography offers several advantages over conventional x-ray techniques for radiographing thick, dense, dynamic systems. These advantages include (1) high penetrating power, (2) high detection efficiency, (3) very small scattered background, (4) no need for a conversion target and the consequent phase space broadening of the beam, (5) inherent multipulse capability, and (6) the ability to tolerate large stand-off distances from the test object and containment vessel for both the incoming and outgoing beams. Additionally, proton radiography provides the unique possibility of measuring both the density and the material composition of a test object with a pulsed system. Protons interact with matter through both the long-range Coulomb force and the short-range strong interaction. Focusing protons using a magnetic lens allows the magnitude and Z-dependence of the interaction to be changed simply by looking at an object through different angular apertures and, thus, leads to the capability for assessing material composition. Multiple images can be made on a single axis by using multiple detectors, lenses, and irises. P-25 leads this effort together with a strong cross-divisional team that includes P, DX, LANSCE, T, and X Divisions.

Booster Neutrino Experiment at FNAL

G. B. Mills [(505) 667-7330], W. C. Louis, V. D. Sandberg, R. L. Tayloe (P-25), collaborators from Columbia University, Louisiana State University, and University of California at Riverside

Los Alamos has long been a world leader in subatomic-particle physics, especially in the field of the elusive neutrino particle. The recent success of the LSND at LANSCE has excited the physics community around the world. The LSND experiment has been in operation since 1993, and plans are to continue its operation until roughly the year 2000. The startling discovery of neutrino oscillations at LSND has given Los Alamos physicists the motivation to take the next step in this line of research: to make precise measurements of the oscillation phenomena. The ideal setting for these measurements takes us away from Los Alamos to FNAL in Batavia, Illinois. Proton beams from a rapid cycling booster synchrotron at 10 times the energy of the LANSCE beams are available to produce neutrinos at FNAL. The Booster Neutrino Experiment (BOONE) will capitalize on the technology developed for the LSND experiment. It will reuse much of the equipment that is currently being used in the LSND experiment. The neutrino beams to be developed at FNAL will give a 40-fold increase in the rate of neutrino-oscillation events over the current LSND experiment. The ultimate goal will be to measure the oscillation parameters with a precision of a few percent. A more challenging goal will be to study the fundamental symmetries of the neutrino mixing matrix, especially the charge-conjugation and parity-reversal properties of neutrinos. These studies require the use of neutrino and antineutrino beams, which can be made available at FNAL.

RHO Experiment: Measurement of the Michel Parameter

R. E. Mischke [(505) 667-6814], J. F. Amann, M. D. Cooper, G. W. Hart, G. E. Hogan, T. Kozlowski (P-25), R. D. Bolton (NIS-6), W. Foreman (NIS-8), R. Harrison (DX-5), C. Pillai (LANSCE-6), S. A. Schilling (ESA-DE), collaborators from the University of Chicago, Fermi National Accelerator Laboratory, University of Houston, Indiana University, Texas A&M University, Valparaiso University, University of Virginia, and Virginia Polytechnic Institute and State University

The energy spectrum for positrons emitted in normal muon decay contains a portion that is independent of polarization, and the shape of this portion is governed by the Michel parameter, ρ. In this project we measured ρ with the MEGA positron spectrometer. The standard model predicts ρ to be 0.75; it is currently known to within 0.3% of that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. Collected data will enable us to measure ρ with a precision of 0.05%, but we are still evaluating the systematic errors. Such a precision would allow us to check the reported deviations from the standard model in neutron decay. Our analysis should be complete by early 1997.

PHENIX Experiment at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory

J. M. Moss [(505) 667-1029], V. Armijo, M. J. Bennett, J. G. Boissevain, M. Brooks, T. A. Carey, D. J. Clark, B. V. Jacak, W. W. Kinnison, D. M. Lee, M. J. Leitch, L. J. Marek, P. L. McGaughey, M. M. Murray, P. Reimer, B. Schlei, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, H. W. van Hecke (P-25), J. Kapustinsky (LANSCE-DO), T. Kozlowski (LANSCE-12), collaborators from NIS Division, ESA Division, and institutions in Canada, China, Germany, India, Israel, Japan, Russia, South Korea, Sweden, and the United States

The quark-gluon plasma (QGP) is a postulated phase of matter in which quarks and gluons are deconfined. Proof of its existence has, to date, eluded experimentalists, although theoretical speculations about its nature abound. If the QGP phase transition does occur, then the characterization of that transition is of intense interest and importance to nuclear and particle physics.

The PHENIX detector is a large, multipurpose detector designed to detect the QGP and characterize its properties at the Relativistic Heavy Ion Collider (RHIC) being built at Brookhaven National Laboratory. PHENIX is being constructed by a large collaboration of physicists and engineers from universities and laboratories around the world. The detector design as a whole focuses on leptons (that is, electrons and muons), photons, and hadrons. Los Alamos collaboration members continue to have a significant impact on this major thrust of the nationwide nuclear-physics effort. P-25 members are responsible for the construction of the muon arms and the silicon multiplicity/vertex detector (MVD). The Los Alamos PHENIX muon-tracker team leads the conception, design, construction, and commissioning of the two large muon spectrometers that are crucial to the search for signatures of the quark-gluon plasma. The Los Alamos PHENIX MVD team leads the conception, design, construction, and commissioning of the MVD. Both construction efforts continue to meet major milestones. The Muon Station 2 has been fully prototyped and tested; it met or exceeded all requirements, including those for resolution and efficiency. The Station-3 full-size prototype was constructed and tested to demonstrate the feasibility of the design. The silicon-MVD preliminary design and safety plan have been reviewed with high marks, and there has been a successful beam test to demonstrate the design.

PHENIX Spin Program

J. M. Moss [(505) 667-1029], J. G. Boissevain, M. Brooks, T. A. Carey, D. Clark, J. Kapustinsky, W. W. Kinnison, T. Kozlowski, D. Lee, M. Leitch, J. McClelland, P. L. McGaughey, M. Murray, J. Simon-Gillo, J. P. Sullivan, H. W. van Hecke (P-25), PHENIX Collaboration

The scattering of high-energy, polarized muons from polarized protons at the European Center for Nuclear Research (CERN) revealed a big surprise about ten years ago. The spin of the proton receives only a small contribution from its valence quarks, those elusive building blocks of matter that determine most of the proton's other attributes. More recent experiments have refined and confirmed the CERN results, but they have added little hard evidence about the location of the missing spin. We hope that a new generation of polarized proton experiments, to be carried out at the Relativistic Heavy-Ion Collider at Brookhaven National Laboratory (BNL), will allow us to determine directly the contribution of specific degrees of freedom (such as quarks and antiquarks) to the proton's spin. The highly successful Los Alamos/RIKEN (Institute for Physical and Chemical Research, Tokyo [Wako], Japan) collaboration culminated two years of work, resulting in the final specification of the RIKEN contribution to the spin-structure function program of the PHENIX detector. RIKEN funding will purchase the PHENIX south-arm magnet plus the associated muon tracking and identification systems. This contribution greatly enhances the high-mass dimuon acceptance of the PHENIX detector and permits us to carry out a large menu of experiments on unique spin-structure function. Equally important, the muon upgrade will substantially increase the physics reach of the relativistic heavy-ion program.

Education and Outreach

A. P. T. Palounek [(505) 665-2574], J. F. Amann (P-25)

As members of three education programs run by the Laboratory, P-25 group members continue to be active in education and outreach activities. Group members visited every teacher and school in the TOPS (Teacher Opportunities to Promote Science) and TOPS Mentor programs at least once; conducted regional meetings for TOPS teachers, TOPS mentors, and TOPS alumni; and led several workshops in Los Alamos and Albuquerque. During the most recent workshop, TOPS mentors built (from scratch) a simple lightning detector designed by physicists from NIS-1 and P-25. Group members were also active in the PRISM (Preservice Institute for Science and Math) program. As a part of this program, we guided students through a comparison of the transmission qualities of various brands of sunglasses.

Experiment E907 at the Brookhaven National Laboratory Alternating-Gradient Synchrotron: Hypernuclear Physics

J.-C. Peng [(505) 667-9431], C. Edwards, C. Morris (P-25), collaborators from institutions in the United States, Croatia, and Japan

Los Alamos led the effort to propose a new hypernuclear experiment at the BNL Alternating-Gradient Synchrotron (AGS) using the LANSCE Neutral Meson Spectrometer (NMS) to measure the (K^-,π^0) reaction. Our proposal for this experiment was approved by the AGS Program Advisory Committee in late 1994. The experiment will demonstrate the feasibility of using the (K^-,π^0) reaction as a novel tool to produce Λ-hypernuclei with resolution significantly better than the existing (K^-,π^-) and (π^+,K^+) experiments, and it will measure the Λ-hypernuclear π^0 weak decay modes never before studied. The NMS and associated equipment were moved from LANSCE to the AGS in December 1995, and the first test run was completed in May 1996. The LANL team will assume responsibility for the NMS operation and physics direction in this experiment.

Pion Research

C. M. Riedel [(505) 665-4516], J. F. Amann, C. L. Morris, D. Tupa, J. D. Zumbro (P-25), M. A. Espy (P-21), S. I. Penttila, S. J. Seestrom (P-23), R. L. Boudrie (DX-6), J. N. Knudson (LANSCE-7), B. K. Park, M. W. Rawool-Sullivan (NIS-6), collaborators from institutions in the United States, Canada, Croatia, Germany, Japan, Russia, Switzerland, and the United Kingdom

We are currently analyzing pion data from the final 1995 LANSCE run and from previous runs. Of particular interest are the recent data taken with the NMS from the $p(\pi^-,\pi^0)$ reaction. The pi-nucleon charge-exchange database has historically been weak, and these recent measurements are expected to contribute to topics such as chiral symmetry breaking in the nucleon and isospin symmetry breaking in the pi-nucleon system. We expect to finish analyzing data collected at LANSCE, including pion charge-exchange data taken with the NMS as well as other elastic and inelastic pion-scattering experiments, and we will soon publish the final measurements of the low-energy cross sections and intermediate-energy analyzing powers for the pi-nucleon charge-exchange reaction. This work is being done in collaboration with colleagues from a number of institutions.

The NA44 Experiment: Relativistic Heavy-Ion Collisions at the European Center for Particle Physics

J. P. Sullivan [(505) 665-5963], J. G. Boissevain, D. E. Fields, B. V. Jacak, J. E. Simon-Gillo, W. E. Sondheim, H. van Hecke (P-25), collaborators from institutions in Denmark, France, Japan, Sweden, Switzerland, and the United States

Heavy-ion collisions at very high energies provide an opportunity to recreate the conditions that existed very early in the universe, just after the big bang. Experiment NA44 at the European Center for Particle Physics (CERN) is a second-generation relativistic heavy-ion experiment that searches for evidence that quarks and gluons are deconfined in matter at very high energy densities. The experiment focuses on correlations among identical particles as a function of transverse momentum in order to provide a closer look at the space-time extent of the central-region heavy-ion collisions. A long lifetime of matter in the central region is an indication of the formation of deconfined quarks and gluons.

In 1995 and 1996 the experiment took data with 160-GeV/nucleon lead-ion beams. Among the heavy-ion experiments at CERN, NA44 is unique in its ability to compare correlations of identified pions, kaons, and protons. Comparison of pion and kaon results clarifies the effects of resonance decays versus the time evolution of the emitting source. The high statistics from NA44 allow a careful study of the behavior of the chaoticity parameter (which is usually not well understood) and the exact shape of the correlation function. NA44 also measures single-particle distributions. Measurements of the distributions of protons emitted in Pb + Pb collisions and measurements of the ratio of negative- to positive-pion production both suggest significant stopping in these collisions, meaning that the protons and neutrons in the incident nuclei do not pass through one another in the collision (that is, they do not have transparency) but are slowed down significantly.

Members of the collaboration also interact with theoretical colleagues to study correlation functions predicted by the Relativistic Quantum Molecular Dynamics (RQMD) event generator and to compare those predictions with NA44 data. This work has provided the first detailed explanation of the information contained in the shape of the correlation function.

Measurements of Beta Asymmetry and Atomic Parity Nonconservation: Fundamental Symmetry Studies with Trapped Radioactive Atoms

D. Tupa [(505) 665-1820] (P-25), S. G. Crane, R. Guckert, M. J. Smith, D. J. Vieira, X. Zhao (CST-11), S. J. Brice, A. Goldschmidt, A. Hime, S. K. Lamoreaux (P-23)

With the advent of optical and magnetic traps for neutral atoms, a new generation of fundamental symmetry experiments can exploit point-like, massless samples of essentially fully polarized nuclei. At Los Alamos we are probing the origin of parity violation in the electroweak interaction by attempting to measure the beta-spin correlation function in the beta decay of ^{82}Rb confined to an atomic trap. By exploiting the geometry and the intrinsic features of such traps, we plan to measure the beta-spin correlation as a continuous function in both energy and angle of the emitted beta particles relative to the nuclear polarization. This continuous measurement would allow us to simultaneously extract new physics, such as the existence of right-handed currents, and recoil order effects, such as weak magnetism. With these traps we may also extract further information, such as the recoil ion momentum, that would allow a study of a much wider range of correlation parameters. Finally, we envision a new generation of atomic parity nonconservation experiments that test the neutral current portion of the weak interaction.

In these experiments, measurements with a series of radioactive isotopes of cesium and/or francium could eliminate uncertainties about atomic structure that presently limit the precision. A fundamental ingredient for performing these symmetry measurements is the efficient trapping of selected radioactive species. To this end we are using a magneto-optical trap (MOT) that is coupled to a mass separator. To date we have developed one of the world's largest MOT traps; it can trap up to 4×10^{10} atoms. By coating the inside of the glass trapping cell with a special nonstick coating of Dryfilm, we have measured a trapping efficiency of 20%. If we couple the MOT to a mass separator, we can introduce the species of interest into the trap without the deleterious effects of gas loading. In recent work using the mass separator–MOT system, we have successfully trapped stable ^{85}Rb, and we are currently attempting to trap a million ^{82}Rb atoms using a 2-mCi mother source of ^{82}Sr. We have also made good progress in modeling and designing the beta-asymmetry detection system and polarization trap.

P-DO: Physics Division Office

High-Current, Cold-Cathode Discharge Sources for Ion Implantation

D. J. Rej [(505) 665-1883] (P-DO), M. Nastasi (MST-4), N. V. Gavrilov, G. A. Mesyats (Institute of Electrophysics, Yekaterinburg, Russia)

We are developing reliable, high-efficiency, high-power ion sources that are applicable to a broad class of material-surface modification processes (e.g., the production of wear- and corrosion-resistant metals and polymers). The reverse magnetron, a plasma configuration invented at the Institute of Electrophysics in Yekaterinburg, Russia, is a high-current glow discharge with a cold cathode in crossed electric and magnetic fields. Prototype ion sources of ~150 cm^2 have been constructed that have operated successfully and reliably at 50 mA and 40 keV in reactive gases. Our program is directed toward developing a 1000-cm^2 source, with emphasis on (1) studying ignition and stable-discharge operation under low gas pressures with high currents; (2) optimizing conditions for formation of the ion-plasma emitter that produces a high ion current density with uniformity over a large area; and (3) decreasing contaminants generated by cathode erosion. Ion-implantation experiments were performed with carbon, nitrogen, and oxygen ions implanted into stainless steel over a wide range of temperatures and current densities. Significant increases in the surface hardness were observed in carbon and nitrogen implants, with the best results at intermediate temperatures of 400–500°C, resulting in case depths of 5–10 times the ballistic ion ranges. Improvements in wear of up to 100 times were observed.

Materials Processing with Intense, Pulsed Ion Beams

D. J. Rej [(505) 665-1883] (P-DO), H. A. Davis, J. C. Olson (P-24), M. Nastasi (MST-4), G. E. Remnev (Nuclear Physics Institute, Tomsk, Russia), V. A. Shulov (Moscow Aviation Institute, Moscow Russia)

Intense, pulsed ion beams (IPIBs) are an emerging technology that has been developed throughout the world over the last two decades, primarily for nuclear-fusion and high-energy-density physics research. IPIBs are created in magnetically insulated vacuum diodes from which 10- to 1000-kA beams of low-Z ions are accelerated to energies typically between 10 keV and 10 MeV in 10- to 1000-ns pulses. Physics Division is collaborating with two Russian institutes to develop IPIBs for the surface treatment of materials. The short range (0.1–10 μm) and high energy density (1–50 J/cm^2) of these short-pulsed beams make them ideal for flash-heating a target surface in a way that is similar to the more familiar pulsed laser processes. IPIB surface treatment induces rapid melt and solidification at up to 10^{10} K/s, which causes amorphous layer formation and the production of nonequilibrium microstructures. On the Anaconda accelerator at LANL, a 300-keV, 30-kA, 1-μs intense beam of carbon, oxygen, and hydrogen ions is used for the surface treatment of AISI-4620 steel, a common material used in automotive gear applications. Treated surfaces are up to 1.8 times harder than untreated surfaces and have no discernible change in modulus over depths of 1 μm or more. Qualitative improvements in the wear morphology of treated surfaces are observed.