3. Project Descriptions

Physics Division, in collaboration with the Dynamic Experiments (DX) and Applied Theoretical and Computational Physics (X) Divisions, conducts joint research activities with scientists from the premier All-Russian Institute of Experimental Physics (VNIIEF), which is the Russian counterpart to Los Alamos. These joint projects apply VNIIEF's unique capabilities to fundamental problems in high-energy-density science. Shown here is the team that performed the first High-Energy Liner experiment in Sarov, Russia. This experiment used a disk-explosive magnetic generator to implode a 1-kg, ~50-cm-diameter aluminum liner at velocities above the upper limit of two-stage light gas guns. This was the largest liner ever tested using advanced diagnostics.

BIOPHYSICS (P-21)

MRIVIEW: An Interactive Tool for Brain Imaging

D. Ranken [(505) 665-1781] (CIC-12) and J. S. George (P-21)

MRIVIEW is a software tool for viewing and manipulating volumetric magnetic resonance imaging (MRI) head data, and for using this data as an anatomical reference in studies of brain function. MRIVIEW supplies methods for reading in raw MRI data, viewing this data in either two or three dimensions, segmenting structures in the data, reconciling coordinate systems between the MRI data volume and data obtained from brain functional modalities, and viewing combinations of anatomical and functional information. MRIVIEW has three basic operating modes: a two-dimensional (2-D) mode for viewing and segmenting MRI slice data; a restricted three-dimensional (3-D) mode used for coordinate reconciliation; and a 3-D model-viewing mode.

In the 2-D mode, the MRI data volume is viewed as a series of slice images in one of the three standard orientations (sagittal, coronal, or axial). The user can page through these images eight at a time. A wide range of structure segmentation methods can be accessed while operating in the 2-D mode. These segmentation methods range from user-guided slice-by-slice flooding for labeling structures of interest, to an automatic volumetric method incorporating 3-D morphological and flooding operations.

In the 3-D model-viewing mode, MRIVIEW provides methods for generalized viewing and manipulation of 3-D MRI data volumes, and for combining these volumes with geometric models or volumes containing functional data. In this mode, the user can interactively rotate, translate, select cut planes, and perform other manipulations on a coarse model in a small graphics window, and then have the program draw a high-resolution rendering of the model (or models) in a larger graphics window. The display properties of each of these objects, such as color and rendering method used, can be manipulated independently. A variety of methods are provided for creating combined displays of MRI volumes and geometric models. The model viewer can also be used to make movies of objects in the system while they are being systematically rotated or cut by a moving cut plane.

MRIVIEW is written in IDL (Interactive Data Language), a product of Research Systems, Inc. IDL is a scientific programming language that provides a wide range of tools for data analysis and visualization, as well as features for developing graphical user interfaces. These tools work on UNIX workstations and PC and Macintosh platforms. IDL has a data parallel syntax, enabling manipulation of multidimensional arrays using arithmetic and logical operators. IDL also provides an efficient interactive mode for exploration and prototyping, as well as compiled operation for increased efficiency.

Megan: A Software Package for MEG and EEG Analysis and Visualization

E. Best [(505) 665-6187] (CIC-12) and J. S. George (P-21)

Neural electromagnetic (NEM) methods (magnetoencephalography [MEG] and electroencephalography [EEG]) allow noninvasive study of neuronal activity in the brain by measuring the magnetic field outside the head or the electric potential on the scalp. For decades, EEG (and more recently MEG) have been employed for investigating the temporal dynamics of neural population activity. The more recent use of NEM techniques for localizing current sources within the brain creates additional technical and analytical requirements. We have developed the software package MEGAN in response to the requirements for reliable signal processing, data visualization, source localization, and temporal analysis capabilities, as well as a convenient user interface, with the intent of making it available to the brain mapping community.

MEGAN currently handles MEG data from several sensor systems and is being extended to accept user-written modules to read data from other systems and to provide full support for EEG data. It supports both continuous and averaged evoked-response data. Continuous data may consist of spontaneous activity or may contain embedded sensory or behavioral responses; MEGAN provides capability for retrospective averaging relative to a stimulus or response record. This capability facilitates experimental paradigms that employ rapid or complex designs that produce temporally overlapping responses. MEGAN provides a rich variety of visualization options for selecting epochs of spontaneous data, data conditioning, and viewing of the data in a variety of forms, for example as field distributions or as waveform displays. All of the forms of data that MEGAN handles can be written to our standard netMEG file, a flexible, extensible, self-documenting, and highly portable file, written using the netCDF format. We have developed a code to read the netMEG file into programs written in C, Fortran, MATLAB and IDL. MEGAN is written in IDL, which has many advantages as a development and interactive runtime environment.

Imaging Brain Function with Magnetoencephalography

R. H. Kraus, Jr.
[(505) 665-1938], M. Espy,
A. Matlochov, L. Atencio, and
P. Ruminer (P-21)

Our project's goals are to develop, test, and evaluate sensor systems, numerical techniques, and computational models for functional imaging of the human brain using MEG. MEG measures a direct physical consequence of neuronal currents, with millisecond temporal resolution comparable to the temporal dynamics of the brain activity to be measured. In contrast, positron emission tomograpny (PET) and functional magnetic resonance imaging (fMRI) measure hemodynamic changes secondary to neuronal activity and are limited by the relatively sluggish vascular response to neuronal activity. Our project exploits Los Alamos-patented superconducting imaging technology to develop a high-performance whole-head MEG sensor array, combined with flux-locked loop approaches to noise reduction, advanced approaches to the electromagnetic forward and inverse problems, and computational models of brain anatomy derived from anatomical MRI. The high temporal resolution of MEG is particularly important for studying neurological disorders such as epilepsy in which temporal information is of major diagnostic value, and for fundamental studies of synchronization and oscillatory brain activity. This project benefits from collaborations with the University of New Mexico School of Medicine, the Albuquerque VA Medical Center, and Good Samaritan Hospital in Los Angeles, which are focused on clinical applications of MEG. This project has resulted in a number of applications for superconducting quantum interference devices (SQUIDs) in nonbiological Department of Energy (DOE) missions, including the DOE/Defense Program Enhanced Surveillance Program.

SQUID Microscope for Nondestructive Evaluation

M. A. Espy [(505) 665-6218], L. Atencio, R. H. Kraus, Jr., and A. Matlachov (P-21)

We have designed a SQUID microscope for use in the Enhanced Surveillance Program's nondestructive evaluation of the nuclear weapons stockpile. This microscope provides the unique ability to detect and characterize material defects and features deep within a component, even through numerous intervening layers of various materials. The development and testing of this microscope is discussed in detail in a research highlight in Chapter 2.

Bayesian Inference Applied to the Electromagnetic Inverse Problem

D. M. Schmidt [(505) 665-3584], J. S. George, and C. Wood (P-21)

To address the difficulty of estimating current distribution in the brain from surface EEG and MEG measurements (the so-called electromagnetic inverse problem), we have developed a new probablilistic approach based on Bayesian inference. Instead of aiming for a single "best" solution, our approach estimates the probability distribution of solutions upon which all subsequent inferences are based. This approach emphasizes the multiple solutions that can account for any set of surface EEG/MEG measurements. This work is described in detail in a research highlight in Chapter 2.

Optical Imaging of Neuronal Population Activity

D. Rector [(505) 665-6230] and J. S. George (P-21)

Optical imaging techniques can provide microscopic-level information about the individual and collective behavior of neuronal populations. We are developing an advanced image probe and digital acquisition system for high-performance functional neural imaging based on intrinsic light scattering signals. Two methods of reflectance mode illumination are being explored for fluorescence and polarized-light measurements. The system will incorporate an acousto-optic tunable filter to illuminate tissue with specific wavelengths for spectroscopic measurements. Our preliminary studies in the hippocampus and medulla have demonstrated several different optical changes associated with neural activation, including fast light-scattering changes concurrent with neural swelling and electrical transmission, and slower changes in light absorbence associated with hemodynamic coupling to metabolic demand.

Time-Resolved Photon Migration Tomography and Spectroscopy

J. S. George [(505) 665-2550] and D. Rector (P-21)

We are combining advanced illumination and time-resolved imaging strategies with computational models to develop optical methods for tomographic imaging and localized spectroscopy in scattering media. The sensitivity of light to physiological and biochemical parameters can provide information about the state and function of biological tissues not accessible by other techniques. This work exploits a novel photon-counting imager developed at Los Alamos for remote imaging applications. The detector is coupled to a light-collecting fiber-optic bundle detector system to measure the arrival time history and amplitude of the transmitted light emerging from many locations over the surface of the scattering medium. Time-resolved data are used to reconstruct the absorption and scattering properties of tissues using an iterative, model-based reconstruction procedure employing adjoint differentiation and gradient descent.

Single Molecule Detection

A. Castro [(505) 665-8044] (P-21)

Our efforts in the area of single-molecule detection and spectroscopy focus on the development of novel methods for the ultrasensitive detection and analysis of biological molecules and their applications to molecular biology and medical diagnosis. Recent developments include the implementation of a technique for the rapid, direct detection of specific nucleic acid sequences in biological samples without the need for enzymatic amplification. 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 with complementary sequences to the DNA target. The two probes are labeled with two different fluorescent dyes. The probes are mixed in the sample under investigation, and, if the target is present, 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. Simultaneous detection of the two probes signifies the presence of a target molecule. We have applied this method to the detection of specific sequences of DNA from a variety of sources. Most notably, we have demonstrated the detection of DNA from *Bacillus anthracis* at trace concentrations and in the presence of large amounts of unrelated DNA. *Bacillus anthracis*, the agent that causes anthrax disease, is the weapon of choice in biological warfare.

Miniature Flow Cytometer for Detecting Biological Agents

R. C. Smith [(505) 667-7931], C. Briles, and K. Wilson (P-21); and G. C. Salzman (LS-5)

In a collaboration with the Life Sciences (LS) Division, personnel from the Biophysics Group (P-21) are developing a miniature flow cytometer (MiniFCM) for the U.S. Army Chemical and Biological Defense Command at Aberdeen Proving Ground as part of their Biological Integrated Detection System (BIDS). The instrument weighs 60 lbs, has a volume of less than 2.4 ft^3, and consumes less than 250 W of power. It will be used to detect the presence of biological agents in aerosol clouds. This project has an associated cooperative research and development agreement with Bio-Rad Laboratories.

Remote Ultra-Low-Light Imaging

R. C. Smith [(505) 667-7931] (P-21)

This project, a collaboration among members of P-21 and the Nonproliferation and International Security (NIS) Division, is sponsored by the Office of Nonproliferation and National Security of the DOE and other federal agencies. Remote ultra-low-light imaging (RULLI) technology allows us to detect individual photons and measure their position and arrival time with high accuracy, opening avenues for novel applications such as detection of small objects in low Earth-orbit and measurement of foliage canopy density. This project is discussed in detail in a research highlight in Chapter 2.

Cyrax: A 3-D Laser-Mapping and Imaging System

K. Wilson [(505) 667-7823], R. C. Smith, and D. Neagley (P-21); B. Kacyra and J. Dimsdale (Cyra Technologies); and J. J. Zayhowski (MIT)

This project centered around research and development of Cyrax, a portable, 3-D laser-mapping and imaging system that can produce accurate digital models of existing structures in a simple and cost-effective manner. Cyrax, a joint effort among Cyra Technologies, Los Alamos National Laboratory, and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory, earned an R&D 100 award from *R&D Magazine* as one of 1998's best innovations. This project is discussed in detail in a research highlight in Chapter 2.

Landmine Detection

K. Wilson [(505) 667-7823] (P-21) and R. Moses (T-3)

Antipersonnel landmines, which are buried dielectric scattering objects, are difficult to detect because they contain no metal. However, according to a theory developed by the Fluid Dynamics Group (T-3) of the Theoretical (T) Division, if the dielectric constant of landmines is different from the soil, then they should scatter radio-frequency energy. The U.S. Army is interested in a system that exploits this factor because it would use less power and be lighter than ground penetrating radar systems. In support of an Army contract exploring such a system, P-21 measured the impedance changes due to landmine simulants to verify the T-3 theory. The measured results were not significantly different from the theoretical model except for antenna-sized holes and rises. Such holes and rises caused more complex interaction than the simple one-dimensional (1-D) model could assess. Height variations of the measuring equipment need to be corrected by an algorithm, also developed in T-3, to increase contrast or recognition of buried dielectric objects. Although the results showed promise, the signals are very small, registering as changes of a few percent in the antenna impedance. The background changes are only slightly less. More effort will be required to produce a system that has a lower rate of false-positive detections.

Advancing X-Ray Hydrodynamic Radiography: Multipulse X-Ray Detectors

K. Albright [(505) 667-0617] (P-21)

The second axis of the future dual-axis radiographic hydrotest facility (DARHT II) has radiographic imaging requirements that can not be met with traditional methods of rotating-mirror film or single-frame intensified charge-coupled device (CCD) cameras. Two difficult problems that imaging techniques must overcome on DARHT II are gamma-ray scatter from thick high-Z targets and issues associated with high energy per pulse. The extent of these problems can be lessened with improved x-ray detectors. P-21 has identified CCD sensor technology that provides on-chip storage of multiple frames, leading to a much higher effective frame-rate than a conventional sensor. A system using this technology may achieve 100 ns per frame and capture 4 to 10 sequential frames at specified times of interest. P-21 is also developing a second approach that will use a parallel array of custom solid-state sensor/analog storage chips to record at 5 ns per frame and store up to 1,000 frames of data. A prototype system with forty channels is being developed to test this concept.

Structural Genomics

J. Berendzen [(505) 665-2552] and L. Flaks (P-21); J. Newman, M. Park, T. Peat, G. Waldo, and T. C. Terwilliger (LS-8)

Modern molecular biology has developed tools for rapidly determining the complete sequence of DNA bases of an organism, known as its genome. With this revolution firmly launched, P-21 personnel are working with LS Division to solve the 3-D structures of the proteins the DNA encodes. This work is described in detail in a research highlight in Chapter 2.

HYDRODYNAMIC AND X-RAY PHYSICS (P-22)

Nuclear Weapons Archiving Project

K. Croasdell [(505) 667-2483] (P-22)

The role of the Hydrodynamic and X-Ray Physics Group (P-22) in the Nuclear Weapons Archiving Project centers on four major tasks. First, we are involved in collection and re-analysis of data from past reaction history experiments at the Nevada Test Site (NTS). P-22 has re-analyzed the reaction history for 20 to 25 past NTS events per year since fiscal year (FY) 94. These include experiments related to a variety of weapon systems, including W-78, B-61, W-76, W-80, and W-88. The FY99 effort should result in the re-analysis of about the same number of events. In FY98 we re-analyzed four events not directly related to a stockpile device, but important to weapon physics issues, and more re-analysis of this type will be required in FY99. All data are placed on the Weapons Archiving and Retrieval Project (WARP) system in the Computational Science Methods Group (XCM) for use by the weapons community.

Our second major task is experimental procedure documentation and training. In FY98, subject matter experts from P-22 worked with Bechtel personnel to videotape procedures and “lessons learned” for fielding the reaction history experiment. These classified tapes are currently managed by P-22. In addition, over the past two years we reviewed, updated, and expanded a glossary of terms that relate to weapons testing. This glossary will also reside on the WARP database in XCM. Work has also continued on the electromagnetic pulse (EMP) experimental report procedure handbook, and our efforts continue toward establishing a contemporary computing platform for production software relating to the reaction history experiment.

Our third major task is the collection and analysis of data from past advanced diagnostics experiments. To facilitate research and categorizing the special experiments fielded by P-22 and its predecessors during the testing years, we have enlisted the help of a retiree who was employed in the P-22 anchor station where the advanced diagnostics were recorded. The documentation from these advanced diagnostics is currently being retrieved and sorted to ensure that future re-analysis of these experiments will be possible.

Finally, our fourth major task is the completion of physics reports on the most recent NTS events. Event physics reports are proving to be difficult to prepare, although the reports for the Divider and the Whitefaces experiments are nearly complete because two diagnostic physicists who were involved in fielding the experiments are preparing the reports (both are currently retired). Other reports have been given lower priority because the physicists that fielded them are currently involved in higher-priority contemporary experiments assigned to P-22.

Pegasus Pulsed-Power Facility

D. Bartsch [(505) 667-9977] (P-22)

From January 1997 to the present, we fired approximately 40 shots at the Pegasus Pulsed Power Facility. Some of these shots were in the high voltage mode, in which an array of detonators is used to punch through an insulating layer to reach current levels up to 12 MA. These shots addressed a wide variety of physics, technology development, and material property issues in support of the Weapons Program. Physics issues addressed during the past two years of Pegasus shots include geometric- and inclusion-disruption of shocks in materials, and ejecta studies. Technology studies include a variety of liner stability shots with seeded instabilities, as well as a shot series to develop an impactor-driver liner system for multimegabar shock studies on Pegasus and, once it is operational, Atlas. Several shots have been used to develop a pyrometry technique for measuring the strength of materials undergoing the high-strain and high-stain-rate of a cylindrically imploding liner system.

A variety of experiments were conducted to address material-property issues, including the Megabar, High-Strain-Rate, and Liner Stability experiments. The Megabar experiment focused on developing a composite liner with a high-density impactor layer for shock generation on Pegasus at levels up to ~6–7 Mbar. The third shot in this series, which used a platinum impactor, reached the required velocity and was diagnosed with pins and x-ray radiography to hold together during the radial run-in. Incipient Bell-Plessett instability may have been observed. For these liners, the Pegasus driver was run at maximum operating voltage and current, and the liner was designed to run at maximum velocity consistent with an unmelted impactor. This work feeds into the development of Atlas liners, and it also applies to the high-density impactor, which scales to tens of megabars on Atlas.

The High-Strain-Rate experiment used the convergence effects of a cylindrical liner implosion to measure material strength properties at strains of over 100% and strain rates of up to 10^6 on sample materials such as aluminum driver liners. Work done in distorting the sample layer against the yield strength of the material heats the sample. The temperature rise was observed with multichannel pyrometry—a diagnostic under development for use on these experiments as well as for other Los Alamos activities. Initial shots have given a data point for 6061-T6 aluminum, a material for which there is some existing data, but additional work on configuration of the liner and diagnostic is in process to obtain clean data during the entire implosion. Other materials will be studied on Pegasus and this activity will carry over to Atlas.

The Liner Stability experiment was conducted in collaboration with Russians from the premier All-Russian Institute of Experimental Physics at Arzamas-16 (VNIIEF) to study the effects of material strength on liner stability. Two shots were designed and fielded in conjunction with an extensive liner-stability series to study the effects of seeded instabilities. This is a critical issue for Atlas because we need to know the initial smoothness required for liners to achieve useful implosions. Two more shots will be done in collaboration with the Russians early in FY99.

Diagnostics for Liner Stability Experiments at Pegasus

D. A. Clark [(505) 667-5054], D. V. Morgan, P. J. Rodriguez, and L. Tabaka (P-22); G. Rodriguez (MST-10); and collaborators from X and DX Divisions and Bechtel Nevada

We performed a series of experiments to compare imploding cylindrical liner performance with magnetohydrodynamic (MHD) modeling at the Los Alamos Pegasus II pulsed-power machine. Liner instability growth originating from initial perturbations machined into the liner was observed with high resolution. Three major diagnostics were used: radiography, VISAR (which stands for velocity interferometry for a surface of any reflector), and fiber-optic impact pins. For radiography, three flash x-ray units were mounted radially to observe liner shape at three different times during the implosion. Liner velocity was measured continuously with VISAR for the entire distance traveled in two experiments. Optical impact pins, distributed axially and azimuthally in the central diagnostic assembly, provide a high-resolution measure of liner symmetry and shape near the end of travel. Liner performance has compared well with predictions.

Composite Liner, Multimegabar Shock-Driver Experiments at Pegasus

J. C. Cochrane, Jr. [(505) 667-1227], R. R. Bartsch, D. A. Clark, D. V. Morgan, W. E. Anderson, J. L. Stokes, and L. R. Veeser (P-22); H. Lee, R. L. Bowers, and W. L. Atchison (X-PA); H. Oona (DX-3); and collaborators from Bechtel Nevada

Multimegabar shock driver development involves a series of experiments in support of the Los Alamos High-Energy-Density Experiments program. The purpose of these experiments is to develop techniques to impact a uniform, stable, composite liner on a high-Z target to produce a multimegabar shock for equation-of-state (EOS) studies. Aluminum liners with a thin layer of platinum on the inside are used to increase shock-induced pressure in the target. To date, experiments have been done on the Pegasus II capacitor bank with a current of ~12 MA driving the impactor liner. The driving field is ~200 T at the target radius of 1 cm.

We have gathered data on the stability and uniformity of the imploding liner when it impacts the target cylinder, and we have done three experiments with emphasis on liner development. Shock pressures greater than a megabar have been produced with an aluminum target cylinder. A platinum target cylinder should produce shock pressures in the 5-Mbar range. Load diagnostics for the series include radial radiography, optical impact pins, and inductive probes for current measurements.

Shock-Induced Flows in Strengthless Materials at Pegasus

D. M. Oró [(505) 665-0441] (P-22) for the Atlas collaboration

Experiments on the Pegasus II pulsed power facility are being conducted to study the evolution and flow of strengthless materials resulting from a shock in the material. Of particular interest is vorticity, jetting, and mixing induced in the materials by a shock wave passing through a nonuniform boundary. The experiments provide an important benchmark for hydrodynamics codes, and are a precursor to experiments planned on Atlas, in which the materials will be pre-ionized before being shocked. This work is covered in detail in a research highlight in Chapter 2.

Atlas Power Flow Development

T. McCuistian [(505) 667-7022] (P-22)

A series of ten shots was recently fired on Pegasus II to test current joints that may be used in making electrical connections on Atlas. Tests on Pegasus II were able to simulate the linear current density (A/cm) and action ($\int I^2\,dt$ A^2s/cm^2) that will exist at the most demanding Atlas current joints. A total of 32 different current joints were tested at ~5 MA each. The reduced dimension of the Pegasus II current joints relative to the Atlas current joints provided comparable linear current densities (~100 kA/cm) and actions ($\sim 6 \times 10^4$ A^2s/cm^2) to the relevant Atlas joints. Current joints were tested between aluminum, alodined aluminum, silver-plated aluminum, copper, and stainless-steel flanges. Some current joints were made using gasket materials of indium, soft aluminum (Al 1100), annealed copper, and stainless steel. Various geometries such as knife-edge joints, current nibs (which are regions of small surface contact area between parallel surfaces), and contact regions at various angles were also tested.

Isentropic Compression Experiments at VNIIEF

L. Veeser [(505) 667-7741] (P-22)

Los Alamos National Laboratory and VNIIEF are performing a set of joint experiments to explore the conductivity and possible metalization of argon and krypton compressed to up to five times normal solid density. These materials remain monatomic at high compressions; consequently, their behavior involves their atomic structure, and it is not complicated by molecular changes. The experiments use a magnetic field of several megagauss, generated by a Russian MC-1 generator, to compress a metallic tube containing solidified argon or krypton. A probe in the center of the tube measures the electrical conductivity to the sample tube walls, and a 70-MeV betatron serves as an x-ray source for radiographic measurements of the compression at three times near-peak compression. Several of these experiments for argon compressed to between four and five times solid density, roughly 5-Mbar pressure, indicate a conductivity in the range of order 10 Ω^{-1} cm^{-1}, well below that of a metal. For krypton, similar compression shows a conductivity of 1,000 Ω^{-1} cm^{-1} or more, indicating likely metalization. At slightly lower compressions, a little under four times normal solid density and ~4-Mbar pressure, the argon conductivity remains about the same while that of krypton appears to have dropped significantly. We are presently analyzing and interpreting the data from several shots that occurred in the summer of 1998.

Russian Collaboration on Magnetized Target Fusion

J. Benage [(505) 667-8900], B. Anderson, R. Bartlett, G. Idzorek, and L. Tabaka (P-22)

In August 1998 a team of physicists, engineers, and technicians from P-22, the Dynamic Experimentation (DX) Division, and Bechtel Nevada, traveled to Sarov, Russia, to participate in a series of experiments at VNIIEF. These experiments focused on measuring the properties of target plasmas suitable for implosion in magnetized target fusion experiments. The focus of the experiments was to produce a high-temperature, long-lived plasma suitable for a magnetized target implosion experiment. The goal of the Los Alamos team was to field diagnostics to determine three characteristics of these plasmas: the temperature of the plasma, the lifetime at high temperature, and the levels and types of impurities in the plasma. To determine the temperature and lifetime, several sets of silicon diode arrays with x-ray filters selected for the expected temperature range and located at appropriate positions were used. For a measurement of the impurities, a time-resolved ultraviolet (UV) spectrometer was fielded. Our efforts in these experiments were successful. We were able to obtain good diode signals for nearly all channels, and we will be able to obtain lifetime information and temperature information. The time-resolved spectrometer fielded by DX Division also obtained some excellent spectroscopy data. The spectroscopy data, along with the diode signals, should allow us to determine a reasonable temperature–*vs.*–time curve for the plasma. This data will be very important for determining whether these plasmas are appropriate as a target plasma for implosion and whether further investigation is required.

Cerenkov Detection of Deuterium-Tritium Fusion Gamma Rays from Inertial Confinement Implosions

J. M. Mack [(505) 667-3416], S. E. Caldwell, H. Hsu, and C. S. Young (P-22)

As fusion ignition conditions are approached using the National Ignition Facility (NIF), independent high-bandwidth fusion burn measurements become essential. Neutron time-of-flight methods are being pursued and should be complemented by direct and indirect gamma-ray methods. New analyses of gamma measurements from implosions at the Nova facility indicate the likely observation of 16.7-MeV gamma-rays produced as a deuterium-tritium (D-T) reaction byproduct. Related neutron/photon Monte Carlo calculations suggest that the number of direct (16.7-MeV) and indirect (neutron-induced) gammas are comparable and consistent with experimental results. This supports the proposition that neutron-induced and 16.7-MeV gamma rays were observed using photo-conductive detectors (PCDs). However, PCD systems are limited to 45-ps time resolution; systems with better than 20-ps resolution are needed.

Another means of detecting 16.7-MeV D-T fusion gamma rays is the conversion of these photons to electrons and eventually to (optical light) Cerenkov photons. Fast-gas Cerenkov detection system designs are being developed and optimized for use on NIF targets. These designs are intended to achieve faster detection speeds (10–20 ps) and provide improved energy selectivity for detecting 16.7-MeV gamma-rays. We have recently developed capability to perform *ab initio,* time-dependent Monte Carlo simulations of photon/electron/Cerenkov cascade generation and transport in generalized 3-D geometry with geometrical optics included. Such studies provide information critical to our end-to-end design analyses.

Fabrication Defect Studies

S. E. Caldwell [(505) 667-2487] (P-22); S. R. Goldman (X-PA); M. D. Wilke (P-23); W. W. Hsing (Lawrence Livermore National Laboratory); D. C. Wilson (X-TA); and G. T. Schappert, S. B. Boggs, S. C. Evans, T. J. Sedillo, and P. J. Walsh (P-24)

This project studies the propagation of nonplanar shock waves using the Nova laser at Lawrence Livermore National Laboratory. In our experiments, shocks are ablatively driven by 190-eV radiation from a Nova hohlraum and imaged in two dimensions using time-resolved x-ray radiography. In our first experiment, two pieces of medium-density copper-doped beryllium [Be(Cu)] at 2.0 g/cc were separated by a 15-µm layer of aluminum at 2.7 g/cc. The shock motion was parallel to the aluminum layer. The radiographs demonstrate that the presence of the higher-density aluminum retards the velocity of the shock traveling within the Be(Cu) some distance away from the interface. The lateral extent of the perturbation grows with time. When the aluminum is replaced with a low-density plastic (CH) (1.1 g/cc), the opposite effect is seen, *i.e.*, the shock front within the Be(Cu) near the CH travels ahead of the shock front more distant from the CH.

This effect must be taken into account in the design of inertial confinement fusion (ICF) capsules, which may have joints or other defects, because a small-area defect can lead to a large-area perturbation in the shock front. The quantitative results of this program have been used by the Applied Theoretical and Computational Physics (X) Division to evaluate the calculational capabilities of two hydrodynamics codes.

Integrated Experiments on Nova and Z

R. Chrien [(505) 667-1674], G. Idzorek, and S. Caldwell (P-22); B. Wilde, G. Magelssen, F. Swenson, and D. Wilson (X-TA); and D. Peterson and W. Matuska (X-PA)

We are conducting a series of integrated experiments using Livermore's Nova laser and Sandia National Laboratory's Z pulsed-power facility. In these experiments, we have created an experimental test bed for radiation hydrodynamic calculations that is producing weapons-relevant results. The results are being used to test and guide new code development in the Advanced Strategic Computing Initiative (ASCI) Program. Significant new diagnostic capabilities are being developed in the course of this work. The success of these experiments adds a major new thrust to the use of above-ground experiments (AGEX) facilities in the Science-Based Stockpile Stewardship (SBSS) Program.

Subcritical Experiments at NTS

L. R. Veeser [(505) 667-7741] for this DX Division/Physics Division collaboration

In 1997 and 1998, three major subcritical experiments were fielded at the NTS by DX Division in collaboration with Physics Division, other Los Alamos Divisions, Sandia National Laboratory, and Lawrence Livermore National Laboratory. The first two experiments, called Rebound and Stagecoach, focused on the plutonium EOS. The third experiment, called Cimarron, focused on the ejecta produced when a shock in the plutonium releases into the surrounding vacuum. These experiments are discussed in detail in a research highlight in Chapter 2.

Optical Impact Pins on the Cimarron Subcritical Experiments at NTS

D. A. Clark [(505) 667-5054], P. J. Rodriguez, and G. D. Allred (P-22); and collaborators from Bechtel Nevada.

P-22 mounted optical impact pins on the Cimarron subcritical experiments at the NTS to measure the free-surface velocity of the material under study. The pins consisted of a length of 80-µm optical fiber with one end mounted in a 0.029-inch-diameter stainless steel tube that was between 0.25 inch and a few inches in length. The tube provides rigidity and alignment for the glass fiber. When a fast-moving surface strikes the end of the fiber pin, a shock is induced into the glass, increasing its temperature and generating light. A photodetector and transient recorder at the output of the fiber pin measured the time of arrival of the light pulse and its amplitude. Detection and recording of the light pulses was done in an instrumentation trailer above ground. The fiber optic path length between the trailer and the device underground was about 1 km.

Optical pins are used on various experiments because of their simplicity, flexibility, accuracy, and ability to produce a time history if several subsequent shocks are induced into the pin. They are very compatible with rigid requirements for environmental seals and placement geometry associated with the subcritical experiments. A challenging part of preparations for the subcritical experiment was the successful development of tiny welded containment tubes, or “pin wells,” that meet transportation and environmental-seal requirements. The pin wells provide physical support and positioning for the optical pins. Some of the wells have small-radius bends, but the flexible fibers can be easily inserted into the wells.

Optical pins were also mounted and tested on four “full up” surrogate packages tested at Los Alamos firing sites, and they were used to support development of other diagnostics, such as VISAR and pyrometry, on several small shots designed for that purpose. Information provided by the optical pins on all of these recent tests has been of high quality and has provided valuable support of other diagnostics mounted on the devices.

Infrared Pyrometry

D. Holtkamp [(505) 667-8082] and B. Wright (P-22)

During FY98, P-22 performed a number of experiments in optical pyrometry of shocked metal surfaces. Two seven-channel optical pyrometers were fielded during the Stagecoach subcritical experiment in March, resulting in new data on the temperatures of shock-compressed nuclear material. These pyrometers used a combination of liquid-nitrogen-cooled and room-temperature detectors to measure surface radiances between 1 and 5 µm in wavelength. The remote liquid nitrogen fill system worked well even in the harsh, difficult underground environment. We also developed a new, much more sensitive pyrometer for the Cimarron event that uses liquid-nitrogen-cooled and room-temperature detectors, but also extends the wavelength range to visible wavelengths using sensitive photomultiplier detectors. This extension into the visible is an important advance because it improves the accuracy of temperature measurements dramatically.

We also performed two experiments using very low-temperature pyrometers on Pegasus. In two experiments in FY98, High Strain Rate 2 and 3, we improved our understanding of how to successfully perform very-low-radiance temperature measurements (corresponding to a temperature rise threshold of less than 100°C) in the difficult experimental environment of an imploding liner with very high pulsed currents coursing through it. We have obtained good data and expect to obtain even better results in the near future.

The 1997 Dirac High-Magnetic-Field Experiment Series at Los Alamos

D. A. Clark [(505) 667-5054], P. J. Rodriguez, L. J. Tabaka, and K. C. Forman (P-22); J. D. Goettee, C. Mielke, and D. G. Rickel (DX); and W. Lewis and B. R. Marshall (Bechtel Nevada)

During the summer of 1997, a series of high magnetic-field experiments was conducted at Los Alamos National Laboratory. It was the second in the series named for P. A. M. Dirac, whose contributions to quantum theory are basic to the physics under study. The experiments included collaborators from Japan, Russia, Australia, and several U. S. laboratories, including Louisiana State and Florida State Universities and the National High Magnetic Field Laboratory. Four experiments using Russian-built MC-1 flux compression generators (FCGs), which can reach fields as high as 10 MG, and four smaller strip generator experiments at fields near 1.4 MG were completed. P-22 recorded data for microwave and fiber-optic experiments, participated in the design and setup of several experiments, and was responsible for measurement of the high magnetic fields.

Two of the MC-1 FCG shots focused on microwave magnetoresistance measurements of wide-parabolic quantum-well and high-temperature superconducting samples at temperatures less than 2°K. The wide-parabolic quantum-well data found experimental evidence of 2-D electron gas behavior that had been predicted long ago. The high-temperature superconducting experiments looked for the reappearance of superconductivity in $YBa_2Cu_3O_7$ semiconductor samples at magnetic fields above 800 T. Other experiments on the microwave shots included a search for metal-semiconductor-insulator transitions in molecular conductors. The other two MC-1 FCG shots focused on magnetization measurements of Mn_{12} and MnF_2. A Faraday rotation technique was used to make the magnetization measurement for the Mn_{12} sample. Other experiments were mounted on the MC-1 shots below the liquid helium cryostat and operated at approximately 77°K. They included spectrographic absorption in ReCl and MoCl, a study of AuGe for thermometry, reflectivity of GaAs at 630 nm, and optical transmission of cobalt-60. Faraday rotation in quartz crystals was the primary technique for measuring the magnetic field for each MC-1 shot. Inductive pickup probes were installed in all devices to measure the fields electrically. The entire series was very successful, and excellent data were returned from almost all experiments and diagnostics.

Big G

G. Luther [(505) 667-3178] (P-22)

This project aims at redetermining the Newtonian gravitational constant, G. During the year, the project facility was relocated from the end of Frijoles Mesa to a location more central to the Laboratory. While rebuilding the apparatus, we will add several improvements. A new control and analysis program is being implemented, and a bifillar suspension system has been designed to reduce the dependence on temperature control and lack of vibration. In addition, a new small-mass system is being constructed. A prototype of this system has been built and tested, and we are constructing a redesigned vacuum chamber to contain the system.

Single-Photon Ionization of Helium by Compton Scattering and the Photoelectric Effect

D. V. Morgan [(505) 665-6679] and R. J. Bartlett (P-22)

Helium is the simplest neutral atomic system in which electron-electron correlation effects can be studied. The existence of doubly-ionized helium from interaction with a single photon results directly from these correlations for both photoabsorption and inelastic (Compton) scattering. However, the final states associated with double ionization in these two processes differ considerably. For photoabsorption, there is a high probability that the photon energy is transferred almost entirely to the primary photoelectron, while for Compton scattering most of the initial x ray energy is given to the scattered x-ray, and hence the ejected electrons are comparatively slow. At x-ray energies between 4.5 and 12 keV, the strongly energy-dependent photoionization cross section falls rapidly, whereas the Compton scattering cross section is a slowly increasing function of energy with a “crossover” at approximately 6.3 keV. Theoretical calculations for the double-to-single ionization ratio in the crossover region are performed independently because of the intrinsic difference between Compton scattering and the photoelectric effect.

We have developed a technique for distinguishing the helium ionization states caused by Compton scattering from those caused by the photoelectric effect by observing the different recoil energies of the helium ion associated with the two processes. Using this technique, we have determined the ratios of the double-to-single ionization cross sections of helium for the photoelectric effect and Compton scattering for several energies between 4.5 and 12.0 keV, and we have compared these results with previous measurements and theoretical calculations.

Interferometry for DARHT Plasmas and Hydrodynamics

M. Wood [(505) 665-5-6572], B. Wright, D. Fulton, and J. Studebaker (P-22)

The future DARHT facility is a large radiography facility based on the bombardment of metal targets with high-energy electron beams. To ensure operation within the proposed specifications, we are characterizing the products of a relativistic beam-target interaction. The beam-target interaction, necessary for producing the gamma rays for radiography, also produces plasmas and rapid hydrodynamic motion of targets under conditions that are very unfavorable to measurement. P-22 has successfully fielded two interferometric diagnostic systems at different frequencies to address two issues that affect the success of the DARHT program. These two issues are (1) the question of whether or not ions generated promptly by the beam-target interaction adversely affect the focusing of the electron beam, and how to alleviate any problems that do exist; and (2) the question of whether or not the hydrodynamic expansion of the target will interfere with subsequent shots nearby on the same target, and how to fix this problem if it exists.

The first interferometric system is a Mach-Zehnder configuration at the microwave frequency of 94 GHz. This system was fielded on both the Integrated Test Stand (ITS) machine at Los Alamos and the Experimental Test Accelerator (ETA-II) at Livermore. ITS operates at approximately 5.5 MeV with a current of 4 kA, and ETA-II operates at about 6.5 MeV with a current of 2 kA. Both of these machines are lower-energy accelerators for investigating the physics that will affect the final DARHT design. Using this measurement system, we were able to observe the early temporal evolution of the plasma coming from beam-target and laser-target interactions with the intent of helping to answer the question of whether ions generated by the interaction affect the focusing of the electron beam. Measured phase shifts and amplitude diminution at two different locations have enabled us to distinguish primary (relativistic) and secondary electron populations during the electron beam by changing the polarization plane of the microwaves. Furthermore, distinct signatures of both fast (low-Z) and slow (high-Z) ions have been observed in a number of different types of targets after the departure of the electron beam. These observations have led to estimations of the ion density and geometry during the experiment. Late time observations indicate the beginning of the hydrodynamic expansion of the target, with increased collisionality due to the presence of neutral atoms.

To monitor the later-time hydrodynamic expansion of the targets, we have constructed a HeNe-based Michelson interferometer system for use on ITS, and consulted in the design and construction of a HeNe-based Fizeau, 2-D interferometer on the ETA-II machine. With the diagnostic on ITS, we have observed the expansion of the front of hydrodynamically driven material, and measured expansion velocities in close agreement with previous measurements performed by P-22. These measurements have also provided excellent benchmarks for X Division to model the hydrodynamic expansion. Their modeling shows good agreement with local temperature predictions, helping to provide the distinction between several choices of ionization models.

NEUTRON SCIENCE AND TECHNOLOGY (P-23)

The LANSCE Rotor Ultracold Neutron Source

R. Hill [(505) 667-8754] (P-23)

A source of ultracold neutrons (UCN) produced by the technique of Doppler-shifted elastic scattering has been placed into operation at the Los Alamos Neutron Science Center (LANSCE) Manual Lujan Neutron Scattering Center (MLNSC) by the Neutron Science and Technology Group's (P-23's) Weak Interaction Team. A beam of cold neutrons with velocities, V_n, of about 400 m/s is directed onto a package of crystals moving with a velocity, V_c, in the neutron beam direction of about 200 m/s. This is accomplished by rotating the package on the end of a 90-cm-long arm at 40 Hz and synchronizing the motion of the rotor with the proton beam so that the package arrives at the position of the beam at the time when 400 m/s neutrons are present. Under these kinematic conditions, the elastically scattered cold neutrons are Doppler-shifted down to very low velocities (corresponding to the transverse momentum components), producing storable UCN with resultant velocities less than about 8 m/s. The elastic scattering process is enhanced by Bragg scattering from the crystals which have a lattice spacing of about 10 Å, corresponding to a neutron velocity of about 400 m/s. Maximum UCN production occurs when the condition for Doppler shifting ($V_n = 2V_c$) is simultaneously met with the condition for Bragg scattering (n = 10 Å). The rotor was first used in late 1996 and achieved significant UCN production in mid-1998.

Since the MLNSC beam was operating at 20 Hz, this corresponded to a detected UCN rate of about 600 per second for a proton beam current of about 20 A. We have made improvements to the cold neutron moderator and intensities of 100 A are anticipated. The crystal package has also been improved so significant improvements in UCN production are expected.

A Low-Duty-Factor, High-Current Spallation Neutron Source

S. Seestrom [(505) 667-0156] (P-23)

We are working to develop a low-duty-factor, high-current spallation neutron source at LANSCE. This source will provide the most intense UCN source in the world, and it will also provide pulsed cold and fast neutrons. A UCN source of such intensity will allow a wide range of research, providing a new range of sensitivity for studies of the fundamental properties of the neutron, and allowing us to probe the structure of weak interactions in neutron beta decay. We will produce

UCN by using 800-MeV protons from the LANSCE accelerator to produce fast neutrons that we then moderate into cold neutrons. When these cold neutrons strike a volume of frozen deuterium in our apparatus, they cool to UCN. It takes only a few seconds to build up to equilibrium UCN in the storage bottle. The proton beam is then shut off and the shutter between the deuterium and the storage bottle is closed. This short timing is fortunate because it would be difficult to sufficiently cool the deuterium if the proton beam operated continuously. The UCN trapped during each proton beam pulse can be bled into UCN guides and transported to various experiments. LANSCE Area B is currently considered the ideal location for this source because it already has the appropriate infrastructure (*e.g.*, cooling water, power, a crane, *etc.*).

We have tested a prototype of this UCN source. First, we measured the rate of UCN production by cold neutrons incident on a solid deuterium sample at the Hahn Meitner Institute in Berlin. Based on those results, we constructed a stand-alone system and tested it at LANScE's Area C and Blue Room. The UCN production rate is about what we have predicted, and we are currently exploring how to get the UCN out of the deuterium and out of the cryostat.

Cold Neutron Radiography

T. McDonald [(505) 665-7294] (P-23)

A neutron radiography technique, which we refer to as time-gated energy-selected (TGES) radiography, has been demonstrated at the LANSCE MLNSC for producing radiographic images from only a narrow energy range of cold neutrons. Time of flight is employed to obtain a neutron pulse having an energy distribution that is a function of the neutron arrival time at the imager. The neutron imager is formed on a short-persistence scintillator and is lens-coupled to an intensified cooled CCD camera. The intensifier is gated off except during the time in the neutron pulse when the energy range of interest is present. Some materials exhibit a large change in scattering cross-sections across the Bragg cutoff energy, and material discrimination of these materials can be achieved by imaging above and below their Bragg cutoff energies using TGES radiography. We have recently assembled an improved imager for carrying out TGES radiography, which includes a high-resolution, 1,600 × 1,600 CCD camera and a fiber-optic-coupled, large-format 40-mm diode intensifier. The imaging system will be used in the next run cycle at the MLNSC.

Fundamental Symmetries with Trapped Atoms

A. Hime [(505) 667-0191], S. J. Brice, A. Goldschmidt, and R. Guckert (P-23); S. G. Crane, D. J. Vieira, W. A. Taylor, and X. Zhao (CST-11); and D. Tupa (P-25)

We are pursuing a measurement of the positron-nuclear spin correlation function from the beta decay of ^{82}Rb confined to a Time-Orbiting-Potential (TOP) trap. This purely magnetic trap provides a rotating beacon of spin-polarized ^{82}Rb nuclei which can be exploited to measure the parity-violating correlation as a continuous function of the positron energy and emission angle relative to the nuclear spin orientation. This project is discussed in detail in a research highlight in Chapter 2.

Quantum Computation using Cold Trapped Ions

R. J. Hughes [(505) 667-3876], D. J. Berkeland, D. Enzer, M. Gulley, M. H. Holzscheiter, D. F. V. James, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, A. G. Petschek, V. Sandberg, M. Schauer, and D. Tupa (P-23)

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. Our work on this project is described in detail in a research highlight in Chapter 2.

Development of Algorithms for Quantum Computers

R. J. Hughes [(505) 667-3876], P. Hoyer, and J. M. Ettinger (P-23)

In 1994 it was shown that a quantum computer, using the “quantum parallelism” afforded by the superposition principle, could be used to find the prime factors of composite integers much more efficiently than with any conventional computer. Because integer factorization and related problems that are computationally intractable with conventional computers are the basis for the security of modern public-key cryptosystems, this single result has turned quantum computation from a strictly academic exercise into a subject whose practical feasibility must be urgently determined. In addition, it is of great interest to determine the class of problems that are amenable to more efficient solution on a quantum computer than on classical computers. Integer factorization is a particular instance of the more general problem of finding a “hidden” subgroup of an Abelian group, given a function that takes on constant but distinct values on the cosets of the subgroup. We have been investigating the generalization of this problem to non-Abelian groups and believe that the techniques we have developed will open up new applications for quantum computational algorithms.

Quantum Cryptographic Key Distribution Over Optical Fibers

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

The secure distribution of the secret random bit sequences known as “key” material, is an essential precursor to their use 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 (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, becoming 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. During the past year we constructed a quantum cryptography system and installed it for our sponsor in the Washington, D.C., area.

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

R. J. Hughes [(505) 667-3876], W. T. Buttler, S. K. Lamoreaux, G. G. Luther, G. L. Morgan, J. E. Nordholt, and C. G. Peterson (P-23)

Cryptanalysis techniques and algorithms are advancing rapidly, and by the start of the 21st century they 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 to 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 designed, constructed, and tested a quantum cryptography system that used single-photon transmissions to create and transmit cryptographic random numbers between sending-and-receiving instruments separated by a 1-km outdoor optical path. This work is discussed in detail in a research highlight in Chapter 2. We are now planning to extend the transmission range to more than 2 km in a new system that incorporates active control to compensate for turbulence-induced beam wander, and we are developing plans for a surface-to-satellite test experiment.

Cryptographic Key Generation using Long-Baseline Radio Interferometry

R. J. Hughes [(505) 667-3876], J. E. Nordholt, S. K. Lamoreaux, J. Knight, D. M. Suszcynsky, and W. T. Buttler (P-23)

The need for secure, encrypted communications is becoming increasingly important in many areas, but the secure generation and distribution of the secret random number sequences known as cryptographic keys is an essential precursor to their use in encryption hardware and software. Existing methods of key distribution are cumbersome, impractical for many applications, and not demonstrably secure. We are developing a new technique for two parties to generate on-demand a shared secret key from simultaneous observations of the correlated radio noise from astronomical objects. These correlated radio emissions over baselines of up to several thousand kilometers are used by astronomers to study extra-galactic sources, and by geophysicists measuring continental drift rates. However, the radio emissions from the brightest radio sources can be detected with commercially available radio equipment using small antennas, and the necessary frequency and time standards are now readily available to allow the rapid generation of highly (80%) correlated raw key streams by two widely separated observers. Three stages of theoretically secure data analysis, known as advantage distillation, privacy amplification, and error correction, are used to distill a shorter, secret, error-free key. Even though an adversary may make her own observations of the same radio emissions, this three-step procedure ensures that she retains less than one bit of information about the final key. Potential advantages of this method of key generation are its convenience (couriers are not required to transport key), its guaranteed security (in contrast to the conditional security of public key distribution systems), and the compactness of the hardware required. We have constructed a system to generate key material in this way and expect to have our first results before this document goes to press.

Optical Approaches to Quantum Information

P. Kwiat [(505) 667-6173], J. Mitchell, P. Schwindt, and A. White (P-23)

Researchers in P-23 have been making great strides in the investigation of "interaction-free measurements," in which the existence of non-transmitting objects (absorbers or scatterers) can be ascertained with arbitrarily small absorption/scattering taking place. This year we have made a complete theoretical study of the effects of losses on system efficiency, and confirmed the results experimentally. (See the research highlight on this topic in Chapter 2.) Using a fast switching system, we have produced true efficiencies of up to 73%, which is the world's first demonstration to break the 50% limit, and demonstrated the feasibility of up to 85% efficiency. Also, we performed a series of experiments investigating the practical implementation of interaction-free “imaging,” where the techniques are used to take a pixellated 1-D image of an object, again with the goal of negligible absorption or scattering. Finally, we have begun a complete theoretical treatment of the fairly complicated problem of coupling to a quantum object, such as a single atom or ion, which can be in a superposition state. We have demonstrated, for example, that the quantum state of the object can be transferred to the interrogating light, allowing the production of macroscopic entangled states of light and Schrödinger-cat states.

In related research, we have performed the world’s first comprehensive test of the wave-particle duality, in which the relationship between the amount of wave-like (interference) and particle-like (definite trajectories) behavior is quantified. Using a unique tunable source of various pure, mixed, and partially-mixed states of light, we have demonstrated that, contrary to popular belief, lack of particle-like information does not necessarily imply wave-like behavior, and *vice versa*. We have also demonstrated several novel types of “quantum erasers,” in which wave-like behavior can be recovered if one erases the particle-like information. Curiously, it was demonstrated that even for mixed states, where no particle-like information exists, one can still recover interference. These studies have direct relevance to the growing field of quantum information, specifically quantum computation, where proposals for error correction based on quantum erasure rely on an understanding of the phenomenon when non-pure states are involved.

Finally, we have designed and demonstrated the first all-optical implementation of a quantum circuit. Recently it was shown that all of the essential operations of a quantum computer could be accomplished using only standard linear optical elements (*e.g.*, beam splitters, wave plates, polarizers, *etc.*). In this technique, the individual bits are represented by different spatial or polarization modes of light. This summer we realized a simple optical implementation of Grover’s algorithm for efficiently searching a database. In our example, a database of four elements is searched with a single query, in contrast to the classical expected value of 2.25 queries. Whereas an exact one-to-one correspondence with Grover’s algorithm would require over 25 optical elements, our “compiled” version required only 11. The quantum computer is no more than an interferometer, albeit a complicated one. The difference from a genuine quantum computer with distinct entangleable registers is that the optical implementation requires a number of elements that grows exponentially with the number of bits. Nevertheless, we intend to extend our work to circuits involving several bits, and also to investigate several proposed schemes of “quantum control.”

The Penning Fusion Experiment

M. Schauer [(505) 665-6014] (P-23)

The Penning fusion experiment (PFX) is an experiment and theory effort to investigate the feasibility of using Penning-trap-like devices for fusion confinement. Penning traps use static electric and magnetic fields to confine charged particles for periods lasting up to hours, but due to the nonneutral nature of the confined plasmas, the densities attainable in these devices is limited. The limiting value occurs when the repulsive force of the space charge of the plasma balances the confining force resulting from the rotation of the plasma in the external magnetic field. This is referred to as the Brillouin limit. For a pure electron plasma in a 1-T field, the Brillouin density limit is of the order of 10^{12} cm^{-3}, while for an atomic deuterium ion plasma in the same magnetic field, the limiting value is of the order of 10^9 cm^{-3}. The major goal of PFX is to demonstrate that this limiting value can be exceeded in some small volume at the trap center while preserving it when the plasma density is averaged over the entire volume of the trap.

PFX is divided into two stages. The first stage, completed in FY97, demonstrated that a dense core plasma can be attained in a nonthermal pure electron plasma through spherical focusing. Basically, electrons with a beam-like energy distribution are injected into a trap that is designed such that the electrons are focused to a spot in the center. The results of these experiments indicate a focus spot with a radius of roughly 50 µm and a peak density of nearly 40 times the Brillouin limit. The details of these data can be found in numerous recent publications (*e.g.*, T. B. Mitchell, *et al.*, *Physics Review Letters* 78, 58 [1997]; D. C. Barnes, *et al.*, *Physics of Plasmas* 4, 1745 [1997]; M. M. Schauer, *et al.*, *Review of Scientific Instruments* 68, 3340 [1997]).

The second stage of PFX was funded in FY98 and will concentrate on reproducing these results with positive ions. Due to limitations of the approach used in the first stage experiments, a quite different architecture will be used in the second stage experiments. Here, a uniform electron cloud, with density near the Brillouin limit, will be confined in a modified Penning trap, and the resulting space charge will then provide trapping for positive ions. Through careful tailoring of the vacuum trapping fields, the resulting well will produce spherical focusing for the ions. This will allow eventual use of deuterium and tritium ions for maximum fusion power, but initial work will concentrate on producing a focused plasma of hydrogen ions.

Sudbury Neutrino Observatory

A. Hime [(505) 667-0191], T. J. Bowles, S. J. Brice, A. Goldschmidt, and J. M. Wouters (P-23); M. M. Fowler, G. G. Miller, and J. Wilhelmy (CST-11); and collaborators from Lawrence Berkeley National Laboratory, the University of British Columbia at Vancouver, Brookhaven National Laboratory, Carleton University at Ottawa, the Centre for Particle Physics in Ottawa, Chalk River Laboratories, the University of Guelph, Laurentian University at Sudbury, Oxford University in England, the University of Pennsylvania, Queens University at Kingston, and the University of Washington

During the past thirty years, extensive theoretical and experimental effort has culminated in what is now commonly referred to as the solar neutrino problem, wherein the neutrino signals registered in terrestrial detectors exhibit an energy-dependent deficit in comparison to the predictions of solar models. The results yield a tantalizing hint that neutrinos possess non-zero rest masses and that mixing occurs in the lepton sector, marking evidence for physics beyond the standard model. New generation experiments are thus designed to resolve the solar neutrino problem using techniques that do not rely upon solar model calculations for their interpretation, but rather directly search for the physics manifest in neutrino oscillations.

The Sudbury Neutrino Observatory (SNO) is a real-time, solar neutrino laboratory that uses 1,000 tonnes of heavy water to carry out two basic measurements on the 8B solar neutrino flux. The charged-current (CC) interaction on deuterium can proceed only through electron-neutrino interactions. The flux and energy spectrum of electron neutrinos is measured from the ensuing Cerenkov radiation collected in an array of 10,000 photomultiplier tubes surrounding the 12-m-diameter acrylic vessel housing the heavy water. The neutral-current (NC) interaction can proceed with equal probability by all active neutrino species. The total integrated flux of neutrinos reaching the Earth is deduced upon counting the number of free neutrons liberated in the detector from the NC-disintegration of deuterium. If electron neutrinos produced in the sun's core experience flavor transitions to other active neutrino states then a ratio of the CC (electron-neutrino) flux to the NC (total-neutrino) flux will provide the "smoking gun" that neutrino oscillations are responsible for the solar neutrino deficit.

Presently in the commissioning phase, it is anticipated that the SNO detector will become fully operational in early 1999. The holy grail of SNO is a robust measurement of the CC/NC ratio. Our team has thus focused on the NC-measurement, and originated the design and development of an ultra-low background array of ^{3}He-proportional counters to be deployed throughout the heavy-water volume. In this way, the NC-signal can be measured independently but simultaneously with the CC-spectrum. Full-scale construction of an 800-m array of NC-detectors is presently underway in collaboration with our colleagues at the University of Washington.

Milagro Gamma-Ray Observatory at Fenton Hill

C. Sinnis [(505) 667-9217], T. J. Haines, C. M. Hoffman, and R. S. Miller (P-23); G. Gisler (NIS-2); and collaborators from the University of California at Irvine, the University of California at Riverside, the University of California at Santa Cruz, the University of Maryland, the University of New Hampshire, New York University, the University of Utah, and George Mason University

The Milagro Gamma-Ray Observatory is a new type of detector designed to map and study the very-high-energy (VHE) (30 GeV–30 TeV) gamma radiation in the universe. Milagro is sensitive to gamma rays with energies above ~250 GeV and is the first detector capable of continuously monitoring the entire overhead sky in this energy band. The large aperture and high duty cycle make Milagro ideally suited to study the long-term behavior of known sources of VHE gamma rays (pulsars and active galaxies), discover new sources of VHE gamma radiation, and search for "bursts" of VHE gamma radiation.

The Milagro detector is located at Fenton Hill, about 35 miles east of Los Alamos in the Jemez Mountains. The detector consists of a 6-million-gallon water reservoir, built by the Laboratory to study geothermal energy generation. The reservoir is 25-ft deep, 270-ft long, and 200-ft wide. We have installed a new liner and a light-tight cover. The cover can be inflated for installation and maintenance operations. The reservoir is instrumented with 723 photomultiplier tubes (PMTs) distributed in two layers. The top layer (450 PMTs) will be covered by 1.5 m of water, and 7 m of water will cover the bottom layer (273 PMTs). The PMTs are suspended by Kevlar string from a grid of sand-filled PVC. The grid spacing is 3 m. The PMTs detect the Cerenkov light generated by the charged particles in extensive air showers (the particle showers generated by nuclear and electromagnetic interactions as the primary cosmic rays dissipate their energy in the atmosphere). At ground level, the extensive air shower is shaped like a pancake with a diameter of 50 m and a thickness of 1 m. The pancake is oriented perpendicular to the direction of the primary cosmic ray. By measuring the arrival time of the shower over a large area, the direction of the primary cosmic ray can be determined to within about 0.7°. The event rate in Milagro will be over 1 kHz.

In the past year, we operated a prototype detector nicknamed Milagrito. With a duty factor above 85%, Milagrito recorded nearly 10 billion cosmic ray showers. While data analysis is still in progress, we have detected gamma radiation from one active galaxy (Mrk 501). The prototyping of components and investigation of the water Cerenkov technique were the most important contributions of Milagrito. We found the failure rate of the PMT bases to be unacceptably high, and new bases were manufactured and installed on all of the PMTs. Most importantly we discovered that the arrival time distribution of the Cerenkov light was much wider than expected. To solve this problem, reflective cones were manufactured and placed around every PMT.

Currently all of the PMTs and reflective cones have been installed and the reservoir is filled with 2.5 million gallons of water. The laser calibration system, cable plant, electronics, and the data acquisition system are complete. We began engineering runs in November 1998 and physics running will begin in the spring of 1999. By the end of 1999 we should produce the first-ever map of the TeV Universe.

Camera Research and Development

G. Yates [(505) 667-7529] (P-23)

Design and fabrication of two prototypes for a high-speed, intensified, shuttered, multiport CCD camera (model GY-11) were nearly completed in FY98. The intensifier/shutter component has been verified to be capable of shuttering in the 100 to 200-ps range. This design incorporates a stripline microchannel plate image intensifier (MCPII) designed at Los Alamos and manufactured by Philips Components. It is gated by injecting electrical gate pulses into a microstrip impedance-matching transmission line. The stripline design minimizes impedance variance across the MCPII to reduce gate-pulse reflections, and the microstrip design matches the 4 to 5-W impedance of the MCPII to the 50-W impedance of the gate-pulse generator. Three circuit boards designed to control, measure, encode, and recode the MCPII gain and gate variables in real-time have been completed, and preliminary testing was accomplished during the last two months of FY98. One remaining circuit board, which will allow real-time viewing of the analog video from the 16 ports of the GY-11 camera, has yet to be fabricated. The CCD component of the GY-11 camera is in test status. Images have been obtained from individual segments, and preliminary dynamic range and resolution have been characterized. The coupled system response has yet to be assessed. Auxiliary circuitry, including power supplies, control, cooling, *etc.*, are in various stages of testing.

Recording media are in the design phase, with two different designs underway: one for DOE use on subcritical experiments at NTS, and a second for Department of Defense (DOD) use in military range-gated applications for the U.S. Air Force and Army. The DOE unit will store between 2 and 10 frames, whereas the DOD unit will store 1 to 2,000 frames. Both systems will be deployed in FY99. Both the DOE subcritical experiments and the DOD range-gated experiments require infrared spectral sensitivity in the 1- to 2-μm range. We are currently looking at two different technologies to accomplish this. One is to use Intevac proprietary transferred-electron photocathodes, and the second is to use optical parametric oscillators and amplifiers for wavelength conversion. Preliminary experiments have been done on both techniques.

In addition, new packaging/housing for the image intensifiers for our proton radiography cameras is in design. The major changes are to use a metallic housing for radio-frequency shielding and for electrical safety. Commercially available high-voltage connectors have been incorporated into the new design for computer control of the intensifier gate width and gain.

Finally, the GY-11 MCPII component was used on range-gate experiments for the U.S. Army at Redstone Arsenal in July 1998 to image military vehicles through smoke screens. Images were obtained from the reflected laser beam bouncing off the vehicles stationed beyond the smoke screen, demonstrating the technique of range gating.

Infrared Pyrometry for Temperature Measurements of Shocked Free Surfaces

A. W. Obst [(505) 667-1330] and M. D. Wilke (P-23); and collaborators from Bechtel Nevada

Measurements of the time-dependent absolute temperature of surfaces shocked by high explosives provide valuable constraints on the equation of state of materials and of the ejecta from those shocked surfaces. These temperatures lie typically in the range of 0.04 to 0.2 eV, corresponding to shock heating of surfaces to temperatures from about 400°K to about 2,000°K. These temperatures are equivalent to infrared wavelengths in the range of 1 to 8 µm. Blackbody infrared spot pyrometry using 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 not the absolute value of the emissivity.

First-generation pyrometers have been fielded over the last two years, both locally and at NTS. The detector system uses infrared lenses to image a spot (whose diameter is determined by the optics) onto a gold mixing rod. The mixing rod allows spatially homogenized samples of the infrared emission to be transferred to 1-mm-diameter infrared fibers (typically 3 to 7 channels). The other end of the fibers goes to a detector box, which is protected from the high-explosive shock. The infrared radiation from each fiber is focused through a doublet lens system onto HgCdZnTe infrared detectors operated at –40°C. Filters are placed between the doublets to transmit infrared radiation only from moderately narrow bands. Limited comparisons with thermographic-phosphor techniques have produced good temperature agreement on local copper flyer-plate experiments. The emissivities employed were constrained to follow the static wavelength behavior.

A second-generation pyrometer has been designed. This consists of seven InSb channels mounted in a cryogenically cooled vacuum canister operated at 77°K. Low-pressure gas in a “cryotiger” geometry makes this a very affordable option, compared to the much more expensive Sterling coolers or the unwieldy liquid nitrogen approach. Limited tests using a commercial InSb liquid nitrogen-cooled detector suggest very high detectivity, at least two orders of magnitude higher than the four-metal detectors used above. The useful wavelength range should be from below 1 µm to about 6 µm, pending the results of a newly-installed sapphire window on the test detector. Broad-range dichroic splitters coupled with narrow-range infrared filters will provide a much smaller footprint than the above mixing-rod geometry.

Large uncertainties in inferred dynamic emissivities can be addressed, for example, by the use of laser polarimetry, or ellipsometry, near one of the seven wavelength channels. This has been proposed and is being studied. Such modulated (for background mitigation) laser systems are commercially available and are being investigated. Such an ellipsometer also serves as a useful melt diagnostic, and this has also been proposed.

Dynamic Temperature and Velocity Measurements using Neutron Resonance Spectroscopy

V. W. Yuan [(505) 667-3939], J. D. Bowman, and G. L. Morgan (P-23); D. J. Funk, D. Idar, J. Mace, and R. L. Rabie (DX-2); R. M. Boat, E. M. Ferm, L. M. Hull, and R. K. London (DX-3); D. M. Murk and H. L. Stacey (DX-4); B. I. Bennett (X-NH); C. E. Ragan (X-TM); and S. Bingert (MST-6)

Neutron Resonance Spectroscopy (NRS) provides a way to measure temperatures inside dynamically-loaded systems. A successful realization of this capability will provide previously unobtainable temperature information important to the shock physics, weapons physics, and industrial communities. Our collaboration uses epithermal neutrons produced when a spallation target/moderator is struck by single LANSCE beam pulses (2×10^{13} protons) to measure temperatures on time scales ranging from tens of microseconds down to the sub-microsecond level. The development of remotely locatable neutron sources of equivalent brightness would permit the porting of the temperature measurements to other facilities such as NTS or Atlas. Temperatures are determined by accurately measuring the Doppler broadening of resonance line-shapes, which appear in the transmission spectra of neutrons passing through the sample.

To optimize the time resolution of our measurements and to maximize the neutron flux at our samples, we have developed a source target/moderator assembly (TMA) that provides a bright neutron source that can be located a factor of six times closer than is possible with the normal MLNSC source. To realize optimal benefits from the TMA, we run our experiments using single proton storage ring (PSR) beam pulses that are delivered to Target 2 at the Weapons Neutron Research (WNR) blue room. For the present flux levels at the MLNSC, static, single beam-pulse temperature determinations have been performed that demonstrate a statistical sensitivity of 30°K. We have performed measurements in dynamic systems to study temperatures in shocked metals (after the passing of the shock wave) and in the interior of an explosively-driven metal jet. Additional experiments to look at the temperatures in detonating high explosives, in the dead zones of explosives, and at the frictional interface of shocked materials are planned. We have quantitatively studied distortions to our measured resonance line shapes—distortions that result from the slowing of neutrons in the moderator, the emission of phosphorescent light in our detectors, and the presence of backgrounds in the detected signal. We are currently developing and testing new detectors with potentially reduced gamma-ray sensitivities and an absence of phosphorescence.

PLASMA PHYSICS (P-24)

Indirect-Drive ICF Experiments with Multiple Beam Cones at the Omega Laser Facility

T. J. Murphy [(505) 665-5697], C. W. Barnes, A. A. Hauer, J. A. Oertel, and R. Watt (P-24); J. M. Wallace, N. D. Delamater, E. Lindman, and G. Magelssen (X-TA); P. Gobby and J. B. Moore (MST-7); and collaborators from Livermore and the University of Rochester Laboratory for Laser Energetics

Indirect-drive ignition target designs for the NIF use cylindrical hohlraums with several beam cones illuminating each end of the hohlraum. Independent pulse shaping of the different beam cones will be used to reduce time-dependent flux asymmetries on the capsule. Recently, the Omega laser facility was activated at the University of Rochester's Laboratory for Laser Energetics. Designed for direct-drive inertial confinement fusion applications, the facility consists of 60 beams arranged symmetrically around a spherical target chamber. With the closing of the Nova laser facility at Livermore scheduled for mid-1999, the ability to use Omega for indirect-drive experiments has become important.

Symmetry experiments have been performed on the Omega laser facility using cylindrical hohlraum targets with as many as 40 beams arranged into multiple beam cones. These experiments constitute a first step in the development of "beam phasing," in which beams arranged in multiple beam cones form multiple rings of beam spots on the inner surface of a cylindrical hohlraum. These experiments also demonstrate the ability to model hohlraums incorporating multiple beams cones and to tune the time-integrated capsule flux asymmetry by adjustment of the beam pointing.

Studies of Convergent Hydrodynamics in Cylindrical Implosions

C. W. Barnes [(505) 665-5687], W. W. Hsing, J. A. Oertel, and R. G. Watt (P-24); J. B. Beck, N. M. Hoffman, and D. L. Tubbs (X-TA); and S. R. Goldman (X-PA)

Understanding hydrodynamic instability in convergent and compressible systems is important for ICF ignition and nuclear weapons research. Cylindrical implosions can provide physical insight into hydrodynamics issues because cylindrical geometry allows for excellent diagnostic access along a line of sight and simplifies modeling implosions to two dimensions. Cylindrical implosions have been performed using indirect drive the Nova laser at Livermore and using direct drive at the Omega laser at the University of Rochester. This work is discussed in detail in a research highlight in Chapter 2.

Tetrahedral-Hohlraum Design for Effectively Using the Omega Laser in Indirect Drive

K. A. Klare [(505) 667-7719] (P-24) and collaborators from P-24, X-PA, MST-7, Lawrence Livermore National Laboratory, and the University of Rochester Laboratory for Laser Energetics

The Omega laser facility at the University of Rochester provides 60 laser beams surrounding 12 pentagonal and 20 hexagonal ports. An effective use of most or all of these beams in indirect drive can be done using the tetrahedral geometry. A spherical hohlraum has four equally spaced circular laser entrance holes—connecting lines would form the edges of a regular tetrahedron. The 15 most perpendicular beams are sent into each laser entrance hole. The laser beams are focused inside the hohlraum and the diverging beams land on the sphere with spot sizes having a reasonable power for conversion to x-rays. These x-rays can implode a central spherical capsule or uniformly irradiate a portion of the sphere opposite to each laser entrance hole.

The positions of the laser beams within each hole are determined by the needs to clear the entrance hole, to clear the exit hole for six beams, and to avoid a central target capsule for six beams. The laser spots must not be too intense or too diffuse for good x-ray conversion. Special programs were written in a mathematical language (IDL) for a display program

(QD3D) to test these 3-D problems and assess the clearance of other objects like shields and backlighters. The result is a schematic display with the thin gold hohlraum and two of its near holes, which are shown as wire-frame disks, and the two far holes, which are shown as solid disks. Each laser beam is shown as input and output opaque cones with black spots where they land. A diagnostic stray-light shield in wire frame dominates one side.

High Convergence ICF Implosions in Tetrahedral Hohlraums at Omega

G. R. Bennett [(505) 667-9318], A. Hauer, and T. J. Murphy (P-24); J. M. Wallace (X-PA); and R. S. Craxton and J. D. Schnittman (University of Rochester Laboratory for Laser Energetics)

The NIF, currently under construction at Livermore, will be a 1.8-MJ, 192-beam laser facility with a mission to implode and ignite fusion burn and gain in a ~2-mm-diameter ICF capsule. The beams will be directed into each end of a cylindrical hohlraum (radiation case), such that two spatially and temporally separated laser rings per entrance hole irradiate the gold wall. Rapid thermalization of the resulting x-ray radiation will implode the ICF capsule to temperatures and mass-densities comparable to those in nuclear weapon detonations and certain classes of stars.

A possible difficulty of such an implosion is the time-dependent and time-averaged “drive” that the fuel capsule experiences. In particular, with careful beam pointing and temporal phasing of the laser cones, the NIF cylindrical hohlraum will at best achieve $P_2(\cos\theta) \equiv 0$ and a negligible $P_4(\cos\theta)$ mode, which is the *n*th Legendre polynomial moment, in the drive uniformity. Calculations of this hohlraum configuration indicate ignition yields may be very sensitive to beam pointing and phasing errors, implying ignition could become a rather hit-or-miss affair.

Tetrahedral hohlraums (four laser entrance holes placed on each vertex of a tetrahedral), on the other hand, exhibit zero l = 1, 2, and 5 spherical harmonic components independent of beam refraction, spot motion, *etc.* In addition, with carefully chosen pointing and temporal phasing, the l = 3 and 4 contributions can be zeroed for all times. Clearly, this inherent symmetry may have significant advantages. To this end, Plasma Physics Group (P-24) researchers are investigating high-convergence ICF implosions in such hohlraums using all 60 beams of the 30 kJ Omega laser at the University of Rochester. Our first experiment, performed in September 1998, already indicates an implosion quality comparable to a cylindrical hohlraum. With capsule design refinements during 1999, we hope to improve upon this further, and at the same time gain a better understanding of the hohlraum physics in this unique geometry.

Studies in Support of Core Science and Technology Issues for the NIF

N. A. Kurnit [(505) 667-6002] and R. F. Harrison (P-24)

Earlier studies of nonlinear optics issues of importance to the design of the NIF, such as self-focusing and Raman scattering, have been completed and replaced primarily by issues of damage and spatial filter fabrication. We have shown that it is possible to obtain very high damage thresholds by grazing incidence from a glass substrate, and tapered glass spatial filter pinholes have been fabricated and recently tested at Trident (in collaboration with S. Letzring and R. P. Johnson) based on this concept. Such pinholes show promise of providing the desired spatial filtering without causing closure for high-power glass-laser systems such as the NIF, Omega, and the proposed Trident Upgrade.

Planar, Ablative Rayleigh-Taylor Instability Experiments

G. T. Schappert [(505) 667-1294] and S. E. Caldwell (P-24); D. E. Hollowell (XTA); and R. J. Mason (XPA)

This project is a continuation of our experimental program on ablative Rayleigh-Taylor instability growth in copper foils driven by hohlraum radiation generated by the Nova laser. The purpose of our research is to experimentally explore the Rayleigh-Taylor instability in a high-density material and obtain results that can be modeled by various laboratory codes, thus benchmarking these codes with real experiments. The experimental techniques involve time-resolved x-ray radiography of a corrugated copper target as its imposed corrugations grow. The analysis of the transmission images then results in a determination of the corrugation development and the amplitudes and harmonics generated. At this point we are still in the process of resolving some differences between the experimental results and the code predictions. The experimental issues involve instrument calibrations, such as the modulation transfer function of the gated imagers. These are being investigated in the laboratory. The code issues are being addressed by X Division. The next step in the project is to investigate the classical Rayleigh-Taylor instability in corrugated copper targets by hohlraum-driving such a target with a layer of a low-Z material on top. This will generate a material pressure in addition to the ablative pressure on the copper surface. Calculations indicate a larger instability growth because of the added pressure and reduction in ablative stabilization. Since Nova will shut down in Spring 1999, these experiments are planned for the Omega laser facility at the University of Rochester's Laboratory for Laser Energetics.

Laser-Plasma Interaction Experiments in a Single Hot Spot

D. S. Montgomery [(505) 665-7994], R. P. Johnson, J. A. Cobble, and J. C. Fernández (P-24); and H. A. Rose (T-13)

Interaction experiments using realistic lasers are often difficult to interpret, even for well-defined plasma conditions, since the laser-beam intensity and phase structure are complicated. Parametric instabilities such as stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), and self-focusing can occur to varying degrees within individual "hot spot" structures in such laser beams, and it is uncertain how instabilities produced in an ensemble of hot spots might interact with each other. This further complicates understanding of the onset and nonlinear behavior of these instabilities. These issues are still present in interpreting experiments using random-phase-plate-smoothed laser beams. Experiments studying the interaction from a single hot spot, such as from a diffraction-limited laser beam, might overcome many of these issues.

We have begun a series of experiments funded by Laboratory-Directed Research and Development (LDRD) using the Trident laser facility to study SRS, SBS, and self-focusing in a diffraction-limited (single-hot-spot) laser beam. These experiments are discussed in detail in a research highlight in Chapter 2 and summarized below. A separate heater beam is used to create a quasi-homogeneous, large-scale, hot plasma with T_e ~1 keV, L ~1 mm. Imaging self-Thomson scattering from electron-plasma and ion-acoustic waves is used to measure time-resolved spatial profiles of the electron density, electron and ion temperature, and flow velocity. A diffraction-limited beam interacts with this well-characterized plasma, and the plasma density and acoustic damping are systematically varied. The laser-intensity profile is characterized as a diffraction-limited speckle, whose width is $\sim f\lambda$, and length is $\sim 8f^2\lambda$, where f is the f-number of the focusing optic, and l is the laser wavelength. The parameters for the diffraction limited laser are $\lambda = 527$ nm, 200 psec, $f/7$, and the intensity can be varied between 10^{14} W/cm^2 and 10^{16} W/cm^2. The transmitted beam angular distribution is measured to indicate the activity of self focusing and beam steering in the plasma, and SRS and SBS backscattered light are also measured. Since the laser has a single, well-defined intensity, the instabilities can be studied in regimes where only one or a combination of the instabilities are active by varying the laser and plasma conditions.

Initial experimental results show evidence of beam breakup by filamentation and beam steering in these high-Mach-number, transverse-flow plasmas. We also observe SRS and SBS to be anti-correlated in time when both instabilities are present. We have used the techniques developed in these LDRD-funded experiments to enhance our experimental capabilities on larger-scale experiments. Initial experimental results have been obtained using imaging Thomson scattering to locate ion-acoustic waves associated with SBS in a large-scale plasma driven with an random-phase-plate-smoothed laser. The self-Thomson scattering technique has also been used to characterize other laser-produced plasmas on Trident.

Characterizing Saturated SBS Levels of a Realistic Speckled Laser Beam in a Fusion-Relevant Plasma at Trident

J. C. Fernández [(505) 667-6575], J. A. Cobble, D. S. Montgomery, and R. G. Watt (P-24); B. Bezzerides and S. R. Goldman (XPA); E. L. Lindman (XTA); H. A. Rose (T-13); and collaborators from Lawrence Livermore National Laboratory and the University of Nevada at Reno

There is now ample evidence that the reflectivity of laser light due to SBS from long-scale plasmas normally saturates when the laser intensity is increased sufficiently. Unfortunately, the observed saturation levels are often very high. This potentially high laser reflectivity from SBS is a concern for indirect-drive laser fusion because the efficiency of the laser drive could be seriously compromised. As a necessary first step before SBS can be controlled, we have applied a large diagnostic complement to laser-produced plasmas at the Trident laser facility to attempt to characterize the nature of this saturation. The first phase of this research has been completed and published. Our results indicate that in spite of the observed saturation of SBS with laser intensity, a significant increase in the saturated SBS reflectivity can result from increasing the fluctuation levels from which SBS grows, *i.e.*, by seeding SBS. This is done by injecting into the plasma a modest external light beam at a wavelength near that of the scattered light. This indicates that the saturation mechanism (not presently understood) is not robust and depends on the initial plasma conditions.

The next, presently ongoing, step in this research is to apply collective Thomson-scattering imaging diagnostic techniques to this system. As a result, we shall ascertain the spatial location of the SBS activity in our long-scale plasma with and without seeding the SBS. That way we can determine whether the changes in SBS amplitude are due, for example, to changes in the spatial gain rate of the instability or to excitation of SBS in plasma regions which would not otherwise support SBS without a very strong initial seed.

Laser System for Imaging Turbulence in a Gas Shock Tube

N. A. Kurnit [(505) 667-6002] and R. P. Johnson (P-24)

DX-Division personnel (R. F. Benjamin, P. Vorobieff, and P. M. Rightley) are nearing completion of assembly and testing of an illumination source for gas shock-tube studies. This source has already been demonstrated to obtain interesting and useful data on the Richtmyer-Meshkov instability. Detailed modeling of such experiments provides a stringent test of hydrodynamics codes. The 0.532-µm illumination source, assembled from largely existing components, replaces a series of leased lasers with which the earlier experiments were performed, and will provide a more accessible and versatile system for continuing experiments.

Magnetized Target Fusion

K. Schoenberg [(505) 667-1512] and F. Wysocki (P-24)

Magnatized target fusion (MTF) is a truly different approach to laboratory fusion that promises a low-cost, fast development path. MTF uses an inertial driver, in the form of a metalic liner, to compress and heat a magnetized target plasma to thermonuclear burn conditions. In 1998, a small team of Los Alamos scientists in collaboration with other laboratories and academia proposed to the DOE a proof-of-principle demonstration of MTF. Specifically, we proposed to form and pre-heat a compact torioid target plasma and then compress it to near-fusion-burn conditions with demonstrated imploding liner technology. The proposal was peer-reviewed in May 1998 by a panel of fusion experts. Based on their positive recommendations, the DOE Office of Fusion Energy Science will begin funding MTF research in FY99.

Dynamic Properties of Materials

A. Hauer [(505) 667-5643], G. Kyrala, and A. Foresman (P-24)

P-24 (in collaboration with other groups in Physics Division, X Division, DX Division, T Division, Oxford University, Edinburgh University, and the University of California at San Diego) is using the Trident laser system to pursue studies of the dynamic properties of materials that are of interest to the ICF program and to weapons science. The high-intensity pulses from the Trident laser drive shock waves varying in pressure from tens of kilobars to several megabars into condensed materials. Separate beams of the laser system can be used to create accurately synchronized, powerful x-ray and optical pulses. Using this configuration, the group has developed new diagnostic methods such as transient x-ray diffraction. This method has in turn been used to measure the dynamic properties of phase changes in materials. The methods developed on Trident are being applied to materials of central interest to ICF, such as beryllium. In addition, studies are underway to apply the methods developed on Trident to larger scale experiments on pulsed-power and explosive systems.

Equation-of-State Measurements using Laser-Driven Radiation Cavities

D. S. Montgomery [(505) 665-7994], W. W. Hsing, and A. H. Hauer (P-24); and R. Kopp (XTA)

We have evaluated the use of laser-heated radiation cavities (hohlraums) on the Trident laser facility to drive high-pressure uniform shocks in solid materials. The creation of such shocks might be used to perform high-accuracy EOS measurements. We have irradiated 1-mm-scale hohlraum targets using 4×10^{11} W laser power with two beams of the Trident laser. We have evaluated the shock conditions using time-resolved optical breakout from the free-surface of several different packages mounted on the hohlraum. Measurements of shock breakout from 27-μm-thick flat aluminum packages indicate pressure uniformity better than 1% over a 300-μm diameter. Data from wedged aluminum packages are used to infer radiation temperature and shock steadiness, and indicate a brightness temperature of 100 eV. The relative shock speed appears constant to ~1% over a thickness of 30 to 50 μm in the aluminum wedge. Finally, initial Hugoniot data have been obtained for copper using the impedance-match technique, with aluminum as the reference material. Pressures up to 4 Mbar are demonstrated in the aluminum. The data are in good agreement with current SESAME models, and with other experiments. The accuracy of the shock-speed measurement is presently ±3% and is currently limited by the metrology of the target thicknesses and by signal-to-noise in the optical breakout times. Future improvements can be expected to reduce the errors in shock speed to ~1%.

Advanced X-Ray Optics for High-Energy Density Physics

G. R. Bennett [(505) 667-9318], A. Hauer, and P. J. Walsh (P-24); and T. W. Barbee, Jr. (Lawrence Livermore National Laboratory)

The study of high-energy density regimes developed with above-ground devices often involves temporally resolved x-ray radiography of extremely small features, the scales of which can seriously limit data quality. For example, the study of very-high-pressure EOS driven by laser-produced shocks may restrict sample thicknesses such that the x-ray spatial resolution of existing instruments (along with poor signal-to-noise ratios and non-uniform x-ray backlighter sources) limits experimental EOS accuracies to approximately 10%. Poor signal-to-noise ratios are a particularly adverse trademark of present x-ray imaging techniques in both high-energy-density physics (HEDP) and ICF experiments.

To address this issue, P-24 researchers have directed attention towards significantly improving both 1-D and 2-D temporally resolved x-ray imaging quality at 5 to 25 keV or even higher. The result is a decision to use grazing-incidence-reflection focusing from multilayer-coated, spherical mirrors of the quality used on the Hubble Space Telescope Upgrade. In addition, P-24 researchers have developed (1) a novel ray-trace optimization algorithm in conjunction with analytic geometric aberration corrections for extracting maximum design performance; (2) an analytical optical-transfer function representing the statistical effects of atomic-scale surface scattering; (3) two instrument designs for the NIF laser system presently under construction at Livermore; and (4) a 1-D x-ray microscope, the 4.316-keV 1DKB, which is nearly completed for use at both the Trident laser facility at Los Alamos and the Omega laser at the University of Rochester. Rigorous analysis of the exquisitely fabricated mirrors, atomic surface statistical effects, and all other inherent defects indicates that the 1DKB instrument will provide significant spatial resolution and enormous signal-to-noise improvements for certain classes of HEDP and ICF experiments. Applying the same analysis to existing grazing-incidence instruments closely predicts their 3- to 5-μm spatial resolutions.

Physics Support for Atlas Development

B. P. Wood [(505) 665-6524], C. Munson, and G. Kyrala (P-24)

A small team has been formed to provide physics support for the design and initial operation of the Atlas pulsed-power facility. P-24 staff have contributed to this effort by examining experimental campaigns that are likely to be conducted on Atlas. The first of these deals with additional investigation of Rayleigh-Taylor mix experiments, which have been the subject of an ongoing campaign using the Pegasus facility. Other experimental configurations investigated deal with adiabatic compression of materials to extremely high pressures, EOS-measurement experiments, and conditions for the generation of strongly coupled plasma targets.

Friction Studies

G. A. Kyrala [(505) 667-7649] (P-24); J. Hammerberg (XNH); D. Oro, J. Stokes, and D. Fulton (P-22); and W. Anderson (MST-7)

We are using the Pegasus pulsed-power facility to examine the effect of dynamic friction upon sliding interfaces. We are using an aluminum liner accelerated by the Pegasus capacitor bank to launch shocks into two dissimilar materials perpendicular to their interface. The differential in shock velocity has been observed to cause a relative motion of the material parallel to the interface. By implanting opaque wires into the materials and by using x-rays to image the wires, we study how the interface moves and we also measure the distortion of the material due to this friction effect. A first shot was conducted on Pegasus and we were successful in performing the imaging. Future shots are planned, and the work will be extended to other conditions and materials.

Decontamination of Chemical and Biological Warfare Agents using an Atmospheric-Pressure Plasma Jet

G. Selwyn [(505) 665-7359] and H. Herrmann (P-24)

The atmospheric-pressure plasma jet (APPJ), a Los Alamos invention, represents a new realm of highly collisional plasma physics. A nonthermal, uniform-glow, radio-frequency plasma discharge operated at atmospheric pressure produces chemically reactive species that can be blown onto a surface. This method has been shown to kill Anthrax surrogate spores ten times faster than thermal sources, and to oxidize certain nerve gases and mustard blister-agent simulants. It offers a dry, fast, nondestructive, safe, portable, and environmentally sound method of decontamination that can be applied to sensitive equipment (electronics, optics, computers, *etc*.) and the interiors of military vehicles (planes, tanks, ships, *etc*.), which cannot tolerate harsh conventional decontamination treatments using “wet” chemistry. Military, industry, and university collaborations have been established to develop this technology, and testing on actual chemical warfare agents is proceeding at the U.S. Army’s Aberdeen Proving Ground.

Plasma-Based Removal of Surface Radioactive Contamination

C. Munson [(505) 667-7509] (P-24); P. Chamberlin (retired) and J. Veilleux (CST-7); and J. R. Fitzpatrick (NMT-2)

This project focused on the development and demonstration of plasma-based techniques for the removal of surface radioactive contaminants such as plutonium and uranium that form volatiles with fluorine. Early work by Joseph C. Martz demonstrated the removal of plutonium from the surfaces of contaminated material coupons in a down-stream plasma-immersion reactor that used a mixture of CF_4 and O_2 as the plasma precursor gas. Development work during this LDRD project focused on more aggressive plasma conditions (a combination of physical sputtering and reactive ion etching), as well as much more scalable plasma generation techniques. Tests involved both prepared material coupons contaminated with depleted uranium, and a number of material samples contaminated with depleted uranium during Los Alamos experimental work. In addition, a significant investigation of contaminant removal from high-aspect-ratio crevices was performed. Because of the developmental work performed, several companies remain interested in further developments in this area.

Advanced Technology PSII Precommercialization Project

C. Munson [(505) 667-7509] and B. Wood (P-24); and K. Walter and M. Nastasi (MST-8)

This project, which is ultimately supported by the DOD/NIST Advanced Technology Program, is a follow-on to a CRADA between Los Alamos and General Motors (GM), which significantly advanced the state of the art in industrially relevant plasma source ion implantation (PSII) technology and techniques. Primary objectives of the overall program focus on driving high-risk, but potentially very high-return, fledgling technologies toward commercial application. Program participants include GM, Boeing, DuPont, Asea Brown Boveri, Litton Electron Devices, Nano Instruments, Diversified Technologies, Ionex, PVI, Empire Hard Chrome (EHC), A. O. Smith, Harley-Davidson, Kwikset, the University of Wisconsin (UW), and ERIM. Los Alamos’s role in this program is to provide scientific and technical developmental support to the program participants, as well as scale-up development and demonstrations involving industrial components. Because of this program, PSII surface treatment is now available on a limited prototype basis from EHC in Chicago, and it will be available from two additional service providers (PVI and Ionex) within the next year. The success of this project earned the major program members (Los Alamos, GM, UW, EHC, and North Star Research in Albuquerque) one of *R&D Magazine*’s prestigious R&D 100 awards in 1997.

Specific research being conducted at Los Alamos includes scale-up and demonstration of the application of diamond-like carbon (DLC) coatings to industrially relevant numbers (~1,000 simultaneously) of automotive pistons; PSII surface modification of full-scale industrial dies and tooling components; development of techniques for the application of adherent DLC coatings to 400-series steel materials (a subproject with Boeing), surface engineering of manufacturing components and materials through PSII and DLC coatings (a subproject with DuPont), and application of high-hardness DLC coatings to industrial components using a cathodic arc source (another portion of the DuPont subproject).

R&D 100 Award LDRD Support of PSII Activities

C. Munson [(505) 667-7509] and B. Cluggish (P-24); and K. Walter (MST-8)

Los Alamos has established a tradition of recognizing winners of the R&D 100 award by providing one year of LDRD support for small projects related to the award. This project is one example. We focused primarily on the investigation of the plasma sheath dynamics involved in PSII of very large, complex targets.

In order to successfully commercialize PSII techniques, it is necessary to maximize the number of components that may be treated simultaneously in a given facility. This requires an understanding of the complex interactions between the 3-D assembly of target components and the initial plasma generated around this assembly, as well as the interactions between the target surfaces, the background plasma and neutral gas, and the plasma sheaths, which dynamically evolve during the PSII process. Since the energies involved in the PSII process are so large (tens of keV) compared to the energies of the background plasma (~eV), and energetic secondary electrons are generated by ions impacting the target surfaces, significant energy is available for the potential development of instabilities in the plasma during the plasma sheath evolution. Langmuir probe measurements within a target assembly during PSII have been used to characterize the dynamic sheath conditions, and to identify two instabilities driven by the complex interactions present. This work is described in detail in a research highlight in Chapter 2.

Characterization of Dipole Interactions in Dusty Plasmas

H. R. Snyder [(505) 665-8364] and G. S. Selwyn (P-24); and M. S. Murillo and D. Winske (XPA)

We constructed a radio-frequency plasma chamber incorporating an electrostatic trap for studying various properties of dusty plasmas. Our plasma system is capacitively coupled with an asymmetrical electrode geometry. We introduce well-characterized glass microspheres of various diameters (1.0 to 50 μm) into the trap to simulate dust grains and measure properties of the dust using laser light scattering techniques in conjunction with a digitizing video capture system. In particular, we observe a crystalline phase in which the microspheres form strings aligned with the electric field, and we measure the intergrain spacing. This alignment, which has been observed in other experiments, appears to be a ubiquitous property of dust in radio-frequency plasma chambers. Because the strings behave fairly independently, it has been suggested that the dust has an acquired dipole moment. Such an interaction qualitatively describes vertical alignment of dust within a string and horizontal repulsion between strings. We have developed several estimates for the dipole strength based on nonuniform charging and ion focusing to compare with the suggested mechanism of induced dipoles within the dust. A simple theory has been developed that predicts the lattice spacing for various dipole mechanisms.

Wear- and Corrosion-Resistant Coatings for Gun Barrels

B. P. Wood [(505) 665-6524], B. Cluggish, A. Mytnikov, and D. Pesenson (P-24); and M. Hakovirta (MST-8)

The goal of this work is to demonstrate a process for producing adherent refractory metal coatings for wear and corrosion resistance on the insides of large-caliber (120-mm) gun barrels. Work in FY98 has centered around understanding the physics of drifting, cathodic-arc-produced plasmas in magnetized, biased pipes. Two papers describing this work have been published in *IEEE Transactions on Plasma Science*. Implantation on the inside surfaces of pipes was achieved by biasing the pipe to voltages of less than 5 kV; however, high negative voltages (greater than 10 kV) were mostly unsuccessful due to electrical arcing through the plasma. Ongoing experiments are being conducted to determine an efficient magnetic cusp design for turning an axial plasma flow into radial plasma flow impinging on the pipe walls.

High-Average-Power, Intense Ion Beam for Material Properties and Other Applications

B. P. Wood [(505) 665-6524], L. Bitteker, and W. J. Waganaar (P-24)

We are developing a repetitive, intense ion-beam source that uses a magnetically insulated diode with an active plasma anode. This source will produce a 250-kV, 12-kA, 1-µs pulsed beam of any gaseous species of ion. Applications include materials surface treatment by rapid melt and resolidification; high-rate coating production; a diagnostic neutral beam for the next generation of tokamak; and a portable, intense, pulsed-neutron source for neutron radiography, neutron resonance spectroscopy, and criticality measurements. During FY98 (the final year of this three-year LDRD project) we completed construction of the plasma anode, and characterized its operation in hydrogen and argon, both with and without magnetic insulation. Numerical modeling of gas flow through the anode nozzle suggested changes in operating pressure which were successfully adopted, and changes in plenum volume which may be incorporated in the future. Most accelerator components were fabricated, and low-voltage testing of the accelerator was in progress by the end of FY98. We have obtained funding in FY99 to complete the system and pursue pulsed-neutron-source applications.

Production of Superior DLC Coatings for Tribological Applications

B. P. Wood [(505) 665-6524] and D. Pesenson (P-24); and M. Hakovirta (MST-8)

We are investigating the production of superior DLC coatings by cathodic-arc for tribological applications. An important aspect of this research is the design of efficient magnetic ducts for filtering solid particles from the plasma stream used to create the coatings. DLC coatings have been produced with hardnesses as high as 77 GPa—higher than any reported in the literature. Initial production-line tests of industrial parts coated with this and similar processes have been encouraging. A dual cathodic arc has been constructed which will allow production of nano-layered DLC-metal composites.

Generation of 1.54-µm Radiation for an Eye-Safe Laser Lidar

N. A. Kurnit [(505) 667-6002] and R. F. Harrison (P-24); and R. R. Karl, Jr., J. P. Brucker, J. Busse, W. K. Grace, W. Baird, and O. G. Peterson (CST-1)

An existing helicopter-mounted 1.06-µm laser lidar system was modified to produce pulse energies of up to 250 mJ at the “eye-safe” wavelength of 1.54 µm by means of Raman scattering of the Nd:YAG radiation in methane. Although this had been demonstrated a number of times before, we believe this is the highest energy to be demonstrated by Raman scattering at this wavelength. This was accomplished by using a folded multipass geometry without focusing in the Raman cell so as to avoid breakdown of the methane that can lead to soot formation, as well as avoiding the generation of higher Stokes and anti-Stokes radiation that can limit the amount of energy converted to the desired first Stokes. The folding mirrors allowed a long path to be compressed into a space that was compatible with the helicopter requirements, and they were also coated to suppress the buildup of second-Stokes radiation. This system was successfully flight-tested by Chemical Science and Technology (CST) Division and Army personnel, and it produced over 2 W of average power in a series of flights measuring returns from simulants of chemical and biological weapons agents. Eye-safe 1.54-µm radiation is useful in such tests because the downward-looking nature of the system allows testing without concern for the safety of ground personnel.

MIT Alcator C-Mod Tokamak Collaboration

R. Maqueda [(505) 667-9316] (P-24)

In FY97–98, we designed, fabricated, installed, and operated an infrared viewing system to look at heating on the armor tiles of the tokamak wall and divertor regions of the Alcator C-Mod tokamak. The Alcator C-Mod tokamak is a compact, high-magnetic-field tokamak with very limited diagnostic access. We had to develop a 5-m infrared periscope that is sensitive to surface temperatures above 30°C while giving as broad a field of view as possible of the inner wall and still allowing us to position a sensitive infrared video camera outside of most of the magnetic and nuclear radiation fields around the machine. First data has been obtained, and after careful calibrations, this viewing system has allowed us to monitor the temperature rises on the molybdenum armor tiles during plasma operation.

Columbia University HBT-EP Tokamak Collaboration

Glen Wurden [(505) 667-5633] (P-24)

We built a 1-MW ion cyclotron radio frequency oscillator unit for the HBT-EP tokamak to allow beta-limit experiments to be conducted while studying MHD modes and their control by active means. The oscillator unit will be coupled through a Los Alamos-supplied transmission line and matching box to a Princeton University-supplied ion cyclotron radio frequency antenna. The equipment will be used for the first time in New York in FY99. Up to four Los Alamos undergraduate students learned about high-power electronics while working on the project, and were key to getting the project done within budget ($100k) during FY98. During FY97, we collaborated at Columbia University using two Los Alamos-built high-power (10-MW each), wide-band (0–30 kHz) amplifiers for stabilization of internal plasma modes in the same HBT-EP tokamak.

International Thermonuclear Experimental Reactor Diagnostic Reports

C. W. Barnes [(505) 665-5687], B. P. Wood, and G. Wurden (P-24)

Los Alamos has continued to lead the U.S. home-team design effort in fusion product diagnostics for the International Thermonuclear Experimental Reactor (ITER). In addition to coordinating effort on other systems, detailed design was done and documented on the neutron-activation and the neutron-source-strength monitor systems as part of completion of the ITER engineering design activity. We also wrote a section of the ITER Diagnostic Design Description for bolometry, describing the backup design for bolometers using our new infrared imaging bolometry idea for a radiation-hard system.

As part of an ITER research and development effort, we developed an intense, pulsed, diagnostic-neutral beam; characterized the active plasma anode source of the CHAMP intense ion beam; and established electric and magnetic fields, plasma velocity (about 2.7 cm/µs), and proper operation with the electron-insulating magnetic field. The main pulse of plasma is produced by the second half-cycle of ringing current through the anode fast-coil, with some additional plasma (about 10 times less) produced on the third half-cycle.

Imaging Bolometer Development for Long-Pulse Fusion Experiments

Glen Wurden [(505) 667-5633] (P-24)

The concept of a new type of bolometer that is able to image the radiation emitted by a plasma with unprecedented spatial resolution was developed and prototyped in FY97–98. A digital infrared camera is used to measure the temperature of a special segmented foil/mask, which converts the broad-band plasma radiation to heat. As part of a U.S.-Japan collaboration, and also a funds-in-agreement, we fabricated a prototype and shipped it to the National Institute for Fusion Science in Tokyo, Japan. There, we tested the concept on the Compact Helical Stellarator (CHS) while looking at 200 to 400 kW of plasma radiation produced by electron cyclotron and neutral beam heating. Los Alamos also filed U.S. Patent papers on the idea, although our prior publications ruled out any international patent rights. The U.S. Patent is pending. Two invited talks and papers were presented on the topic at both an international ITER diagnostics workshop in Varenna, Italy, and at the High Temperature Diagnostics conference in Princeton.

SUBATOMIC PHYSICS (P-25)

MEGA

M. D. Cooper [(505)667-2929] (P-25) and collaborators from P-25, NIS-6, NIS-8, DX-5, LANSCE-6, ESA-DE, the University of Chicago, Fermilab, the University of Houston, Indiana University, Texas A&M University, Valparaiso University, the University of Virginia, Virginia Polytechnic Institute, and Virginia 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. An experiment called MEGA (an acronym for "muon decays into an electron and a gamma ray") was designed to make such a search at the Los Alamos Meson Physics Facility (LAMPF), now known as LANSCE. The final year of data taking for this experiment was 1995. The combined data from the summers of 1993–1995 should yield a statistical precision that improves the current world sensitivity to this process by a factor of 25 to roughly 3×10^{-12}. We have extracted the kinematic properties for all possible candidates, and we are carefully scrutinizing the final sample of about 5,000 events. We are currently in the final stages of extracting a result from the data.

RHO

R. E. Mischke [(505)667-6814] (P-25) and collaborators from P-25, NIS-6, NIS-8, DX-5, LANSCE-6, ESA-DE, the University of Chicago, Fermilab, the University of Houston, Indiana University, Texas A&M University, Valparaiso University, the University of Virginia, Virginia Polytechnic Institute, and Virginia State University

The MEGA positron spectrometer was used to measure the Michel parameter rho (ρ). This parameter governs the shape of the polarization-independent part of the energy spectrum for positrons emitted in normal muon decay. The standard model predicts ρ to be 0.75; it is currently known to be within 0.3% agreement with that value. Deviations from 0.75 might indicate the need for right-handed currents in the standard model. The energy spectrum for over 2×10^8 positrons was recorded and data were taken under several conditions to help with the analysis of systematic errors. Despite these precautions, energy-dependent systematic errors will limit the accuracy of the result to a level that is currently being evaluated.

The Phenix Detector at RHIC

J. M. Moss [(505)667-1029], V. Armijo, M. Bennett, J. G. Boissevain, M. Brooks, T. A. Carey, D. J. Clark, G. W. Hart, D. M. Lee, M. J. Leitch, L. J. Marek, P. L. McGaughey, M. M. Murray, P. E. Reimer, J. E. Simon-Gillo, W. E. Sondheim, J. P. Sullivan, and H. W. van Hecke (P-25); and W. W. Kinnison (PDO) for the Phenix collaboration

Big Bang cosmology pictures a time very early in the evolution of the universe when the density of quarks and gluons was so large that confinement inside hadrons (neutrons, protons, pions, and related particles) had no meaning. With the commencement of operations in 1999 of the reletivistic heavy-ion collider (RHIC) at Brookhaven National Laboratory, it should become possible to create a small sample of that primordial quark-gluon plasma in the laboratory and to study its exotic properties. The challenge facing the international collaborations involved in the RHIC program is to find signatures of the fleeting transition into the this deconfined phase of matter. The Phenix collaboration currently consists of over 400 physicists and engineers from universities and laboratories in the U.S. and nine foreign countries. The Physics Division, with a long history of experiments at the energy frontier, is playing a major role in defining the physics program for RHIC and in constructing two major subsystems—the multiplicity/vertex detector (MVD) and the muon subsystem—for the Phenix detector, one of two major collider detectors at the RHIC facility.

The MVD is the smallest and among the most technically advanced of the Phenix systems. It will be located very close to the region where the two beams of 100-GeV/nucleon ions intersect. Its function, as the name implies, is to give the precise location of the interaction vertex and to determine the global distribution and intensity of secondary charged-particle production, a crucial parameter in fixing the energy density achieved in the collision fireball. Although these functions are crucial to the entire Phenix physics program, the MVD must satisfy an additional exacting requirement of having little mass and being almost invisible to the passage electromagnetic radiation. Thus the 28,000 channels of silicon-strip detectors (in a hexagonal cylinder along the beam direction) and 6,000 channels of silicon-pad (in two endcaps), along with their electronics, cabling, and cooling equipment, will weigh only about 11 kg. The MVD will present less than 1% of a radiation length to the Phenix electron detectors, which view the interaction region through the MVD. This project is centered at Los Alamos but involves significant collaboration with universities in the U.S. and Korea. Much of the state-of-the-art electrical engineering of the MVD system is provided by NIS-4 and by Oak Ridge National Laboratory. The exacting schedule toward first physics operation of RHIC requires that the MVD be operational in the center of the Phenix detector in October 1999.

The muon subsystem, the largest of the Phenix subsystems, consists of two large conical magnets and associated position-sensitive tracking chambers at opposite ends of the detector. Muon identification is accomplished by recording muon penetration of a series of large steel plates interspersed with detection planes, all of which follow the magnets at each end of the detector. The muon subsystem plays a central role in the Subatomic Physics Group's (P-25's) physics agenda at RHIC. It is optimized for examining experimental observables in a kinematic regime that can be guided by the predictions of perturbative quantum chromodynamics (QCD). The muon subsystem is also a crucial element in the other major physics program at RHIC: elucidation of the spin structure of the nucleon via the collision of high-energy polarized protons. The muon capability has been on the Physics Division's agenda from the beginning of the RHIC detector collaborations. Its realization as a funded construction project follows many years of strong advocacy by Division personnel within the Phenix collaboration. A key milestone was achieved in 1995 when a working group of physicists from P-25 and the

Institute of Chemical and Physical Research (RIKEN) in Japan secured sufficient funding to complete the entire muon subsystem. The construction of the muon subsystem, although administratively centered at Los Alamos, is truly a world-wide effort. The muon tracking effort is led by Los Alamos and is largely carried out at P-25's facilities. During the past year, a major milestone was achieved in the construction and successful operation of the world's largest cathode-strip readout tracking chamber, which measures 2×3 m. This prototype is one of eight chambers that form a plane in the largest of the three tracking stations in each of the two muon magnets. When completed, each muon magnet will contain a complex of three tracking stations with a total electronic channel count in excess of 40,000. An important step in the muon subsystem construction project during the coming year is the commissioning of a factory at Brookhaven where mass production, testing, and assembly of components will be carried out. The current plan is to have one of the two muon arms instrumented for physics data collection during the first year of RHIC operation (late 1999 to 2000), with the other arm completed a year later.

High-Energy Nuclear Physics

M. J. Leitch [(505)667-5481] (P-25) and collaborators from P-25, NIS-6, Abilene Christian University, Argonne National Laboratory, Fermilab, 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

We are leading a research program centered at Fermilab that has studied parton distributions in nucleons and in nuclei and the nuclear modification of QCD processes such as J/ψ production. This program began in 1987 with measurements of the Drell-Yan process in fixed-target p-A collisions, which showed that the antiquark sea of the nucleon was largely unchanged in a heavy nucleus. In our most recent measurements we also showed that there is a large asymmetry between down and up antiquarks. The latter is presumably due to the nucleon's pion cloud. In addition we showed that the production of heavy vector mesons such as the J/ψ was strongly suppressed in heavy nuclei and mapped out this effect over broad ranges. Although the causes of this suppression are not yet fully understood, it is already clear that absorption in the final state plays an important role, as do energy-loss of the partons and shadowing of the gluon distributions.

These physics interests have also led us to become involved in the RHIC program, where we are part of the PHENIX collaboration. At PHENIX we intend to pursue similar measurements of p+p and p+A collisions to study the modification of parton structure functions and QCD processes in nuclei at RHIC's larger center-of-mass energy. We will also study kinematic regions that can be reached in a collider detector like PHENIX but were not accessible in Fermilab fixed-target measurements. The PHENIX muon detectors were conceived in large part as a result of our interest in pursuing muon measurements, and the PHENIX spin program was begun when we convinced several Japanese groups led by RIKEN to join PHENIX to study spin aspects of parton structure functions.

The expertise that we already have in understanding nuclear effects on parton structure and QCD processes and the new measurements that we plan to make at PHENIX will be critical in understanding these effects in nucleus-nucleus collisions. Only after these phenomena are well understood will we be able to determine whether a quark-gluon plasma is made in heavy-nuclei collisions.

In addition we are considering further work at Fermilab to extend our measurements of the asymmetry between up and down antiquarks in the nucleon sea to larger values of antiquark momentum fraction. Such extensions will be critical in determining what the correct nonperturbative model is for this asymmetry. A letter of intent for this extension to our recent measurements has been submitted to Fermilab with Don Geesaman at Argonne taking the lead. We plan to participate in this program at a level that agrees with our effort at PHENIX.

NA44 Relativistic Heavy Ion Experiment

J. Sullivan [(505) 665-5963] (P-25)

Experiment NA44 at the European Center for Nuclear Research (CERN) is a relativistic heavy-ion experiment that searches for evidence that quarks and gluons are deconfined in matter at very high energy density. The experiment focuses on correlations among identical particles as a function of transverse momentum to provide a closer look at the space-time extent of the central region of heavy-ion collisions. A long lifetime of matter in the central region is an indication of the formation of deconfined quarks and gluons. 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. In 1996 the experiment took data for the last time. However, the analysis of the data is still in progress. In the last year, NA44 results were published that showed that the size of the region that emits pions grows as a function of the total charged particle multiplicity in S+Pb collisions. We also published the first results of pion correlations from Pb+Pb collisions at 158 GeV per nucleon. We expect all analysis to be complete within one year.

Hypernuclei Physics

J.-C. Peng [(505)667-9431], C. Riedel, and C. Morris (P-25); J. O'Donnell (P-23); and collaborators from Arizona State University, Brookhaven National Laboratory, the University of Colorado, Hampton University, the University of Houston, the University of Kentucky, Louisiana Technical University, the University of Minnesota, the University of Zagreb, and Tohoku University

We proposed Experiment 907 (E907) at Brookhaven's Alternating-Gradient Synchrotron (AGS) to study the feasibility of using the (K^-, π^0) reaction as a novel tool to produce lambda (λ)-hypernuclei with energy resolutions significantly better than the existing (K^-, π^-) and (π^+, K^+) experiments. This experiment is also capable of measuring the π^0 weak-decay modes of λ-hypernuclei never studied before. The LANSCE neutral meson spectrometer and associated equipment were moved to the AGS for this experiment. A new data acquistion system and a new array of active target chambers were also successfully implemented for E907.

During 1997–1998, E907 received approximately three months of beam. Preliminary results show that an energy resolution of 1.5 MeV has been achieved. This resolution is a factor of two better than any previous hypernuclear experiments. Measurements on a carbon target have provided the first hypernuclear spectrum using the (K, π^0) reaction. In addition, the π^0 energy spectrum resulting from the weak-decay of light λ-hypernuclei has also been measured. We are currently analyzing the 1998 data. Preliminary results from E907 have already been presented at several conferences.

Liquid Scintillator Neutrino Detector

W. C. Louis [(505)667-6723] (P-25) and collaborators from P-25, LANSCE-7, the University of California at Riverside, the University of Cincinnati, Columbia University, Embry-Riddle Aeronautical Univeristy, Fermilab, Louisiana State University, Louisiana Tech University, the University of Michigan, and Princeton University

The liquid scintillator neutrino detector (LSND) experiment at LANSCE has obtained evidence for neutrino oscillations by observing an excess of events in both the $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ and $\nu_\mu \rightarrow \nu_e$ appearance channels. These two channels are independent of each other and together provide strong evidence for neutrino oscillations in the $\Delta(\mathrm{m}^2) > 0.2$ eV^2 region. The LSND results imply that at least one of the neutrino states has a mass greater than 0.4 eV, and therefore that neutrinos contribute more than 1% to the mass density of the universe. In addition to the significance of these results to cosmological models, the existence of neutrino oscillations has great significance for nuclear and particle physics because they imply that lepton number is not conserved and that there is mixing among the lepton families. The LSND experiment, which had its last run in 1998, has also made precision measurements of neutrino-Carbon and neutrino-electron scattering.

Booster Neutrino Experiment

W. C. Louis [(505)667-6723] (P-25) and collaborators from P-25, LANSCE-7, the University of California at Riverside, the University of California at San Diego, the University of California at Santa Barbara, Embry-Riddle Aeronautical Univeristy, Louisiana State University, Louisiana Tech University, Southern University, and Temple University

The proposed booster neutrino experiment (BooNE) recently obtained approval at Fermilab to make a definitive test of the LSND neutrino oscillation results. The BooNE detector will consist of a 12-m-diameter sphere filled with 770 tons of mineral oil and covered on the inside by the 1,220 phototubes from LSND. The detector will be located 500 m away from the neutrino source, which will be fed by the 8-GeV proton booster. After one year of running, BooNE will observe approximately 1,000 $\nu_\mu \rightarrow \nu_e$ oscillation events if the LSND results are indeed due to neutrino oscillations. Furthermore, if oscillations are observed, BooNE will be able to make precision measurements of the oscillation parameters and to test for charge-conjugation-parity violation in the lepton sector. The BooNE detector should be operational by the end of 2001, and first results are expected a year later.

Electric Dipole Moment of the Neutron

M. D. Cooper [(505)667-2929] (P-25) and collaborators from P-25, P-21, P-23, LANSCE-DO, the University of California at Berkeley, California Institute of Technology, Harvard University, Institut Laue-Langevin, the University of Michigan, the University of New Mexico, the National Institute of Standards and Technology, Simon Fraser University, and the University of Sussex

An opportunity exists at Los Alamos to improve the limit on the electric dipole moment (EDM) of the neutron by more than two orders of magnitude to 4×10^{28} e*cm. The continuing reason for interest in the EDM stems from the observation of violation of time-reversal invariance in the neutral kaon (K^0) system. Many theories have been developed to explain the kaon problem, but most have been ruled out by their prediction of a sizable EDM for the neutron. Today, new classes of highly popular models (*e.g.*, supersymmetry) predict values for the EDM that are within the potential reach of experiment. In addition, if the observed baryon-antibaryon constitution of the universe is due to time-reversal-violating symmetry breaking at the electroweak scale, the range of predicted values for the EDM is also measurable.

The proposed experiment draws heavily on the ideas described by R. Golub and S. Lamoreaux [*Physics Reports* 236, 1 (1994)]. Ultracold neutrons (UCN) will be produced via the superthermal mechanism in a dilute mixture of ^{3}He in superfluid ^{4}He. The increased sensitivity arises from (1) an increased electric field allowed by the excellent dielectric properties of superfluid ^{4}He, (2) a dramatic increase in the number of UCN resulting from the production mechanism, and (3) an increased storage time due to the low temperature of the walls. Current work on the project is centered around experimental verification of the feasibility of the experiment, which is needed before a proposal can be submitted.

Ultracold Neutrons

C. Morris [(505)667-5652] (P-25) and collaborators from P-25, P-23, LANSCE-DO, the Hahn Meitner Institute in Berlin, Institute Laue-Langevin in Genoble, Princeton University, the University of California at Berkley, the University of Washington, and California Institute of Technology

Solid deuterium converters have been proposed as a source of UCN for some time. Recently it has become clear that coupling a solid deuterium moderator to the high densities of cold neutrons available from a pulsed-spallation neutron source may provide a UCN source with several orders of magnitude higher neutron density than is possible from reactor driven sources such as the Institute Laue-Langevin.

Two experiments were mounted this year to attempt to verify these predictions. In the first, UCN production from a solid deuterium converter was measured in a cold beam line at the HMI reactor in Berlin. The production rates were found to be in agreement with predictions.

Based on this result an experiment has been mounted at LANSCE to measure the UCN production rates and lifetimes from a 1-L volume of solid deuterium coupled to a spallation source on the proton radiography beam line at LANSCE. These tests are currently underway. Although the initial runs gave UCN rates roughly two orders of magnitude lower than predicted, the measured rates were large enough to provide a world class UCN source. Several problems with the initial experiment, which may explain the observed rates, have been isolated and are being remedied for future runs.

Fundamental Symmetry Measurements with Trapped Atoms

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

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 rubidium-82 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 goal is 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 rubidium-82 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 rubidium-82; 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 Computation using Cold, Trapped Ions

D. Tupa [(505)665-1820], M. Gulley, and V. Sandberg (P-25); R. J. Hughes, M. H. Holzscheiter, P. G. Kwiat, S. K. Lamoreaux, C. G. Peterson, and C. Simmons (P-23); and M. Schauer (P-24)

Quantum computation is a new computational paradigm that is much more powerful than classical computation because it allows for 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, and the other to 866 nm.

Proton Radiography

C. Morris [(505)667-5652], J. F. Amann, J. G. Boissevain, C. J. Espinoza, J. Gomez, G. W. Hart, G. E. Hogan, H. A. Thiessen, H.-J. Ziock, and J. D. Zumbro (P-25); J. B. McClelland (P-DO); and collaborators from P-23, DX Division, LANSCE, T Division, X Division, ESA Division, Lawrence Livermore National Laboratory, Lawrence Berkeley National Laboratory, Brookhaven National Laboratory, the Indiana University Cyclotron Facility, and Bechtel

There are two goals for the proton radiography program. The first is to demonstrate that high energy proton radiography is a suitable technology for meeting the goals established for the advanced radiography program, and the second is to develop the capabilities of 800-MeV proton radiography for meeting immediate programmatic needs. These goals are highly coupled since most of the techniques developed for 800-MeV radiography can be used at higher energies. Most of the effort in the last year was focused on the 800-MeV program because of funding restrictions that limited progress in our planned 25-GeV demonstration at Brookhaven's AGS.

This year, a three lens system has been constructed and tested in Line C at LANSCE. This system has been used to demonstrate the utility of an upstream focus for dynamic alignment, background measurements, and beam tayloring, including graded collimation. Material identification has been demonstrated using both step wedges and other static objects with the downstream lenses. Finally, a camera system capable of recording seven time-frames has been developed and used in a number of dynamic experiments aimed at studying the temperature and lot-dependence of corner turning in insensitive high explosives. Our proton radiography work is described in detail in a research highlight in Chapter 2.

Carbon Management and Mineral Sequestration of CO_2

H.-J. Ziock [(505)667-7265] (P-25)

Today, the world energy use is dominated by fossil fuels, which account for between 80 and 85% of the total. The reasons for this include their abundant supply, high energy-density, acceptance by the public, ease of use, ease of storage, existing infrastructure, and most importantly their low cost. The only thing that presently threatens their continued widespread use is the possible environmental consequence of the vast amounts of CO_2, a greenhouse gas, released into the atmosphere as a result of their combustion. Without question, the use of fossil energy has raised the level of CO_2 in the atmosphere by roughly 30%. This change far exceeds natural fluctuations during the last few thousand years. Since 1800, the CO_2 content of the atmosphere has risen from a stable level of 280 ppm to about 365 ppm today. Nevertheless, the virtues of fossil fuels, their dominance of the market place, and the continued rapid growth in world energy demand will guarantee a continued important role for fossil energy throughout the next century. Mitigation of these CO_2 emissions is becoming an important global issue as CO_2 emissions are accelerating rapidly, and the emissions can easily reach 10 times current levels in the next 50 years due to a combination of population growth and an improved standard of living throughout the world.

Our proposed solution to this problem is to react CO_2 with common mineral silicates to form carbonates like magnesite or calcite, a reaction which is exothermic and thermodynamically favored under ambient conditions. The reaction is well known to geologists because it occurs spontaneously on geological time scales. The main advantages of the mineral carbonation method are (1) it is a natural process that is known to produce environmentally safe and stable material; (2) raw materials for binding the CO_2 exist in vast quantities, far exceeding even the most optimistic estimates of fossil energy reserves; (3) a single mineral carbonation plant could operate on the scale of emissions from several to tens of large power plants; (4) the production of mineral carbonates insures a permanent fix rather than storage of the CO_2, thereby guaranteeing no legacy issues for future generations; (5) the process favors integration into future power plants as well as application to existing power plants; and (6) implementation of the process has the potential to be economic and to produce additional value-added products.

We recently received approval of our five-year direct-research LDRD proposal titled "Cradle to Grave Carbon Management." We have identified two primary areas to be addressed. The first is the production of an alternate energy carrier, hydrogen, from fossil fuel, while simultaneously forming a pure CO_2 exhaust stream. The second is the subsequent disposal of the CO_2 through mineral sequestration. The hydrogen production will involve two different techniques. One reacts coal with water and calcium oxide, using the energy released in the carbonation reaction of calcium oxide to supply the energy needed to drive the shift reaction on water to yield hydrogen while simultaneously capturing the CO_2. The CO_2 would then be re-released at high pressure for use in the subsequent sequestration process by heating the calcium carbonate to high temperatures. This step would also yield calcium oxide, which would be recycled. The second technique would work on natural gas and would involve the use of short-contact-time catalysis reactors to generate hydrogen and CO_2. Those gases would then be separated using hydrogen separation membranes. The mineral sequestration area would also investigate two possible approaches. One would rely on an above-ground industrial process, and the second would investigate injection of supercritical CO_2 into appropriate underground strata.

Theory

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

The theory component of P-25 consists of a staff member and a number of short- and medium-term visitors from universities and laboratories throughout the world. Theoretical research focuses on basic issues of strong, electromagnetic, and weak interactions topics that complement the present activity of the experimental program and that impact possible future scientific directions in the group. As such, the theoretical component of P-25 facilitates interaction between experimental and theoretical activities in the nuclear and particle physics community and contributes to a balanced scientific atmosphere within the group.

Recent theoretical activity has focused on neutrino interactions and masses, parity violation in chaotic nuclei, deep inelastic scattering, hadron properties in free-space and in nuclei, and QCD at finite temperatures.

Education and Outreach

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

P-25 group members continue to be active in education and outreach activities, both as participants in programs sponsored by the Laboratory, and as individual citizens who volunteer their time for various activities. In the recent past, group members have acted as judges for the New Mexico Supercomputing Challenge, consulted for the TOPS (Teacher Opportunities to Promote Science) Program, participated in career days and college days at New Mexico schools, and visited nearby classrooms regularly. We also coordinated, organized, and participated in the Teacher's Day at the annual meeting of the American Physical Society's Division of Nuclear Physics.

The Group sponsors several high school, undergraduate, and graduate students to work on our projects. These students study computing, engineering, and electromechanical technical support as well as physics. A few students are writing theses based on the work they do at P-25.

PHYSICS DIVISION OFFICE

Scaling Considerations for Global Weather Sensors

G. Canavan [(505) 667-3104] (PDO); and J. Moses and R. C. Smith (P-21)

Long-range weather predictions have great scientific and economic potential, but require global observations. Small constant-pressure balloon "transponders" could serve as Lagrangian trace particles to measure the vector wind, temperature, and water vapor, which are the primary initial conditions for long-term numerical forecasts. The wind field, which is the most important factor, is difficult to measure and is poorly sampled at present. We are exploring the use of distance-measuring-equipment (DME) triangulation of signals from roughly one million transponders to sample the wind field with sufficient accuracy for two-week forecasts.

DME uses small, low-power transmitters on each transponder to produce intermittent transmissions that are detected by several small receivers and forwarded to the ground station to process the position, velocity, and state information. Thus, each transponder consists of a balloon with a small radio, and each should only weigh a few grams and cost a few dollars. Satellites used for readout should weigh a few kilograms and cost around $1M. If the receivers can be carried on high-altitude balloons, the cost per receiver might be reduced by one to two orders of magnitude. The number of transponders required depends only on the spatial resolution required, and the number of receivers depends only on the altitude. DME has the advantage of all-weather operation, and since the transponders are low-cost, even losses due to rain and ice are not a major concern. Preliminary design efforts in collaboration with Livermore produced an LDRD project to design and test prototypes of the balloon transponders and receivers and to prepare for field tests of the concepts using live transponders and local DME recievers in Spring 1999.

Cosite Problems in Army Communications

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A study for the Army Science Board documented the "cosite" problems encountered when the DOD's approximately $10B worth of tactical frequency-hopping radios are used in close proximity. The problem is caused by the crude frequency spectrum of high-power transmitters and their uncorrelated hopping over inadequate frequency bands. We have identified and documented the problems, and have recommended procedures for tests and remediation.

Strategic Stability and Arms Control

G. Canavan [(505) 667-3104] (PDO)

Stability models are used to analyze the first strike stability of strategic and theater configurations and arms-control strategies. We have analyzed strategic force reductions together with the impact of de-alerting measures at each stage using the START I, II, and III models, and the results compared favorably with those of STRATCOM, NATO, and the Russian general staff. We also prepared a detailed analysis of the arms-control stability of the India-Pakistan configuration for the DOD, and we analyzed the feasibility and practicality of the "freedom to mix" offensive and defensive forces for the U.S. Congress.

Future Military Space

G. Canavan [(505) 667-3104] (PDO)

We participated in a year-long study of the future of military space for the U.S. Army and U.S. Air Force Scientific Advisory Boards. The study concentrated on deficiencies in transferring information from national assets to combat forces, requirements for improved real-time information on mobile forces, the orderly transition from the cold war emphasis on strategic concerns to current theater concerns, and the competition between wireless and fiber military and commercial communications capabilities in satisfying faster-than-expected demand growth. The results were reported to the highest levels of the Army and DOD.

Hypervelocity Impact Signatures

G. Canavan [(505) 667-3104] (PDO)

We performed a first principle analysis of the observables from 10 to 30 km/s impacts of 1-kg to 1,000-ton objects on solids, and we produced a set of predictions to guide the design and calibration of visible and active sensors for the Clementine asteroid impact experiment to be performed in 2001. We also inverted these predictions to infer the strength of meteors impacting the Earth's atmosphere from their optical signatures. We are exploring this as a possible method for the U.S. Air Force Space Command, the agency responsible for satellite optical signal data reduction.

Defining Experiments for Atlas

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A team of scientists was formed this year to assess, invent, and design an experimental agenda for the Atlas pulsed-power facility. Our goal is to understand and define weapons physics requirements and to use these requirements as the principal driver for defining the Atlas experimental program. This necessitates close collaboration with X-Division and Livermore colleagues. The team has been active in the following areas: defining and modeling of experimental concepts, defining diagnostic requirements, defining foundational experiments using Pegasus II and explosive pulsed-power, and articulating experimental requirements as they dictate Atlas machine design features.

We have now defined an initial ~200 shot suite of experiments for Atlas, including experimental topics in dynamic materials properties, implosion physics and hydrodynamics, dense ionized matter, and basic science. Specific experiments we are defining include hugoniot EOS experiments above 10 Mbar; multiple-shock EOS; adiabatic compressions to pressures well above 1 Mbar; dynamic phase transitions (especially melting); effects of strain and high strain-rate (in the ranges of 200% and

10^4 to 10^6 s^{-1} respectively); Rayleigh-Taylor instability mixing; dynamic friction at high interfacial velocity; Bell-Plesset instability; strongly-coupled plasma EOS and transport; hydrodynamics in strongly-coupled plasmas; magnetized target fusion; and experiments in ultrahigh magnetic fields (>1,000 Tesla).

Most of these experimental concepts have been modeled with one-dimensional computations and in some cases with two-dimensional calculations. These calculations have led to initial target designs and definition of diagnostic requirements. The team hosted an interlaboratory workshop in March to assess diagnostic issues for Atlas shock-driven experiments. Our examination of Atlas radiography requirements has led to development of an Atlas Radiographic Test (ART) object, which mocks up many of the features of realistic Atlas targets. We plan to field the ART object at various candidate radiographic sources to help guide the program's radiographic strategy; our first test used the 60-MeV betatron source at Arzamas-16 in Russia.

Surface Engineering with Plasmas and Particle Beams

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A partnership between four Russian Institutes, two U.S. corporations, and Los Alamos National Laboratory is underway to develop and commercialize five plasma-based methods for the modification of material surfaces. We are using cathodic arcs, hollow-cathode discharges, surface-barrier discharges, and intense electron and ion beams to enhance the surface properties (*e.g.*, hardness, toughness, wear, corrosion, electrical conductivity, and gas permeation) of a variety of commercially vital metal and polymer materials. Technical thrusts are equally divided between four areas: (1) plasma science; (2) plasma source development for commercialization; (3) material processing including ion implantation, coatings, and alloying; and (4) materials science.

Los Alamos highlights during 1998 include the delivery, installation, and operation of an ion source and implanter from the Institute of Electrophysics in Yekaterinburg at the Los Alamos Center for Materials Science. The plasma source is a pulsed-glow discharge with a cold hollow cathode in a weak magnetic field. Extraction and focusing of positive ions by an acceleration and ion-optical plate system enables the formation of a homogenous, large-area ion beam with an average current of up to 50 mA at acceleration voltages of up to 50 kV. With the cold cathode, reactive gases can be discharged with minimal materials sputtered from the cathode. Detailed characterization of ion current density over the ion source area has confirmed a uniform beam over the central 150 cm^2. Surface modification experiments by ion implantation of nitrogen into aluminum and chromium substrates have also been performed.