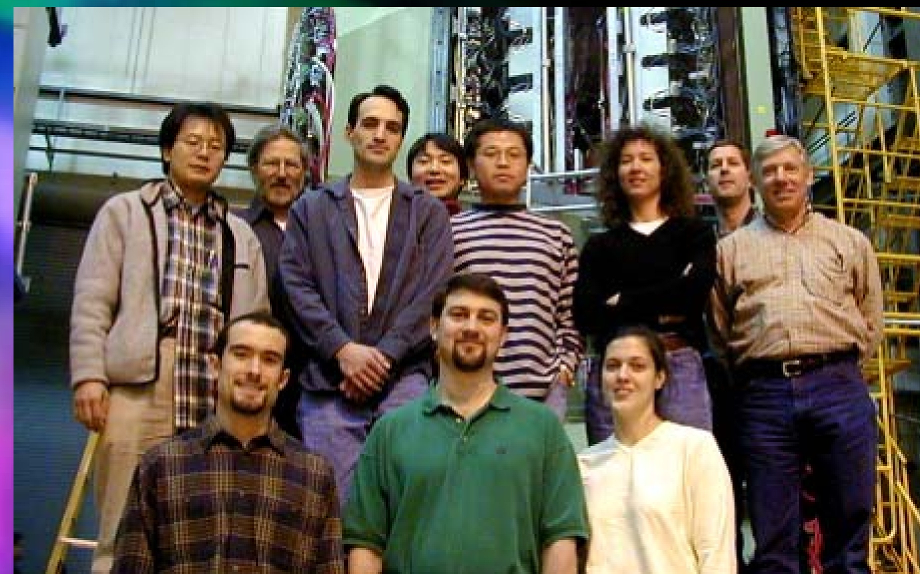
Appendix A: Project Descriptions



A portion of the PHENIX muon tracking team (only a limited number are at BNL at any one time) in front of the first muon spectrometer built at BNL. The people in the picture are (left to right):
Front row: Andy Brown (Abilene Christian University student), Rusty Towell (P-25 [has since become ACU faculty]), and Mellisa Brown (ACU student). Back row: Hideyuki Kobayashi (RIKEN-BNL Research Center), Dick Mischke (P-25), Andrew Hoover (New Mexico State University student), Jiro Murata (RIKEN-BNL Research Center), Ming Liu, Melynda Brooks, Mike Leitch, and Dave Lee (all P-25).

Biophysics (P-21)

Structural Genomics

Joel R. Berendzen [(505) 665-2552] (P-21)

L.-W. Hung and L. Flaks (P-21), and researchers and collaborators in the Bioscience Division and elsewhere, have been developing and promoting the field of structural genomics over the last four years. This year, the dream of a broad-based attack on protein structures has been made real through establishment of a National Institutes of Health (NIH)-funded Center for Structural Genomics based in Los Alamos. Associated with the Center is an international consortium, the Mycobacterium Tuberculosis Structural Genomics Consortium. This Consortium consists of 60 laboratories from 30 institutions in 9 countries. It has the stated goal of solving and analyzing roughly 400 structures of proteins from the bacterium that causes the disease Tuberculosis (TB). TB kills more adult humans in the world than any other pathogenic organism. The resulting database of linked structural and functional information is expected to form a lasting basis for understanding pathogenesis by TB bacteria and should pinpoint new targets for drug action against the disease.

To accomplish this, we are developing scalable technologies that will make structural genomics feasible. Further, we will demonstrate an approach to structural genomics that allows researchers around the world to collaborate on a defined set of structural targets. Consortium laboratories have collectively thus far been responsible for 3.3% of all protein structures in the Protein Data Bank and have extensive records of methods development for high-throughput structure determination and analysis. The Consortium will have centralized facilities that will carry out an increasing fraction of routine tasks such as protein production, crystallization, and x-ray data collection. P-21 researchers are responsible for overseeing the primary x-ray data-collection facility (beamline X8-C at Brookhaven National Laboratory). In addition, we are developing new methods and instrumentation for improved data collection and analysis.

Single-Molecule Detection of Specific Nucleic-Acid Sequences

Alonso Castro [(505) 665-8044] (P-21)
L. Bennett, R. Cortes, K. Lamia, L. Paz, K. Tripp, and B. Shera (P-21)

The detection of specific nucleic-acid sequences is of fundamental importance in the fields of genetic and medical research, clinical chemistry, and forensic science, among others. The most common method for the identification of specific DNA sequences is the Southern blot. Despite its popularity, Southern blotting suffers from some limitations, mainly because it involves a series of manually intensive procedures that cannot be run unattended and cannot be readily automated; casting gels, applying samples, and running and subsequently staining the gels are all time-consuming tasks that are susceptible to poor quantitative accuracy and poor reproducibility. In most cases, in order to improve sensitivity, a radioisotope must be incorporated into the probe, which raises a set of safety and environmental concerns. The development of various techniques for enzymatic amplification of the target sequence before analysis alleviates the sensitivity problem. The polymerase chain reaction (PCR), for example, selectively increases the concentration of the target sequence relative to unrelated sequences, thus enhancing both the specificity and sensitivity of the assay. Amplification methods, however, may introduce ambiguities resulting from contamination, from variability in amplification efficiency, and from other mechanisms not fully understood.

Our single-molecule detection methods promise to combine the advantages of flow-based analytical systems (system automation, speed, reproducibility) with the unsurpassed sensitivity of single-molecule detection. The sensitivity of these methods allows for the direct detection of specific genes without the need for using amplification methods such as PCR and exhibits advantages over current methodologies in terms of sensitivity, specificity, and speed. Also, the high sensitivity of the method means that sample size and reagent use are minimal, which should result in significant cost savings relative to existing analytical methods. Ultimately, assay reliability and low operating costs, combined with high sensitivity, may be the primary advantages of using single-molecule detection methods in the analytical laboratory. We anticipate that the nonradioactive approaches for the ultrasensitive detection of specific sequences described here will find applications in a wide variety of fields, such as gene identification, gene mapping, medical diagnostics, and biotechnology. When the size of the target is also determined, it will be possible to determine both the quantity and molecular weight of specific target DNA molecules in complex samples, without the need for DNA amplification. The simplicity of the assay chemistry (probe hybridization in solution phase under DNA-denaturing conditions) promises reliability. The high level of target specificity demonstrated in the present experiments suggests that single-molecule detection, coupled with single-molecule electrophoresis, could be used successfully for many applications in analytical genetics. This project is discussed in greater detail in a research highlight in Chapter 2.

Electric Dipole Moment of the Neutron

M. D. Cooper [(505) 667-2929] (P-25);
M.E. Espy (P-21) and collaborators from P-25; P-21; P-DO;

Los Alamos Neutron Science Center; University of California, Berkeley; California Institute of Technology; Harvard University; Institut Laue-Langevin, Grenoble, France; University of Michigan; University of New Mexico; National Institute of Standards and Technology; Simon Fraser University; and the University of Sussex

A novel experiment has been proposed at Los Alamos Neutron Science Center (LANSCE) to measure the neutron electric dipole moment (nEDM) with 250 times greater sensitivity than permitted by current experimental limits, within reach of the “big bang” theory of the matter/anti-matter asymmetry in the universe and predictions from grand-unified supersymmetric theories. A key component to experimental design is understanding whether or not superconducting quantum interference device (SQUID) sensors can detect the precession frequency of the ^{3}He used as polarizer, spin analyzer, and detector for the neutrons. SQUIDs would dramatically reduce the dominant source of experimental systematic error. The experiment requires a novel use of SQUIDs at very low noise levels and at temperatures much lower temperatures than the 4 K SQUIDs typically operate at. Preliminary work has already demonstrated the required noise performance of 3e-6$\Phi_0/\sqrt{\mathrm{Hz}}$ at 4 K. The nEDM measurement brings an experiment of recognized scientific importance to LANL. The proposed SQUID work also has scientific impact benefiting the larger SQUID community and biological and weapons projects within P-21.

A cryostat that will allow us to perform the tests of SQUID noise as a function of temperature has been located. Ironically, this cryostat belongs to researchers at the Los Alamos contingent of the National High Magnetic Field laboratory. However, they will turn off the magnetic fields for our work. This system will allow us to explore SQUID noise over an even greater temperature range than previously thought—from the proposed temperature of 0.3K to ≈10K. A probe to couple to this system has been designed and is currently being assembled. The required temperature sensors and SQUIDs for these experiments have been purchased and tested. The temperature experiments will be conducted in March 2001. To identify and resolve design issues affecting the SQUIDs, we are currently working with collaborators involved with the other aspects of the experiment

SQUID Array Microscope

Michelle Espy [(505) 665-6218] (P-21)
R. H. Kraus, Jr., T. Lobb, A. Matlachov, and P. Ruminer (P-21);
J. Mosher (NIS-9)

Nondestructive evaluation, or NDE, is a field devoted to finding out if objects are developing fractures, flaws, or other mechanical problems without investigators actually having to tear apart the object to find out. This approach can be very valuable if your object is something like an aircraft wheel, subject to enormous stress every day and prone to accruing cracks in places where you cannot see them without removing the wheel and disassembling it. Performing the NDE of an aging nuclear weapon can save large amounts of time and expense by showing what is happening to it inside, and thus eliminating the need to actually open it up.

Conventional NDE techniques include ultrasound, x-rays, and conventional eddy-current testing. Eddy-current inspection works by injecting or inducing currents into a conducting sample and then looking at how these currents flow. If the sample has no flaws, the current will flow unimpeded. If the sample contains a flaw, such as an inclusion or rust spot, the current will flow differently through that material. If the flaw is a crack, the current will flow around it. The trick is in the measurement of how the currents are flowing. Conventional eddy-current techniques use a receiver coil that measures the impedance changes as it scans across the sample. In P-21, we have developed a system that replaces the receiver coil with a linear array of superconducting quantum interference devices (SQUIDs). The array of SQUIDs directly measures the magnetic fields produced by the eddy currents in the sample. The result is an NDE system with unsurpassed sensitivity to features that are very small or deeply buried.

SAMi (SQUID Array Microscope) is an NDE tool of unsurpassed sensitivity. SAMi uses eddy-current induction methods to induce eddy currents in the sample of interest and then map the magnetic fields produced by the eddy currents. Small features in the sample will cause the eddy currents to deviate and produce anomalies in the magnetic field. These anomalies can be seen even if the feature is very small or buried under intervening layers of conductive or nonconductive material. In cases where the feature of interest is very small, deeply buried, or buried under an insulating layer, the SAMi has strong advantages over conventional NDE techniques. SAMi uses a novel white-noise induction method (patent pending) that induces at multiple frequencies simultaneously, providing information about the depth at which a feature is located. We have used SAMi to look at a host of NDE problems from small, deeply buried cracks to the inspection of welds. SAMi has proven to be as robust as it is sensitive and is able to operate without magnetic shielding even in a noisy laboratory environment. It is our hope that other SAMis will be deployed to various laboratory and industrial sites to help solve NDE problems ranging from the stockpile applications to aircraft worthiness. This project is discussed in greater detail in a research highlight in Chapter 2.

MRIVIEW: An Interactive Neuroimaging Software Package

Douglas Ranken [(505) 665-1781] (CCN-12)
J. S. George (P-21)

MRIVIEW is a tool for viewing and manipulating volumetric magnetic resonance imaging (MRI) data and for using this data as an anatomical reference in neuroimaging applications. 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 multiple imaging modalities, viewing combinations of anatomical and functional information, and building models of structures within the head. MRIVIEW is written in Interactive Data Language (IDL) and can be used on any of the numerous platforms supported by IDL. Recent modifications to MRIVIEW provide more flexibility with MRI data formats, permit segmentation of multiple objects in an MRI data set, and provide capabilities for viewing time series of functional data. The MRIVIEW 3-D Model Viewer has been rewritten using an object-oriented design.

Previous versions of MRIVIEW permitted 128 gray levels for representing anatomical MRI data. The current version of MRIVIEW can still be used with this memory-efficient representation, as well as with 256 (8-bit) or 65536 (16-bit) gray-level representations. MRIVIEW has a tool for spatial resampling of MRI data, so that aspect ratios can be adjusted for viewing, or memory-efficient representations of the data can be created. Three-dimensional visualizations of combinations of MRI and functional data can be computationally and memory intensive. MRIVIEW's flexibility in data representation allows a user to reduce the data resolution when necessary to achieve acceptable performance on a given computing platform during performance of complex visualization tasks. DICOM v.3.0 part 10 file format has been added to the list of MRI file formats readable by MRIVIEW.

The existing segmentation capabilities in MRIVIEW have been extended to permit the segmentation of multiple objects in an anatomical MRI data set. Applications of this capability include labeling of the major compartments of the brain as well as smaller substructures. The current implementation allows the segmentation of up to eight objects within an MRI data set and will be extended to allow an unlimited number of objects. Segmented objects can be arranged in containment hierarchies. This method can be used to both speed up the semi-automatic segmentation process and to create an anatomically motivated arrangement of segmented objects. The segmentation information is stored using the bitplanes of a separate segmentation volume. Once a segmentation is complete, it can be combined with the original MRI volume to conserve memory and speed up display operations in the 2-D and 3-D operating modes of MRIVIEW.

Time series results from magnetoencephalography MEG, electroencephalography (EEG), or other functional modalities can now be viewed with MRIVIEW as movie sequences. This capability has been used to view a Bayesian analysis of an MEG visual evoked response data set. Distributed, probabilistic source models of activity for each latency in the time series are represented as voxel intensities in a functional volume. Functional volumes are combined with the anatomical MRI in a preprocessing step. The resulting series of volumes is viewed in the 3-D viewing mode of MRIVIEW. Solutions at different latencies can be viewed by moving a slider or played as a movie. Arbitrary coronal, sagittal, and axial slice views can be selected while the movie is playing, using MRIVIEW's volume interrogation capabilities.

The 3-D Model Viewer in MRIVIEW has been rewritten using IDL's object-oriented programming constructs and by taking advantage of the Object Graphics classes included with IDL. The Object Graphics classes are written using OpenGL, and they use graphics hardware acceleration when it is available. The new 3-D Model Viewer provides a wide range of capabilities for viewing combinations of brain functional and anatomical information. MRIVIEW is being used as a platform for the development and implementation of new capabilities such as the Bayesian Inference and multistart methods for MEG and EEG source localization developed at LANL. This work involves the development of techniques for parallel processing within the IDL environment. MRIVIEW functionality is also being extended by building linkages to other software packages for functional neuroimaging.

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

Elaine Best [(505) 665-6187] (CCN-12)
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; in addition, its convenient user interface reflects our intent of making it available to the brain-mapping community.
MEGAN currently handles MEG data from several sensor systems and has been 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.

Time-Resolved Photon Migration Tomography and Spectroscopy

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

Combining advanced illumination and time-resolved imaging strategies with computational models has allowed the development of methods for optical 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 LANL for remote imaging applications. The remote ultra-low-light imaging (RULLI) detector incorporates a stacked microchannel-plate intensifier coupled to a crossed delay line. The precise timing of current pulses allows computation of the location and arrival time of single photons. The detector can be used with imaging optics to produce high-resolution spatial maps, useful for applications such as optical mammography. Alternatively, the detector can be 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. Using an iterative, model-based reconstruction procedure employing adjoint differentiation and gradient descent, we can then use time-resolved data to reconstruct the absorption and scattering properties of tissues.

LANL investigators have previously shown that noninvasive spectroscopy techniques can be used to map patterns of metabolism and hemodynamics within the human head. Our recent work suggests that fast, intrinsic optical signals tightly associated with neurophysiological activation can be imaged using high-performance video techniques. We anticipate that fiber-optic arrays allowing time-resolved illumination and detection from many sites in parallel will allow precise noninvasive mapping of these signals.

Synchronization of Spiking Neurons in a Computer Model of the Mammalian Retina

Garrett Kenyon [(505) 667-5644] (P-21)
B. J. Travis (EES-5); K. R. Moore (NIS-1); J. Theiler (NIS-2); J. Jeffs (P-21); and D. W. Marshak (University of Texas Health Science Center, Houston)

In man-made imaging devices, the output from each pixel changes continuously in proportion to the light intensity at the corresponding location. In the mammalian retina, however, the output neurons, called ganglion cells (GCs), do not vary their responses continuously but rather encode information as sequences of uniform impulses or spikes. Analysis of spike trains recorded from individual GCs provides strong support for the hypothesis that information in the optic nerve is “rate-coded.” According to the rate-code hypothesis, it is the average number of spikes that arrive within a given time window that is important, while the exact sequence of interspike intervals is ignored. Within the last decade, however, the dominance of the rate-code hypothesis has been challenged by the results of new experiments in which pairs of visual neurons, both in the retina and within the visual cortex, are monitored simultaneously. These studies have shown that many pairs of visual neurons exhibit a stimulus-selective synchronization. The stimuli in such experiments typically consist of narrow bars of light projected against a uniform background. Pairs of neurons, which may be separated by many degrees of visual angle, are found to fire synchronously when stimulated by a single, long bar of light, while the same pair of neurons fires asynchronously when stimulated by two separate light bars. Extrapolating these results to the case of more complex images, one can imagine how the different components of an image could be segmented by separately synchronized groups of neurons.

These results demonstrate how, under some circumstances, synchrony can encode stimulus parameters more robustly than the firing rates of individual cells. Similar results were obtained in experiments examining how brightness and size are encoded by the degree of synchrony as compared to the firing rate. This project is discussed in greater detail in a research highlight in Chapter 2.

Validation of a New 150-SQUID Array and Superconducting Imaging-Surface System for Magnetoencephalography

Robert H. Kraus, Jr. [(505) 665-1938] (P-21)
M. Espy, A. Matlachov, M. Peters, and P. Ruminer (P-21)

The goals of this project are to develop, test, and evaluate novel superconducting quantum interference device (SQUID) sensor concepts and devices, new models of electromagnetic sources in the brain, numerical techniques, and computational models for functional imaging of the human brain using magnetoencephalography (MEG) in conjunction with other modalities. MEG directly measures a physical effect of neuronal currents with the high temporal resolution particularly important for studying neurological disorders such as epilepsy, where temporal information is a major diagnostic, and also for fundamental studies of synchronization and oscillatory brain activity.

Technical Progress (FY 2000)

We have realized significant advances in several areas over the past year; however, this report will specifically focus on very recent and exciting progress on the whole-head MEG system and validation of the forward model physics. The whole-head MEG system is based on the LANL-patented principle of superconducting image surface (SIS) gradiometry, where magnetic sources are imaged on the surface, and magnetometers near this surface sense the combined fields as if the sensors were gradiometers. Preliminary results demonstrated higher performance, lower noise, and additional shielding of background fields using simpler fabrication techniques that should reduce production costs.

We have developed a finite-element forward model that describes source interactions with the SIS. This is a computational model that exactly describes the complex shape of the whole-head SIS, allowing us to precisely describe the interaction between a superconducting hemisphere with a brim (or "helmet") and any arbitrary source. Numerous model calculations have been performed to predict shielding from fields resulting from various sources external to the helmet as well as from sources within the helmet. Our calculations demonstrated reduced shielding near the edge, with significant shielding expected well inside the helmet.

A 25-coil phantom was designed and built to test the system using the LANL coordinate measurement facility. The accuracy of this localization procedure is <±0.001 in. (<±25 μm). The recently completed whole-head system with all 150 sensors placed in the array was used to perform the first complete array measurements of the LANL whole-head SIS system for MEG. Signals were measured from each phantom coil by every sensor in the whole-head SIS array for two independent locations of the phantom within the SIS array. Consequently, data sets for 50 separate phantom locations were measured. Using the inverse technique typically applied to MEG data for localizing sources within a sensor array, we initially localized each sensor position based on data from 25 phantom signals. This provided a correction to the sensor geometry array produced from simple machining diagrams. The resulting "cold" sensor geometry array was used in all subsequent phantom coil localization procedures (using typical inverse methods). Inverse source localization performed to locate each of the 50 phantom coils resulted in a mean error of less than 0.2 mm. This localization accuracy is more than a factor of 5 better than any previously published result and an order of magnitude better than most published figures. Further, the accuracy of source localization for our system was independent of source orientation, unlike other systems where source orientation dramatically impacts source localization accuracy.

A new data-acquisition and control system has been developed, integrating portions of the MEGAN software package with high-speed computer hardware to provide users with real-time signal processing and source localization during data acquisition. This is an extremely important advance, because data can be quickly analyzed to determine if “reasonable” results are being obtained.

In addition to the whole-head SIS system for MEG, we have completed the micro-MEG system Dewar and have begun testing this system with a new SQUID sensor array. This unique system will be capable of imaging cortical and brainstem activity and function with high spatial and temporal resolution. The microscope will use a SQUID sensor array and a SIS concept patented by LANL. The system will be optimized to obtain spatial resolution better than 100 μm and temporal resolution better than 0.5 ms for in vivo measurements. High-temporal resolution of the imaging activity of individual neuronal columns will provide a new level of understanding of the connectivity, communication, and propagation of information within the brain.

We obtained four linear SQUID arrays from a collaborator-vendor, a company in Jena, Germany. Each unique, high-critical temperature SQUID array consists of 11 SQUID sensors on a single substrate, the arrays representing the only devices of their kind in the world. Extensive testing of crosstalk between the sensors, one of the most critical parameters, has been completed with exceptional results. After completing resolution measurements with single arrays to determine sensitivity, we found that our ability to discriminate between neighboring sources was better than 120 μm at a sensor-source separation of 1 mm.

A new SQUID microscope dewar, based on technology developed for and lessons learned from the system built for the Enhanced Surveillance Program (DOE/DP), has been fabricated and initial tests completed. The dewar employs a unique stainless design with extremely thin integrated windows near the SQUID arrays to minimize Johnson noise from the metal.

Optical Imaging of Neuronal Population Activity

David Rector [(505) 665-6230] (P-21)
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. We are currently investigating the biophysical mechanisms of scattered light changes within crustacean nerves, and applying similar procedures to detecting neural activation noninvasively in human subjects.

Virtual Pinhole Confocal Microscope

David Rector [(505) 665-6230] (P-21)
J. S. George and D. M. Ranken (P-21), B. Peterson (SciLearn, Inc.), and J. B. Kesterson (VayTek, Inc.)

For 400 years, optical microscopy has been the principal method for the study of biological structure at the cellular level. Over the past century, the application of photography has allowed investigators to capture and distribute microscopic images to a wide audience. The advent of electronic imaging is producing another revolution in scientific microscopy that is redefining the frontiers of speed, temporal and spatial resolution, sensitivity, and perhaps most importantly, the capacity for quantitative photometric, spectral, and geometric measurements. Confocal microscopy systems offer a number of advantages for quantitative imaging including improved image contrast, resolution, and limited depth of field. The limited depth of field of scanned confocal microscopes has supported applications not previously feasible, such as the optical sectioning and volumetric reconstruction of complex subcellular structures or mapping the spatial and temporal distributions of intracellular ions. At LANL, we have developed a novel approach for confocal microscopy that uses available illumination, detection, and data-processing technologies to produce an imager with a number of advantages: reduced cost, faster imaging, improved efficiency and sensitivity, improved reliability, and much greater flexibility.

Our virtual pinhole microscope (VPM) uses a method analogous to slit scanning for fast, full-field scanning. Because the system integrates image-processing techniques, it can correct image degradation associated with slit scanning. Even using standard video technologies, the VPM provides full-frame imaging rates comparable to those of most laser-scan confocal instruments. The second key technical strategy is the use of a “virtual pinhole”—a synthetic aperture constituted after readout of a solid state video imaging array—typically a charge-coupled device (CCD), charge injection device (CID), photodiode array camera, or similar device. In general, the synthetic aperture is implemented in software on the host computer or in a specialized digital signal-processing engine after digital-image acquisition. The key to virtual aperture (pinhole) microscopy is in the algorithms used to reconstruct confocal images from a time series of spatially subsampled images. Because functional parameters are implemented in software, it is possible to adjust key parameters (such as effective aperture size) to optimize image tradeoffs, even after the basic data are acquired. This project is discussed in greater detail in a research highlight in Chapter 2.

Remote Ultra-Low-Light Imaging

W. Robert Scarlett [(505) 665-6968] (P-21)
K. Albright, D. Beck, J. Bradley, C. Briles, D. Jones, N. Nahman, E. Raby, and K. Wilson (P-21); F. Ameduri (NIS-1); D. Casperson, C. Ho, and J. Theiler (NIS-2); R. DesGeorges and M. Hindman Miles (NIS-3); P. Montano and R. Withaker (NIS-4); and D. Thompson (CADI)

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 Department of Energy 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, studies of light propagation in clouds, optical imaging of the brain, and measurement of foliage canopy density. Current activities include development of advanced sensors and fielding systems for various applications.

Bayesian Inference Applied to the Electromagnetic Inverse Problem

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

To address the difficulty of estimating current distributions in the brain from surface electroencephalogram (EEG) and (magnetoencephalogram) MEG measurements (the so-called electromagnetic inverse problem), we have developed a new probabilistic 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. We began by developing a purely spatial analysis, analyzing only the spatial data at each instant in time when the data were acquired.

We have since been extending this to a spatial-temporal analysis that analyzes the full spatial-temporal data set in a single analysis. This work was presented at the international conferences on "Functional Mapping of the Human Brain" and on "Biomagnetism." A journal article is in preparation. In addition, we applied the techniques developed for the brain mapping analysis to the very general problem of density estimation.

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

Kerry Wilson [(505) 667-7823] (P-21)
D. Neagley and R. C. Smith (P-21); J. Dimsdale and B. Kacyra (Cyra Technologies); and J. J. Zayhowski (Massachusetts Institute of Technology)

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.

Dynamic Optical Imaging of Neural Physiology

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

During the last two decades, optical imaging methods have been used to visualize the detailed spatial topography of functional organization within neural tissue. These methods exploit the light absorbance changes associated with changes in blood flow and blood oxygenation that occur in the seconds following neural activation. By integrating over long exposures, the methods may capture, in control images, fluctuations associated with cardiac, respiratory, and other physiological cycles, thereby allowing effects of activation to be isolated in difference images. However, neuroscience is increasingly focused on dynamic spatial and temporal aspects of network function. Our recent imaging studies in the rat brainstem have demonstrated several distinct dynamic optical responses associated with neural activation, including fast intrinsic signals that track the millisecond dynamics of neurophysiological activation. With adequate time resolution and increased sensitivity, it will be possible to make movies of transient neural responses and to probe time-correlated network behaviors.

Optical signals are small and arise from a number of different physical mechanisms, making recording and interpretation of such signals difficult. We are investigating the biophysical mechanisms that underlie the optical responses in order to establish the source of fast signals and determine the most effective ways to make measurements. We plan to investigate the spectral dependence of the optical signals and to characterize the timing of at least four temporal components that we have identified. Polarized light and confocal imaging strategies will be applied to improve contrast and reduce contributions from surrounding tissue. We also plan to explore the use of differential interference contrast microscopic techniques, which may allow identification of cells in thick tissue samples.

For optimal performance, we have designed specialized optical probes and a high-performance data-acquisition system capable of real-time control and online processing. The system is highly optimized for spatial and temporal resolution and sensitivity for detecting small changes in scattered light. The optical system utilizes perimeter illumination to provide a form of dark-field microscopy in order to optimize contrast for scattered light changes. Placing optical components in direct contact with the tissue reduces mechanical artifacts from blood pressure and respiration cycles. We are developing a modified optical system to provide confocal images for better depth discrimination. The imaging system employs high speed charge-coupled-device or complementary-metal-oxide-semiconductor sensors with good signal-to-noise and supporting high frame rates. Our custom scanning and acquisition hardware gains flexibility and performance through field programmable arrays and embedded digital signal processors, allowing continuous data streaming to the host computer for archive and on-line display and analysis.

The fast intrinsic optical signals, which correspond closely to neuronal electrical activity, may allow us to characterize the dynamic functional relationships between neurons within a network. We have now imaged such fast signals in isolated nerves and in brainstem and hippocampal tissue in vivo. Our next step is to establish the feasibility of imaging fast optical signals in a well-characterized cortical structure—the rat somatosensory cortex. Initially, these imaging experiments will be performed in a preparation with the overlying skull removed; we will also explore the feasibility of imaging in a rat preparation with an intact skull. Eventually, we expect to record fast responses noninvasively from human cortex using techniques of photon migration tomography.

Hydrodynamic and X-Ray Physics (P-22)

Detector Characterization for Nuclear Detonation Detection

Roger J. Bartlett [(505) 667-5923] (P-22)
D. Casperson, J. Distel, and J. Valencia (NIS-2); M. Sagurton (LANL/SFA)

X-ray and particle detector systems are flown on the GPS satellite platforms for the monitoring of global nuclear detonations. These systems are part of the U.S. nuclear detonation (NUDET) detection program. These instruments have an array of detectors that monitor electromagnetic radiation from the soft x-ray to well into the gamma regions and monitor a wide gamut of particle fluxes. It is extremely important to minimize the number of false responses while still maintaining sensitivity to "real" events. Thus, it is very important to characterize the response of the detector systems, to understand their response to background radiation and particle fluxes, to measure any aging effects caused by the space environment, and to determine their long-term stability.

We have focused our work during this review period on the low energy (100 eV to ~20 keV) detectors. These are carbon cathode x-ray diodes (XRDs) with thin film filters and diamond photoconductive detectors (PCDs). The response of these detectors has been measured over the energy range from ~70 eV to ~6000 eV at LANL's synchrotron beam lines and at the National Synchrotron Light Source (NSLS) of Brookhaven National Laboratory. A number of similar detectors have been measured over a six-month period. Over this interval of time, the detectors are quite stable. However, the measured variation among the detectors was greater than a factor of 2. The PCDs are more sensitive than the XRDs, but their long-term stability and their susceptibility to particle damage are unclear at this time. Continued stability measurements, effects of cathode surface treatment, and particle damage and response are future areas of investigation.

Beam-Emittance Diagnostic for the DARHT Second Axis Injector

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Low beam emittance is key to achieving the required spot size at the output focus of the Dual-Axis Radiographic/Radiography Hydrotest (DARHT) facility's second axis. The nominal electron beam parameters at the output of the injector are 2 kA, 4.6 MeV, 2-μs pulse width, and a root mean square (RMS) radius less than 1 cm. Emittance is measured by bringing the beam to a focus in which the emittance is a dominant influence in determining the spot size. The spot size is measured from Čerenkov or optical transition radiation (OTR) generated from a target intercepted by the beam. The current density in the focused DARHT beam would melt such a target in less than 1/2 μs. To prevent this, we have designed a direct current (DC) magnetic transport system that defocuses the beam on the target to prevent overheating and that uses a 60-ns, full-width at half maximum (FWHM) pulsed solenoid to selectively focus portions of the beam.

The fast focus must produce ≈1 kilogauss field over an effective length of ≈50 cm to bring the beam to a focus on the target. The fast-focus field is generated with a 12-turn coil located inside the beam-transport vacuum chamber, with the entire fast-coil structure within the bore of the DC magnet. The return current path at the nominal vacuum wall dictates the requirement for the pulsed coil diameter of ≈15 cm. Because the drive system is to use 40 kV to 50 kV technology and much of the inductance is in the drive and feed circuit, the coil design has three 120° segments.

We have utilized beam envelope and electron trajectory calculations, as well as target heating calculations, as part of the design process. The OTR imaging system is provided by Ken Moy of Bechtel-Santa Barbara.

DT Reaction History Measurements on the National Ignition Facility

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A gas Čerenkov detector is being developed for use on the National Ignition Facility (NIF), which is now under construction at the Lawrence Livermore National Laboratory. Fusion reactions from this facility will take place on a time scale of 10s of picoseconds (ps). Traditional methods for measuring burn rates are based on neutron detection, but these methods are limited by time-of-flight dispersion of the neutrons traveling from the burn location to the detector. At NIF, detectors will not be placed within 50 cm of the target, so time resolving the reaction history will not be possible by neutron detection. A gas detector can record the 16.7 MeV gamma rays produced by the DT fusion reaction. The detector first converts gamma rays to high-energy electrons primarily through Compton conversion and pair production. Čerenkov light is emitted by those electrons with energies greater than 12 MeV when traveling through CO_2 gas with an index of refraction set to 1.00083. The critical conversion processes (gamma-to-electron and electron-to-visible-light) involve small-angle processes, which take place throughout the volume of the detector, leading to variable path lengths from target to recorder. A light-collection system has been designed such that the inherent time resolution of the detector is ≈7 ps when the threshold is set to 12 MeV. The thresholding properties of the Čerenkov detector lead to rejection of gamma rays produced by neutron scatter from materials near the burn region and also from bremsstrahlung produced by laser/plasma interaction.

A low-bandwidth (300 ps time resolution) version of the detector was built by Physics Division and tested with a pulsed electron beam at the Idaho Accelerator Center. This test confirmed the sensitivity of the detector, as predicted by our Monte Carlo simulations. The detector was then installed on the OMEGA laser at the University of Rochester and successfully recorded 16.7 MeV gammas as a proof-of-principle demonstration. A high-bandwidth version (30 ps time resolution) is due for testing during the summer of 2001.

Fiber Optic Impact Pins and Radiography Support for the Thoroughbred Subcritical Experiment

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B. G. Anderson, R. D. Fulton, D. M. Oro, P. J. Rodriguez, J. K. Studebaker, and L. J. Tabaka (P-22) and collaborators from Bechtel-Nevada.

P-22 provided diagnostic support for the Thoroughbred subcritical experiment at the Nevada Test Site (NTS). X-ray radiographic sources and fiber-optic impact pins were fielded as part of the extensive diagnostic suite supported by many LANL groups and teams from other laboratories.

The fiber-optic impact pins measure time-of-arrival of the free surface material at specific points above the surface. The data are compared with those from other diagnostics and often provide supplementary information. Two packages were fired in the NTS experiment, “Natasha” and “Boris.” Seventeen optical pins were mounted on the Boris package and 10 were mounted on the Natasha package. All optical pins returned very clean data, which were used as part of the model verification effort. The x-ray radiographic sources used for Thoroughbred consisted of four LANL-designed pulsed x-ray sources based on the Plattsflash developed for Pegasus. These sources are part of a diagnostic to provide time-resolved radiographs of the experiment. The sources have a pulse length of approximately 20 ns and produce strong tungsten-line radiation as well as bremsstrahlung radiation with maximum endpoint energy of 300 keV. Four time-resolved snapshots of the experiment under dynamic conditions were produced. The sources were controlled by an x-ray controller, interlocked to a sophisticated interlock system, and monitored by the DX-7 diagnostic monitor system. All sources performed to specification during the experiment. Complete checklists were utilized for all operations. The system was fully compliant with LANL-LS 107-03.0 and ANSI 43.3-1993.

Advanced Liner Technology Experiment, ALT-1

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G. Rodriguez (MST-10)

In October 1999, a delegation of experimentalists from P-22 and MST-10 participated in a joint experiment at the All-Russian Scientific Research Institute for Experimental Physics (VNIIEF) in Sarov, Russia. The purpose of the experiment was to measure the behavior of a magnetically imploded solid metallic liner in the upper current performance level (30 MA) of the U.S. Atlas capacitor bank. Instrumentation fielded was as follows: Faraday Rotation measurement of the current to the liner, velocity interferometer system for any reflector (VISAR) to continuously measure velocity of the inner surface of the imploding liner, and an array of sixteen fiber-optic impact pins to measure time-of-arrival of the liner at a particular radius.

The experimental device was designed and fabricated by VNIIEF and powered by a ten-element VNIIEF disk explosive magnetic generator (DEMG). The central measuring unit (CMU) was jointly designed and built. VNIIEF fielded a comprehensive set of diagnostics for generator performance. LANL diagnostics and recording equipment was prepared and tested at Los Alamos and shipped to Sarov for the experiment. Data were recorded for subsequent analysis by both participants. The experiment was successfully conducted on November 3, 1999.

All of the LANL diagnostics worked as expected. The DEMG provided the proper current, and the liner imploded without becoming unstable. Peak current was 32 MA and rise time to peak was 3.7 µs. Liner performance was very close to Atlas parameters, reaching 12.8 km/s upon arrival at the CMU. Pin data indicate that the liner was smooth and solid at the end of travel. These results demonstrate, for the first time, that actual liner performance is stable at Atlas conditions.

Diagnostics on the Ranchero Imploding Liner Series

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Ranchero is the designation for a pulsed power source developed by the Dynamic Experimentation (DX) Division. Ranchero consists of an explosive-driven, coaxial flux compression generator coupled to a load through an exploding-foil opening switch. The tests discussed below were conducted to show that Ranchero could support development of the Atlas capacitor bank system by providing an Atlas-like current pulse for power-flow component development.

The load for the Ranchero imploding liner series was a thick-wall aluminum cylinder, similar to the type of liner that will be employed on Atlas for hydrodynamic experiments. DX and Physics (P) Divisions fielded a suite of diagnostics to measure both generator performance and liner dynamics. P-22 diagnostics were primarily focused on measuring load behavior. A diagnostic probe system in the center of the liner was designed to support fiber-optic pin measurement of arrival time and a velocity interferometer system for any reflector (VISAR) measurement of liner velocity. Additional optical fibers were fielded to look for arcing in the load region. P-division also fielded one of three flash x-ray images of the liner. In addition to the liner measurements, P-22 also provided Faraday rotation current measurements of the generator current and output current to aid in understanding Ranchero system performance.

The Faraday rotation current measurements were in good agreement with Rogowski coil measurements performed by DX-division. Peak generator currents greater than 25 MA were recorded. Output current measurements confirmed that the foil fuse could provide a rise-time of ≈5 µs, similar to the expected Atlas rise-time. Peak output current was about 15 MA, lower than pre-shot predictions, suggesting that there are still technical issues to be resolved concerning generator and fuse operation near peak current.

Open-ended fiber-optic pins were placed around the outer edge of the liner to look for light from electrical arcing and current loss. No emission was detected. This is consistent with the post-shot liner dynamics analysis that showed full current delivery to the liner.

Liner motion was quantified by an Materials Science and Technology (MST) Division-fielded VISAR measurement of inner surface velocity and by liner position measurements using fiber-optic pins and x-ray images. The measured velocity and positions were all internally consistent and in excellent agreement with post-shot calculations that we performed by using the measured output current. Liner velocity was lower than predicted due to the lower than expected output current.

All of the diagnostics fielded by P-22 worked as planned, and the results provided valuable information for understanding system performance. The Ranchero liner implosion series demonstrated the capability of the Ranchero system to drive precision liner experiments. However, the lower-than-expected output current suggests that further testing will be required before Ranchero can be used for testing Atlas components.

VISAR on Proton Radiography Experiments at LANSCE

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Eight-hundred MeV proton radiography (P-RAD) has been effectively used to investigate material dynamics such as high-explosive burn and shock propagation in system components. The purpose of the VISAR (velocity iInterferometer system for any reflector) for the P-RAD project is to apply and optimize the P-RAD capability to the study of spall. Spall is fracture along a surface when tension from colliding rarefactions exceeds the material strength. The standard diagnostic for inferring that spall has occurred is VISAR. A VISAR analysis complements P-RAD experiments by providing a continuous record of surface velocity between radiographic frames. Velocity “features” such as oscillations and pullback signatures, not measurable with radiographs alone, can be recorded by the VISAR. Radiographs can show subsurface features, such as spall layers and shock fronts, which may be related to the velocity signatures. Characterizing spall is important to developing an understanding of what happens to a free surface when subjected to a shock, a problem of great interest to the weapons program.

P-22 took the lead role in establishing a permanent VISAR capability for P-RAD experiments at the Los Alamos Neutron Science Center (LANSCE). To achieve this capability, researchers had to accomplish several tasks. A suitable feedthrough that enabled VISAR fiber optics to pass through the containment vessel for the explosive experiments had to be designed, fabricated, and then tested at an outdoor firing site. A VISAR had to be designed, parts ordered, and the system assembled. Optical fibers were installed in the P-RAD area, and a support system for timing and data recording was established.

All of the tasks were completed, and VISAR was used on an explosive-driven spall experiment. A good spall signature was seen by the VISAR. Eleven proton radiographs were taken on the same experiment, the spall layer visible in these radiographs. Surface velocity both recorded by the VISAR and calculated from the radiographs agree to within experimental error.

We now have an improved tool that allows us to measure velocity features, such as oscillations and pullback signatures, and to observe subsurface phenomena, such as spall layers and shock fronts on the experiment.

Magnetized Target Fusion Experiments at Shiva Star

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Two experiments were performed to allow us to observe the behavior of a high-convergence, large aspect ratio, imploding liner at the U.S. Air Force Research Laboratory (AFRL) Shiva Star capacitor bank facility in Albuquerque, New Mexico. The experiments were designed to test the performance of a very large imploding liner as a first step for development of a magnetized target fusion (MTF) experiment. It was shown that the liner performance was stable and that similar liners can be used as flux conserver shells in MTF experiments.

We can utilize MTF to achieve fusion conditions by compressional heating of a magnetized target plasma inside an imploding flux conserver shell. MTF requires a magnetized plasma target such as the field reversed configuration (FRC). The required flux conserver is unusually tall with an aspect ratio—or length to diameter ratio—of at least 3:1 to achieve fusion relevant parameters. The radial convergence ratio is required to be better than 10:1. To our knowledge, this is the tallest (>3:1 aspect ratio) successful experiment at the highest convergence (>13.5:1) that has ever been carried out.

Experimental measurements with B-dot and Faraday rotation measurements of magnetic flux compression of a seed magnetic field show that the time history of an aluminum liner's radial position and speed are consistent with redundant diagnostics and a model. Fiber-optic impact detectors (FIDs) show the symmetry and arrival time of the implosion. The radial symmetry appears to be better than 1% (*i.e.*, ±300 μm out of an initial liner radius of 4.89 cm).

The FID is a glass 100-μm fiber whose end is polished and covered by an opaque 25-μm-thick aluminum foil. The fiber is mounted inside a 0.75 mm diameter by 2-mm-long stainless steel capillary tube and then mounted with its face pointing radially out on the central measurement unit. When the liner arrives at the FID fiber, it shock-heats the end, and the fiber emits a burst of optical blackbody radiation. The fiber leads to a photomultiplier preamplifier with quasi-logarithmic response. A fast-rising signal with no precursor signifies a solid metal impact. This signal furnishes a precise measurement of the impact time, with a resolution in this application of 20–50 ns (although much better resolution is possible). The sharp rise time of the shocked signal is usually unambiguously recorded, unless there is a temporally smeared shock front, as was the case for our FIDs installed near the glide plane.

P-22 fielded 16 FIDs on each of the experiments. Excellent data were recorded from all of the pins. Radiographs and machine current measurements were made by the Shiva Star staff. P-24 recorded several B-dot signals that measured magnetic symmetry during the implosion. Data from both experiments showed that the high-convergence liner implosion was stable and symmetrical, and that the next step in the MTF series should be pursued.

This work was performed in cooperation with the MTF effort in Plasma Physics (P-24). Please see project descriptions in that section and a research highlight in Chapter 2 for more information on the MTF effort here at the Laboratory.

Analysis of the Nuclear Weapon Reaction-History Archive with Modern Tools

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Because of the ban on actually testing a device, the next best proof that a needed change in a stockpile system will not affect yield is for investigators to calculate the weapon's effects and match the Nevada Test Site (NTS) test data before the change, then calculate the weapon's effects after the change and see if the calculation still matches the past NTS test data. If it does not match the data, then further study is needed to determine the effect of the change on the yield and whether the yield is changed enough to allow us to invalidate the stockpiled weapon. This project is discussed in greater detail in a research highlight in Chapter 2.

MeV Radiography on Stallion

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D. Oro and J. Parker (P-22); N. King (P-23); R. Carlson and A. Hsu (DX-7); G. Cunningham, M. Ulibarri, and S. Watson (DX-3); and other collaborators from the Atomic Weapons Establishment, United Kingdom, Bechtel-Nevada, Mission Research Corporation, Naval Research Laboratory, Pulsed Sciences International, and Sandia National Laboratory

Stallion, the next LANL subcritical experiment (SCE), is a dynamic-spall experiment using a layered assembly of weapon materials designed to provide improved knowledge of the behavior of nuclear weapon parts and materials. Spall is the phenomenon whereby the tension caused by a reflected shock wave can exceed the material strength, causing an internal failure of the material with the concomitant separation of a layer of material from the bulk of the material. Spall caused by the "Taylor wave" pressure profile associated with a high-explosive drive can be a complex phenomenon requiring sophisticated diagnostics. To this end, LANL has teamed with Sandia National Laboratory (SNL) to create and lead a national team to develop a new radiographic source capable of the resolution and penetration necessary for Stallion. We have worked with the Naval Research Laboratory (NRL) to implement the "rod-pinch" diode concept on an existing inductive voltage adder (IVA) accelerator, SABRE, at SNL.

These experiments have been immensely successful, yielding a 0.8 mm diameter radiographic source producing 3R at 1 m with an endpoint energy of 2.25 MeV. This result is an order of magnitude improvement over the existing state-of-the-art medium energy source, Mini-B at the Atomic Weapons Establishment (AWE) in the United Kingdom. The prototype radiographic source was designed at Pulsed Sciences International (PSI) and is currently under construction at LANL by personnel from the Physics (P) and Dynamic Experimentation (DX) divisions, aided by the accelerator design expertise of SNL and supported by Bechtel-Nevada (BN). It is scheduled to be operational by the summer of 2001. We have proceeded with detector development on a parallel path. A PixelVision charge-coupled device (CCD) camera, identical to those used at the Dual-Axis Radiographic Hydrotest (DARHT) facility, was chosen as the imaging system, with a new lens implemented to accommodate the required field-of-view. Large area fluorescer development is proceeding at the Materials Science and Technology (MST) Division and BN to produce the large panes of lutetium oxyorthosilicate (LSO), a fast, bright fluorescer required for the final detector system. Initial experiments at SNL with a classified static mockup object have produced images of quality exceeding radiographic chain model predictions, leading to a high confidence in the results expected for Stallion. The local confirmatory test of the complete system is scheduled to occur in early 2002. The SCE itself is currently scheduled to occur in 2004.

High Strain-Rate Experiments

David B. Holtkamp [(505) 667-8082] (P-22)

The heating effects of high strain and high-strain rate can alter the material state of matter and can significantly influence the force equations. These material properties can be studied in a cylindrical geometry by radially imploding a liner (thin metal shell) using pulsed power technology. As the shell converges toward the axis, the cylindrical dimensions thicken by a factor of ≈3 in typical experiments. Distortion of the volume elements leads to strain heating as the material is taken far beyond normal linear strain limits. Moreover, the rapid distortion because of a cylindrical implosion can lead to strain rate heating similar to viscosity effects in fluid flow. In order to refine the calculational codes (*e.g.*, Steinberg-Guinan model) on liner heating, it is necessary to measure the liner inner surface temperature during its compression. The duration of this experiment is approximately 10 μs, and the final absolute temperature is expected to be approximately 400 K–500 K (the liner inner surface remaining solid during the implosion).

To measure such low temperatures, we must work in the infrared range, since 500 K surfaces emit little light shorter than 2 μm wavelength. The difficulty with infrared detectors is that their sensitivity and their linearity are somewhat poorer than most visible detectors, and their level of noise is generally higher, even with a cooling system. In addition, signal amplifiers must be used to allow practical high-speed recording and these electronics generally increase the level of noise. If we are to measure temperatures lower than 400 K in dynamic experiments, we must produce amplifiers and detectors that have as high a gain as possible with extremely low noise. Furthermore, we must use rather fragile 1-mm-diameter optical fibers to couple enough infrared (IR) light from the inner surface of the liner to the detectors. In addition, using optical fibers allows one to preserve the detectors even while the liner and fibers are destroyed in the course of the experiment.

A new multichannel IR pyrometer has been constructed that is capable of measuring low temperature changes (<100°C) at high speed (multi-MHz). The pyrometer has four IR channels spanning 1–11 μm and uses 1-mm optical fibers to relay the light from the center of a pulsed-power experiment to the detectors. Broad IR passbands are used to increase sensitivity while preserving high accuracy in the temperature measurement (<15% for the absolute temperature up to 1300 K). An application of the pyrometer in material property measurements of high strain at high-strain rate is described.

For this experiment, we use a high-current source at the Pegasus II facility at LANL to provide a shock-free, radial implosion of a metal cylinder. Axial currents (up to 12 MA at a quarter-cycle time of 7–8 μs) are generated by the Pegasus II capacitor bank. Drive voltage is reduced for high-strain-rate experiments to give a peak current of about 5.4 MA at 6.3 μs. The axial current in the cylindrical liner applies an inward radial pressure and accelerates the liner radially. Skin effect prevents the current from penetrating to the inner surface, which carries the cylindrical sample material. The final velocity of the liner is about 4 mm/μs at the time of collision with the 0.5-cm-radius pyrometer optical head. For some tests, the sample material is high-strength 6061-T6 Aluminum and is subjected to a strain rate of up to about 10^6 s^{-1} at a strain of about 100%.

Fiber Optic Shock Profile Detectors for Z

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D. Ortega, J. S. Sandoval, and R. G. Watt (P-22); R. E. Chrien (X-2)

Imploding wire arrays on the Sandia National Laboratories (SNL) Z-machine produce a radiation source with a bolometric temperature of several hundred electron volts (eV). By surrounding the z-pinch implosion with a hohlraum, investigators can create a nearly Planckian source of about 140 eV temperature, with peak radiation powers of several hundred terawatts (TW) and integrated energy of 2 MJ or more. In this energy rich environment, we can field a dozen experiments, all driven by an identical source. To monitor the radiation flowing from the hohlraum through our experiment without perturbing the radiation flow, we have developed a fiber-optic shock probe. The probe is placed outside the experimental package and measures the radiation induced shock in the wall of the package.

The passive shock breakout (PSBO) diagnostic consists of PolyMicro 100-micron fiber (#FVP-100-110-125) that is tightly coupled onto the outside surface of our 25-micron gold wall packages. As the multi-megabar shock breaks through the wall and enters the fiber, the fiber is shock heated to luminescent conditions. An intense light pulse with about 100 ps rise time is transmitted via the fiber to a streak camera. In addition to the light produced by the shock, a large amount of Čerenkov light is detected by the fiber. The Čerenkov light is generated by high energy photons created by Bremsstrahlung (deceleration radiation) electrons, which are produced by current losses in the Z-power flow channel. At the camera, an ND-2 (attenuation 100×) filter improves our signal/noise ratio and prevents the camera streak from being distorted due to saturation effects. With the ND-2 filter and a 3-cm-thick steel radiation shield in place, the Bremsstrahlung-induced Čerenkov light in the fiber is reduced sufficiently to see a clean shock breakout signal.

In a typical experiment, a 2.4-mm-diameter hemispherical pod package is attached to the hohlraum, allowing radiation into the open end. A planar fixture with 150-micron-wide radial slots positions fibers every 10° from equator through pole and back to the equator on the opposite side. The streak camera records clearly show the arrival of the radiation front along the inside surface of the package wall.

The PSBO system developed by LANL is the first diagnostic apparatus to have successfully measured multimegabar shocks in the harsh radiation environment of a z-pinch experiment. Our PSBO system has provided data that are being used to test weapons design codes as part of the Stockpile Stewardship program.

"Compatible" High-Definition Television

George Nickel [(505) 667-4342] (P-22)

Work in P-22 on image processing and compression methods has led to the realization that high-definition television (HDTV) signals and signals compatible with the current receivers can be sent in one of the currently used 6-Mhz channels. Existing receivers would show a good picture without the need for a converter, and new HDTV receivers with additional software could display images of a quality almost as good as those attainable with a dedicated channel. Because of the possible commercialization advantages inherent in the savings in valuable bandwidth (the present plan being to use a separate channel for the old and new receivers during some interim period), extensive numerical simulations were done to validate the idea, and a patent application has been filed so that licensing agreements can be negotiated.

One might think that there could be no "room" in a single channel for the HDTV signal—which uses the most modern digital transmission methods—and the old signal, which uses amplitude modulation and wastes much of the available bandwidth with sychronization pulses and "dead time" while the beam is retracing back to the left side of the picture. The modern receivers are essentially digital computers that reconstruct an image from a set of digital "symbols" that occur with certain probabilities to represent a given image. The number of bits needed to transmit these symbols is called the "entropy" and depends on the distribution of those probabilities. There is a general theorem of information theory that the total entropy can only remain the same or decrease when an initial set of symbols is divided into two sets (the entropy is the same only if both sets have exactly the same sets of probabilities). By dividing the symbols into a "low resolution" portion for the old receivers and another portion for the high resolution image features, one can transmit most images while saving nearly enough bits to recover the lost bandwidth due to the archaic transmission methods used to date. Additionally, although the low-resolution data are not compressed, the effect is small, because that component has an intrinsically high entropy and so its compression does not lead to big savings in bits.

It is hoped that broadcasters will recognize this new technology in time to prevent the needless duplication of television channels while the new technology is becoming accepted.

Experimental Investigation of Rayleigh-Taylor Instability

George Nickel [(505) 667-4342] (P-22)
C. Tomkins (P-22)

Hydrodynamic instability plays a role in many applications central to LANL's mission. One classic example of instability is the Rayleigh-Taylor problem, a phenomenon that occurs along the interface of two fluids across which the density gradient opposes the pressure gradient (a simple example of this situation is a heavy fluid sitting on top of a light fluid). The surface becomes unstable and subsequently distorts so that "fingers" of one fluid protrude into the other fluid and mixing occurs. Unfortunately, experimental reproduction of this instability has proven difficult. We propose a novel approach to the problem, using fluids of different compressibilities in a pressurized vessel. This simple approach has the potential to permit more thorough diagnostics of the flow than is currently possible and to make possible the accumulation of a relatively large data set for statistical analysis.

Dynamic Ejecta and Spall Observations Using Multiframe X-radiography

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Experiments are being conducted to allow us to study the formation of surface ejecta and spallation layers in shocked tin targets. Multiframe x-radiography provides a method for dynamically observing the spall development, dimensions of the layers, and ejecta transport as a function of time. These data can then be utilized to assist in spall model development and to provide a benchmark for calculational accuracy. Ultimately, this diagnostic capability is being developed for future experiments on plutonium targets at the technical area (TA)-55 gas gun.

The tin target is shocked using the single stage gas gun at TA-39 and is radiographed across its diameter. X-ray images are obtained using four flash x-ray diode sources, a sodium-iodide fluor, and a charge-coupled device (CCD) framing camera. The x-ray sources are driven by small, portable 450 kV Marx units and generate an x-ray spectrum up to ≈300 keV with ≈35% of the total dose corresponding to tungsten K-line radiation (≈60 keV). Although the solid tin target is radiographically opaque at these x-ray energies, the spallation layers are revealed upon passing the target through a stainless steel suppressor plate. Following analysis and calibration, the temporal evolution of spall layer dimensions, as well as ejecta trajectory, velocity, density, and particle size can be extracted from the sequence of radiographic images.

Microwave Interferometry for Electron-Beam-Loss-Induced Plasmas

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W. M. Wood (P-22); and collaborators from the Los Alamos Neutron Science Center, Dynamic Experimentation Division, and Bechtel-Nevada

The second axis of the Dual-Axis Radiographic Hydrodynamic Test facility (DARHT II) is currently being constructed to provide orthogonal, multiframe radiography of hydrodynamic tests. DARHT II is designed to produce highly energetic x-rays by generating and accelerating a relativistic electron beam into a high-density target. However, a fraction of the total beam current will impact stainless steel surfaces within the beam line before the beam strikes the target, and thus it will produce a plasma. Although it is generally accepted that a high-density plasma within the electron beam can affect beam propagation, the potential plasma density, distribution, and temporal evolution within the DARHT II beam line are not currently understood. As a result, a microwave interferometric technique is being used to investigate these issues.

The 94 GHz interferometer is arranged in a Mach-Zehnder configuration and measures the line-integrated plasma density between transmit and receive horns located inside the beam line. The plasma is formed by primary beam electrons impacting surfaces covered with gaseous adsorbates, and these electrons thereby generate ions, neutrals, and secondary electrons. The free electrons within the neutral plasma induce a phase shift in the microwaves propagating between the feed horns, a shift that is related to the plasma density. Correlating the phase, amplitude, and temporal signature with the distribution and quantity of beam charge lost provides a method to determine when, where, and how much plasma is created within the beam line. Beam loss experiments—performed at the THOR facility—in which a beam current of ≈1.2 kA at ≈1.8 MeV for a duration of ≈1.2 μs was produced, have shown that plasma densities of $1e^{10}$-$1e^{12}$ cm^{-3} can occur near the impacted surfaces. The plasma is observed shortly after the leading edge of the beam arrives and peaks ≈2 μs after beam departure, with the plasma density scaling linearly with total beam charge lost. The extent to which such a plasma affects beam dynamics will be investigated during the upcoming commissioning of DARHT II.

Electron Spectrometer for DARHT

David M. Oro [(505) 665-0441] (P-22)
and collaborators from the Dynamic Experimentation Division and Bechtel-Nevada

An electron spectrometer originally designed for use at Dual-Axis Radiographic Hydrodynamic Test facility I (DARHT I) and pulsed high-energy radiographic machine emitting x-rays (PHERMEX) will be employed during the commissioning of the DARHT II accelerator beam. The spectrometer consists of a 60° sector electromagnet and detector viewed with a streak camera. Time-resolved measurements of the electron energy of the accelerator beam can be made with an absolute uncertainty of 1% and a relative uncertainty of ≈0.5%. Current work is focused on understanding potential beam-dynamic effects resulting from the relatively long electron beam duration (≈2 μs) of DARHT II that could affect the transport into and through the spectrometer and thereby affect the beam energy measurement.

Improvements in Multiframe, Low-Energy X-Radiography

David M. Oro [(505) 665-0441] (P-22)
B. Anderson, R. Olson, and J. Studebaker (P-22); and collaborators from Bechtel-Nevada

The multiframe x-radiography system originally developed for use on the now defunct Pegasus II pulsed-power facility continues to be a useful tool for experimentalists at LANL, providing data on a number of experiments at various facilities. The system's four x-ray sources are arranged such that four x-radiographs can be taken of a target along nearly identical lines-of-sight. Each x-ray source is driven by an independently triggered, compact, pulsed-power unit connected to the source through a high-voltage cable. The x-rays emanating from the source are converted to light in a fluorescer and are subsequently recorded with an imaging system. The desire to temporarily field this system at a number of locations requires changing the imaging system from the four independent, single-frame intensified charge-coupled device (ICCD) cameras used in the semipermanent Pegasus installation to a system that is more compact and easier to field and operate. To this end, the imaging system currently in use consists of a microchannel plate (MCP)-gated, four-frame framing camera with a CCD readout. This system, originally developed by a P-23–Bechtel-Nevada collaboration for use in NTS experiments, has reduced the time required to field the diagnostic and permitted fielding the system at locations where it would have been difficult, if not impossible, to field the original imaging system because of that system's size.

Research is ongoing to improve the x-ray output of the sources. Currently, the sources produce ≈270 milli-Roentgens at 30 cm with an end-point energy of ≈275 keV. Design modifications to the x-ray source are currently being evaluated that have the potential for a moderate increase in these parameters without any changes to the pulsed-power unit. Improvements in the pulsed-power unit have the potential to increase the end-point energy to >600 keV, with a commensurate increase in dose, while maintaining the advantage of using a high-voltage cable to connect the pulse-power unit to the x-ray source. Such improvements will allow radiography of larger, higher-density targets than is currently achievable with the system.

Currently, LANL has the capability to field at least two of these four-frame x-radiography systems simultaneously. Aside from experiments at Pegasus II, these systems have been fielded on subcritical experiments at the Nevada Test Site (NTS), hydrodynamic experiments at the Shiva Star pulsed-power facility at the U.S. Air Force Research Laboratory in Alburqueque, spall and ejecta experiments at the technical area (TA)-39 single-stage gas-gun, and high-explosive driven hydrodynamic experiments at the Eenie firing site. It is expected that in the near future the system will be fielded on the Atlas pulse-power facility.

A New Electrical Diagnostic for Liner Implosion Symmetry

Jerald V. Parker [(505) 667-1599] (P-22)
D. Clark and J. Stokes (P-22); W. Broste (Bechtel-Nevada)

The Pegasus II pulsed-power facility provides a unique capability to perform high-precision impact experiments. An important benefit of electromagnetic drive is the high symmetry of the cylindrical impactor. Precision measurements of liner symmetry are usually performed with an array of impact pins in the target that register the time of impact at several axial and azimuthal locations. This technique cannot be used, however, if the target geometry is incompatible with installation of impact pins.

A new electrical technique has been developed to measure impact symmetry that does not require any sensors in the target. A symmetric array of six or more magnetic probes is mounted at a radius well outside the initial position of the liner. During the liner implosion, these probes produce a voltage proportional to the liner velocity. At impact, there is a step change in the probe signal as the liner velocity changes. Despite the fact that the probes are far removed from the impact (10-cm probe radius versus 1.5-cm impact radius), there is a measurable time difference between the signal steps if the liner does not strike the target symmetrically. An analysis of this effect shows that one can obtain quantitative measurements of the $m = 1$ distortion of the liner and limits on the $m = 2$ distortion. Measurements using the Pegasus II capacitor bank have resolved $m = 1$ asymmetries as small as 13 μm amplitude, far smaller than the resolution of conventional radiographic methods.

In addition, it is possible to obtain semiquantitative information about the axial uniformity of the liner from details of the signal timing. Analysis of 11 Pegasus II experiments shows that axial straightness of 60–80 μm is achieved for liners with moderate convergence. In contrast, when liners are driven to high convergence or have initial perturbations, the axial nonuniformity may exceed 1 mm.

Diagnostic Developments at DARHT II

Patrick Rodriguez [(505) 667-2498] (P-22)

There are many challenges facing the designers of DARHT II. One challenge is to construct 140 precision, robust, vacuum-compatible diagnostics—B-dot and diamagnetic sensors. For the DARHT II diagnostics team, this is accomplished by replacing the typical Teflon dielectric of a standard 0.085-in. diameter, semirigid coax with a hollow glass dielectric for use as the sensing element. The glass coax is heated and configured to shape, a copper center conductor is reinserted through the glass tube, and the assembly is interconnected. By replacing the standard Teflon dielectric with glass, experiments achieve several benefits. The first benefit is radiation hardening. Exposure of the diagnostics to the DARHT II electron beam will degrade carbon-based polymers in time, and the diagnostics may fail prematurely. With glass construction, radiation degradation is minimal and detector service life is increased. Second, the construction of the glass-sensing element is such that there are no virtual leaks to compromise the stringent vacuum requirements of the DARHT II accelerator. Additionally, glass greatly reduces the gas load from carbon-based outgassing.

Cathode Temperature Camera

Our goal is to measure the temperature, temperature uniformity, and emissivity of the DARHT II cathode using multispectral imaging pyrometry. We will photograph the cathode at operating temperature (900° C–1100° C) using a Photometrics charge-coupled device (CCD) camera with a stock Nikon lens (probably 35 mm f/2) and narrow-band interference filters, at wavelengths of 0.40, 0.45, 0.50, 0.60, 0.80, and 1.0 mm. The filter bandpass is close to .04 mm. The filters are chosen to cover the spectral range of the camera. Filters are mounted on a motor-driven filter wheel which sits in front of the camera lens. We use a stacked pair of interference filters at each wavelength to increase the blocking of out-of-band light. We convert these photographs to thermal images of the cathode after calibration of the system using a calibrated-cavity blackbody. To get the most accurate temperatures, we use our bluest filters to get as far as possible towards the blue end of the emission spectrum of the cathode.

The calibration of the system has two phases. In phase one, we measure the relative spectral responsiveness of the camera with each filter. We only need the shape of the responsiveness to within an unknown scale factor to be determined in phase two. These measurements are done using a spectroradiometer. We also determine the size of any corrections necessary for lens roll-off and filter angle tuning. We verify that the exposure times and aperture settings of the camera are accurate. We also measure the spectral transmission of the window between the camera and the cathode.

Phase two consists of a final temperature calibration of the camera with each filter. We take pictures of a calibrated cavity blackbody (Most likely a Mikron M300 with a 2-in.-diameter aperture). We vary the temperature of the blackbody and record camera counts.

Both of these efforts are collaborations with Bechtel-Nevada. We are in the final production stages of 140 detectors. Additionally, we are in the process of calibrating and characterizing the camera and detectors for deployment in the commissioning station of DARHT II later this summer.

DARHT II Construction Project

Larry J. Rowton [(505) 665-1645] (P-22)

The second axis accelerator for the Dual-Axis Radiographic Hydrodynamic Test facility (DARHT II) is a linear-induction accelerator producing a 2-kA electron beam. It can be upgraded to a 4-kA operation for increased experimental x-ray doses. The injector is a Marx-generator-driven diode source producing a 3.2 MeV electron beam with a 2 µs nominal pulse width. The beam is then accelerated to 4.6 MeV through eight special induction cells designed to match the injector output. Finally, the beam is accelerated to 20 MeV using an additional eighty standard induction cells. The design goal for flatness of the energy of the 20-MeV, 2-kA pulse is ±0.5% over the 2 µs flat region.

Since February 2000, P-22 personnel have partnered with DX-8 personnel to install the DARHT II injector. This project involves designing the installation procedure and design and construction of specialized tools and equipment to install the various components. The injector has been designed and constructed by Lawrence Berkeley National Laboratory (LBNL) and then shipped to LANL for installation.

The diode is housed inside a 13-ft diameter by 31-ft tall vacuum vessel. For an acceptable cathode lifetime, the vacuum around the cathode must be maintained in the low 10^{-8} torr range. The vacuum vessel is pumped by four Cryotorr 400 cryopumps. Each pump has a pumping speed of about 6000 $L \cdot s^{-1}$ for oxygen and nitrogen and 16000 $L \cdot s^{-1}$ for water vapor.

During calendar year 2000, P- and DX-Division personnel have installed the Marx tank, part of the oil-handling system, and some of the internal Marx hardware. Both the vacuum vessel and the vacuum system are about 80% complete. The insulating column and the cathode hardware are installed inside of the vacuum vessel. By the end of next month, we expect to have the vacuum vessel and its vacuum system complete. Leak checking of the vacuum vessel and an operational check of the pumps will begin at that time.

Study of Inertial Instability and Fracture of Cylindrical Tubes of Solid Aluminum Using the Pegasus Facility

John L. Stokes [(505) 667-4900](P-22)
R. D. Fulton, D. Morgan and D. Oro (P-22); A. Obst (P-23); H. Oona (DX-3); W. Anderson (MST-7); E. Chandler and P. Egan (Lawrence Livermore National Laboratory); and W. Broste and other Bechtel-Nevada collaborators

Until the demise of the Pegasus pulsed-power machine, we collaborated with Elaine Chandler and Pat Egan, Lawrence Livermore National

Laboratory (LLNL), on a series of experiments that studied the effect of yield strength on perturbations and failure mechanisms in aluminum. These experiments provided data that tested the material strength, Richtmeyer-Meshkov (R-M)-driven instability growth and failure models used in codes for programmatic needs. We tested both 1100-O and 6061-T6 aluminum alloys at 140 and 300 kbar shock pressures and one at 500 kbar shock pressure. The experiments were in cylindrical geometry and had a shock profile similar to the Taylor wave produced by high explosives. Different shock pressures were obtained by varying the current produced by Pegasus that drove the liner into the target at the desired speed.

Typical targets had an unperturbed section and also different perturbations parallel to the axis of symmetry machined in other sections. We had three radial x-ray pictures and as many as four axial x-ray pictures, all timed independently in each experiment. Thus, we obtained a large amount of information as a function of time on each shot.

The 500-kbar experiment showed a uniform density in the spalled region, as predicted. All other experiments showed two "spalled" layers of aluminum on the inside and some spall on the outside of the remaining aluminum. The perturbed targets showed evidence of the perturbations in the two spalled layers but none in the remaining aluminum. A region of low density followed the two spalled layers. No effect was observed due to yield strength differences, even though the yield strength differed by a factor of 8 between the 1100-O and 6061-T6 aluminum alloys used in these experiments. The speed of the innermost surface was calculated quite well. However, the two layers of spall were not represented very well in the calculations. The R-M part of the experiments followed the calculations in a much better way.

On the 140 kbar 1100-O aluminum experiment, a 120° section was replaced with an unperturbed section of a new 0.9999 pure aluminum. This aluminum had much larger grain size than the other 1100-O aluminum. The results were the same for both aluminum types. The effect of the larger grain size was not very noticeable.

Much work needs to be done so that we will be able to better model the data obtained in these experiments and to understand the implications of these data.

Comparative Behavior of Titanium and 304 Stainless Steel in a Magnetically Driven Implosion at the Pegasus II Facility

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The PEGASUS II facility, a pulsed-power capacitor bank capable of delivering several megamperes of current to a cylindrical conducting liner, was used for the magnetic implosion of a thick-walled cylinder to study two-dimensional high-strain-rate flow in different materials. Boundary conditions of loading (dynamic pressure) were monitored by the measurement of the magnetic field outside the composite cylinder. We studied the kinematics of flow using three radial x-ray radiographs at different azimuthal angles and at different times after the start of current through the cylinder. The composite liner consisted of separate stacked cylinders of 304L stainless steel or titanium between copper cylinders. We found that a magnetically driven, composite, thick-walled cylinder is able to preserve cylindrical symmetry at the level of strain large enough to initiate material instability and at the same time avoid typical geometric instability for thin-walled cylinders. The results are contrary to the behavior expected based on uniform plastic flow of these materials. This can be explained by the plastic flow instability and formation of multiple shear bands in titanium.

Fusion Space Propulsion

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Recently, NASA has been developing interest in the use of fusion power for advanced space propulsion systems. This interest arises from the need to reduce the trip times for human exploration of the solar system from years to months. Fusion power offers the opportunity to couple energy from nuclear reactions directly to the propellant flow, thereby avoiding most of the mass penalties associated with generation of electricity and rejection of heat by a closed thermodynamic cycle. During the past year, we participated in the development of the NASA program in fusion space propulsion, including service as co-chair (P. J. Turchi) of the NASA Workshop on Fusion Propulsion.

Our in-house efforts have focused on magnetized target fusion (MTF), which offers a potentially attractive regime for controlled fusion. This regime, between magnetically and inertially confined fusion approaches, may provide the proper combination of high-energy density and moderate power density to permit satisfactory values of specific power at acceptable levels of initial-mass-in-low-earth-orbit (IMLEO). One class of MTF system uses liner compression of magnetically confined plasma (*e.g.*, field-reversed configuration [FRC]). Within this class, several possibilities exist for technological approaches. These possibilities comprise the use of solid, liquid, or plasma liners, and the compression of plasmas involving D-T, D-D, and so-called advanced fuels (*e.g.*, D-^{3}He). Furthermore, the fusion energy may heat a steady-state reservoir of propellant by injection of the reacted-FRC or may transfer energy directly to the propellant (in the case of plasma liners). We are examining issues associated with several schemes for employing MTF for space propulsion. These issues include overall system performance and details such as stabilization and control of liner dynamics.

Near-Term Liner Experiments for Hydrodynamics and Pulsed-Power Studies

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The implosion of cylindrical liners using multimegampere electrical currents represents a precision experimental technique for studying material dynamics in converging geometry. Such studies allow close comparisons of experimentally derived and calculated results essential for validating hydrodynamic computer codes. Success with the Pegasus capacitor bank at LANL demonstrated that liner implosion techniques can contribute to a variety of stockpile stewardship efforts. The Atlas pulsed-power facility, completed at LANL in January 2001, will extend these capabilities to higher-energy experiments.

During FY 2000, we undertook a series of experiments designed to develop aspects of liner-implosion technology for Atlas and to provide useful data on hydrodynamic features for comparison with new codes. Four near-term liner experiments (NTLXs) were performed on the Shiva Star pulsed-power bank at the U.S. Air Force Research Laboratory (AFRL) at Kirtland Air Force Base, at peak currents in excess of 15 MA. Such currents are about half the design levels for Atlas but twice the values used on the now-disassembled Pegasus bank.

Each NTLX test involved precision implosion of an aluminum liner, initially 10 cm in diameter and 1 mm thick, onto a target cartridge consisting of an acrylic cylinder 3 cm in diameter embedded in a surrounding cylinder of tin with an outer diameter of 4 cm. Shots one and three were conducted using a configuration in which the acrylic cylinder was coaxial with the aluminum liner and the tin cylinder to produce a symmetrical, converging shock wave. Shots two and four had the axis of the acrylic cylinder shifted radially by 4 mm with respect to the common axis of the liner and the outer surface of the tin, producing an asymmetrical implosion. In both arrangements, propagation of the shock in the acrylic was observed by x-radiography and optical shadowgraphy. These experimental results were then compared with synthetic radiographs generated from RAGE computer code calculations of shock motion. The NTLX experiments have provided useful and challenging data for validating the computer codes.

The NTLX liner cassette and target cartridges employed on Shiva Star are designed to work equally well on Atlas. Initial tests are planned on Atlas at higher currents to assess the operation of Atlas with a liner implosion load. A set of additional Atlas shots related to nuclear-weapon studies will then be performed during FY 2001, while the facility remains in operation at LANL.

The success of the NTLX project involved the efforts of about three dozen people, including researchers from P-22, MST-7, AFRL, and Maxwell Laboratories, Inc., for the design and fabrication of the experimental hardware; X-1, X-2, and AFRL for calculations of liner dynamics and shock behavior; and P-22, MST-10, AFRL, and Bechtel-Nevada for the development and operation of diagnostics and instrumentation.

Spall Strength and Shock-Release Kinetics following the Alpha-Epsilon Phase Transition in Iron

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D. B. Hayes, R. S. Hixson, and J. E. Vorthman (DX-1)

Spall, the dynamic fracture of a material, can occur when the tensile stresses from colliding rarefaction waves exceed the strength of the material. (Rarefaction waves are pressure waves induced by the reduction in density following shock waves, and they travel in a direction opposite the shock waves.) By passing rarefactions through a sufficiently thick sample, they can be made to rise relatively slowly to allow detection of dynamic features of the spall. We are interested in spall of a material after it transforms from alpha to epsilon phase and then reverts to alpha. Studies of recovered targets of iron, spalled in this manner, indicate increased shock hardening relative to targets shocked to below the alpha-epsilon transition. We also studied the kinetics of shock release from the epsilon state for the case where spall is suppressed by placing an impedance-matched window adjacent to the target. This project is discussed in greater detail in a research highlight in Chapter 2.

Integrated Experiments on Omega and Z

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The success of the science-based stockpile stewardship (SBSS) program depends on the Accelerated Strategic Computing Initiative (ASCI). This program of new 3-D code development requires validation by comparison of simulation results to experimental data. In the absence of new underground tests, this validation must be done by comparison to the historical Nevada Test Site (NTS) database and by comparison to modern experimental results obtained in above ground experimental (AGEX) facilities. We are conducting radiation hydrodynamics experiments at both the Laboratory for Laser Energetics Omega laser at the University of Rochester, in New York, and at the Z accelerator at Sandia National Laboratories (SNL), in Albuquerque, New Mexico. Both facilities provide an experimental tool useful for radiation hydrodynamics experiments using millimeter-scale physics packages and radiation temperatures in the 130–230 eV range. Weapons-physics issues may be studied in these experiments.

At the 60-beam Omega laser facility, a 15-beam subset of the laser containing 7.3 kJ in a 1 ns pulse is capable of driving a hohlraum 1.6 mm in diameter by 2.8 mm long to temperatures of 195 eV for times on the order of 1 ns. Experiments to date have studied hydrodynamics using both x-ray imaging and x-ray induced fluorescence spectroscopy as a diagnostic. Both techniques have been successfully used in previous experiments at other facilities in this program. Most recently, experiments at Omega are beginning to study point projection x-ray backlighting geometries to probe the interior of complex physics packages and study the physics evolution without perturbations due to windows in the wall of the package. This diagnostic technique uses several of the remaining beams from the system to illuminate a zinc back-lighter disk in order to produce 9-keV zinc line radiation. This radiation is used to probe a target consisting of multiple layers of gold foil in steps up to about 10 μm total thickness. The physical thickness and x-ray opacity changes between the steps are designed as a surrogate for the opacities seen in a complex physics package. Results to date show the ability of the x-ray source to penetrate the surrogate target (and thus the real package) with both adequate spatial (≈25 μm) and temporal (~80 ps) resolution to perform the designed experiment. This test has used gated x-ray framing cameras developed over the last decade for the national inertial confinement fusion (ICF) program.

The Z accelerator at SNL is capable of producing two different radiation environments for driving physics packages. The Z "vacuum hohlraum" (VH) is a single cylindrical wire array that contains 300 11–12-μm-diameter tungsten wires magnetically imploded by the self-field of a 20-MA current flowing in them. Self-stagnation of the cylindrical array at the center of a gold-lined, 1-cm-tall, 2.5-cm-diameter stainless-steel cylinder produces a radiation field in the 145-eV range for times of order 5 ns. This radiation field also has a foot at up to 30 eV for about 80 ns before the main power peak, a feature that can be used or discarded at will by intercepting the radiation in a thin plastic foil before it gets to an experimental package. The VH drive can be used to drive up to 12 physics experiments simultaneously, due to the large area of the hohlraum wall, allowing the experimenter to conduct A–B comparisons of two radiation hydrodynamics packages which are identical except for a single varied component. This simultaneity removes the uncertainties associated with shot-to-shot drive variation.

The Z "dynamic hohlraum" (DH) is also a wire array implosiono but uses two concentric arrays of 7.5-μm tungsten wires which impact each other and later impact a central 14 mg/cm^3 plastic foam at the center of a 5-cm-diameter hohlraum. This source produces axially directed radiation at 220 eV for 5–6 ns, without a leading foot, the radiation allowed to escape through a radiation exit hole in the two-wire-array feed electrodes (the "glide planes"). A physics experiment can be put on either end, to be driven by the escaping radiation. This allows two simultaneous experiments, so one can again perform A–B comparisons or execute two separate experiments. The high drive temperature can access different radiation flow conditions than is the case for the lower drive temperature VH configuration. In both Z geometries, experiments using physics packages 2–5 mm in diameter can be performed, allowing significant timescale and length-scale increases over those that are accessible on the Omega facility. An interesting example of a simple experiment that has been conducted in both the VH and DH geometry is to load a small cylinder with a low density SiO_2 foam and study radiation propagation by examining both time of occurrence and radial spatial uniformity in time of the shock breakout from a closed end opposite the radiation drive. This experiment has motivated improvements in the radiation packages available in two of the ASCI codes. Physics experiments done on both Omega and Z frequently differ only in the spatial scales and timescales available, allowing the experimenter to span a space of experimental conditions with similar experiments and diagnostics at two distinct facilities.

Double-Shell Implosions in the Inertial-Confinement Fusion Program

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The National Ignition Facility (NIF), a large laser presently under construction at Lawrence Livermore National Laboratory (LLNL), is designed to produce 1.8 MJ of 0.35-μm light in a 500-TW, temporally shaped, laser pulse for defense applications and inertial-confinement fusion (ICF) ignition. The possibility of capsule ignition and gain at NIF, given the laser energy and power available, is far from a certainty and requires further laboratory experimentation and theoretical simulation to remove as many uncertainties as possible in order to reduce the risk of failure. This project is discussed in greater detail in a research highlight in Chapter 2.

Neutron Science and Technology (P-23)

Low-Energy Solar Neutrino Spectroscopy

Tom Bowles [(505) 667-3937] (P-23)

During the past thirty years, extensive effort has been invested in order to show that the number of observed solar neutrinos falls significantly short of that predicted by the standard solar models. A direct measurement of the dominant p-p low-energy solar neutrinos is crucial to resolve this problem. Low energy solar neutrino spectroscopy (LENS) appears to be the only experiment likely to permit investigators to make this measurement.

A central requirement for LENS is the ability to observe the initial neutrino interaction in a ytterbium-loaded scintillator followed by a delayed-coincidence 72 keV gamma with a half-life of 50 ns. It is essential that the scintillator produces at the highest possible light output in a time short relative to 50 ns. In addition, the detector must collect as much light as possible. Finally, we must develop the pulse-fitting techniques that allow us to search for and separate delayed coincidence signals.

To study these issues, we constructed a test cell and electronics system to measure scintillator samples. We recorded the entire pulse waveform of the signals, which allows us to see if the shape is consistent with delayed coincidence. Data have been taken with different scintillators and are being analyzed to select the best instrument. We also modeled the optical performance of two possible configurations for LENS: an array of scintillator modules that are 50- × 50- × 400-cm long and a single spherical scintillator. In general, we concluded that if the scintillator has very high transparency for the scintillation light, a spherical design is preferred. At present, the attenuation length in various scintillator samples is only about 2 m, thus pointing toward a modular design. The LENS collaboration is working to improve the transparency, and the detector design will be fixed once we determine what is the maximum transparency we can achieve.

A New Ultra-Cold Neutron Source for Fundamental Physics Measurements at LANSCE

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Ultra-cold neutrons (UCNs) are neutrons of sufficiently low energy that they cannot penetrate the potential barrier formed by a variety of materials. They have a number of characteristics that make them uniquely suited to high-precision measurements of the properties of the decay of the neutron, properties which are intimately tied to fundamental physics. For example, the neutron decays with a lifetime of about 890 seconds into a proton, an electron, and a neutrino. During this phenomenon, there is an angular correlation between the direction of the spin of the decaying neutron and the angle of emission of the electron. Measurement of this correlation, called "A," when combined with knowledge of the neutron lifetime, determines the values of the vector and axial vector weak coupling coefficients. We tested our prototype source at proton currents comparable to those to be used for a full-scale production UCN source. The result of the test was the highest density of UCNs stored in a bottle thus far. The linearity of the number of detected neutrons with incident proton charge was also encouraging, because it indicates that the full-scale source would not be limited by beam heating or other effects of higher proton currents.

We have proposed a new experiment to measure the A correlation using UCNs produced at a new full-scale UCN source to be built at the Los Alamos Neutron Science Center (LANSCE). Our predictions are that steady-state UCN densities of about 300 stored UCN/cm^3 will be achieved, as opposed to the 10 UCN/cm^3 we stored in our test run and the 41 UCN/cm^3 that had previously been achieved by a production source. A density of 300 UCN/cm^3 will allow us to make, with previously unattainable precision, measurements of neutron decay asymmetries and hence of the weak coupling constants. This project is discussed in greater detail in a research highlight in Chapter 2.

Development of a Dark Matter Experiment

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E. Esch and A. Hime (P-23)

One of the candidates postulated by physicists to account for the dark matter of the universe (which may comprise as much as 90% of its entire mass) is the weakly interacting massive particle (WIMP). These are newly theorized particles, hitherto unobserved, that have a mass equal to or exceeding that of the proton, interact only weakly (at about the strength of the weak nuclear interaction), and are moving very slowly (about 270 km/s, which is the rotational velocity of our galaxy).

In order to detect WIMPs, one can search for their elastic scattering from nuclei, an interaction which results in an impacted nucleus recoiling with a few keV of energy. This requires sensitive detectors (usually cryogenic) and extremely low backgrounds. We have been developing the use of large (120 gm) Si(Li) solid-state detectors for this application. A large array of these (75 kg) is available from our Russian collaborators. If the backgrounds of these detectors are sufficiently low, they could be employed in a sensitive dark-matter search.

We would plan to carry out a dark matter search at our low-background counting facility, deep underground at the Waste Isolation Pilot Plant (WIPP) in southern New Mexico. We have carried out a set of measurements of gamma, neutron, radon, and cosmic ray backgrounds at this site in order to characterize the external background for a WIMP search. The site looks quite suitable for a sensitive WIMP experiment. Unfortunately, in testing the large silicon-lithium detectors, we found that they were not stable, as they experienced extended periods of electrical breakdown that prevents one from establishing the low threshold required to search for WIMPs. After a great deal of work, we established that this breakdown is intrinsic to the detectors and that they are not suitable for a WIMP search. While we are looking into other possibilities for detectors, we have terminated our activity involving development of the silicon-lithium detector into a large WIMP detector.

Measuring the Weak Nuclear Force between Protons and Neutrons

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Our team is developing an experiment to answer long-standing questions concerning the weak interaction of nucleons. This experiment will be done at the Los Alamos Neutron Science Center (LANSCE) spallation neutron source using cold polarized neutrons. Nucleons are bound together to form nuclei by the strong interaction. Both nucleons and nuclei decay through the much more feeble weak interaction. The existence of weak decays of nucleons implies that pairs of nucleons interact weakly as well as strongly. The signature of the weak interaction is parity-violation. This signature will be used to experimentally isolate the small effects from the weak interaction in the presence of the much stronger (10 million times) strong interaction. Although scores of parity-violating asymmetries have been observed in nuclei, a quantitative description of these measurements has yet to be developed. The goal of this experiment is to unambiguously determine the most important coupling constant in the potential that describes the weak force between nucleons. The weak interaction of nucleons involves the basic constituents of the modern theory of weak and strong interactions known as the Standard Model.

In 2000, we conducted a test run using a 1/10 scale prototype of the experiment and an existing cold neutron beam line at LANSCE. The test included a neutron polarizer, spin flipper, cesium-iodine detectors, and beam monitors. Instead of a liquid hydrogen target, we used targets of chlorine, cadmium, and lanthanum. All elements of the apparatus performed as expected, and we were able to observe actual parity-violating effects at the 10^{-6} level, the experiment limited only by counting statistics. This project is discussed in greater detail in a research highlight in Chapter 2.

The Sudbury Neutrino Observatory

Andrew Hime [(505) 667-0191] (P-23)
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During the past 30 years, extensive theoretical and experimental effort has culminated in what is now commonly referred to as the solar neutrino problem, wherein the solar neutrino signal registered in terrestrial detectors exhibits an energy-dependent deficit relative to predictions of solar models. The discrepancy between theory and experiment seems difficult to reconcile with changes to the standard nuclear and astrophysics considered responsible for making the sun shine and lends a tantalizing hint that neutrinos possess nonzero rest mass. Such a discovery would mark evidence for physics beyond the standard model, with profound implications for elementary particle physics, astrophysics, and cosmology. New generation experiments are thus designed to solve this puzzle using techniques that do not rely upon solar model calculations for their interpretation, but rather search directly for the physics manifest in neutrino oscillations.

The Sudbury Neutrino Observatory (SNO) is a real-time, solar neutrino laboratory that uses 1000 tonnes of heavy water (D_2O) as a neutrino target. It is specifically designed to study the flux and energy spectrum of 8B solar neutrinos through three interactions with deuterium. The charged-current (CC) interaction can proceed solely with electron neutrinos. The flux and energy spectrum of electron neutrinos is measured from the ensuing Čerenkov light collected in a spherical array of 10,000 photomultiplier tubes surrounding the 12-meter-diameter acrylic vessel housing the D_2O. Electron neutrinos are also registered through their elastic-scattering (ES) with electrons, a signal which strongly correlates the incident neutrino direction with the sun as its origin. Other neutrino flavors can also participate via the ES reaction, although the signal in this channel is suppressed by about a factor of six relative to that for electron neutrinos. The neutral-current (NC) interaction can proceed with equal probability by all active neutrino species. The total flux of solar neutrinos reaching the Earth is deduced by counting the free neutrons liberated in the D_2O by the NC disintegration of deuterium. If the electron neutrinos produced in the sun's core experience flavor transitions to other active neutrino states (a phenomena that can occur only in the presence of nonzero neutrino mass and mixing in the lepton sector), then a measure of the ratio of the CC to the NC flux (and also the CC to ES flux) can provide the "smoking gun" evidence that the physics of neutrino oscillations is responsible for the solar neutrino deficit.

Over a decade of effort has gone into the construction and commissioning of the SNO detector, which is located 6800 ft underground, in an active nickel mine in Sudbury, Ontario, Canada. The detector has been filled with heavy water since May, 1999. After a preliminary commissioning period, the detector operating parameters were fixed, and we have been running in neutrino production mode since November 1999. Based upon the energy, direction, and position of events reconstructed in the D_2O volume, the signal obtained so far appears to be dominated by 8B solar neutrino events with very little background. We are thus confident that this phase of detector operation will provide an accurate measurement of the electron neutrino flux via the CC channel. As this report is drafted, we are involved in an intense collaborative effort to analyze our first year of solar neutrino and detector calibration data with the intent of soon publishing our first physics results.

Analysis, at present, is focused upon the recovery of the CC and ES signals with a conservatively high-threshold energy. This is due mainly to the difficulty of extracting signals at lower energy where the data are contaminated by background associated with long-lived radioactivity in the detector. This background makes it a particular challenge for extracting the NC signal in this phase of operation, since the gamma-ray signal ensuing from the capture of neutrons on deuterium is largely buried under the background wall. Sensitivity to the NC signal will be enhanced by dissolving salt into the D_2O volume, whereby neutrons capture on chlorine nuclei emitting gamma rays with energy sufficiently above the background wall. Ultimately, the NC signal can be recovered independent of the Čerenkov signals in SNO by deploying an ultralow-background array of ^{3}He proportional counters throughout the D_2O volume. These neutral current detectors (NCDs) have been designed in collaboration with the University of Washington and full-scale construction is presently near completion. The SNO collaboration will soon make a transition to the dissolved-salt phase, with the aim of running in this mode for approximately one year. Subsequently, the salt will be removed from the SNO detector so that the NCD array can be deployed for the long-term operation of the experiment.

Beta Decay of ^{82}Rb in a Magnetic TOP-Trap

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We are pursuing a measurement of the parity-violating, positron-nuclear spin correlation function from the beta decay of ^{82}Rb atoms 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 continuously as a function of both the positron energy and emission angle relative to the nuclear spin-orientation. We have recently succeeded in observing the parity-violating signal in proof-of-principle experiments, the details of which are provided in a research highlight in Chapter 2 of this report.

High-Energy Gamma Astronomy with Milagro

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High-energy gamma-ray astronomy probes nonthermal, energetic acceleration processes in the universe. Cosmic gamma rays up to 10–100 GeV can be directly detected with satellite-based detectors, such as the energetic gamma-ray experiment telescope (EGRET, now defunct) and GLAST (currently under construction). At higher energies, the gamma-ray flux from even the brightest source is too low to be measured with the relatively small detectors that can be placed in satellites; thus Earth-based techniques are used. High-energy gamma rays interact high in the Earth's atmosphere, producing a cascade of particles called an extensive air shower (EAS). Ground-based gamma-ray telescopes detect the products of an EAS that survive to ground level, either the Čerenkov light produced in the atmosphere by the shower particles (atmospheric Čerenkov telescopes [ACTs]) or the shower particles (predominantly electrons, positrons, and gamma rays) that reach ground level (EAS arrays).

After many years of perfecting the technique, ACTs have been successfully employed to detect very high-energy gamma rays (VHE), (≈400 GeV–10 TeV) from several sources including three plerions, at least three active galaxies, and one supernova remnant. These observations have greatly expanded our understanding of the acceleration mechanisms at work in these objects. The early results from Milagrito and Milagro have demonstrated that the water-Čerenkov technique works well and that continuous, sensitive TeV observations of the sky are possible. The observation of TeV photons from the Crab with Milagro verifies the expected sensitivity of the telescope, including the background-rejection capability. The sensitivity of Milagro is being further enhanced by the outrigger detectors now being installed. This project is discussed in greater detail in a research highlight in Chapter 2.

Stability of Nonneutral Plasmas in Inhomogeneous Magnetic Fields

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Confinement of nonneutral plasmas in electromagnetic traps has important implications for many experimental studies. These applications range from precision measurements of particle properties, to studies of crystallization of nonneutral plasmas at cold temperatures, to attempts to achieve densities and temperatures relevant to fusion, to accumulation of exotic particles like short-lived radioactive isotopes, positrons and antiprotons, and last, but not least, to plans for using simultaneous confinement of oppositely charged plasmas for antihydrogen formation.

Stability of nonneutral plasmas in extended (Penning-Malmberg) traps is a field of active research. From different experimental studies, it seems that misalignment and higher-order field components are the main limiting factors for long confinement times. Resonant particle transport has long been suspected as the primary cause of plasma loss in Penning-Malmberg traps, but there are neither theoretical models nor much experimental evidence to support this claim. One question of special interest to us is the possibility of confining charged plasmas in Penning traps, with strong perturbations in the form of superimposed quadrupole or hexapole magnetic fields. Such systems have been proposed for experiments on the formation and confinement of antihydrogen, starting from the charged constituents, antiprotons, and positrons.

We have developed a model which describes the shape of the plasma and shows that a certain class of resonant electrons follow trajectories that take it out of the plasma. Even though the quadrupole field destroys the cylindrical symmetry of the system, this theory predicts that if the electrons are off resonance, the lifetime of the plasma is not greatly affected by the quadrupole field, but near resonance diminishes the lifetime sharply. We then have performed experiments that explore the effects of a magnetic quadrupole field on a pure electron plasma confined in a Malmberg-Penning trap. Experimental results show that the shape of the plasma and the effect on the plasma lifetime agree well with our model. We have been investigating the lifetime, scaling with various experimental parameters such as the plasma length, density, and strength of the quadrupole field. We have confirmed the resonant nature of this effect by observing enhanced transport at certain critical combinations of parameters. This resonant behavior is an important issue, since it suggests that the addition of quadrupole fields to a Penning-Malmberg trap need not render the trap useless, if conditions are chosen carefully.

Quantum Cryptography

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Quantum cryptography was introduced in the mid-1980s as a new method for generating the shared, secret random number sequences, known as cryptographic keys, that are used in cryptographic systems to provide communications security. The appeal of quantum cryptography (or more accurately, quantum key distribution, [QKD]) is that its security is based on laws of nature and information, theoretically secure techniques, in contrast to existing methods of key distribution that derive their security from the perceived intractability of certain problems in number theory, or from the physical security of the distribution process. Our team has pioneered the experimental development of these abstract concepts in three areas: QKD over optical fibers; QKD using single-photon transmissions through the atmosphere; and, most recently, the first demonstration of QKD with “entangled” photons. We have record-setting results in all three areas; no other quantum cryptography group matches the breadth or depth of our activities.

A particularly attractive use of QKD is for "free-space," line-of-sight communications, such as surface-to-aircraft, surface-to-satellite or satellite-to-satellite in low-Earth orbits. Because conventional key-distribution techniques are subject to ever-increasing computational challenges, it is vitally important to develop new technologies for rekeying satellites on-orbit with greater security and convenience. QKD can meet this need in a form that will be compatible with satellite optical communications and imaging systems.

Quantum Computation

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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 developed titanium-sapphire and diode lasers for the calcium ion transitions at 866 nm, 854 nm, and frequency-doubled lasers for the 397 nm transition. We have built a system to trap calcium ions and have used these lasers to cool and image both clouds and individual calcium ions.

We have developed an ultrastable laser at 794 nm and used this laser to induce and observe quantum jumps in trapped ions. We are now attempting to use the ultrastable laser to cool ions to their quantum ground state.

Quantum Optics

Dana J. Berkeland [(505) 665-9148] (P-23)

We are developing an experiment that will open up a new regime of quantum optics, in which modifications to atomic fluorescence from quantum interference can be observed in a controlled system. In an ion trap, two ions can be separated by a few wavelengths of the atomic transition, at which point interactions between the two atoms can measurably affect the properties of their resonance fluorescence. We have constructed a novel, very small trap capable of creating a sufficiently deep potential well to study these super- and sub-radiant phenomena with strontium ions. We have recently had a major success by forming linear crystals of several laser-cooled ions. We plan to use the trap to measure quantum interference effects in the ions' excited state lifetimes, their transition frequencies, and the rate of quantum jumps as a function of ion spacing.

Optical Approaches to Quantum Information

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Optical systems at the photon level are optimal for experimentally investigating basic issues in quantum information science, because they possess well understood and controllable properties. Specifically, entangled states of two or more systems lie at the heart of quantum mechanics (Erwin Schröedinger called them "*the* characteristic trait"), play a crucial role in the transition to the classical realm, and are central to quantum communication and computation. At LANL, we have developed a novel source of polarization-entangled pairs of photons. This source, in addition to being much brighter than all others, has the added feature of being tunable, allowing us to explore previously inaccessible topics in quantum information. We have developed methods of introducing "controlled decoherence" to our correlated photons, enabling generation of quantum states with an adjustable degree of "mixture" (*i.e.*, how classically random they are), as well as an adjustable degree of entanglement (*i.e.*, how non-classical they are). Ours is the only system in the world to permit controlled generation of these sorts of two-photon states. We have used these states to implement the first experimental realization of entanglement "distillation." In this procedure, special measurements are used to recover completely entangled ("clean") states from partially entangled and/or partially mixed ("noisy") states. In one of these experiments, we observed the phenomenon of "hidden nonlocality"—before distillation, the states appear classical, whereas afterward, they display the definite nonclassical feature of nonlocality.

Another first was the demonstration of "decoherence-free subspaces." Decoherence is the main obstacle to large-scale quantum computation. In some systems, each of the qubits couples to the environment in exactly the same way, leading to "collective decoherence." In this case, it was predicted that there are certain states for which each of the constituent parts suffers decoherence, yet the overall state does not. We demonstrated this using our optically entangled photons, and we completely mapped out the robustness of various states to all varieties of decoherence and dissipation. Finally, we have used the correlated photons to implement two quantum cryptography protocols—the nonlocal correlations of the photons allow a sender and receiver to generate a shared random secret key, which is then used to encrypt messages. Because the information is carried in the fragile quantum states of single photons, any attempt at eavesdropping is readily detectable, as we proved experimentally. We recently obtained results for an advanced scheme, in which the visibility of an eavesdropper is further enhanced by 33%. This is the first demonstration of this potentially very important quantum cryptography protocol.

Development of Multiframe Detectors for Ultrafast Radiography with 800 MeV Protons

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For the past few years, the radiograph recording in dynamic experiments at proton radiography (P-RAD) has been done with a set of seven individually gated charge-coupled device (CCD) cameras. These cameras register light from 1.7-mm-thick, and 12.4- × 12.4-cm area, LSO-crystal 3 × 3 mosaic, which serves as a radiation-to-light converter. The rapid electronic shuttering of the CCDs is accomplished by the application of 300–500 ns long, high-voltage pulses to proximity-focused planar diodes mounted in front of the CCDs. Although the system works well, it exhibits a number of limitations. Aside from the issue of cost, the geometry severely limits the number of cameras that can be positioned at one image location and, thus, the number of frames obtained. The system detector quantum efficiency (DQE) is relatively low, which limits the counting statistics. In order to overcome some of these limitations, we have undertaken an R&D project with the long-term goal of developing an "advanced" imaging detector for P-RAD.

We constructed two prototype small-area pixelated detectors, capable of recording signals produced by 800 MeV proton beam micropulses, with a repetition rate of 357 ns. The first detector system was built around a two-dimensional photodiode (PD) array. The array was illuminated by the LSO scintillator mosaic and imaged by a simple optical system, consisting of a turning mirror and a 105 mm telephoto lens. Tests were carried out with an array of 8 × 8 individual PDs, 0.7 mm in diameter. The signals from the PDs are all processed in parallel and digitized simultaneously. The 64-channel custom electronic unit was built at Lawrence Berkeley National Laboratory (LBNL). The electronic chain for each channel consists of a fast gated, low-noise, charge integrator, 5× amplifier coupled to a fast 12-bit analog-to-digital converter (ADC), followed by an on-board first-in, first-out, with storage capacity of 1024 frames. The detector system has shown stable linear response when exposed to a long train of intense pulses. Only occasional fluctuations due to a direct interaction of a stray beam particle with the photo diodes were observed. These were minimized with improved shielding in the subsequent run. Recently, we have begun tests of a "back illuminated" 61-pixel single-chip 2-D PD array, purchased from DEP/Canberra. First results indicate good performance, similar to that of the array of individual PDs.

We are also exploring other, potentially equally viable, but less costly and more easily scalable, detector alternatives. This alternative approach is based on the direct beam particle detection. One of the tested detectors was a simple gas ion chamber, which employs hydrogen as the detector active medium. The principal reason for using hydrogen is to minimize fluctuations because of nuclear reactions within the active medium of the detector. Large signal fluctuations, induced by reactions of beam particles with the detector material, were observed earlier in a thin 2-mm silicon detector. The active region of the hydrogen chamber is thin enough so that the reaction products, which originate in the housing- and/or component-material of the chamber, lose only a small fraction of their energy within a pixel cell.

Another benefit of using hydrogen is the high mobility of positive ions. This enables relatively fast collection of charge and reduces the space charge build-up. Initially, a hydrogen ion chamber was implemented in a simple axial-field geometry (electric field is collinear with the beam). It was operated at 2.5 atm of H_2, with a 4.4-mm-thick active/drift region. The chamber incorporated a wire Frisch grid, positioned 1 mm in front of the anode. The anode was divided into an 8 × 8 array of 1-mm^2 pixels. The signal processing and readout system consisted of the same custom-built LBNL electronics as in the PD tests. The detector was tested with beam up to 6×10^6 protons per mm^2 in 30–120-ns-wide micro-bursts. The ion chamber functioned well for micropulses separated by long time interval (several ms), displaying linear behavior with beam pulse intensity. However, when the spacing between the subsequent microbursts was reduced to 357 ns, the response deteriorated due to rapid space-charge build-up in the active region.

In order to get around the space-charge problem, two alternative solutions were implemented. In one, the active region gap of the original "axial" chamber was reduced to 0.4 mm, and in the other, a linear pixelated gas detector was constructed in a narrow slit geometry (0.4 mm). In the latter detector, the individual pixels are implemented as 8-mm-long anode strips of various widths (1- to 0.35 mm). The strips are collinear with the beam, with the electric field orthogonal to the beam direction. Initial tests with hydrogen gas showed rather fast electron- and ion-collection times (≈280 ns), and minimal build-up of space charge.

Work on the development of these detectors continues, and it also includes testing of a new 16-channel dedicated application-specific integrated circuit (ASIC) electronic analog chip designed at LBNL. Further work continues on interconnection schemes as well as evaluation of alternative detector technologies like secondary electron emitters, and fast photo-conductive detectors (*e.g.*, chemical vapor deposition [CVD] diamond).

Instrumentation and Data Analysis for Space Science

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Space-science work in P-23 focuses on instrumentation developed for three different spacecraft: Deep Space One, launched in October 1998, which has used ion propulsion to fly by an asteroid and will fly by a comet in 2001; the Cassini mission, launched in October 1997, which will go into orbit around Saturn in 2004; and the Genesis Discovery mission, which will be launched in July 2001. Cassini and Deep Space One both carry space plasma analyzers which measure the angular and energy distribution of the ambient plasma encountered by the spacecraft. They also include mass spectrometers which were invented and developed at the laboratory to determine the molecular, elemental, and isotopic content of these plasmas. Deep Space One carries the Plasma Experiment for Planetary Exploration (PEPE) and Cassini is home to the Cassini Plasma Spectrometer (CAPS). PEPE data analysis of the effects of the xenon ion propulsion's effects on Deep Space One has been ongoing, and preparations are being made to analyze plasma from what should be a very rich plasma source when Deep Space One encounters Comet Borrelly in September of 2001. Cassini has just passed closest approach to Jupiter on its journey to Saturn, and CAPS data analysis from the Jupiter system is underway. Meetings are being held to determine the best operational plan for CAPS during its two years of observations while in orbit around Saturn.

The Genesis mission required invention, development, and testing of an instrument called the "Concentrator" to focus solar wind and implant it in ultrapure silicon carbide and diamond targets. A prototype, two engineering, and a flight model of the Concentrator were produced and delivered. The flight model has completed final integration on the Genesis spacecraft, which launched in July, 2001. The Concentrator will collect solar wind for nearly two years at the equilibrium point between the Earth and the sun. Concentration is necessary to collect enough solar wind so that key isotopic ratios which will help understand solar nebula formation processes can be measured. These include the $^{17}O/^{16}O$ and $^{18}O/^{16}O$ ratios to ±0.1%, $^{15}N/^{14}N$ to ±1%, noble gas isotopic ratios, and $^{13}C/^{12}C$. After collecting the solar wind, the Concentrator will parachute back to Earth inside the spacecraft's sample-return canister. The targets will then be removed and analyzed in laboratories around the world.

Ellipsometry and Pyrometry in the Study of Dynamic Material Properties

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Measurements of the time-dependent absolute temperature of high explosive (HE)-shocked surfaces provide valuable constraints on the equation of state of materials and of the state of ejecta from those surfaces. In support of these dynamic surface temperature measurements, we are developing techniques for measuring the dynamic surface emissivity of shocked metals in the near-IR. These consist of time-dependent polarimetric laser measurements using several approaches. Besides providing data on the dynamic emissivity for pyrometric temperature measurements, ellipsometry may also provide a signature of melt in shocked metals. Obtaining this signature is accomplished by comparing the polarization states of a laser beam before and after scattering from the shocked sample. For a number of reasons, the wavelength was chosen to be 1550 nm. Also, high-speed modulation of the laser beam helps mitigate background shock light.

Three such laser ellipsometers have been built or are being built. One instrument, purchased from CRI, is being tested on the DX-1 gas gun. It includes a 200 mW laser viewed by 4 polarimetric channels and recorded in 12-bit 100-MHz digitizers. A second polarimeter driven by a 1200-mW laser and viewed by 6 polarimetric channels is under construction here in P-23. A third similar instrument is under development in Santa Barbara at Bechtel-Nevada (BN/STL). Single-wavelength ellipsometry in the near-IR should help reduce the uncertainty in emissivity, at least in this spectral region. A limited effort is being pursued for improving pyrometric temperature measurements at the low temperatures encountered under these shock conditions. Multiwavelength emissivity measurements in the near-IR using laser ellipsometry would also be desirable. However, IR polarimetry still presents some formidable challenges.

The Penning Fusion Experiment

Martin Schauer [(505) 665-6014] (P-23)
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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 because of the nonneutral nature of the confined plasmas, the density 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 value 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 it is preserved when the plasma density is averaged over the entire volume of the trap.

PFX is divided into two stages. During the first stage, completed in FY 1997, it was demonstrated that a dense core plasma could 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 second stage of PFX was funded in FY 1998 and work in this stage has concentrated on development of a more versatile system. Because of limitations of the approach used in the first stage experiments, a quite different architecture is used in the second stage experiments. Here, a nonthermal electron cloud is confined in a modified Penning trap, and the resulting space charge provides trapping for positive ions. In the last year, we have successfully demonstrated trapping of positive ions in such a trap. We are presently working to improve experimental diagnostics and to provide for spherical focusing of the trapped ions by tailoring of the vacuum trapping fields. This will allow for eventual use of deuterium and tritium ions for maximum fusion power or for the implementation of temporal compression as developed in the periodically oscillating plasma sphere (POPS) concept.

Neutron Decay Correlation Measurements with a Pulsed Cold Neutron Beam

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Precision measurements of the neutron beta-decay correlations A, B, a, and b, provide important tests of the standard model of electroweak interactions. We are designing an experiment at the Los Alamos Neutron Science Center (LANSCE) to measure all four correlations to an order of magnitude better accuracy than existing measurements. The experimental design relies on the pulsed nature of the LANSCE beam. One crucial feature of the experiment is the type of detector chosen for detecting both the proton and electron from the neutron decay, namely the silicon strip detector. With this project, we are proving the feasibility of using this type of detector to measure the neutron beta-decay correlations. Once this is accomplished, we will be ready to design and construct the full experiment. This world-class experiment will contribute to maintaining LANL's core competency in nuclear science.

Very thin dead layer silicon detectors, which are capable of detecting the low-energy protons, are available commercially. We have constructed an apparatus for measuring detector dead layers using 3.2 MeV alpha particles. Using this apparatus, we measured the dead layers of sample detectors and have obtained a value of 56 ±13 nm. This dead layer corresponds to losing only 5 keV for 30 keV incident protons. These detectors, however, have intrinsically high contact resistances, which cause the signal rise times to be long, making it impossible to achieve few-ns timing resolution. We have worked with the manufacturer on two new designs (with lower distributed resistances) which will solve this problem, and we have tested sample detectors. One method, applying a thin (<25 nm) layer of aluminum over the silicon, appears to solve the resistance problem with negligible increase in the detector dead layer.

The next step is to study the timing characteristics for full-thickness detectors. We have obtained a suitable detector design with an area of 5×5 cm^2 and a thickness of 1.5 mm and are currently measuring the timing properties. For this thickness, the timing resolution is dominated by the combination of charge carrier drift times and noise. Since both of these properties improve as the detector is cooled, we will be studying the timing characteristics as a function of temperature. Once this work is complete, we will design a custom detector which is suitable for testing with a neutron beam. This detector will have all of the characteristics required for the final experiment but to reduce costs will only be approximately 1/4 the full area. Once this is done, we will be ready to develop the full experiment.

Development and Application of Diagnostics for Ejecta/Spall Measurements (Holography, Piezoelectric Probes)

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A phenomenon that takes place when a metal surface undergoes shock loading is the emission of ejecta. Ejecta can be in a solid or liquid phase and can travel up to twice the free surface velocity of the metal. Because the micromechanical processes occuring in shock metals are complicated, it is difficult to calculate or predict the mass, size, and velocity of the ejecta particles. These quantities depend on material properties such as inclusions, voids, and surface roughness, as well the shock strength and temporal profile.

In order to characterize the ejecta particle size distributions, we developed and implemented an in-line Fraunhofer holography diagnostic at the Pegasus pulsed-power facility. This measurement was then implemented at the U1A facility for both the Cimarron and Thoroughbred experiments. In all cases, the diagnostic provided particle-size distributions for samples with various material properties and shock-wave pressures.

For the current fiscal year, we are advancing this diagnostic with the development of a shorter wavelength laser (353 nm) and improved optics. With these advances, we expect to achieve close to 1.0 micron resolution. This diagnostic is also being adapted to the two stage gas gun and the TA-55 gas gun. In addition, we are analyzing data from previous experiments and developing a model for the ejecta particle-size distributions.

On large integrated experiments conflicts with other experimental measurements may make it nearly impossible to perform the holography measurement, and so we have started to investigate the use of piezoelectric probes for measuring surface ejecta. These probes measure pressure from which the ejecta mass can be inferred. The probes are difficult to calibrate but are relatively easy to implement in experiments. We are also investigating other holography techniques, including holographic interferometry for measuring surface contours of shocked metal surfaces at one or more times during the dynamic motion of the shocked metal surface. In all these cases, we are providing critical, previously unknown experimental ejecta data for shocked metal surfaces.

Camera Research and Development

George Yates [(505) 667-7529] (P-23)
T. McDonald (P-23)

Fabrication of two prototypes for a high-speed, intensified/shuttered, multiport charge-coupled device (CCD) camera (model # GY-11) was completed in FY 1999. Testing and characterization was continued in FY 2000, with major testing of individual components completed. The coupled system response testing was started in 2000 and continues into 2001. Shuttering capabilities of 100 ps/frame for the image intensifier have been verified by collaborators at Sandia National Laboratories (SNL) in joint range-gated experiments in a scattering chamber. Readout speed of the CCD camera has been recorded at 500 μs/frame. The cameras have on-board 10-bit analog to digital converter ADCs for digital output video.

The recording media for the GY-11 camera consist of two different frame grabbers, which are essentially high-speed digital memory units which accept the digital data from the camera. One unit is for use on Department of Energy (DOE) experiments and the other is for Department of Defense (DoD) experiments. The DOE unit storage capability is 1–10 frames for use on subcritical tests for which the camera/shutter can be synchronized, where a few frames are sufficient to record images of interest, and where fast readout capability of the GY-11 camera to beat shock wave destruction is essential. The DoD unit can store up to 2000 frames for range-gated experiments which require long tracking intervals and where the images being recorded are not necessarily synchronized to the camera/shutter. Both recorders are operational and have successfully recorded frames from the GY-11 camera. Both are being configured for deployment in the field during calendar year 2001.

The major task for the calendar year 2000 was to explore infrared sensor technologies for use with the GY-11 camera, to permit operation in the 1–2 micron range for “eye-safe” operation for DoD military LADAR applications, and for “temperature” experiments for DOE. Image intensifiers with “transferred electron” photocathodes and laser stimulated nonlinear optical crystals, potassium titanyl phosphate (KTP) and lanthanum boron oxide (LBO), in Optical Parametric Oscillator/ Amplifier configurations were compared for sensitivity, resolution, image quality, fielding complexity, and cost. The experiments were a collaboration between LANL and SNL researchers, principally under the DOE/DoD Joint Munitions memorandum of understanding. The test results have been compiled into two Society of Photo-Optical Instrumentation Engineers reports.

New ADCs for the GY-11 camera have been designed and are currently in fabrication. The software and fabrication package designs have been upgraded to reflect improvements and modifications which will be incorporated in future builds of the GY-11 camera. Two additional units are planned for fabrication in early calendar year 2001. The cameras are expected to be “transitioned” into a DoD military application during 2001 and fielded on a DOE experiment in 2002.

Neutron Resonance Spectroscopy: The Application of Neutron Physics to Shock and Material Physics

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Neutron resonance spectroscopy (NRS) has been developed as a technique that uses Doppler-broadened neutron resonances to take fast snapshots of internal temperatures in dynamically loaded samples. The use of neutron resonances to measure temperatures in static samples was first pioneered at the Los Alamos Neutron Science Center (LANSCE) by British experimenters in the mid-1980s. Many of the detectors and experimental techniques for NRS were first developed in nuclear-physics symmetry experiments performed at LANL in the late 1980s and early 1990s. The time scale for the NRS measurements is very fast—one microsecond or faster. Examples of dynamically loaded systems studied by NRS are a metal through which a shock wave has just passed, high explosives behind the burn front after they have been detonated, or an explosively driven metal sheet jet (a jet of molten metal extruded past the neutron beam in the form of a flat sheet).

NRS has obtained successfully timed data in an experiment to measure the internal temperature of a metal immediately following the passage of a shock wave. No previous experiment has yet measured this thermodynamic quantity, one important to understanding the equation of state for shocked metals. In contrast to other techniques which seek to measure surface temperatures, NRS measures internal, volume temperatures. NRS offers the possibility of determining temperatures on very fast time scales in systems where previously temperature information had been unavailable. We have successfully measured the temperature in a sheet metal jet, and variations that we detected in the measured temperatures have led to the discovery of thickness ripples in the jet.

NRS experiments also provide important tests of critical modeling calculations; this work is currently ongoing in another LANL division. Future NRS experiments are planned to understand the physics of shock-induced friction and the equation of state of high explosives after they have been detonated. This project is discussed in greater detail in a research highlight in Chapter 2.

Plasma Physics (P-24)

Studies of Mix and Turbulence in Convergent Geometries

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The study of mix and turbulence is important for both inertial confinement fusion (ICF) ignition and nuclear weapons physics. Of particular interest is the study of mix between two materials under the conditions of compression, convergence, miscibility, and in the presence of strong shocks.

Two types of experiments have been conducted on the Omega laser at the University of Rochester. Both types involved implosion of a hollow plastic cylinder filled with foam. The first experiment measured the growth and mode coupling of imposed perturbations on the outside of the cylinder as a test of Rayleigh-Taylor instability predictive capability. New imaging and image-analysis techniques were developed and tested using undriven targets. Large amplitude perturbations were machined into a cylinder that was then radiographed with x-rays in the usual way. New techniques developed from analysis of this experiment were found to be adequate to test our modeling. In the second set of experiments, a thin, high-density material was inserted into the plastic/foam interface. Passage of a strong shock through this interface created large mix regions via the Richtmyer-Meshkov instability process. This instability is an important focus of our scientific interest. Our experiments demonstrated the technique and have been successfully modeled by codes at both LANL and the Atomic Weapons Establishment (AWE). Mix between two shells has also been observed and used to test mix models.

Hydrodynamic Studies with Radiation Drive

James A. Cobble [(505) 667-8290] (P-24)
S. Caldwell (P-24); B. Wilde (X-2)

Radiation-driven hydrodynamics experiments in Nova-Laser hohlraums have been performed in 1-D ridge and in cylindrical-bump geometry to test the difference between left-right and axial symmetry and to benchmark codes. Eight 1-ns, square-pulse Nova beams inject ≈15 kJ into the hohlraum to supply the radiation drive on the ridge or bump feature, which protrudes into the hohlraum from the wall, while two delayed beams irradiate a titanium foil for backlighting the package outside the hohlraum at 4.75 keV. Pinhole-camera x-ray imaging is accomplished by backlighting a ridge or bump target perpendicular to the radiation drive, and data are recorded on direct exposure film. The images are time resolved by the 200-ps duration of the backlighter beams. By varying the timing of the backlighter from shot to shot, we are able to determine the progress of the hydrodynamic shock through the material and to deduce shock velocities. The unshocked targets have a "top-hat" profile. Bubble formation is notable on the leading edge of the shock front for the bump-style target.

Materials Processing using an Atmospheric-Pressure Plasma Jet

Hans Herrmann [(505) 665-6157] (P-24)
I. Henins, J. Park, and G. S. Selwyn (P-24)

Plasmas have been extensively used for materials-processing applications for the past 30 years. Yet, either because the operational cost for the plasma-based method exceeds the cost for an alternative method, or because the demands imposed by vacuum processing are excessive, these applications have generally been limited to select, high "value-added" uses, such as steps required for manufacture of semiconductor devices, magnetic media, or deposition of energy-efficient films for architectural glass. In these applications, plasmas are used because they provide a rich source of chemically active species that either react with a surface or that react with each other to produce secondary, short-lived chemical precursors needed for thin-film deposition. The success of plasma-processing technology stems from its low-temperature operation and the fact that no other method can provide the same nondestructive, materials-treatment capability. As such, plasmas are typically used for selective film etching, surface treatment to enhance “wetability” or improve adhesion, and in the manufacture of thin films, including diamond-like carbon and films having desired metallic, dielectric, or other composite properties.

The atmospheric-pressure plasma jet (APPJ) source produces a stable, homogeneous, and uniform discharge at atmospheric pressure using 13.56 MHz radio frequency power and a predominate fraction of helium feed gas. Unlike the silent discharge, the APPJ operates without any dielectric electrode cover yet is free of filaments, streamers, and arcing. The gas temperature of the discharge is typically between 50° C and 300° C, so thermal damage to materials is easily avoided. The cylindrical design represents only one variation of the APPJ-source technology. In some applications, especially where large area surface treatment is needed, it may be more desirable to use a similar design but with flat, parallel, planar electrodes. A clear advantage of this approach is that the electrode size may be readily scaled up. A problem that users must face in employing APPJ applications is the high use rate of helium feed gas. Helium is used to stabilize the discharge and for electrode cooling, by virtue of its high thermal conductivity. For this reason, most commercial applications that employ APPJ technology will have to use equipment to recirculate and repurify the feed gas. While this slightly increases the capital cost of the equipment, the operating costs are greatly reduced. Complete systems for filtering helium are commercially available.

Processing materials at atmospheric pressure provides clear advantages over traditional, vacuum-based plasma processing. In addition to reducing the capital cost of equipment and eliminating constraints imposed by vacuum-compatibility, high-pressure and low-temperature plasma processes offer unprecedented improvements for the generation of active chemical species, high chemical selectivity, minimal ion densities that result in low surface damage, and surface-treatment methods unattainable by other means. Even situations such as water and wastewater treatment pose potential opportunities for plasma processing—provided that the materials-processing cost is acceptably low. We describe several variations of this unique plasma source and some of its potential applications. This project is discussed in greater detail in a research highlight in Chapter 2.

Magnetized Target Fusion

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A new project called magnetized target fusion (MTF), which involves LANL and the Air Force Research Laboratory(AFRL) at Kirtland Air Force Base, is aimed at a qualitatively different approach to fusion energy. Unlike conventional tokamak and laser fusion approaches, MTF has the potential of creating fusion energy in an inexpensive apparatus. The MTF approach to fusion preheats and injects fusion fuel into an aluminum cylinder with a volume the size of a beer can. Then the cylinder is rapidly compressed by magnetic forces that ensue from drawing a giant electrical current pulse axially along the wall of the cylinder. The compressed, high-density plasma fuel then burns in a few microseconds. The process is analogous to that of a diesel engine, which compresses fuel to conditions where it burns more readily.

The essential advantage of MTF is its potential to be tested for scientific feasibility and even developed to the stage of prototype power generation, while requiring the use of an apparatus that costs orders of magnitude less than either conventional magnetic- or inertial-confinement fusion approaches. In recent years, the focus of effort for fusion researchers, especially in the United States, has shifted from scientific feasibility to economic practicality. If successful, the cost savings implied by the MTF approach would allow fusion to be developed on a much faster time scale than conventional fusion. This project is discussed in greater detail in a research highlight in Chapter 2.

Trident Operations

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Trident is LANL's multipurpose laboratory for developing instrumentation and for conducting experiments requiring high-energy laser-light pulses. As a user facility, it is operated primarily for inertial confinement fusion (ICF) research, weapons physics, and basic research. Trident features include flexible driver characteristics and illumination geometries, broad resident diagnostic capability, and flexible scheduling.

The Trident facility includes a frequency-doubled Nd:glass laser driver capable of delivering approximately 500 J of energy to target in a 1-ns pulse, a high-vacuum target chamber, a basic optical and x-ray diagnostics suite, and ancillary equipment and facilities. A dedicated staff maintains and operates the facility and assists visiting experimenters. Target fabrication is available through LANL's Target Fabrication Facility.

During the past two years, approximately 27 experimental campaigns have been completed with 13 different principal investigators involved. Areas of special emphasis have been laser-plasma interaction studies, dynamic materials properties, and instrument development, characterization, and maintenance.

The development of a high spatial quality probe beam has allowed for a series of unique laser-plasma interaction studies involving a single laser hot spot in a plasma. These experiments are free from the complexities of the laser-plasma systems used in conventional experiments. This allows us to study the nonlinear behavior of parametric laser-plasma instabilities. Information from these experiments and their models can then be used to guide larger scale experiments such as those planned for the National Ignition Facility (NIF).

Techniques for measuring the dynamic properties of materials under high pressure are also being refined at Trident. Transient x-ray diffraction has been used to study crystal behavior under the loading of laser produced shocks. Lengthening the laser drive pulse to 100s of nanoseconds has also allowed the use of laser launched flyer plates to study the behavior of materials under high pressure. An imaging line VISAR is being used to diagnose spall characteristics and phase changes of various materials.

Trident has played a unique role in instrument development. Due to the laser's relatively high shot rate and flexibility, several instruments destined for use on larger facilities such as Z, Omega, Nova, and potentially NIF have been tested here. The use of Trident provides a cost-efficient means for testing, characterizing, and maintaining instruments before they are used for essential measurements at larger Department of Energy facilities.

Friction Studies on Atlas

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J. Hammerberg (X-7); D. Oro and P. J. Turchi (P-22); W. Anderson (MST-7); R. J. Faehl and R. K. Keinigs (X-1)

We will use the Atlas pulsed-power facility to examine the effect of dynamic friction upon sliding interfaces. We will rely on an aluminum liner accelerated by the Atlas capacitor bank to launch shocks into two dissimilar materials perpendicular to their interface. The differential in shock velocity has been observed on the Pegasus pulsed-power device (now decomissioned) 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 radiograph and image the wires, we studied how the interface moved and we measured the distortion of the material because of this friction effect. Three shots were conducted on Pegasus for this campaign. Future shots on Atlas are planned, and the work will be extended to other conditions and materials.

Friction Studies at P-RAD

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We are designing experiments to use the proton radiography (P-RAD) beam to image the distortion of slipping interfaces. This effort is complementary to one at the Los Alamos Neutron Science Center (LANSCE) to use neutron resonances to measure the temperature at the interfaces. A dynamic target is being designed to be used at both facilities, thus establishing a solid foundation for the comparison with the theory of interfacial friction and its effects. The effort is part of a Laboratory-Directed Research and Development project at P-RAD.

"ACE" Experiments at OMEGA

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S. Batha and J. Workman (P-24); S. R. Goldman (X-1)

The aim of this project is to use existing inertial confinement fusion (ICF) facilities to provide data for code validation to calculate effects of features on hydrodynamic behavior of hohlraum-driven experiments. A second goal of the effort is to provide new 3-D data to validate 3-D radiation hydrodynamic codes, in particular, to measure integrated behavior in perturbed geometries and compare it with advanced modeling. We are investigating an extension of the program from laser-driven experiments to pulsed-power-driven machines.

MIT Alcator C-Mod Tokamak Collaboration

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

The magnetic fusion team of the Plasma Physics Group (P-24) continues to collaborate in the Alcator C-Mod Tokamak experiment at the Massachusetts Institute of Technology. This is a compact, high-magnetic-field tokamak with a closed lower divertor and very limited diagnostic access. We continue to use an infrared periscope to image a section of the lower divertor with an infrared camera that measures the surface temperature of the molybdenum first wall and allows us to infer the heat load into these surfaces. Because of the supra-linear dependence of the thermal radiation with temperature, it is important to make use of the 12-bit digitization of the focal plane array of the infrared camera. During the 1999–2000 period, we implemented a new all-digital capture system for the infrared images, one capable of operating in the high-field environment surrounding the experiment, an important upgrade from the "8-bit" video images captured previously. This diagnostic continues to be operational and will be of increased importance in the low-density, high auxiliary heating power, and long-pulse experiments planned for the upcoming campaigns of Alcator C-Mod.

National Spherical Torus Experiment Participation

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G. A. Wurden (P-24)

The National Spherical Torus Experiment (NSTX) is a new fusion science facility located at the Princeton Plasma Physics Laboratory and managed by the Office of Fusion Energy Sciences of the U.S. Department of Energy. The mission of this facility is to establish the key physics principles for the spherical torus (ST) concept, a low-aspect ratio tokamak, those principles eventually leading to a cost-effective route to an attractive fusion power source. The key physics principles to be explored in NSTX are the following: high confinement regimes under high β (ratio of plasma pressure to magnetic-field pressure) conditions, high bootstrap current (*i.e.*, diffusion driven current) fraction, and noninductive current startup and current drive by coaxial helicity injection (CHI). The magnetic fusion team of the Plasma Physics Group (P-24) is a participant on NSTX, together with another 12 institutions from around the U.S.

As part of the NSTX Team, P-24 is fielding a fast-framing intensified digital camera capable of registering 1000 digital images per second during the plasma discharges at NSTX. This diagnostic device became operational dating from the very first plasma in February 1999 and turned out to be an invaluable tool for machine operation and physics research, helping the experiment to achieve 1 MA flattops of toroidal plasma current, H-mode confinement regimes during auxiliary heating by neutral beam injection, and over 250 kA of toroidal current driven by CHI. The fast-framing camera is also being used as part of a gas puff imaging (GPI) diagnostic, in which a localized edge gas puff is imaged with high spatial resolution (1–2 mm) as it encounters the edge plasma. The neutral gas puff then "illuminates" the edge turbulent structure, which is the aim of our study because of its relevance in H-modes and other transport-barrier physics, radio-frequency heating (wave coupling through the edge), power and particle handling in the scrape-off layer (plasma sheath outside the core), and penetration of the CHI driven current into the core.

Laser-Plasma Interactions in a Single Hot Spot

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Understanding the growth and saturation of laser-driven parametric instabilities such as stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), and self-focusing is important for the success of laser fusion. SRS is the scattering of light by plasma waves as it passes through a plasma, the light undergoing a decrease in frequency equal to the vibrational frequency of the scattering plasma waves; SBS is light scattering by sound waves in the plasma. These instabilities can occur throughout the underdense (transparent) plasma in targets designed to achieve ignition, such as those for the proposed National Ignition Facility (NIF), and they may also constrain experimental designs for weapons physics and high-energy-density physics experiments planned on NIF. One major reason researchers are concerned with laser-plasma instabilities (LPI) is that they can significantly reduce the amount of laser energy absorbed by the target. Other deleterious effects can be produced by these instabilities, such as target preheat due to fast electrons generated by SRS and degradation of the implosion symmetry caused by flow-induced beam steering, beam spraying, and crossed-beam energy transfer. Quantitative prediction of the onset and saturation of these instabilities under given laser and plasma conditions is the goal of research in this field and will lead ultimately to the control of those instabilities. This project is discussed in greater detail in a research highlight in Chapter 2.

Physics Support for Atlas Development

Carter P. Munson [(505) 667-7509] (P-24)
G. Kyrala and B. Wood (P-24)

Several small, multidisciplinary shot teams were assembled to develop more detailed experimental designs for experiments to be conducted on the Atlas pulsed-power facility. Initial experimental focus areas included hydro features, friction, spall, and high-strain rate experiments, as well as considerations of the development of advanced liner technology. Because of funding limitations, these activities have been further reduced in scope, with a primary focus in P-24 concentrating in the area of friction.

Advanced Technology Plasma Source Ion Implantation Precommercialization Project

Carter P. Munson [(505) 667-7509] (P-24)
B. Wood (P-24); M. Nastasi (MST-8)

This project, which has been supported by the U.S. Department of Defense/National Institute of Standards and Technology Advanced Technology Program, is an outgrowth of research and development conducted jointly by LANL, General Motors (GM), and the University of Wisconsin, Madison, and is an initiative 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 focused on driving high-risk, but potentially very high-return, fledgling technologies in PSII toward commercial application. Program participants included 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 Environmental Research Institute of Michigan (ERIM). LANL's role in this program has been to provide sound scientific advice and technical developmental support to the program participants, to investigate issues pertinent to scale-up of the technology to industrially relevant conditions, and to conduct processing tests involving industrial components. Because of this program, PSII surface treatment is now available on a limited prototype basis from EHC in Chicago, and PVI in Oxnard, CA. (A third facility was established at Ionex in Bellaire, Michigan, but this company is being reorganized under another name. The parties involved intend to offer PSII services when this reorganization is completed.) The success of this project earned the major program members (LANL, GM, UW, EHC, and North Star Research in Albuquerque) one of *R&D Magazine's* prestigious R&D 100 awards in 1997.

Specific research conducted at LANL included the following: 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). The LANL portions of this project were completed during FY 2000, culminating in the configuration and testing of major components of complete PSII facilities at each of the three proposed vendor sites.

Next Generation Sophistication in Defense and High-Energy-Density Physics Exploratory Research

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The major goal of this project is to help address well-defined physics and data needs of the nuclear-weapons program through the development of advanced experimental measurement capabilities, the experimental measurements of dynamic materials properties, and the associated theoretical and computational designs intended to maximize the physics return of the Atlas pulsed-power and other experimental facilities. Focus areas include the development of capabilities for conducting strongly coupled plasma (SCP) hydrodynamics experiments and the characterization of phase transitions in a dynamic environment. The program encompasses the following initiatives: development of an SCP target; laser-driven, shock based measurement of the equation-of-state (EOS) properties of an SCP; comparison of experimental data with currently proposed SCP theories; utilization of dynamic melt diagnostic techniques developed for probing material surfaces; and evaluation of other advanced diagnostic techniques, such as neutron resonance and photo-electron spectroscopy, for application to dynamic experiments.

During the past year, extensive optical measurements of the dynamic melting characteristics of metals have been performed. By observing the temporal response of the dielectric constant and second harmonic generation to ultrashort laser pulses incident on metallic surfaces, we have monitored heat-induced structural deformations and phase transitions. Dielectric constant measurements indicate that the heat-induced structural deformations and phase transitions in metals are tied to electronic disorder and band structure collapse. By comparison, fundamental/second harmonic measurements indicate a disordered lattice due to electronic heating and suggest that a nonthermal component exists in the heat-induced structural deformation and phase transition in gold. This work has resulted in a number of publications and in a significantly increased understanding of the detailed physics of phase transitions in metals.

In the SCP EOS experiment, initial images of the SCP plume have been obtained using the x-ray microscope (which is necessary to obtain the required spatial resolution for determining shock propagation velocities, and hence SCP EOS information). The x-ray microscope is currently being optimized for optical throughput

Initial SCP target preparation experiments have been performed using a cylindrical target geometry in the Colt facility, and data from these experiments are being analyzed. In addition, evaluation and hardware testing was conducted on the Continuous High Average Power Mircrosecond Pulser (CHAMP) system as a possible relatively compact, intense source of pulsed neutrons for neutron-resonance spectroscopic measurements in dynamic experiments.

A Neutron Bang-Time Diagnostic for Indirectly Driven Experiments on Omega

Thomas J. Murphy [(505) 665-5697] (P-24)
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In inertial confinement fusion (ICF), a laser pulse or other radiation source is used to drive the implosion of a capsule containing deuterium or a mixture of deuterium and tritium to conditions such that nuclear fusion occurs, and, typically, fusion neutrons are emitted. The time between the start of the drive pulse and the average time of neutron emission ("bang time") is a measure of the coupling of the radiation into hydrodynamic motion of the capsule, and the ability to predict this bang time is a measure of our understanding of the dynamics of an ICF implosion.

A detector for measuring bang time from an inertial confinement fusion target has been designed, fabricated, and installed on the Omega laser facility at the University of Rochester. Detector operation is based on a plastic scintillator with subnanosecond decay time and a commercial microchannel plate photomultiplier tube (PMT). This detector is designed for yields of 5×10^7 DD neutrons and higher and is shielded to prevent interference from hard x-rays generated in the target. To prevent x-ray detection in the microchannel plate from affecting the timing results, the scintillator is coupled to the PMT by a 30-cm-long, lead glass light guide.

This detector was built to support ICF experiments performed by the LANL ICF and Radiation Physics Programs and is currently undergoing characterization. The goal is to measure the average time of neutron emission relative to some point on the laser pulse, to an accuracy of 100 ps.

Preconceptual Designs for National Ignition Facility Diagnostics

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T. Archuleta, C. W. Barnes, R. R. Berggren, J. R. Faulkner, J. L. Jimerson, R. P. Johnson, K. A. Klare, D. S. Montgomery, J. A. Oertel, L. Schrank, and P. J. Walsh (P-24); R. G. Watt (P-22); R. E. Chrien and D. C. Wilson (X-2)

The National Ignition Facility (NIF) is a 192-beam laser system currently under construction at Lawrence Livermore National Laboratory. When completed, NIF will be able to deliver 1.8 MJ of laser energy to a target. On its current schedule, NIF will deliver first light to target chamber center in late FY 2004 and will be completed in late FY 2008. NIF will be used to perform experiments in inertial confinement fusion (ICF), high energy density physics, nuclear weapons effects testing, inertial fusion energy, and basic science.

In support of these missions, a set of "core" diagnostics has been identified. The LANL ICF program has supported the development of preconceptual designs for five of them. These include the neutron time-of-flight/bang-time system, the high-yield neutron activation system, the sensitive neutron spectrometer, the time-resolved x-ray imager, and the full aperture backscatter station streaked spectrometer. These preconceptual designs document the need for and the specifications of these systems, and the approaches being considered for instrumentation. These designs were presented at the Thirteenth Topical Conference on High-Temperature Plasma Diagnostics.

High Convergence ICF Implosions in Tetrahedral Hohlraums at Omega

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The goal of the inertial confinement fusion (ICF) program is to compress and heat a capsule containing fusion fuel to a density and temperature such that a self-sustaining fusion reaction occurs. Current designs for ignition targets which utilize large lasers or pulsed power devices require a convergence ratio (initial to final radius ratio) of approximately 40. One measure of the quality of an implosion is the ratio of the measured neutron yield to that obtained from a 1-D spherically symmetric calculation with no allowances for mixing of capsule material and fuel (so called “yield over clean” or YOC). A large body of work now exists from various facilities showing that the YOC decreases sharply with increasing convergence ratio in indirectly driven ICF implosions. A number of models have tried to incorporate 3-D effects, various mix models, and nonideal conditions but have not been able to fully explain yield degradation for high-convergence capsules.

Two of the effects that we considered as possible candidates to explain the discrepancy between experiment and model are the 3-D nature of experiments that have been performed thus far in cylindrical hohlraums with five-fold laser beam illumination and the time-dependent swings in the flux asymmetry on a capsule. To address these issues, we performed experiments, not in the usual cylindrical hohlraums but in spherical hohlraums with a tetrahedral arrangement of holes through which the laser beams enter. These hohlraums are more simply known as tetrahedral hohlraums. They are believed to have much better symmetry properties than cylindrical hohlraums. Despite the better time-averaged and time-dependent symmetry, the YOC for these implosions was not improved over implosions in cylindrical hohlraums, suggesting that other effects need to be considered that are not associated with flux asymmetry.
An ion diffusion model is being developed that holds promise in explaining yield degradation. Attempts to model different implosion experiments have yielded promising agreement when this model is incorporated into a 1-D implosion code.

A Streaked Optical Pyrometer for the Omega and Trident Laser Facilities

John A. Oertel [(505) 665-3246] (P-24)

We have recently designed and constructed an optical telescope to measure the radiation-drive temperature in an inertial confinement fusion (ICF) hohlraum. Accompanied by pressures of ≥100 Mb, hohlraum radiation temperatures for ICF can exceed 200 eV, and have been measured by several methods. One of the most precise and technically mature methods of measuring radiation temperature is by streaked optical pyrometry (SOP), a technique that has been used for nearly 20 years. In this measurement technique, laser radiation drive interacts with the hohlraum wall and launches a shock wave. A section of the hohlraum wall is cut out and replaced with a wedged or stepped low-Z witness plate, usually aluminum. The shock-heated witness plate emits a flash of light that breaks out with a velocity relative to the hohlraum temperature as $T_R = 0.0126 v_s^{0.63}$. Where T_R is the hohlraum temperature and v_s is the shock velocity. The brief flash of light from the witness plate is imaged and magnified onto the slit of a streak camera, with an optical fiducial added for absolute timing.

In our instrument, the collection optics are mounted in a cylindrical optical cell and inserted into the Omega or Trident vacuum target chamber by a ten-inch instrument manipulator (TIM). The TIM allows precision alignment of the SOP without breaking chamber vacuum. The optical elements of the telescope consist of a debris shield, primary mirror, and secondary mirror. Light from the object plane comes out of the telescope collimated, passes through a high quality quartz vacuum window at the rear of the TIM, and enters a light-tight enclosure mounted on the wall of the target bay. After the collimated beam comes into the enclosure, a spherical telescope focuses the light to the slit of a large format streak camera.

Though the optical system is capable of spatial resolution better than 30 line pairs/mm (lp/mm) at the image plane, the streak camera limits the entire system to 10.9 lp/mm. The f/7, 11.7× magnification system has a field of view of 6 mm and is limited by the 50-mm aperture in the TIM vacuum window. Mirror reflectivity and transmissive optics allow visible light from 200 nm to 1 μm, although for our temperature measurements, bandpass and notch filters have been included to limit the spectrum.

Planar, Ablative Rayleigh-Taylor Instability Experiments

Gottfried T. Schappert [(505) 667-1294] (P-24)
S. H. Batha (P-24); D. E. Hollowell (X-2); R. J. Mason (X-1)

This project is a continuation of our experimental program on ablative Rayleigh-Taylor (R-T) instability growth in copper foils driven by laser-generated hohlraum radiation. The purpose of our research is to explore experimentally the R-T instability in a high-density material and obtain results that can be modeled by laboratory codes, thus benchmarking these codes with real experiments.

Because the NOVA laser at Lawrence Livermore National Laboratory (LLNL) was shut down in 1999, we successfully transferred these experiment to the OMEGA laser at the Laboratory for Laser Energetics (LLE) at the University of Rochester. The next step in the project was to investigate the classical R-T instability in corrugated copper targets by driving such targets tamped with a layer of a low-Z material above the corrugations. This generates 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.

This phase of the project was completed. A comparison of experimental results with RAGE simulations showed that the code sensed and amplified very short wavelength perturbations (1–5 microns), well below the 45-micron disturbances mechanically imposed on our foils. We invoked the code's electron thermal conduction package so as to add a degree of "fire polishing" that could be expected to eliminate such unexpected growth. This led to the discovery and the repair of an indexing error in the code's electron thermal conduction algorithm. We thus obtained reasonable simulations to compare with the data, presented an invited talk at the plasma physics meeting of the APS in November 2000 and prepared a paper accepted for publication in *Physics of Plasmas*.

We then started the next phase in this project: the development and dissipation of the bubble and spike structure characteristic of the late time R-T instability. This phase cannot be followed experimentally with our present laser capability, because neither the ablative drive nor the imaging beams last long enough. To circumvent this limitation, we performed experiments with copper targets that had been milled to simulate the late time bubble-spike structure of the R-T instability. We could then observe part of the dissipation phase of these structures with the available laser drive, without having to R-T grow the structure. The experiments were conducted in March 2000, and the data analysis is now complete. A qualitative comparison with code calculations is quite good, but some quantitative differences between the experimental results and the code predictions remain.

Ballistic Missile Defense: Understanding High-Altitude Nuclear Effects

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R. Gerwin (P-24); D. Winske (X-1)

The FY 2000 Defense House and Senate Authorization Committee Conference Bill states, "The development of effective ballistic missile defenses is one of the highest national priorities, and Department of Energy's national laboratories are valuable, multi-mission, national-security assets that can and should contribute to this effort." As national missile defense (NMD) continues to develop as a national defense priority, we are developing a program with the Ballistic Missile Defense Organization to assess the consequences of high-altitude nuclear events (explosions) (HANEs) on U.S. missile defense, communications, and satellite-surveillance capabilities.

HANEs will dramatically disturb the upper atmosphere and geomagnetic field in the areas of antiballistic missile engagement. Deleterious effects will follow from high-energy (beta) electrons, prompt and delayed γ-rays generated by radioactive decay, and lower-energy electrons produced by weapon-debris heating and interaction with the low-density atmosphere at high altitudes. Beta particles from a nuclear detonation at high altitudes will create an artificial radiation belt that can damage nonradiation-hardened electronics. Furthermore, γ-rays from fission fragments can severely damage focal plane arrays in infrared (IR) seeker systems. In addition, the resulting density structures set up in the upper atmosphere could degrade radar systems that look at or through the post-HANE environment.

Our initial assessment of HANE effects are twofold. Working with group X-1, we are developing plasma-based simulations of coherent radiation propagation through perturbed media, to determine the phase distortion sensitivity of theater missile defense radar. We are also developing first-principle simulations of the energetic particle belt that is formed following a HANE. In order to predict the duration of this effect, we must consider both belt population by fission electrons with some additional acceleration processes, as well as the rapid loss of electrons from early time pitch-angle scattering.

Sustained Spheromak Physics Experiment Collaboration

Zhehui (Jeff) Wang [(505) 665-5353] (P-24)
G. A. Wurden and C. W. Barnes (P-24)

The Sustained Spheromak Physics Experiment (SSPX) at Lawrence Livermore National Laboratory (LLNL) exists to explore the key scientific issues of the spheromak concept that will ultimately determine its suitability as a source of magnetic fusion energy. We provided a multi-chord CO_2 interferometry and a multichannel H_α light detector array to study density and hydrogen-atom-related physics. Through these diagnostics, we have gained insight about the gas-breakdown process, and calculated the spheromak toroidal current to the density ratio (so-called J/n parameter), which is a key parameter related to spheromak plasma temperature. These diagnostics have also yielded interesting new results about the line-integrated density and H_α fluctuations, which are caused by the complicated magnetohydrodynamics (MHD) mode activities in SSPX. This analysis shows that the density and H_α diagnostics may complement edge probes as useful tools for MHD mode studies.

Rotating Magnetic Field Current Drive Experiment at the University of Washington

Stephen J. Tobin [(505) 665-1877] (P-24)
G. A. Wurden (P-24)

We completed construction and testing of twin high-power radio frequency oscillators at LANL before installing them on the Translation Confinement and Sustainment (TCS) experiment located at the Redmond Plasma Physics Laboratory (RPPL) of the University of Washington. The current of each 180-MW oscillator unit produces a 90 G rotating magnetic field (RMF) that generates and sustains the field-reversed configuration (FRC) plasma. The goal of this ongoing research collaboration is to sustain the magnetic flux of a hot FRC that has been translated to a confinement chamber where the RMF drives the poloidal currents—those sustaining the magnetic flux. Our initial experimental campaign focused on forming and sustaining an FRC from a preionized gas.

Some of our findings to date include the following: (1) Extension of the lifetime of the FRC from ≈100 μs to ≈1 ms. It was initially expected that the lifetime of the FRC would become limited by particle inventory at ~1 ms; however, this is not the case. Instead, the lifetime is limited by how long the RMF remains on. (2) The spinning up of ions, because of collisions with the driven electrons, diminishes the driven current by less than 10%. (3) The current is driven primarily in the outer edge of the FRC.

In an effort to penetrate further, thus driving more current, the frequency was recently decreased by a factor of two. Experiments are continuing in FY 2001.

Development of Imaging Bolometry

G. A. Wurden [(505) 667-5633] (P-24)
M. Langner (P-24)

In collaboration with the National Institute for Fusion Science in Toki, Japan, we are operating two prototype imaging bolometers on the superconducting large helical device (LHD). Using data obtained with up to 5 MW of heating power applied to the 30 m^3 plasma, we are developing automated analysis routines which apply a matrix of calibration coefficients to the raw infrared image digital video data to produce movies of the plasma radiation profiles. Both bolometers are essentially pinhole cameras using ultrasensitive infrared cameras to measure the thermal response of a blackened metallic foil to plasma radiation, but the instruments differ in how a plasma image is developed. One uses a segmented mask to achieve spatial resolution with many thermally isolated pixels, while the other uses a postprocessing Fourier reconstruction technique with only one large foil. The technique is basically proven now and ready for application on other fusion plasma experiments around the world.

Subatomic Physics (P-25)

Electric Dipole Moment of the Neutron

Martin 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 from ideas elaborated by other researchers. Ultracold neutrons (UCNs) will be produced via the superthermal mechanism in a dilute mixture of ^{3}He in superfluid ^{4}He. The increased sensitivity of this method arises from the following: (1) an increased electric field allowed by the excellent dielectric properties of superfluid ^{4}He; (2) a dramatic increase in the number of UCNs 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, a study which is needed before a proposal can be submitted. An experiment to measure both the diffusion coefficient of ^{3}He and its distribution in a superfluid has been performed on a cold neutron beam at the Los Alamos Neutron Science Center (LANSCE), and the data for a number of temperatures and concentrations are under analysis. The next experimental tests will focus on the production of highly polarized ^{3}He by a quadrapole filter and on the scheme for applying high voltage to the measuring cell in the superfluid.

New Limit for the Lepton-Family-Number Nonconserving Decay $\mu^+ \rightarrow e^+\gamma$

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It is generally believed that the standard model describing the electroweak force is a low-energy approximation to a more fundamental theory. Yet there is no clear experimental evidence either to guide the model's extension to additional physical processes or to predict its parameters. One of the model's assumptions is lepton-family-number conservation, which has been empirically verified to high precision but is not the consequence of a known theory. Lepton-family-number conservation is the idea, based on experimental observation, that the property of being an electron or a muon must be maintained even when particles transform through reactions. Neutrino oscillations would be the first evidence that this principle is not absolute.

Many theoretical extensions to the standard model allow lepton-family-number violation within a range that can be tested by experiment. The predictions of the rate for a given family-number nonconserving process vary among these extensions, and the most sensitive process depends on the model. We report here a new limit for the branching ratio of the decay $\mu^+ \rightarrow e^+\gamma$ from the analysis of data taken by the MEGA experiment at the Los Alamos Meson Physics Facility (LAMPF), now known as the Los Alamos Neutron Science Center (LANSCE). This project is discussed in greater detail in a research highlight in Chapter 2.

Theory

Mikkel B. Johnson [(505) 667-6942] (P-25)
J. Raufeisen (P-25); J. D. Bowman (P-23); and collaborators from institutions in the United States, Germany, Israel, Russia, and Taiwan.

The theoretical component of P-25 consists of a staff member who collaborates with 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 Drell-Yan reactions of nucleons on nuclei as a probe of quark propagation in nuclear matter, parity violation in chaotic nuclei, QCD at finite temperatures, phase transitions in the early universe, and the electric dipole moment of the neutron.

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, as well as the nuclear modification of quantum chromodynamic (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. This measured asymmetry 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 we mapped out this effect over broad ranges in the kinematic variables. 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 does energy-loss of the partons and shadowing of the gluon distributions.

These physics interests have also led us to become involved in the relativistic heavy ion collider (RHIC) program, where we are part of the PHENIX (Pioneering High Energy Nuclear Interaction eXperiment) 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 that 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.

At present we are just completing construction of the first of two large muon spectrometers; by early summer, we plan to detect our first J/ψ's via their decay to muon pairs. 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 constitutes the correct nonperturbative model for this asymmetry. A letter of intent for this extension to our recent measurements has been submitted to Fermilab.

Booster Neutrino Experiment

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And collaborators from P-25, the University of Alabama, Bucknell University, the University of California at Riverside, the University of Cincinnati, Columbia University, Embry-Riddle Aeronautical University, Fermilab, Indiana University, Louisiana State University, the University of Michigan, and Princeton University

The proposed booster neutrino experiment (BooNE) will represent a definitive test of the liquid scintillating neutrino detector (LSND) neutrino-oscillation results. The BooNE detector consists of a 12-m-diameter sphere filled with over 800 tons of mineral oil and covered on its inside by 1280 8-inch photomultiplier tubes. 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 1000 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 two years later.

Liquid Scintillator Neutrino Detector

William 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 University, Louisiana State University, Southern University, and Temple University

The liquid scintillator neutrino detector (LSND) experiment at the Los Alamos Neutron Science Center (LANSCE) has obtained evidence for neutrino oscillations by observing an excess of events in both the $\bar{\nu}_\mu \to \bar{\nu}_e$ and appearance channels. These two channels are independent of each other and together provide strong evidence for neutrino oscillations in the $\Delta m^2 > 0.2$ 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 it implies 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.

Studies of Neutrino Interactions and Oscillations at GeV Energies

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D. Casper and H. Sobel (University of California, Irvine)

Neutrino oscillations are characterized as a change in flavor type as the neutrino propagates. This property implies that neutrinos are a mixture of different quantum eigenstates with different masses. The Super Kamiokande experiment has recently produced the first generally accepted evidence for neutrino oscillations. The Super Kamiokande result followed the evidence for neutrino oscillations produced by the liquid scintillator neutrino detector (LSND). LSND was built and operated at LANL using the neutrino flux produced at the beam-stop of the Los Alamos Neutron Science Center (LANSCE) accelerator. The LSND result has merited a follow-up booster neutrino experiment at Fermilab, called BooNE. To extract the maximal physics benefit from the oscillation result, it is very important to study in detail the atmospheric neutrino interactions and the neutrino flux and composition. It is also of extreme importance to the

BooNE experiment to study neutrino interactions in the GeV energy regime, as this will directly reflect the accuracy of understanding the backgrounds to the neutrino oscillation signal.

We are working to fulfill these investigational goals by the following initiatives: 1) jointly developing models of neutrino interactions in the difficult GeV energy range; 2) understanding the existing National Laboratory for High-Energy Physics, Japan (KEK) neutrino beam, and checking the model against data from the KEK neutrino detector; 3) applying those models to the Super Kamiokande data; 4) separating and studying the atmospheric neutrino and anti-neutrino fluxes; and 5) applying the information learned to the BooNE experiment and the next-generation nucleon decay experiment. LANL, in collaboration with the University of California at Irvine (UC Irvine) and other institutions, is providing leadership in these initiatives and in exploring the ramifications of the observed neutrino oscillations.

Recently, we have made arrangements to take the BooNE beryllium target to the high-altitude research program (HARP) set up at the European Laboratory for Particle Physics (CERN). This will allow us to measure pion and kaon production from 8 GeV protons in a charged particle spectrometer. We have begun analyzing various models of neutrino-nucleus reactions. In addition, our collaborators at UC Irvine in the K2K collaboration also plan to take their aluminum target to the HARP apparatus. The combined result will provide good constraint data on neutrino fluxes and enable further work on the neutrino cross sections of interest.

Proton Radiography

Chris Morris [(505) 667-5652] (P-25)
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Over 100 years ago, Wilhelm Roentgen discovered x-rays and utilized their ability to penetrate matter to look within a living human body (his wife's hand). Since that time, x-radiography has been used for a number of applications where the inside of an object must be viewed. A source of x-rays, usually produced by the interaction of an energetic electron beam with a metal anode, is directed at an object, and the transmitted beam is measured on a detector located behind the object. The detector produces an image of the shadow cast by differential absorption of the material that composes the object.

Late-time hydrotest radiography is the experimental cornerstone of the stockpile stewardship program, an important part of the LANL mission. In these experiments, the fissionable material in a weapon primary is replaced by simulator substances, and the material densities and flow—thus the name "hydrotest"—are studied in explosive driven systems. Although these experiments produce no nuclear yield, they can provide data on how material properties influence the progression of a nuclear weapon up to the point in time when nuclear processes begin to dominate the dynamics. In these experiments, data and models developed in science experiments can be integrated and tested, engineering changes can be tested, and aging effects can be measured in systems that are as close to those obtained in a nuclear explosion as is possible under a comprehensive test ban treaty. Until recently, the only late-time diagnostic of the compressed primary in a hydrotest has been flash x-radiography. Considerable resources have been expended to explore the limits of dose and spot size in order to provide the best possible data. It is becoming clear that these data are limited by the physics of electron and gamma ray interactions with matter and do not meet the requirements of stockpile certification.

About six years ago, medium energy proton beams were recognized as having a mean free path (the mean length that particles travel before interacting in material) much better suited to diagnose hydrotest systems than do x-rays. Over the last six years, the techniques needed to perform dynamic experiments using proton beams have been developed, and proton radiography has been demonstrated to provide data on dynamic systems that is far superior to that which can be obtained with flash x-rays, even for thin systems. Dynamic experiments using the 800 MeV protons have become a routine part of the Los Alamos Neutron Science Center (LANSCE) program at LANL. In addition, we have performed experiments using 24 GeV protons from the alternating-gradient synchrotron (AGS) accelerator at Brookhaven National Laboratory, using static test objects to clearly show some of the advantages of proton radiography when compared with the dual-axis radiographic/radiography hydrotest (DARHT), the state of the art flash x-ray machine. This project is discussed in greater detail in a research highlight in Chapter 2.

The PHENIX Detector Program at RHIC

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The relativistic heavy-ion collider (RHIC), located at Brookhaven National Laboratory, began operation in June 2000, with the collisions of co-rotating beams of high-energy gold ions at a center-of-mass energy of 130 GeV•A GeV. The principal goal of RHIC is to create extraordinarily hot and dense matter in the laboratory—matter such as that believed to have fleetingly existed in the first second following the big bang beginning of the universe. This matter is so hot and dense that the fundamental constituents of the protons and neutrons of the atomic nuclei—quarks and gluons—are free to roam over a volume the size of a gold nucleus. This hypothetical state of matter is termed the quark-gluon plasma (QGP). Demonstration of its creation in the laboratory and determination of its physical characteristics are the *raison d'être* of RHIC. RHIC presents a capability to create hot, dense hadronic matter in the laboratory, which has never before been achieved. With its unique capability to detect muons, the PHENIX (Pioneering High Energy Nuclear Interaction eXperiment) detector is in an enviable position among the four RHIC detectors This project is discussed in greater detail in a research highlight in Chapter 2.

Education and Outreach

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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. Group members 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 who 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.

Hypernuclei Physics

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We proposed Experiment 907 (E907) at Brookhaven National Laboratory's Alternating-Gradient Synchrotron (AGS) to study the feasibility of using the (K^-, π°) reaction as a novel tool to produce lambda (λ)-hypernuclei with energy resolutions significantly better than those from the existing (K^-, π^-) and (π^+, K^+) experiments. This experiment is also capable of measuring the π° weak-decay modes of λ-hypernuclei never studied before. The Los Alamos Neutron Science Center's (LANSCE) neutral meson spectrometer and associated equipment were moved to the AGS for this experiment. A new data-acquisition 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 access. Preliminary results show that an energy resolution of 1.5 MeV has been achieved. This resolution is a factor of 2 better than that obtained in any previous hypernuclear experiment. Measurements on a carbon target have provided the first hypernuclear spectrum using the (K^-, π°) reaction. In addition, the π° 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. A paper describing the performance of the active target chambers used in this experiment has been accepted for publication. Other results from this experiment will be submitted for publication in year 2001.

A New Ultracold Neutron Source for Fundamental Physics Measurements at LANSCE

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Ultra-cold neutrons (UCNs) are neutrons of sufficiently low energy that they cannot penetrate the potential barrier formed by a variety of materials. They have a variety of characteristics that make them uniquely suitable for high-precision measurements of the properties of neutron decay, which are intimately tied to fundamental physics. For example, the neutron decays, with a lifetime of about 890 seconds, into a proton, an electron, and a neutrino. There is an angular correlation between the direction of the spin of the decaying neutron and the angle of emission of the electron. Measurement of this correlation, called "*A*," when combined with knowledge of the neutron lifetime, determines the values of the vector and axial vector weak coupling coefficients. We tested our prototype source at proton currents comparable to those to be used for a full-scale production UCN source. The result of the test was the highest density of UCNs stored in a bottle, anywhere in the world to date. The linearity of the number of detected neutrons with incident proton charge was also encouraging, because it indicates that the full-scale source would not be limited by beam heating or other effects of higher proton currents.

We have proposed a new experiment to measure the *A* correlation using UCNs produced at a new full-scale UCN source to be built at the Los Alamos Neutron Science Center (LANSCE). Our predictions are that steady state UCN densities of about 300 stored UCN/cm^3 will be achieved, as opposed to the 10 UCN/cm^3 we stored in our test run and the 41 UCN/cm^3 that had previously been achieved by a production source. A density of 300 UCN/cm^3 will allow us to make measurements, with previously unattainable precision, of neutron decay asymmetries and hence of the weak coupling constants. This project is discussed in greater detail in a research highlight in Chapter 2.

Experiment NA44 at the European Center for Nuclear Research

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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 last pieces of the data is still in progress.

P-25 group members (Alan Hansen, Hubert van Hecke, and John Sullivan) are no longer actively involved in the data analysis but continue to help in preparation of the last NA44 papers.

Physics Division Office (P-DO)

Summary: The Division Office has created a program development capability to assist scientists in exploring new research and development opportunities with the private sector and other government agencies. At present we have two staff members to pursue these opportunities, one in industrial partnerships and one in the threat-reduction arena.

The Laboratory encourages scientists, through the Industrial Business Development Office, to patent their inventions and potentially license these technologies to industry. After several years of work to identify technologies that might be of interest to this sector, Physics Division is beginning to see the fruits of that labor in royalties and funds-in agreements with industry. The technologies span the spectrum from early leading-edge concepts, such as new cancer detection and treatment methods, to largely mature technologies such as proton radiography. Many of the technologies have been sorted into “portfolios” that represent common groupings, such as nondestructive examination or diagnostics packages. The portfolio concept helps to promote our expertise to potential customers and aids in patent strategy development for intellectual property management. The project descriptions below include information regarding some of our most interesting technologies. The groups and the industrial partnership coordinator have become more and more inventive in reaching for exciting new technologies of interest to industry.

We have just recently begun to actively search for new opportunities in the threat reduction arena and have less mature possibilities at this point. The project description on the Future Combat Vehicle is one such possibility.

Advanced Turbine Engines

Don Coates [(505) 667-8946] (P-DO)

We have been intensively pursuing and promoting a new, exciting turbine engine concept, invented in P-24 by David Platts, that offers a number of important potential improvements over current technology. The new design combines the potential for simplification of layout, compact footprint, enhanced cooling of the all-important turbine section downstream of the combustor, and most importantly, improved efficiency. The engine concept has been exposed under nondisclosure agreements (NDAs) to a wide variety of pertinent corporations and government entities, including General Electric, Solar Turbines, Newport News Shipbuilding, the Department of Energy office of Advanced Turbine Systems, M-Dot Aerospace, and the Army Redstone Missile Command. The patent application on the concept is nearly complete at the time of this writing. Following the submission of the patent application, we will proceed further with vigorous promotion of the concept. Our goal is to obtain funding to model the conceptual engine, to build a working prototype to prove the concept's practicability, and to license the invention at the appropriate time during its development.

Diagnostics Packages for Automobile and Turbine Engines

Don Coates [(505) 667-8946] (P-DO)

The Physics Division has, over the years, developed an impressive portfolio of diagnostics technologies, largely designed to understand nuclear weapons phenomena. We have realized that this suite of nondestructive analysis (NDA) technologies is largely unavailable to the outside world and needs to be brought to industry's attention. These diagnostics include advanced radiography in the forms of flash x-ray, proton, and neutron techniques, real time thermography, and flow visualization methods such as electron excitation techniques. Hence, corporations such as Ford Motor Company, Daimler-Chrysler, General Electric, Solar Turbines, Newport News Shipbuilding and M-Dot Aerospace have been brought up to date on these technologies, which are being promoted as a portfolio. As part of these discussions, Ford has asked for help in understanding V-8 engine dynamics such as cooling system flows, piston ring flexing, cylinder head flex, positive crankcase ventilation (PCV) valve operation, hydraulic tappet dynamics, and various other engine dynamics. A combination of proton and flash x-ray techniques are to be used to study the Ford engine's dynamics. Turbine builder, M-Dot, has also indicated interest in radiographing their special engine dynamics problems. To accommodate the tests, we are allocating time on the accelerator proton radiography equipment.

Coupled to the diagnostics portfolio of technologies is the LANL ability to model complex engine phenomena. The two make a particularly impressive coupled package: the computer modeling can be benchmarked with the diagnostics package, thus providing a more powerful and experimentally verifiable simulation. Thus, the combination of diagnostics and modeling is promoted at the same time.

Advanced Lightweight Armor

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A new project being groomed is the development of an advanced new lightweight armor concept that would have direct application to the Advanced Fighting System (AFS) project of the U.S. Army. This new armor is an advanced composite of carbon-carbon with a skin of silicon carbide. Hitco Carbon Composites, Inc., maker of the composite, and LANL are teaming to develop the technology, which looks quite promising in initial testing. The plan is to fund the development of the armor through AFS project sources and utilize Physics Division expertise in carbon and the LANL expertise in testing and modeling to speed development. The expected outcome of the research is an armor that is both much lighter than conventional metal-based armor and cheaper than exotic ceramic-based systems.

Advanced Communications Systems

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In conjunction with Nonproliferation and International Security (NIS) Division, Physics Division has developed a new concept for wireless communication that promises to revolutionize cellular telephone technology. The new concept called "INFICOMM" builds on earlier demonstrated modulated reflector technology, expanding on its promise to greatly reduce handset power requirements. Interestingly, the technology also eliminates the user's exposure to handset radiation, which is of growing concern to the public. When the patent application has been filed, we will aggressively market the technology to key communications commercial concerns. Smaller high-tech companies and various venture capital agencies have already been told of the technology under nondisclosure agreements (NDAs) as part of the marketing strategy.

Another communications technology, invented by George Nickel of P-22, is a uniquely efficient compression strategy/algorithm that allows the simultaneous transmission of High Definition Television (HDTV) and standard analog signals on the same channel. Until this invention, two channels were required for the introduction of HDTV to the public, while still providing standard analog format TV. The patent on this technology has been recently filed, and a concerted effort to promote and license the technology has begun. The technology could save broadcasters many millions of dollars, if adopted, by eliminating their need for duplication of equipment and personnel during the HDTV transition. The American public also wins by having access to both formats more quickly and in a more orderly transition mode.

Cancer Detection and Treatment Technologies

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Development of a new magnetically based technology to conclusively detect and then treat certain forms of cancerous tumors is under investigation by Bob Kraus of P-21. The strategy involves the use of magnetic particles that are coated with cancer-cell binding agents. Detection is to be accomplished with superconducting quantum interference device (SQUID). The treatment strategy involves magnetically "exciting" the particles to induce thermal necrosis by way of viscous heating effects. Modeling of the concept by Brad Wright of P-22 indicates that the artificial "febrile" heating to 110° F can be efficiently induced with minimal collateral damage to healthy tissue. The concept has been explained to a number of biotechnology companies interested in advanced cancer technologies, including KineMed and Coulter Pharmaceutical, as well as to venture capitalist agencies. The patent application has been filed and will be coming up for review at the U.S. Patent and Trademark Office, probably in early 2001. Lab experimentation to support the concept's viability is underway and will greatly improve the probability of funding and licensing of the technology.

3-D Imaging and Measurement

Don Coates [(505) 667-8946] (P-DO)

Using a new form of the laser ranging technology related to the remote ultra-low-light imaging (RULLI) system developed in P-21, a concept of high-speed, 3-D quality-control imaging has been created. The new technique should allow us to image, measure parts, and verify if the parts meet quality standards. Daimler-Chrysler and Physics Division are investigating whether the technology can image body panels and indeed entire automobiles for quality control purposes. The Daimler-Chrysler goal is to have a system that can image, in approximately one minute, an entire vehicle coming off the production line and then generate a map of the production-line vehicle to compare to its desired CAD maps. There currently is no known commercial system that can do this job. Ford Motor Company is also interested in the technology but wants to scan cylinder heads to verify correct shape, location, and combustion chamber size after machining. If our technology can do these jobs, it would represent a revolution in the manufacturing industry and should bring large royalties to Physics Division.

Future Combat System

Joe Mack [(505) 667-3416] (P-DO)

The Civil War CSA cavalry general Nathan Bedford Forrest summed up his military philosophy as "Get there first with the most men." The U.S. Army has recently come to the sobering realization that in the post-Cold War era, it cannot effectively project force around the globe in timely fashion by transporting heavy 80-ton armored vehicles. A force composed of lighter, faster, more lethal vehicles (≈20 tons) would allow them to deploy to remote locations in time to make significant differences in conflict outcome. This force is known as the Future Combat System (FCS).

The FCS represents one the most ambitious efforts ever funded by the U.S. Army. It is assuming breakthroughs in a number of research areas in which LANL is able to contribute. The Army intends the FCS to be a leap forward in technology integration, rather than the usual incremental series of steps. Injection of selected technologies under development at LANL is now being pursued through Army Science and Technology Office and the Defense Advanced Research Projects Agency (DARPA). The plan is to field the first fully equipped system in the 2008 timeframe.

Physics Division, in close cooperation with our Department of Defense Programs Office, has the challenge of integrating and injecting its own *and* Laboratory-wide expertise from several technological connecting points relevant to the FCS. Physics Division has identified several essential capabilities that are likely to become part of the evolving FCS concept. We are currently pursuing one of the key survivability issues: the interaction physics for active protection against incoming kinetic-energy penetrators. The science of battlefield night visualization and looking through foliage and camouflage is being addressed using remote ultra low light imaging methods developed under our RULLI project. New advanced armor concepts are also under study, some of which involve nanoscience and its relation to high-strength/light-weight materials. Other Laboratory-wide active areas include information security, compact nuclear sources for mobility fuels, fuel-cell reformers from diesel fuels, compact EMP projectiles, advanced armor, and compact electromagnetic-pulse projectiles. Evaluation of FCS concepts as they evolve will be assessed within a National Laboratory Team composed of LANL, Lawrence Livermore National Laboratory, Oak Ridge National Laboratory, and Sandia National Laboratories. Technology injection from LANL is being facilitated through a network of key technical divisions including: Applied Physics (X), Theoretical (T), Physics (P), Los Alamos Neutron Science Center (LANSCE), Decision Applications (D), Nonproliferation and International Security (NIS), Materials Science and Technology (MST), Engineering Sciences and Applications (ESA), and Chemistry (C) Divisions.