LA-UR-96-3071

Title: **Russian Collaborations on Lasers and Advanced Optics**

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Submitted to: DOE Office of Scientific and Technical Information (OSTI)

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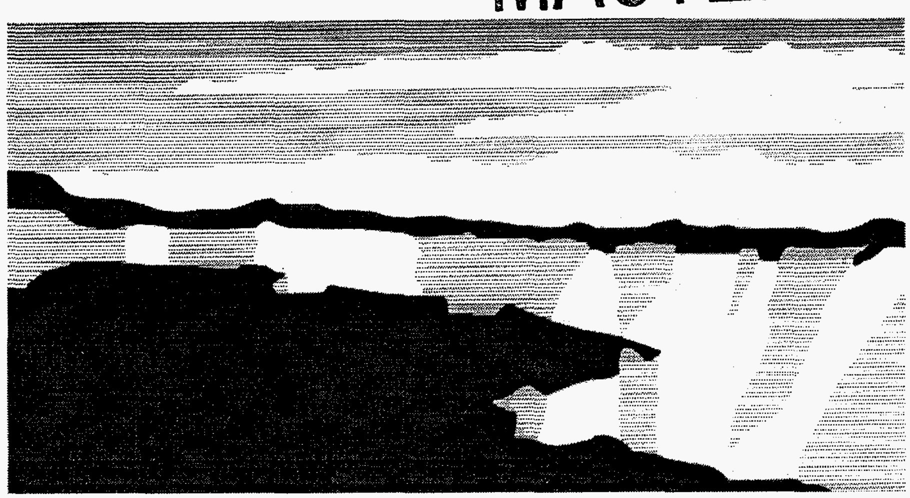

Los Alamos
NATIONAL LABORATORY

Form No. 836 R5
ST 2629 10/91

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Russian Collaborations on Lasers and Advanced Optics

James Munroe*, Daniel Cooper, Vernon Koym, and Edward Salesky

Abstract

This is the final report of a one-year, Laboratory-Directed Research and Development (LDRD) project at the Los Alamos National Laboratory. There are several technological areas where the Russians appear to be well ahead of the West. Russian work in lasers and advanced optics, high power nonlinear optics, and optical phase conjugation in particular, are some of these areas. The objective of this project is to establish collaborations with key Russian scientists in this area to analytically and experimentally validate the technologies and identify potential applications. This technology has the potential to solve very important military, civil, and commercial problems. The emphasis of this project is on civil and commercial applications, but the technologies have dual-use applications.

1. Background and Research Objectives

There are several areas of technology where Russian work is judged to be far ahead of comparable work in the West. The Russians are ahead because they have successfully pursued technologies and used approaches different than their Western counterparts. High-power nonlinear optics and millimeter-wave radar are two of these areas. Partnering with the Russians on applications involving such technologies allows LANL to effectively expand its technology base with a minimal investment.

The objective of this project was to identify appropriate Russian technologies, match these with potential sponsors, and bring the results to the attention of the appropriate program management office. Two general programmatic areas were identified: space debris and environmental remote sensing.

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2. Importance to LANL's Science and Technology Base and National R&D Needs

High-power nonlinear optics is an area of Russian technical strength and therefore a technology where we have much to gain through collaborations. The technological breadth and depth at the Laboratory allows us to quickly build a highly credible competency at Los Alamos in this area. The result will be an ability to execute new programs in remote sensing and advanced conventional weapons. In addition, we expect our work to establish the basis for commercial products and processes that can be transferred to US industry. Los Alamos is well positioned to do all of these things in a way that benefits the national interest.

3. Scientific Approach and Results to Date

3.1. Space Debris

The Situation

As long as the US is committed to the international space station, space debris will remain a life-threatening issue. The problems involved are extremely difficult, offering no easy solutions. LANL has an opportunity to combine some of its core competencies with complementary Russian technology strengths to address several of the major technical issues. At the same time, Air Force Space Command (AFSPC) is looking for new technologies to improve it's capability to detect and track objects in space. They view the technical skills at Los Alamos and the interactions with Russian scientific institutes as major potential assets for accomplishing improved space tracking. LANL can define its role as being uniquely situated to bring the best international science and technology available to address the problems.

Knowledge gaps remain in understanding the effects of impacts by varying debris shapes and materials. A recent study by the National Research Council (NRC) recommends that research should continue to: 1) gather more information about collisions at low earth orbit (LEO), 2) investigate new spacecraft materials, 3) study damage effects on critical spacecraft materials, and 4) improve understanding of catastrophic breakup events.

The Opportunities

Detecting Millimeter Size Debris. The National Aeronautics and Space Administration (NASA) needs good data on the population of millimeter size debris at space station altitudes. Recently the prospect of putting a Russian millimeter-wave radar aboard a space vehicle (e.g., the Mir station) was recognized. NASA had been looking at ground-based radar, with no apparent success. Millimeter-wave radar in space seems to be something that could be easily accomplished and putting it aboard a Russian vehicle could be a quick and inexpensive route. The need is for statistical data on the millimeter debris environment.

Detection and Tracking of Debris Less than 10 cm. Debris smaller than 10 cm, traveling at a nominal 7-10 km/s, carries sufficient kinetic energy to be lethal. The current ability to track such debris is not adequate to protect the space station. Increasing the resolution of ground-based sensors by going to millimeter waves or optical frequencies is possible, but requires enormous amounts of power to cover the entire sky. Space-based sensors have positive and negative attributes. One major complication is the need to periodically reacquire the debris in order to maintain the element set in the catalog; detecting and tracking the object once is not sufficient. Improving the ability to detect and track objects smaller than 10 cm will require some very sophisticated sensor technology.

Detecting Debris at Geostationary Orbit. There is very little data on debris at the commercially and civilly important geostationary altitudes. Whereas debris at LEO will eventually reenter the atmosphere and burn up, objects at geostationary orbit will stay there unless physically removed. Data on the population of debris is badly needed and is very sparse. This is a problem that requires very advanced optical sensors.

Hydrodynamic Modeling and Experimental Validation of Impacts. As the NRC report points out, our understanding of the physics of the debris impacts is incomplete. This knowledge base is necessary in order to design space vehicles and satellites that are more resistant to debris impacts.

Development of New Spacecraft Materials. This is also called out in the NRC report and would be very complimentary to a hydrodynamics program. There are serious plans to put large constellations of satellites into orbit. Advanced materials that extend their operational life could play a very important part.

Improve Understanding of Catastrophic Breakups. This also is called out in the NRC report. Much of the debris in space originates from explosions in space. There is a need to better understand the physics of the resulting breakups. It would help in the design of spacecraft that are less likely to create such debris.

Improve the Ability to Predict Debris Orbits and Decay. Predicting the locations of debris and when they will reenter the atmosphere is an important problem. One aspect needing improvement is decay and reentry predictions for objects in highly eccentric orbits. Another need is an improved ability to propagate debris backward to ascertain the origin if the debris.

3.2 Environmental Remote Sensing

Millimeter Wave Radar

A potential area of interest for environmental monitoring is the application of 94 GHz radar. The radars can be used as small "sounding" packages to evaluate cloud bases and tops, convective-cell lifetimes, and cloud development and storm-system formation. This type of instrumentation could be very complementary to the environmental lidar studies now underway at LANL, since lidars do not operate well under storm or precipitation conditions.

Lidar

An area of intense research activity within Los Alamos is lidar applications to environmental problems. The technical issues involved with using lidar centers around the problem of low photon output and small signals. Nonlinear optical techniques have been proposed to improve the characteristics of the outgoing light and detecting low-light backscattered signals. Our approach has been to utilize expertise both at LANL and at other federal agencies (and some developments in Great Britain) to help work with the Russians, and evaluate the Russian technology and techniques.

Lidar Development. The U.S. Army is interested in environmental applications of lidar to remediation problems associated with decommissioned military bases. We have worked with Army personnel to investigate the utility of Russian technology for this dual-use application.

Russian Lidar Technology. An area of nonlinear optics applications is in lidar observations of low-concentration entrained material. Work at the Passat Enterprises in Nizhny Novogrod has demonstrated the capability of producing high-quality nonlinear optical components and is attempting to develop full-scale integrated instruments. A potential development project has been proposed by Passat personnel that would detect radioactive sources from lidar. The proposal describes modifications to existing equipment and would include building and field testing a usable lidar.

A lidar program funded by the International Science and Technology Collaboration (ISTC) is utilizing the skills and expertise of scientists at the Kurchatov Institute. Specifically, work is in progress on the design stage for an infrared DIAL system to measure air pollutants. We participated in a meeting at the Kurchatov Institute, which involved a demonstration of an excimer laser and a discussion and working session on the ISTC environmental lidar project.

The laser demonstration showed two working systems, a table-top excimer-dye laser and a "space-qualified" excimer laser. The table-top laser was demonstrated at 10 Hz with the capability of going to 100 Hz. We are familiar with the laser system that was shown and have confidence that this system can easily be integrated into a fieldable lidar. The so-called "space-qualified" laser was about 1.2-m in length by 0.75-m in diameter. It was a 10-Hz, 200-mJ system. The other lasers were excimer-dye systems with quoted 100-Hz, 200-mJ output from the excimer and 10% efficiency from the dye system. These other two lasers were not demonstrated.

The working session involving the ISTC proposal included details on the development of instrument capabilities, measurement technique, and to a lesser extent- marketing strategy. The primary technical discussions on the lidar focused on telescope-laser mounting design trade-offs. The goal of the lidar is to measure atomic Mercury and SO_2. The instrument design will use a light-weight 61-cm-diameter Cassegrain telescope, with a excimer-dye laser mounted parallel to the optical axis. The entire lidar will be mounted on a turn-table for 360 azimuthal pointing (scanning), while the telescope-laser combination will be able to traverse 0° to 90° in elevation. It is not clear if the output of the laser and cross sections of the entrained species will allow for scanning.

Lidar System Evaluation. A British lidar team has successfully developed a lidar that utilizes enhanced nonlinear receiver systems to detect low-photon backscattered light. This system is being used to characterize the nonlinear optical properties in much the same way as the Passat Enterprises proposal for ionizing radiation detection. The British lidar system will be used as a "blind" test-bed for further evaluation of Russian technology.