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Overview of the CALIOPE CO₂ DIAL Project

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Abstract: During 1996 the CALIOPE CO₂ DIAL Project developed a new generation of lidar transmitter, receiver, data acquisition, and control technology, constructed new ground and airborne lidar systems, and used them to conduct extensive field tests. New data analysis algorithms were successfully applied to the test data, and CO₂ DIAL capabilities were significantly improved. Recent activities and accomplishments are summarized, and future directions are discussed.

I. Introduction *DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED*

Los Alamos is developing CO₂ laser-based differential absorption lidar (CO₂ DIAL) for CALIOPE. CO₂ lasers address the spectral region from 8 to 12 microns, which is known to spectroscopists as the "fingerprint" region because many chemicals have narrow spectral features here which allow unambiguous spectroscopic identification. The 8 to 12 micron region is also a good atmospheric transmission window, and because CO₂ laser technology is mature, compact, robust, and efficient, the potential utility of CO₂ DIAL for proliferation detection, battlefield chemical defense, and bomb damage assessment applications is high. Figs. 1 and 2 (pp. classified volume) list some of the key proliferation effluents and battlefield chemicals which can be detected with CO₂ DIAL, their expected concentrations and resulting detection sensitivity requirements, and the CO₂ DIAL ranges and sensitivities demonstrated to date.

To date, most applications of CO₂ DIAL technology have involved short-range probing of targets with relatively large concentration - path length products, such as minority species or pollutants in the atmosphere. Proliferation detection, however, will involve much lower concentrations in small volumes, and political constraints on access to targets are likely to necessitate long range operation. Improved range and sensitivity are therefore key objectives, and CALIOPE CO₂ DIAL activities include the fundamental DIAL phenomenology research, component technology development, and comprehensive experiments required to accomplish this.

During CALIOPE's first year a complete numerical model of CO₂ DIAL called System Optimization Numerics for DIAL (SONDIAL) was developed, and two mobile "first generation" CO₂ DIAL systems were assembled from commercially available components to provide detailed experimental validation. Extensive field experiments were conducted at the Nevada Test Site and Los Alamos, and outstanding agreement between field measurements and the SONDIAL model has been achieved. Although they were not optimized for range or sensitivity, the first generation CO₂ DIAL ground systems achieved performance levels which approach operational utility for detecting some important proliferation effluents, as indicated by the results summarized in Figs. 1 and 2.

Based on these theoretical and experimental successes, the SONDIAL model is being used to investigate the performance and optimization of operational CO₂ DIAL systems for battlefield and proliferation detection applications. Fig. 3 (p. classified volume)

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illustrates the top-level specifications and projected performance of two proliferation detection lidar concepts.

II. Current Activities and Near-Term Plans:

A. Overview

The operational proliferation detection concepts in Fig. 3 require lasers and receivers which operate at much higher pulse repetition frequencies and lower pulse energy than were used in the first generation ground field experiments. Because a wide variety of chemicals will be present in real effluent plumes and the ambient atmosphere, operational systems must also be able to deconvolve mixtures of chemicals with overlapping spectra. This requires rapid tuning between many laser wavelengths. In addition, a number of DIAL phenomena are unique to lidar systems based on moving platforms, and these are particularly important in the DIAL regime of interest to proliferation detection. A "second generation" of lidar technology which is adequate for the most important experimental purposes with minimal development time and cost is therefore being developed and fielded in near-term ground and airborne experiments. Development of "third generation" technology which is sufficiently compact, rugged, and efficient for operational systems is also in progress.

In a slight departure from CALIOPE's focus on proliferation detection, in 1996 Los Alamos and two DoD organizations designed, built, and tested an airborne CO₂ DIAL system for battlefield identification and mapping of chemical warfare agents called the Nonproliferation Airborne Lidar Experiment (N-ABLE). N-ABLE is based on the first generation CO₂ DIAL technology appropriate for large, high concentration targets, but it also provided airborne DIAL phenomenology experience germane to second and third generation proliferation detection systems.

Fig. 4 indicates how N-ABLE and the advanced systems and technology development efforts fit together.

B. The N-ABLE Experiment:

For battlefield lidar systems, the most important targets are likely to be clouds of chemical or biological warfare (CW or BW) agents, vehicle, aircraft, or rocket exhaust plumes, or debris from explosions or fires. The large volumes and high concentrations of such targets favor first generation DIAL systems similar to the ones used during the first years of CALIOPE's CO₂ DIAL research. N-ABLE was therefore based on Los Alamos' first generation ground system, and was assembled from existing or slightly modified first generation components. Los Alamos used the SONDIAL model to design N-ABLE and predict its performance, and furnished slightly modified versions of the first generation data acquisition and control (DAC) and receiver systems. Phillips provided the ARGUS RC-135 aircraft, system integration, and project coordination. ERDEC provided a CO₂ laser. All three organizations contributed to N-ABLE assembly, testing, and experimentation. The system was ground tested at Los Alamos during the summer of 1996, and flight tested at Phillips in September and early October. Fig. 5 (p. ___, classified volume) shows the N-ABLE lidar aboard ARGUS, and lists the basic system specifications.

In mid October N-ABLE was deployed to the Idaho National Engineering Laboratory (INEL) for a series of airborne experiments which included system characterization, collection of background spectroscopic data, and detection of chemical plumes released from the line and stack sources. The results are highly encouraging in that nerve agent simulants were

easily detected at ranges as great as 10 kilometers in concentrations well below the lethal threshold against natural backgrounds. Analysis of the data also indicates that some of the deleterious DIAL phenomena introduced by platform motion are tractable, at least to the limits of the N-ABLE data. Detailed results from these experiments are contained in the classified paper by B.R. Foy et al, and the paper by E.P. MacKerrow et al discusses novel data analysis mechanisms which are being developed to mitigate the effects of deleterious DIAL phenomena introduced by platform motion.

C. Second Generation Ground DIAL Experiments:

Second generation component technology approximates the top level specifications indicated in Fig. 3 for operational airborne proliferation detection systems. A second generation laser system and receiver were installed in a ground-based lidar and tested for the first time in May 1996. The laser achieves pulse repetition frequencies of 10 kHz at up to 1 millijoule per pulse, and can be randomly tuned among 160 lines at 150 Hz. As indicated in the classified paper by C.R. Quick et al, low concentrations of chemicals were identified at long range under very adverse atmospheric conditions during tests at the Nevada Test Site. The second generation ground system includes real-time chemometric analysis hardware and software. It was able to identify mixtures of up to four chemicals with overlapping spectra which were released simultaneously in blind tests a few seconds after the measurements were made. The concentrations of chemicals present were also estimated with impressive accuracy under most conditions. See the papers by C.E. Quick et al and H.A. Fry et al for further details.

D. The CALIOPE Airborne Dial (CACDI) Experiment:

The CACDI experiments will be conducted from the ARGUS aircraft to validate SONDIAL predictions of CO₂ DIAL performance in the high pulse repetition frequency, low pulse energy DIAL regime which addresses proliferation detection. The CACDI lidar system (Fig. 6) is based on a laser which produces 1 - 2 millijoule pulses at 10 kHz repetition rates, and is acousto-optically tuned among approximately 80 different CO₂ laser lines in any sequence at the same 10 kHz rate. CACDI passed its preliminary design review in January 1997. Fig. 7 pictures the CACDI laser oscillator with its acousto-optic tuner, which has met all design requirements. More details on the CACDI design and schedule are presented in the paper by D.E. Mietz, et al.

The CACDI experiments will be conducted with natural and artificial backgrounds, highly controlled and realistic chemical plumes, and varying ambient temperatures, humidity, visibility, and trace chemical content. The first flight tests will be conducted in northern New Mexico during the first quarter of FY98. They will be used to de-bug the system, gain operating experience, and partially validate SONDIAL through a variety of phenomenology experiments. Testing against simulated proliferation effluent plumes emanating from realistic (smoke stack) and highly controlled (wind tunnel) sources will be conducted at the Nevada Test Site during the summer of 1998. A third series of tests at a humid, heavily industrialized site (to be determined) is being planned for the spring or late summer of 1998.

F. Third Generation Technology Development:

Third generation systems will be based on compact, rugged, efficient, sealed waveguide CO₂ laser technology. Industrial waveguide laser systems which operate at 100 kHz with 100 microjoules per pulse, and enclose the laser and all of its power conditioning, cooling, and control apparatus in about 1 cubic foot are being used to support the development effort.

The commercial laser cavities have dimensions of inches, are completely sealed, have operating lifetimes of greater than 10,000 hours, and convert electrical power to laser light with efficiencies of up to 20%. Several acousto-optic tuning configurations have been designed, and preliminary experiments have demonstrated tuning from line to line at rates of 70 kHz. See the paper by C.W. Wilson and G.E. Busch, et al, for more details.

Smart focal plane arrays used in conjunction with acousto-optic laser beam steering offer the potential for relaxed optical alignment within the lidar, remote effluent plume location, and all-electric fine pointing and tracking. The concept is illustrated in Fig. 8. A special infrared focal plane array camera which is capable of imaging laser pulses and chemical plumes has been purchased and used for locating released plumes in field experiments. It will be used for the development of smart focal plane array technology. See the papers by R.J. Nemzek et al and K.R. Moore et al for further details.

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