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# **DIAGNOSTIC INSTRUMENTATION AND ANALYSIS LABORATORY**

DIAGNOSTIC DEVELOPMENT AND SUPPORT  
OF MHD TEST FACILITIES

Technical Progress Report  
for the period  
January February, March 1990

Prepared for the United States  
Department of Energy  
Under Contract No. DE-AC02-80ET-15601

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## NOMENCLATURE

A/D:	. . . . .	Analog-to-Digital
AIAA:	. . . . .	American Institute of Aeronautics and Astronautics
ANSI/IEEE:	. . . . .	American National Standards Institute/ The Institute of Electrical and Electronic Engineers
CAMAC:	. . . . .	Computer Automated Measurement and Control
DMA:	. . . . .	Direct Memory Access
GP-IB:	. . . . .	General Purpose Interface Bus
LDV:	. . . . .	Laser Doppler Velocimeter
LIF:	. . . . .	Laser-Induced Fluorescence
Log-IF:	. . . . .	Logarithmic Intermediate Frequency
PC:	. . . . .	Printed Circuit

## ABSTRACT

The Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University (MSU) is developing diagnostic instruments for MHD power train data acquisition and for support of MHD component development test facilities. Microprocessor-controlled optical instruments, initially developed for Heat Recovery/Seed Recovery support, are being refined, and new systems to measure temperatures and gas-seed-slag stream characteristics are being developed. To further data acquisition and analysis capabilities, the diagnostic systems are being interfaced with DIAL's computers. Technical support for the diagnostic needs of the national MHD research effort is being provided. DIAL personnel will also cooperate with government agencies and private industries to improve the transformation of research and development results into processes, products and services applicable to their needs.

## PROJECT OBJECTIVES

Diagnostic and special instrumentation beyond that which is normally required for appropriate control and operation of an electrical power production facility is required for a magnetohydrodynamic (MHD) power system. The DOE coal-fired MHD proof-of-concept program will serve as the precursor to larger scale demonstration facilities and commercially-implemented plants. In order that the transition to commercially feasible plant designs be made as quickly and as effectively as possible, it is essential to determine as much as possible about the detailed component operation of the MHD power train and the Heat Recovery/Seed Recovery system.

Conventional diagnostic sensors are of limited use in characterizing the MHD gas stream and special diagnostic instrumentation systems are needed to provide the means to monitor and collect engineering data to determine specific parameters, both baseline values and fluctuations, and to provide background information for continuing MHD development, solutions to technological barriers, and a basis for future plant designs. The accurate characterization of the thermal, chemical and flow properties is essential for future design optimization.

The scale-up process is a nonlinear extrapolation because many of the physical processes are nonlinear. To decrease the uncertainties in this nonlinear extrapolation to a new, larger design, it is necessary to rely not only on engineering experience with smaller systems, but also on mathematical models which describe the physical processes and the manner in which they behave as design variables are changed. Mathematical models require the input of detailed data; the greater the quantity and quality of data, the more accurate the model and the smaller the uncertainty in the extrapolation to larger designs.

The baseline data obtained by diagnostic measurements at the Component Development and Integration Facility (CDIF) and Coal-Fired Flow Facility (CFFF) are providing important engineering experience and data for developing appropriate analytical models. Tests of these models, as well as information to further develop these design models, will be provided by diagnostic measurements on these facilities. These measurements are essential to minimize the technological risks associated with the ultimate construction of a retrofit MHD facility or a commercial MHD power plant.

Moreover, measurements of selected parameters coupled with empirical correlations or an accurate model can contribute significantly to improved control strategies and the selection of control instrumentation. The direct measurement of a particularly useful parameter for system control may be very difficult, if not impossible. However, another parameter which can be correlated to the parameter of interest may be much easier to measure. The application of advanced instrumentation promises to produce fundamental advances in this area. This type of information will be very important in the selection of control instrumentation for a commercial MHD power plant.

MHD flows represent possibly the most severe environment encountered by gasdynamic diagnostics, and special state-of-the-art techniques and instrumentation systems are required to monitor and collect data for MHD component systems. In addition, these systems are operating under severe environmental and magnetic field conditions. The Diagnostic Instrumentation and Analysis Laboratory (DIAL) at Mississippi State University is developing and applying advanced optical diagnostic techniques and instrumentation systems which provide nonintrusive, remote, real-time measurements and are designed to operate successfully in the industrial-like environment of large-scale facilities. Such diagnostic instrumentation can provide the information required to more clearly characterize the various processes involved in the ash/seed-laden gas stream of the coal-fired MHD flow. Moreover, these systems will provide performance monitors giving real-time indications of

- water leaks,
- nonuniformity in the K-seed,
- flow train discontinuities in the channel,
- flow distributions and turbulence levels,
- combustor performance, stoichiometry,
- proper operating conditions to optimize efficiency and component lifetime,
- the extent of ash rejection by the combustor,
- conductivity, generator performance,
- hot spots (e.g., in the radiant boiler),
- baghouse and/or electrostatic precipitator performance,
- heat transfer characteristics at critical locations,
- the particle loading and size distribution entering the boiler or other system components, and

- stack emissions, pollutant levels,

and will, therefore, further reduce the technical and financial risks associated with scale-up to the retrofit size integrated MHD/steam plant or to a commercial size plant.

Direct instrumentation support and measurements will be provided to the various DOE MHD test facilities. The amount of direct diagnostic support to the MHD engineering development test facilities will be as directed by the Department of Energy.

A number of the diagnostic systems which are fully developed will be used for field measurements at the HRSR and MHD power train facilities. Additional diagnostic systems previously developed are being constructed/modified to provide field-use instruments particularly for the MHD power train. Field tests for system refinements of these instruments will be conducted on the DIAL test stand and the various DOE MHD test facilities before proceeding with field measurements.

DIAL has constructed a test stand that can simulate the gas-slag-seed stream composition, temperature, and metal/fireside environmental conditions for the radiant furnace, superheater, and other MHD system components. The computer-controlled diagnostic instruments being developed are being evaluated and tested on the test stand. Measurements conducted on the test stand also provide useful data for the national MHD program.

## PROJECT DESCRIPTION

In order to meet the overall contract objectives, the scope of work to be performed is outlined by the following tasks.

### *Task 1. Diagnostic Instrument Development*

The following computer-controlled, optical diagnostic instrumentation is being developed for support of the MHD component engineering development. Objectives for the specific instrumentation systems follow.

#### 1.A. Coherent Anti-Stokes Raman Spectroscopy System (local gas temperature and species concentration, temperature and concentration profiles)

*The CARS system is a laser-based, nonlinear, optical technique being developed to provide temperature and species concentration measurements with spatial and temporal resolution. Of the many laser-based techniques, CARS is the best suited for thermometry in high-interference environments because of its coherent, laser-like signal character and high signal conversion efficiency. To obtain a CARS spectrum, two narrow band lasers at pump frequency  $\omega_1$  derived from the pump laser and one broadband dye laser at Stokes frequency  $\omega_2$ , are phase matched and focused in the gas stream thereby generating, through the third-order susceptibility of the medium, a spectrum at anti-Stokes frequency  $\omega_3 = 2\omega_1 - \omega_2$ . The CARS spectrum of a species (e.g. nitrogen) can be sensitive to both gas temperature and species concentration.*

The mobile CARS instrument is ready for field tests. Based on these tests, a few minor modifications may be required. Field measurements are planned throughout the contract period at both CFFF and CDIF. Initially, point temperatures and temperature profiles from  $N_2$  CARS spectra will be measured. Work on improving the capabilities of the present CARS system will also continue. This will include automation of the mobile CARS system. In particular, the CARS signal is focused to a 200- $\mu\text{m}$  core diameter, 0.12 numerical aperture optical fiber with an achromatic lens and is piped to the instrumentation trailer from the test environment. This coupling is very critical and needs to be remotely-controlled. In addition to temperature measurements, field measurements of species concentration

will also be made. For example, temperature and CO concentration can be measured simultaneously using the multiplexed CARS spectra of N<sub>2</sub> and CO. The combined N<sub>2</sub>-CO CARS spectrum is then fit to a computer-simulated CARS model to extract the temperature and CO concentration. Work will continue on simultaneous N<sub>2</sub>-CO CARS to determine the detection limits of this technique for CO concentration measurement in a particle-loaded gas stream.

Likewise, simultaneous CO<sub>2</sub>, H<sub>2</sub> and O<sub>2</sub> concentration measurements in an MHD gas stream can supply the stoichiometry every 1-2 minutes which will enable one to monitor the performance of the combustor in real time. The Raman resonant frequencies of CO<sub>2</sub>, H<sub>2</sub> and O<sub>2</sub> differ less than 200 cm<sup>-1</sup> and can be assessed simultaneously with a single dye laser. Therefore, temperature and the CO<sub>2</sub>, H<sub>2</sub> and O<sub>2</sub> concentrations can be extracted from the simultaneous CO<sub>2</sub>, H<sub>2</sub>, and O<sub>2</sub> CARS spectrum. A computer model will be developed and tested to enable the determination of the simultaneous temperature and CO<sub>2</sub>, H<sub>2</sub> and O<sub>2</sub> concentrations.

Particle-induced laser breakdown is known to produce a nonresonant CARS component which can affect the CARS measurement in a coal-fired flow. One way to alleviate this problem is to employ a two-wavelength dye laser CARS configuration to extract the temperature. Moreover, this technique produces a signal which is 20 times stronger than that of broadband CARS at the same laser power. This and other ways to reduce the effects of particles will be studied.

#### 1.B. Particle Size Distribution System (particle size distribution)

*The Particle Size Distribution System uses optical, in-situ, scattering methods for measurement of particle size distribution. The three-beam, two-color particle size measurement system is designed to measure particles at slow velocity using a single-particle counting method, while an ensemble averaging technique is used for high velocity flows. The system employs the output (green and blue) from an argon ion laser. The green beam is focused on the central axis and the blue beam is divided into two equal intensity beams which are focused and crossed inside the green measurement volume producing an interference fringe pattern. The light scattered from these beams by a particle is processed to extract the particle size.*

A particle passing through a focused laser beam sample volume generates a Gaussian-shaped scattering signal. The peak amplitude, detected at small angles in the near forward scatter direction, is essentially a monotonic function of particle size and virtually independent of the particle refractive index and shape. The scattering signature is, however, dependent on the local sample volume intensity and, hence, the particle trajectory through the sample volume. Two techniques are presently being used to measure particle size -- the single particle counter (SPC) for low velocity flows and the ensemble averaging method (EAM) for high velocity flows. In the latter instrument the small-angle, near-forward scatter (SANFS) signals of the green beam are measured. To eliminate the nonuniformity of response within the sample volume, the measurement volume intensity variation is measured. With this response function, a mathematical inversion technique (termed deconvolution) is employed to extract the particle size distribution from the distribution of SANFS signal amplitudes.

In the case of the SPC instrument, two modes of operation are available, namely, the ripple-validated small-angle, near-forward scatter (RVSANFS) and the ripple deconvolution method (RDM). To reduce the trajectory ambiguity in the RVSANFS method, the single particle scattering signal from the central green beam is used to measure large particles (2-15  $\mu\text{m}$ ) with the ripple signal from the crossed blue beams used to validate the trajectory of the large particles and, hence, discriminate particles not near the central region of the green measurement volume.

On the other hand, for the RDM the amplitude of the ripple signal from the crossed blue beams is used to size particles smaller than 2  $\mu\text{m}$ . In particular, the visibility parameter, obtained from the ripple and pedestal signal, is used to reject data from large particles, and the deconvolution method is applied to the scattering signals from the blue beams to remove the ambiguity caused by the trajectory dependence.

Expected activities include laboratory experimentation, operation on the MSU test stand, and operation in the field. Laboratory experimentation will be related to development of the EAM instrument and continual upgrading of the SPC instrument. It will also include development of calibration techniques and the production and evaluation of aerosols. Operation on the MSU test stand will primarily be done for development of the EAM instrument and development of techniques for use of physical sampling probes. Operation in the field will involve the SPC instrument until the EAM instrument is refined for field operation.

The overall objective is to improve the capability for measurement of particle size distributions by providing several alternate approaches that are feasible in various situations. Realization of this objective requires continual efforts to establish credibility that instruments are accurate and measurements are meaningful. This can only be achieved by continual attention to calibration methods and uses of alternate measurements, where possible, to supply corroborative data.

The particular objectives for the SPC are to finish construction of the system, to prove operation of the system in the field, and to refine the system for convenience in use and performance. Receiving fibers will be added to reduce the susceptibility to noise. Data will also be gathered for comparison of different modes of operation in the field environment; and, field measurements, to characterize the downstream components at the CFFF, will be conducted.

The specific objectives for the EAM are to prove the feasibility of the concept through experimental tests and incorporate this method into the field instrument. This will require continued theoretical and computational efforts to evaluate the parameters for the data reduction model; preliminary work on this is finished. Refinements will be needed as soon as the work is far enough along to justify them; these include the effects of lens aberrations, which will also require some experimental investigation.

Efforts will also begin on development of an experimental configuration for particle generation and laboratory measurements. Experiments will be conducted as soon as feasible on the test stand and, concurrently, field tests of the method will be made to define a suitable instrument package.

1.C. Potassium Emission / Absorption System (time - resolved temperature, K - atom density, electron density)

*The Potassium Emission/Absorption System will rapidly measure (order of milliseconds) the average channel temperature by the line reversal technique, provide the average neutral potassium number density from lineshape information, and provide the average channel electron number density using the Saha equation assuming thermodynamic equilibrium.*

This system has been field tested and is presently being used to provide time-resolved temperature and potassium number density measurements in support of the national MHD effort. Some software enhancement of the instrument is planned; however, the major issue to be resolved is the over estimation of the potassium number density. This is particularly important for wide gas streams and is believed to be caused by the line profile deviating from a Voigt shape in the far wings. Work to resolve this problem will continue.

1.D. Intrusive Multi-Probe System (optical temperature probes -- wall and gas temperature)

*An Intrusive Multi-Probe System has been developed to position various sensors at a precise location in a combustion gas stream for precise increments of time. It is completely computer-controlled and may be operated to both position the probe and acquire the data. Optical sensors, as well as conventional sensors, can be used with this probe insertion system; however, its main use is with techniques where the probe will spend a very short period of time in the gas stream. Such a system interfaced with an optical technique can provide measurement capabilities in regions where, because of path length, optical measurements would not be possible.*

Development and field testing of one viable intrusive sensor has been completed for the measurement of MHD interior wall surface temperatures. This sensor is capable of measuring surface temperatures in the range of 500°C to 2000°C. Field tests have been conducted at

the DOE/CFFF by measuring the front surface temperatures of the superheater tubes during several test runs; the interior wall surface temperature of the furnace has also been measured.

The development of an intrusive sodium line reversal (SLR) sensor, to be used with the multi-probe systems for measuring local gas stream temperatures, is about 60 percent complete. This system uses an intrusive miniature optics system and the SLR principle to make spatially-resolved gas stream temperature measurements. The SLR sensor will provide gas stream temperature measurements from 1700 to approximately 2500 K.

Because surface temperature measurements would usually be required at distances greater than five feet in the MHD power system, an optic system is being developed to add to the existing lightpipe sensor to provide greater intrusive distances. In general, intrusive distances much greater than five feet are not possible with this sensor when accessing surfaces through the standard four-inch ports. This optics/lightpipe sensor system will provide added flexibility and a useful monitor for the larger-scale MHD development systems.

With the equipment on hand the possibility of developing an intrusive, two-sensor system for measuring gas stream temperatures and wall surface temperatures appears to be very viable. This system would provide measurements of gas stream and wall surface temperatures in the range of 500°C to 2000°C and would be especially important for surface and gas temperatures measurements in the region of the superheater tubes in large-scale MHD development systems.

#### 1.E. Faraday Rotation System (electron density to infer conductivity)

*The Faraday Rotation System will provide real-time electron density measurements averaged across an MHD channel. The electrical conductivity scales very nearly linearly with the electron density. The technique is based on the Faraday effect. Linearly polarized light may be decomposed into right (+) and left (-) circularly polarized waves. Since the absorption coefficients and refractive index are different for right and left polarization, the amplitude and relative phase of the polarized waves are affected on passing through a plasma along a uniform magnetic field. Measurement of the rotation of the polarization of a beam of linearly polarized light after passing through a medium (plasma) in the direction of an applied magnetic*

*field determines the electron number density. The system employs radiation in the far infrared derived from a CO<sub>2</sub>-pumped far infrared laser.*

The Faraday Rotation System will provide, directly, the electron density and conductivity of the MHD channel which is essential to the characterization of the power train performance. Most of the major equipment for the system has been obtained. The system assembly for electron density and conductivity measurements on a laboratory plasma are basically complete. Electron mobility modeling and measurements will be addressed and system refinements, such as waveguides and detector vibration isolation for field tests, will follow. Field measurements will take place as soon as possible at CDIF; optical access through the channel side walls is necessary and would require new construction at the CDIF.

#### 1.F. Multi-Purpose Imaging System (K-atom density, pressure profile)

*The Multi-Purpose Imaging System is a laser-excited imaging system suitable for spatially-resolved optical diagnostics. The system is based on the phenomena of laser-induced fluorescence. Here an atomic or molecular species is raised to an excited electronic state by absorption of laser radiation. The emitted radiation when the species returns to the ground state is termed fluorescence. The instrument consists of a laser whose beam is expanded with cylindrical optics into a wide, thin sheet that is directed through the region of interest. A camera lens is then used to focus light emitted by this region onto a charge injection detector, the signal from which is processed by a computer to produce a two dimensional image of the probed region. The versatility of the system comes from the ability to select both the excitation and observation wavelengths to determine various parameters of interest, such as the concentration mapping of selected atomic and molecular species.*

The Multi-Purpose Imaging System (MPIS) is an instrument currently in development which will allow measurements of species (K, Na, OH) concentration profiles in harsh combustion environments. The excitation intensity must be tuned to a resonance absorption with sufficient power that the fluorescence intensity is proportional to species concentration. In addition, measurements of number density and pressure profiles are possible, as well as temperature profiles using two-wavelength, excited-state fluorescence measurements. In

the case of pressure determinations, the excitation intensity must be above that required for level saturation; then the fluorescence intensity is proportional to the pressure.

Previous work has involved the construction of a laboratory-scale system and subsequent measurements of Na concentration images and K laser-induced fluorescence (LIF). The latter measurements have been complicated by collisional quenching, a process whereby the excited states decay non-radiatively. For example, K LIF at 404.5 nm has been observed but at a significantly reduced quantum efficiency as compared to Na. Saturation of the 404.5-nm K line is not possible without increasing the intensity level of the incident excitation wavelength. Addition of a wavelength extension unit (WEX) to the current optical train is planned since this will drastically increase the incident laser power by mixing the 1.06- $\mu\text{m}$  fundamental of the Nd:YAG laser with the low efficiency output of the dye laser in an appropriate crystal. Concentration measurements on K can then proceed. The determination of pressure profiles will begin with the construction of a variable pressure burner which will permit measurements as a function of known pressure. LIF measurements will then be performed to determine the limitations of the technique as applied to harsh environments.

Determination of the fluorescence at two wavelengths will allow the measurement of the populations of the excited species which, in turn, can be used to determine spatial temperature profiles of a region. In order to accomplish this task, an additional detector (camera) will be incorporated with an extended blue wavelength response. This detector will also permit the evaluation of OH fluorescence. Measurements on the MHD power train will require optical access. Access can be expected to be a problem, especially for image capture; therefore, a flexible, image transmitting fiber bundle will be added allowing the fluorescent or scattered laser light image to be routed to the camera which will be located away from the measurement penetration and clear of the upstream plumbing and structure.

The limitations and attributes of the system with respect to species concentration, pressure gradients, two wavelength temperature and number density measurements will be established and concurrently field tests with the system will be conducted. Results from these initial tests will be used to construct a stable, reliable field version of the instrument.

1.G. Differential Absorption Laser Spectroscopy System (species concentration, SO<sub>2</sub>, NO<sub>2</sub>, NO, H<sub>2</sub>O, OH)

*The Differential Absorption Laser Spectroscopy System is a general purpose, nonintrusive instrument for measuring time-resolved, line-of-sight average concentrations of atomic and molecular species. The system employs a two-wavelength dye laser and measures the extinction of the two wavelengths through the gas stream. One wavelength is on, and the other off resonance of the species of interest thereby eliminating particle absorption and scattering effects.*

A general purpose system for measuring average concentrations of individual species (e.g. H<sub>2</sub>O, SO<sub>2</sub>, NO<sub>2</sub>, NO, and OH) is desirable to complement the CARS system, which does not measure the concentrations of these species. Differential Absorption Laser Spectroscopy (DALAS) is a general purpose technique which can, in principle, be applied to any atomic or molecular species; and can be brought on-line by additions to the existing mobile CARS instrumentation. DALAS can also provide time-resolved concentration measurements when concentration fluctuations are of interest. DALAS uses methodology and technology developed over the past decade for Differential Absorption Lidar, a mobile, laser-based remote sensing technique for measuring the concentrations of pollutants in the atmosphere. To implement the technique, frequency doubling crystals, a detector, two boxcar averagers, and a control computer are required.

A DALAS experiment is performed by comparing the transmission of two wavelengths through the sample. One wavelength corresponds to a strong absorption of the species of interest. The other wavelength is a nearby wavelength that the species does not (or only weakly) absorb. Taking the ratio of the transmitted intensities of the two wavelengths "cancels out" background effects, such as light scattering

due to particulates, that are not associated with absorption by the species. If the absorption coefficient of the species is accurately known, or appropriate calibration experiments have been made, then the absolute concentration of the species can be determined.

The DALAS apparatus will use a single laser system to generate both wavelengths. An alternating two-wavelength dye laser pumped by the CARS Nd:YAG laser (10 Hz) will generate on alternate laser pulses the on-resonance wavelength (5 Hz) and the off-resonance wavelength (5 Hz). In particular, a rotating, rectangular optical block is used to refract the dye laser beam to independent wavelength-selection systems, thereby generating two closely spaced wavelengths. The successful operation of this dye laser is not sensitive to the alignment of the dye laser beam and the block; this "ruggedness" is important for field measurements. The visible dye laser beams can be frequency doubled into the ultraviolet by sending them through two frequency doubling crystals -- one crystal for each wavelength. Both wavelengths follow the same path through the plasma onto a single photodiode. The output of the photodiode for on-resonance laser pulses is fed to one boxcar averager; and the output of the photodiode for off-resonance pulses is fed to a second boxcar averager. The ratio of the intensity outputs of the boxcar averagers enables calculation of the concentration of the species.

DALAS can, in principle, be applied to any atomic or molecular species. The focus will be on measuring the concentrations of H<sub>2</sub>O, SO<sub>2</sub>, NO<sub>2</sub>, NO and OH, because the concentrations of these species, though important, are not measured by the CARS system. OH and H<sub>2</sub>O are of interest because they decrease flame conductivity, and hence, adversely effect the performance of the MHD power train system. SO<sub>2</sub>, NO<sub>2</sub> and NO are of interest because they are pollutants and thus their environmental impact is important.

The methodology for observing and recording DALAS signals will be validated. We will optimize the instrumental operating parameters for H<sub>2</sub>O, SO<sub>2</sub>, NO<sub>2</sub>, OH and NO in bench-top flames and the MSU MHD test stand. The system will be field tested prior to field measurements.

1.H. Laser Optogalvanic Spectroscopy System (average gas temperature, qualitative species identification)

*The Laser Optogalvanic Spectroscopy System is a general purpose instrument for measuring line-of-sight average temperatures and will provide qualitative identification of various atomic and molecular species. The system employs a tungsten electrode which is inserted into the gas stream and used to monitor changes in conductivity as a dye laser is tuned into resonance with a particular species.*

A general purpose system for measuring average temperature is desirable, especially one capable of working even when high particulate flow severely limits transmission of optical beams across the MHD flow. Laser Optogalvanic Spectroscopy (LOGS) is such a general purpose technique and can be brought on-line by additions to existing instrumentation. Essentially, a frequency doubling unit with automatic scanning capability is all that is required. Because LOGS uses electrical rather than optical detection, the technique alleviates problems associated with monitoring small absorptions or weak fluorescence in the presence of a strong optical background signal or large path lengths. Hence, LOGS can identify species present and characterize their temperature under conditions where techniques employing optical detection fail. Moreover, only optical access on one side of the gas stream is required for this system.

In LOGS a pulsed dye laser is tuned into resonance with a transition of a species in a plasma; the excited state concentration of that species then temporarily increases. Because the energy necessary for ionization is less for an excited electronic state than for the ground state, the rate of ionization temporarily increases. This process can be monitored as a transient (10<sup>-5</sup> sec) voltage change (in lab flames, typically hundredths of a volt) if a high voltage (typically +400 V) electrode (e.g. tungsten, MP 3410°C) is inserted into the plasma. Although most of the research on LOGS has concentrated on atomic species, twenty-five molecular species (such as NO<sub>2</sub>, HCO, N<sub>2</sub>, CO, CO<sub>2</sub> and H<sub>2</sub>) have been studied to date. Efforts will concentrate on molecular species present in combustion environments, in particular, on OH, C<sub>2</sub>, NO and CO. By scanning the wavelength of a tunable dye laser and recording the optogalvanic signal as a function of laser wavelength, the optogalvanic spectrum (which is analogous to an

absorption spectrum) is obtained. The temperature of the species can be ascertained by the standard technique of ratioing the intensities of different transitions and taking into account their different transition probabilities.

The methodology for observing and recording LOGS signals of atomic and molecular species will be validated in bench-top flames and the MSU MHD test stand and the instrumental operating parameters will be optimized. Effects of electrode "aging," of electrode size, and of particles on the LOGS signal intensity will be studied in benchtop tests in DIAL test stand experiments. The precision of the temperature measurements in MHD environments will be established by comparing temperatures determined by LOGS with that obtained from CARS. Field tests and subsequently field measurements will be carried out during this work period.

#### 1.1. Cross Correlation System (flow velocity)

*The Cross Correlation Velocity System will measure the flow velocity nonintrusively with only limited optical access. The technique involves measuring the fluctuations in gas luminosity, e.g., at two spatially separated locations. The cross-correlation function of these signals gives the time interval between which the signal and a time-displaced version of itself correlates.*

A simple, rugged, accurate and nonintrusive system to measure the gas flow velocity would be a particularly valuable device to help monitor the MHD power train. The cross correlation technique can provide such an instrument and can be used to find the mean velocity of the gas flow. The method can find application where only limited access to the gas stream is available. The technique is based on the naturally occurring fluctuations in, e.g., species concentration, temperature, and particle concentration in a turbulent combustion environment. If a fluctuating variable is measured at two known locations -- one upstream and the other downstream -- then the time required for the fluctuations to travel from one location to another provides the flow velocity.

Preliminary work performed by DIAL indicates that the cross correlation method can be implemented using gas luminosity as the fluctuating variable. We also believe that the correlation of signals obtained by measuring the extinction of laser light at two or more locations can provide the flow velocity. This method would allow velocity measurements where gas luminosity is weak. Other extensions of this basic concept, employing intersecting beams, have the potential for measuring spatially-resolved velocity profiles.

A cross correlation experiment performed by using two identical optical systems for data collection, with one located upstream and the other downstream. Each optical system consists of a focusing lens, a small monochromator, and a photomultiplier tube. The monochromators allow any wavelength of light from 200 nm to 800 nm to be selected. This spans the range from the ultraviolet to visible to the near infrared. The electrical signals from the photomultiplier tubes are amplified, low pass filtered, and sampled (both signals simultaneously) by an analog to a digital converter connected to a computer.

The data analysis consists of computing the cross correlation function of the two digitized signals. If the signals are correlated, i.e., only shifted in time by an amount  $\tau$ , then the cross correlation function will show a peak at  $\tau$ . In this way, by computing the cross-correlation function of the two photomultiplier signals, the time delay required for intensity fluctuations to propagate downstream can be found and thus the flow velocity can be determined.

To implement the system for measurements on MHD channels with large flow velocities will require a fast A/D converter and continuous operation will require large storage capacity and a fast processor to reduce the data as fast as possible.

## *Task 2. Test Stand Operations*

DIAL has a computer-controlled, combustion test stand to simulate the combustion and thermal parameters present at various locations in a fossil-fueled MHD combustion system. Its versatility allows it to be used to simulate any type of combustion condition and effluent gas stream.

The existing DIAL/MHD/HRSR simulation test stand will be used for support of diagnostic instrumentation development, shake-down and evaluation. The test stand has recently been modified to better simulate the MHD gas stream environment. This will further aid in the evaluation of the instruments before they are taken to DOE's MHD engineering development test facilities. In particular, the test stand has been modified to burn a fuel oil/coal slurry which will more accurately simulate a coal fuel MHD combustor. Provisions for an increased flow rate of fuel-air mixture of approximately 700 lb/hr have been made. The test stand control and data acquisition computer has also been replaced with a new system to enhance data collection and control as well as provide much needed memory and disk space.

As the need arises the test stand may also be used to gather data systematically, under controlled conditions, to provide validation data for analytical models.

## *Task 3. Technical Support for the National MHD Program*

The primary objective of this task is to provide diagnostic measurements and support to the national MHD program. The task will include attendance at contractor review meetings and contributions to technical progress reports. It will also include the preparation of a Topical Report for each diagnostic system at the time when it is available for field measurements. Objectives for this task are:

### *3.A. Field Measurements*

#### *3.A.1. Sodium Line Reversal System (SLR) (average gas temperature)*

*The Sodium D-Line Reversal System essentially measures the temperature of the central region of the gas stream. The technique employs a calibrated light source and is based on making a series of intensity measurements on the wing of one of the sodium D-lines.*

This system is field ready and has been used at various MHD facilities in support of the national program. No additional modifications are planned except to maintain the system field ready.

### 3.A.2. Multi-Color Pyrometer System (MCP) (wall temperature and emissivity)

*The Multi-Color Pyrometer measures the wall temperature and emissivity of the wall surface. The technique is based on Planck's radiation law and requires measurement of the radiation intensity from the wall surface at two or more wavelengths, assuming the presence of a graybody radiator.*

The system is field ready and has been used at various MHD facilities in support of the National program. No additional modifications are planned except to maintain the system field ready.

### 3.A.3. Two-Color Laser Transmissometer (TCLT) (average particle size and particle number density)

*The Two-Color Transmissometer measures the average particle size and particle loading in the gas stream. The technique is based on measurement of the extinction of laser light at two wavelengths (e.g., the IR and V regions) and knowledge of the refraction index of the particles.*

This system is field ready and the TCLT units will continue the determination of average particle diameters and loadings at various DOE MHD facilities. Previous work has concerned the study of  $K_2SO_4$  nucleation and real time evaluation of the performance of the CFFF electrostatic precipitator and baghouse. During this work period characterization of the particle size at upstream locations will be carried out. These measurements will concern particulate behavior and ash carry-over in the upstream portions of the facility and have implications on slag/seed interactions and thus seed recovery. In addition, ongoing measurements concerning the CFFF particulate retention components will continue to evaluate the effects of the ESP operating characteristics on particulate properties.

Initial TCLT measurements at the CFFF diffuser exit and at various levels of the radiant furnace have indicated that the average particle diameters at some locations exceed the current measurement range (0.3-4  $\mu\text{m}$ ) of the instrument. Somewhat larger diameters are expected

at upstream locations when compared to the cooler sections of the steam bottoming plant. In regions of high turbulence such as channels, slag can become re-entrained; in addition, fly ash (not  $K_2SO_4$ ) will nucleate at high temperatures. Knowledge of the average particle diameters and loadings would be expected to aid in calculations of heat transfer, erosion and generator performance. Extension of the particle size range would increase the accuracy of the system and allow direct measurements at upstream locations.

In order to increase the upper particle size limit of the TCLT, an isotopic  $CO_2$  laser and accessories will be added. The use of an isotopic lasing medium such as  $C^{12}O_2^{18}$  will permit operation at  $> 9 \mu m$  and will effectively avoid attenuation of the beam by the natural  $C^{12}O_2^{16}$  present as a combustion byproduct. Incorporation of the isotopic  $CO_2$  laser into the TCLT optical configuration will increase the particle diameter measurement range from (0.3-4  $\mu m$ ) to (0.3 -  $\sim 9 \mu m$ ).

The current size of the TCLT optical breadboard is approximately 29" x 86" and weighs about 100 lbs. It should be possible by incorporating fiber optics to route the laser beams from one breadboard unit to multiple port locations using both visible and infrared fibers along with appropriate connectors and optics. In this way, measurements of average particle size and loadings could be made at different locations from the centrally located breadboard. At present, the optical breadboard must remain in close proximity to the penetration position and each measurement location must have one breadboard. The incorporation of fiber optics would result in increased flexibility and moreover, the lasers, etc. can be conveniently removed from the magnetic field regions present at CDIF.

#### 3.A.4. Laser Doppler Velocimeter System (LDV) (local velocity, velocity profile and turbulence level)

*The Laser Doppler Velocimeter measures the gas velocity and turbulence level at a given point in the gas stream. The technique is based on measurement of the modulation frequency of the scattered light from a particle traversing a measurement volume which is formed by intersection of two focused laser beams. A one-color and a two-color*

*system are available which measure one and two components of the velocity, respectively. A velocity profile can be obtained and both forward and back scatter measurements can be made.*

The LDV system is field ready and has provided a number of useful velocity flow measurements in support of the national MHD program. To improve the operation and information derivable from the system, a second pair of transmitting and receiving optical fibers will be incorporated in the LDV optical train. This will allow two colors (green and blue) of incident laser light to be simultaneously transmitted to the measurement site and thus, two components (axial and radial) of particle velocity can be determined. The use of optical fibers is absolutely mandatory for field measurements, especially for difficult measurement sites such as the combustor exit at CDIF.

To complete the two-color optical fiber LDV system, a second signal processor (burst spectrum analyzer) is required. Two signal processors are required for simultaneous measurement of two velocity components of a particle. During prior field measurements at CFFF and TRW, two-component (nonsimultaneous) velocity measurements were made; but it was possible to do so only because physical access to the measurement site was allowed during the test. Protocol at the CDIF facility strictly forbids such access during a test, so a second signal processor will be mandatory for two-component measurements.

Plans also include incorporating smaller stepper motors in both the forward and backscatter traverses so only one power supply will be required to drive both. A remote controlled focusing device for the forward scatter detection system will also be added. This will allow optical alignment to be maintained during traverse of the forward optics for velocity profile measurements.

Recent experience at CDIF proved that Doppler frequencies in the range 50-70 MHz are to be expected for such flows. The only way to be confident that a proper LDV signal is being processed is to capture the transient Doppler burst using a storage oscilloscope. It is desirable, therefore, to add a high speed digital storage oscilloscope to use in such applications.

### 3.A.5. Potassium Emission/Absorption System (PE/AS) (time-resolved temperature)

*The Potassium Emission/Absorption System rapidly measures (order of milliseconds) the average channel temperature by the line reversal technique.*

This system has been field tested and is presently being used to provide time-resolved temperature measurements in support of the national MHD effort. Some software enhancement of the instrument is planned.

### 3.A.6. Gas Analysis System (GAS) (gas composition, e.g., CO, CO<sub>2</sub>, NO, etc.)

*The Gas Analysis System is capable of analyzing gases from fossil fuel combustion processes including NO<sub>x</sub>, CO<sub>x</sub>, SO<sub>2</sub>, O<sub>2</sub> and combustibles. The system requires continuous extraction of a gas sample for analysis. The Gas Chromatograph (GC) can detect CO, CO<sub>2</sub>, N<sub>2</sub> and O<sub>2</sub> using a thermal conductivity detector. Other gases of interest can also be monitored with the GC by selection of the appropriate column. Samples to be analyzed by the Gas Chromatograph are collected and stored in glass sample bulbs for later analysis.*

This system is field ready and no additional modifications are planned except to maintain the system field ready.

## 3.B. Field Tests/Instrument Modifications

### 3.B.1. Coherent Anti-Stokes Raman Spectroscopy System (CARS) (local gas temperature and species concentration, temperature and concentration profiles)

*The CARS system is a laser-based nonlinear optical technique being developed to provide temperature and species concentration measurements with spatial and temporal resolution. Of the many laser-based techniques, CARS is the best suited for thermometry in high-interference environments because of its coherent, laser-like signal character and high signal conversion efficiency. To obtain a CARS spectrum, two narrow band lasers at pump frequency  $\omega_1$  derived from the pump laser and one broadband dye laser at Stokes frequency  $\omega_2$ , are phase matched and focused in the gas stream thereby generating through the third-order susceptibility of the medium a spectrum at anti-Stokes frequency  $\omega_3 = 2\omega_1 - \omega_2$ . The CARS spectrum of a species (e.g., nitrogen) can be sensitive to both gas temperature and species concentration.*

The mobile CARS instrument is ready for field tests. Based on these tests, a few minor modifications may be required. Field measurements are planned throughout the contract period at both CFFF and CDIF. Initially, point temperatures and temperature profiles from N<sub>2</sub> CARS spectra will be measured. Work on improving the capabilities of the present CARS system will also continue. This will include automation of the mobile CARS system. In particular, the CARS signal is focused to a 200 μm core diameter, 0.12 numerical aperture optical fiber with an achromatic lens and is piped to the instrumentation trailer from the test environment. This coupling is very critical and needs to be remotely controlled. In addition to temperature measurements, field measurements of species concentration will also be made.

### 3.B.2. Particle Size Distribution System (PSD) (particle size distribution)

*The Particle Size Distribution System uses optical, in-situ, scattering methods for measurement of particle size distribution. The three-beam, two-color particle size measurement system is designed to measure particles at slow velocity using a single-particle counting method, while an ensemble averaging technique is used for high velocity flows. The system employs the output (green and blue) from an argon ion laser. The green beam is focused on the central axis and the blue beam is divided into two equal intensity beams which are focused and crossed inside the green measurement volume producing an interference fringe pattern. The light scattered from these beams by a particle are processed to extract the particle size.*

Operation in the field will involve the single particle counter (SPC) instrument until the ensemble averaging method (EAM) instrument is refined for field operation. The particular objectives for the Single Particle Counter Instrument are to finish construction of the system, prove operation of the system in the field, and refine the system for convenience in use and performance. We anticipate adding receiving fibers to reduce susceptibility to noise. Data will also be gathered for comparison of different modes of operation in the field environment and field measurements to characterize the downstream components at UTSI will be conducted.

The specific objectives for the Ensemble Averaging Method Instrument are to prove the feasibility of the concept through experimental tests and incorporate this method into the field instrument. This will require continued theoretical and computational efforts to evaluate the parameters for the data reduction model. Preliminary work on this is finished. Refinements will be needed as soon as the work is far enough along to justify them; these include the effects of lens aberrations, which will also require some experimental investigation.

Efforts will also begin to develop an experimental configuration for particle generation and laboratory measurements. Experiments will be conducted on the test stand (as soon as feasible) and concurrently, field tests of the method will be employed to define a suitable instrument package.

### 3.B.3. Intrusive Multi-Probe System (IMPS) (wall and gas temperature)

*An Intrusive Multi-Probe System has been developed to position various sensors at a precise location in a combustion gas stream for precise increments of time. It is completely computer-controlled and may be operated to both position the probe and acquire the data. Optical sensors as well as conventional sensors can be used with this probe insertion system; however, its main use is with techniques where the probe will spend a very short period of time in the gas stream. Such a system interfaced with an optical technique can provide measurement capabilities in regions where, because of path length, optical measurements would not be possible.*

Development and field testing of one viable intrusive sensor has been completed for the measurement of MHD interior wall surface measurements. This sensor is capable of measuring surface temperatures in the range of 500°C to 2000°C. Field tests have been conducted at the DOE/CFFF by measuring the front surface temperatures of the superheater tubes during several runs of the facility; the interior wall surface temperature of the furnace has also been measured.

### 3.B.4. Potassium Emission/Absorption System (PE/AS) (K-number density)

*The Potassium Emission/Absorption System will provide the average neutral potassium number density from lineshape information and provide the average channel electron number density using the Saha equation assuming thermodynamic equilibrium.*

This system is presently being employed to provide potassium number density measurements in support of the national MHD effort. Some software enhancement of the instrument is planned; however, the major issue to be resolved is the over estimation of the potassium number density. This is particularly important for wide gas streams and is believed to be caused by the line profile deviating from a Voigt shape in the far wings. Work to resolve this problem will continue.

### 3.B.5. Faraday Rotation System (FRS) (electron density to infer conductivity)

*The Faraday Rotation System will provide real-time electron density measurements averaged across an MHD channel. The electrical conductivity scales almost linearly with the electron density. The technique is based on the Faraday effect. Linearly polarized light may be decomposed into right (+) and left (-) circularly polarized waves. Since the absorption coefficients and refractive index are different for right and left polarization, the amplitude and relative phase of the polarized waves are affected on passing through a plasma along a uniform magnetic field. Measurement of the rotation of the polarization of a beam of linearly polarized light after passing through a medium (plasma) in the direction of an applied magnetic field determines the electron number density. The system employs radiation in the far infrared derived from a CO<sub>2</sub>-pumped far infrared laser.*

The Faraday Rotation System will provide directly the electron density and conductivity of the MHD channel, which is essential to the characterization of the power train performance. Most of the major equipment for the system has been obtained. The system assembly for electron density and density measurements on a laboratory plasma are basically complete. Electron mobility modeling and measurements will be addressed. System refinements for field tests (such as waveguides and vibration isolation for detectors) will follow. Field

measurements will take place as soon as possible at CDIF. Optical access at CDIF through the channel sidewalls is required and may necessitate new construction at the CDIF.

### 3.C. Field Operation/Developing Systems

#### 3.C.1. General Purpose Spectral Scanning System (GPSS) (emission spectra from UV to near-IR)

*The Spectral Scanning System will detect emission from atomic and molecular species in the gas stream, and provide an intensity versus wavelength record covering the ultraviolet to the near infrared. The system employs receiving optics and a computer - controlled monochromator equipped with a wideband detector.*

Initial spectral emission measurements in the visible region at CDIF indicate it would be valuable to have a spectral scanning system covering the wavelength region from the ultraviolet to the near infrared. Building on existing equipment, construction of a general purpose spectral scanning system is planned. This system will provide a direct qualitative indication of many of the atomic and molecular species present in the gas stream. It would be particularly convenient for studying the MHD channel flow since only a very small optical fiber access hole would be needed. For instance, atomic lines (N, S, C, O, etc.) or diatomic lines (CO, OH, O, NO) could probably be detected at very high temperatures. These measurements would provide useful information for comparison with equilibrium calculations and possibly useful correlations on the operation of the MHD power train.

#### 3.C.2. Visible IR Emission Spectroscopy (VIES) (emission spectra from ultraviolet through near infrared)

*The Visible/Infrared Emission Spectroscopy System will detect wavelength-resolved emission from the ultraviolet through the near infrared. Comparison of the resulting emission spectrum with the spectrum of an available, commercial blackbody radiation source will enable estimation of relative emissivity values. The system employs receiving optics and a computer-controlled monochromator equipped with broadband detectors.*

In order to evaluate the HTAH ceramic for possible use in its combustor, CFFF would benefit from knowledge of its relative emissivity values in CFFF's gas stream. Construction of a visible/infrared emission spectroscopy system built mostly from available equipment

is planned. This system will record the wavelength-resolved emission spectrum of the ceramic in the CFFF gas stream. Estimates of the relative emissivity values would be obtained from comparison of the emission spectrum with the spectrum of an available, commercial blackbody radiation source. In addition, this general purpose system could be utilized to obtain the relative emissivity values of other substances, or to study the emission of atomic and molecular species present in high temperature MHD gas streams.

### 3.C.3. IR Water Detector (IWD)

*Water absorbs infrared radiation at a number of wavelengths, but those located near 1.4, 1.9 and 2.7 microns hold the greatest potential for diagnostic purposes in a combustion stream. The radiation emitted from the walls of a combustion facility provide sufficient intensities of infrared light in these regions to allow simple absorption measurements to be made at a single viewing port. The selection of the optimum region for making the necessary measurements depends upon factors such as the amount of water normally in the combustion stream, the minimum amount of excess water which must be detected, and the inherent absorption strengths of water at the wavelengths under consideration.*

Experiments will be conducted to determine the feasibility of developing an infrared water detector instrument.

DIAL will supply a Mobile Instrument Laboratory (MIL) with computer controlled diagnostic instrumentation for on-site measurements and trained diagnostic operators. Field measurements will be made at the national MHD facilities on an as-needed basis. The Mobile Instrument Laboratory will be used to house the diagnostic equipment for transportation to, and for use at, a particular facility. The Airstream MIL has its own electric power source. Recently an 18-wheeler type trailer has been modified to provide an Advanced Mobile Instrument Laboratory (AMIL) to supplement the Airstream MIL which has been operational for a number of years. This field laboratory is used for the advanced diagnostic systems, such as CARS, FRS, etc., and for simultaneous operation of a large number of DIAL instruments.

Both field laboratories have on-board computers for on-line data acquisition and control of the diagnostic equipment. The existing data analysis system, however, lacks the speed and capabilities necessary to provide quick, report quality, feedback to the facility. To this end, modifications and additions will be made to the on-line data analysis system. The particular goals are:

- speeding up analysis and display so as to provide quick feedback to the facility;
- providing on-line data display using 2D/3D techniques to help visualize and interpret the data and facility behavior;
- producing presentation quality reports for each instrument by the end of the day of measurement; and
- validating data -- which is done manually at present -- automatically by the analysis system.

DIAL has started evaluation of the required advanced instrumentation to control a complete MHD system. As part of the support of the national MHD program, this effort will include evaluation of diagnostic systems for monitoring/control as well as an evaluation of the dynamic characteristics of the complete MHD system when the bottoming cycle is integrated with the topping cycle. Instrumentation will hence be selected to control the MHD power system under all perturbations.

#### *Task 4. Project Management*

The objective of this task is to provide the required management for accomplishment of the Statement of Work with the proposed resources management reporting as required by DOE Order 1332.1A. Contract Reporting Requirements will be part of this task.

#### *Task 5. Technology Transfer*

Technology transfer is a congressionally mandated objective of the Federal Government. To ensure the maximum benefits to PETC's and subsequently DIAL's investment in research and development, DIAL's personnel will cooperate with regional industries to demonstrate the technology for intrusive and nonintrusive diagnostic instrumentation developed for the characterization of MHD systems. Organizations which have already benefited from this actively are Dow Chemical,

USA, Dantec Electronics, NASA and the Stennis Space Center. However important, this task shall in no way interfere with the mainstream efforts of the MHD program.

## DESCRIPTION OF FACILITIES

The combustion test stand is a computer-controlled simulation test facility available for the combustion of fuel oil at up to 800 lbm/hour of fuel and air. A system for using a coal slurry for fuel is presently under development. The air can be preheated to temperatures up to 1100 K (1520°F) by electrical resistance heaters. Downstream of the combustor are refractory-lined sections containing access ports on both sides and the top of each section.

The DIAL test facility has a Hewlett-Packard measurement and control system (HP-1000/A400 minicomputer-based system) with real-time software, graphics, and extensive input-output (I/O) capability.

The microprocessor development laboratory has six PC's, two IBM PS/2-80's, and two Diversified Technology development systems for developing software and firmware for special purpose microcomputers to be used in controlling diagnostic instruments, signal processing, and signal and data analysis. A variety of other PC's and microcomputers (at least twelve) are part of the field instruments and those under development.

Complete laser facilities are available, including YAG and dye lasers, spectrometers and photometers, fiber optics, and other equipment. Discharge lamps, power supplies, vacuum systems, UV optics, monochromators, detectors and processing electronics are also available. In addition, the laboratory has several benchtop laboratory burners controlled by precision gas handling systems.

The department of Electrical Engineering at MSU has the facilities and staff for the design, development and construction of hybrid integrated circuits and printed circuit boards.

The following support facilities are available in DIAL: (1) Electronics Shop, (2) Machine Shop, (3) Instrument Shop, and (4) Gas Sampling and Analysis System.

Modeling and data analysis are done on the newer, more powerful PC's (e.g. PS/2 and 386 PC's) and the VAX 11/780 and VAXstation 3200.

Large scale analysis and modeling is required for various instruments including CARS, LDV, and PE/AS. Other instrument development and refinement projects also require continued modeling support in the areas of general combustion/heat transfer and gas flow modeling.

technical  
progress

Task 1. Instrumentation Development: R. L. Cook

A. *Coherent Anti-Stokes Raman Spectroscopy System (CARS)*

*J. P. Singh and F. Y. Yueh*

Work Performed

Work continued to test the mobile CARS instrument to solve some of the problems with the collinear CARS technique reported previously.<sup>1</sup> Collinear CARS has the advantage of generating a strong CARS signal but it has not been successfully applied to measure the temperature of practical combustors.<sup>1,2,3</sup> The CARS spectra recorded with collinear CARS has some CARS contribution generated outside the focal region.<sup>4</sup> To pinpoint the region which contributed to the cold CARS signal and also to improve the quality of the CARS spectra from collinear CARS, the mobile CARS instrument was modified and aligned with a CH<sub>4</sub>/air burner. The effect of beam waist on temperature profile measurements was checked repeatedly with different focusing lenses. These results were compared with folded BOXCARS measurements.

A schematic diagram of the modified CARS setup and a CH<sub>4</sub>/air burner are shown in Figure 1.A.1. To eliminate the CARS signal from the cold region due to overlap of the pump and Stokes beams, two aluminum cells, one with a GG-495 window and the other with a 532-nm dichroic mirror at 45°, were placed at the two ends of the burner. The GG-495 filter eliminates the CARS signal generated before the argon cell on the transmitter side and the 532-nm dichroic mirror eliminates the CARS generation after the argon cell on the receiver side. The aluminum cell and copper tube on both ends of the burner were purged with argon to eliminate the cold CARS contribution between the flame and the cell windows. CARS laser beams from the mobile CARS laboratory were aligned with the burner which was 40 ft away. The measurement point was 10 mm above the surface of the burner. The flow rate of the air and fuel was adjusted to obtain a stable flame and a stoichiometry of 0.92 was found.

Figure 1.A.2 shows the fitting of the observed spectrum with the computer-simulated spectrum recorded at the center of the flame with a 30-cm focal length lens and collinear CARS. The observed spectrum can be fit quite well with the simulated spectrum. Satisfactory fitting shows that this spectrum has negligible cold CARS contribution. The inferred temperature from the

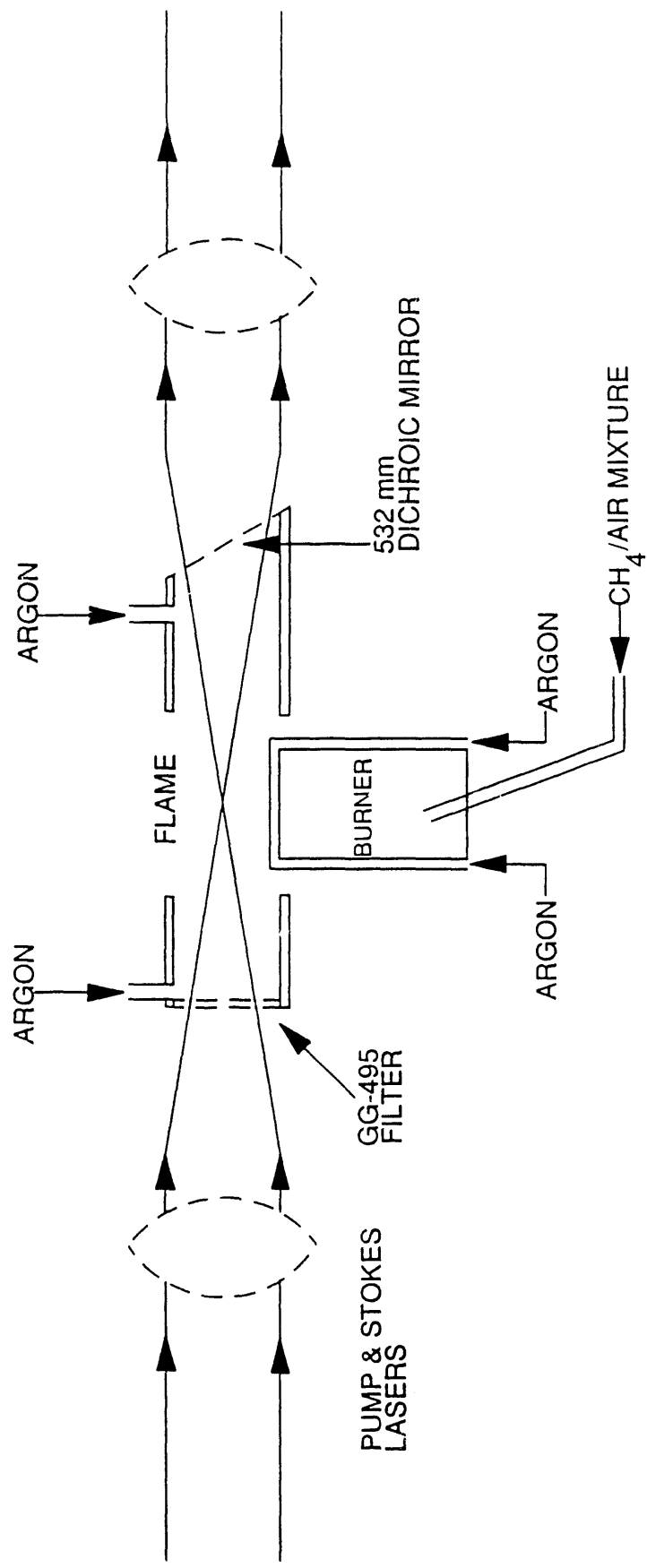


Figure 1.A.1. Schematic of collinear CARS set up with CH<sub>4</sub>/air burner.

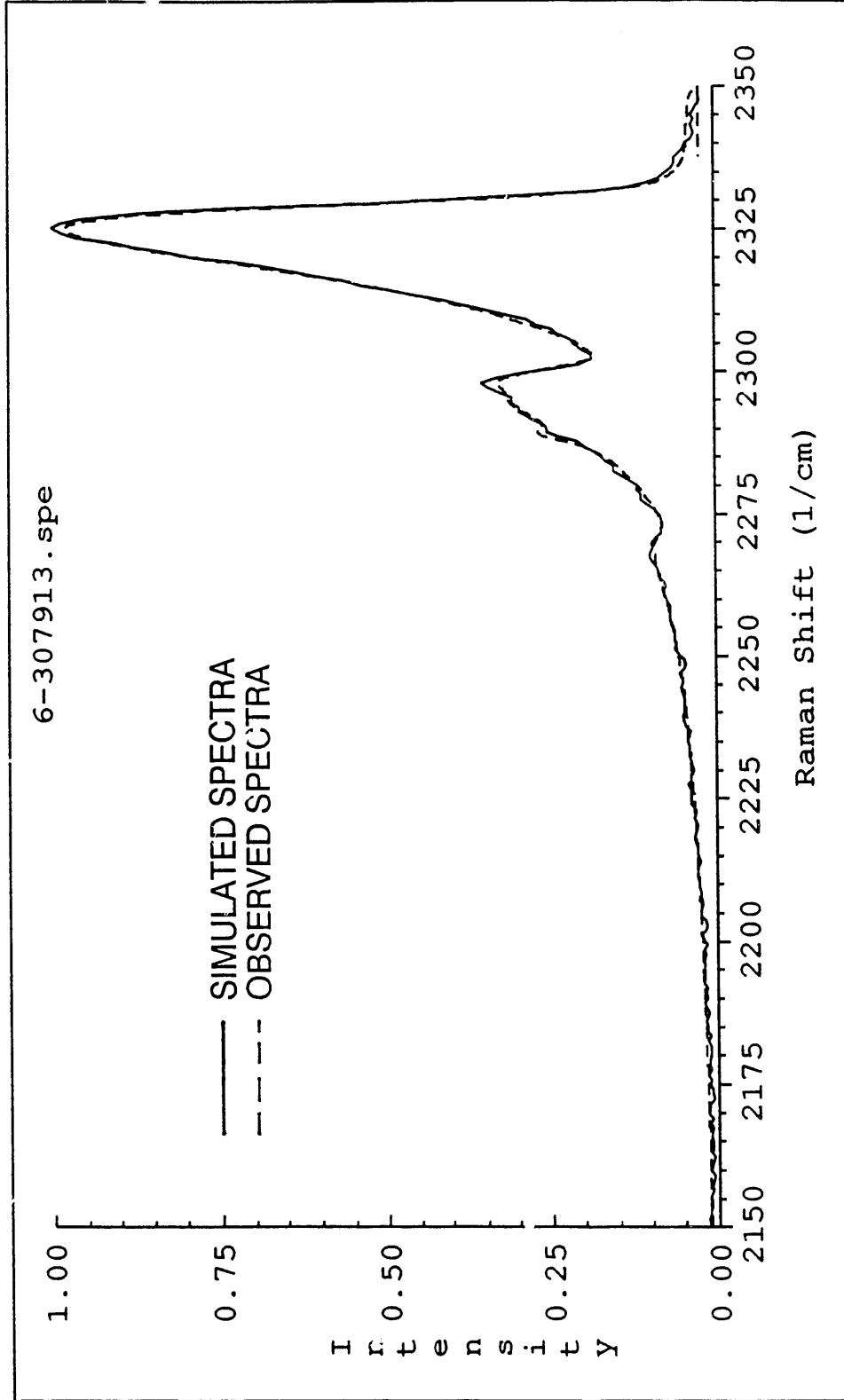


Figure 1.A.2. Fitting of the computer simulated N<sub>2</sub> CARS spectra with the observed spectra at the center of the CH<sub>4</sub>/air flame with a 30-cm focal length lens.

fitting is 2239.4 K. To study the effect of the size of the beam waist at the focal point on the temperature measurement, CARS spectra were also recorded at the center of the flame with a 100-cm focal length lens. These data have some CARS contribution from the cold regions which can be identified from the fit around the data points around the cold band peak as shown in Figure 1.A.3. The intensity of the cold CARS signal was 5-10% of the hot CARS signal depending on the flow rate of the argon. Normally, nitrogen density is about seven times higher in the air than in the flame. Though the nitrogen density between the cell window and flame was reduced significantly with argon purge, still a small amount of nitrogen could be found. Therefore, the CARS signal generated using collinear CARS has some contribution of the CARS signal from outside the flame. The cold contribution was appreciable with the 100-cm focal length lens, compared to the 30-cm focal length lens, due to its longer interaction length. The CARS spectrum generated with the 100-cm focal length lens was fit with simulated spectra and the inferred temperature was 2107 K. The fitting was not as good as in Figure 1.A.2. The same spectra was then fit, as shown in Figure 1.A.3, by excluding 15 data points (3A) at the center of the 0-1 band where most of the cold signal is contributed and the extracted temperature was 2144.2 K. The averaged, inferred temperature at the center of the flame was  $2150 \pm 50$  K measured with the 100-cm focal length lens which is about 75 K lower than that measured with the 30-cm focal length lens. This lower inferred temperature is due to the cold CARS contribution. For comparison CARS spectra were also recorded with folded BOXCARS at the center of the flame. The fitting of these spectra were very similar to the spectra taken with the 30-cm focal length lens with collinear CARS. The flame temperature extracted from the folded BOXCARS measurement was  $2200 \text{ K} \pm 50 \text{ K}$  which is close to the collinear CARS measurement with the 30-cm lens. The temperature of a  $\text{CH}_4/\text{air}$  flame at a stoichiometry of 0.92 calculated from the equilibrium calculation was found to be 2219 K which is in agreement with the folded BOXCARS measurement.

To compare collinear CARS with another technique, the Sodium Line Reversal (SLR) instrument was aligned perpendicular to the CARS laser beam to measure temperature simultaneously with CARS at the center of the flame. The average temperature was found to be  $1952 \pm 150$  K with the SLR measurement. The SLR

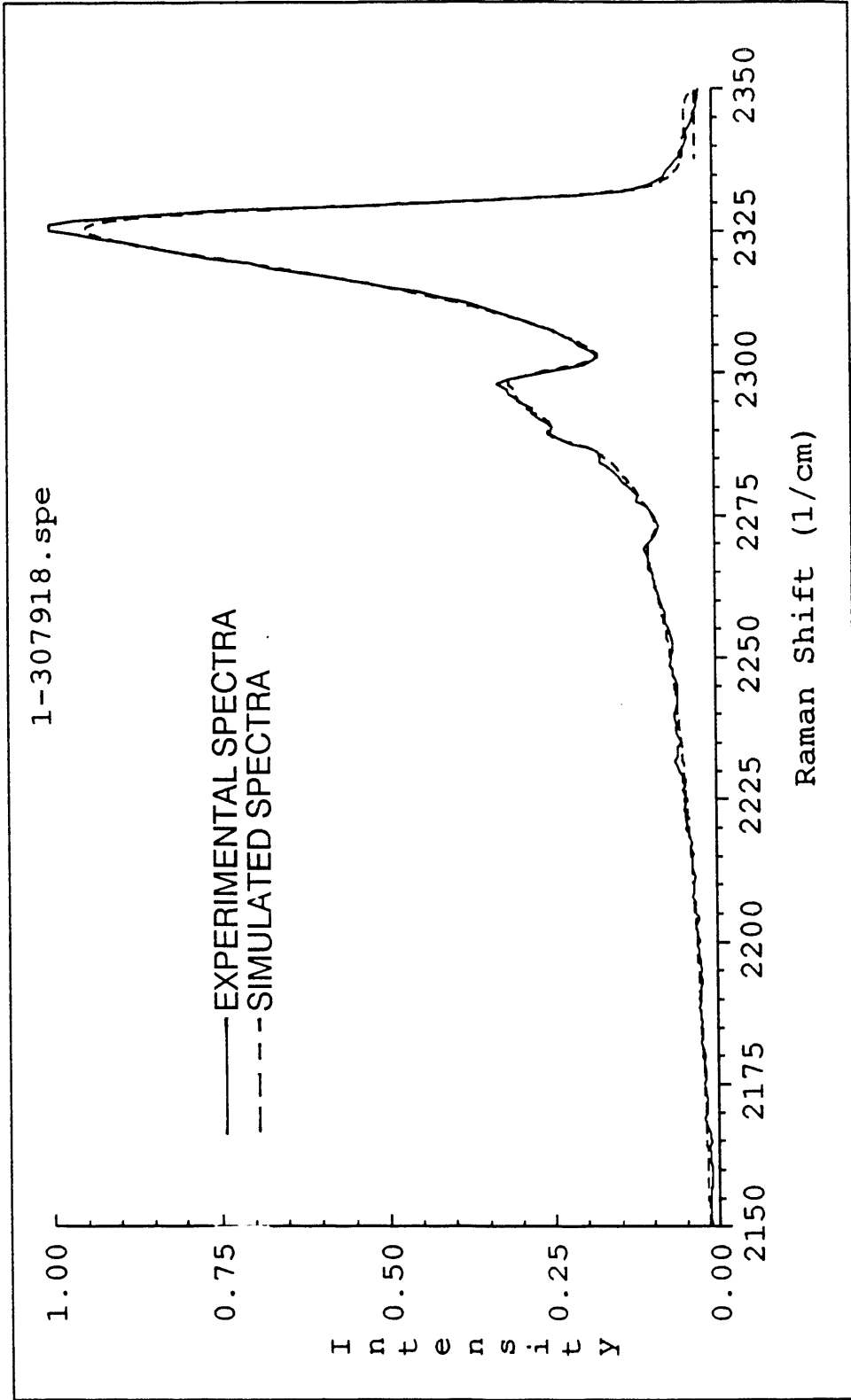


Figure 1.A.3. Fitting of the observed N<sub>2</sub> CARS spectra with a 100-cm focal length lens with computer simulated spectra excluding 15 channels at 0-1 peak.

measurement was expected to give a slightly lower temperature due to the averaging effect. This measurement and the measurement performed close to the flame boundaries show that the temperature measured with SLR is  $\sim 250$  K lower than the measurement from the collinear CARS measurement with the 30-cm focal lens. The measurement with SLR has a much lower inferred temperature due to the averaging of a shorter flame width (15 mm).

The collinear CARS measurement has been extended to measure the temperature profile across the length of the flame. Figure 1.A.4 shows the temperature profile measured with collinear CARS and a 30-cm focal length lens. The measurements were performed with both 70 and 140 cubic-feet-per-hour (CFH) of the argon purge rate to define the boundary of the flame. The data were collected at intervals of 5 mm close to the boundary. The length of the flame was reduced from 10.9 to 10.1 cm when the argon flow rate was increased from 70 to 140 cubic-feet-per-hour. This is due to the squeezing of the flame with argon which was observed visually. The decrease in flame length is more on the transmitter side than the receiver side due to the asymmetrical flow of argon. The temperature within 9.7 cm of the flame is fairly uniform and was found to be  $2225 \pm 25$  K with both argon-purge flow rates. A sharp decrease in the temperature is observed at the boundaries. The temperature gradient was found to be 162 K/mm. The CARS spectrum recorded at the boundary of the flame has some contribution from the cold region. Temperature profile measurements have also been made with a 100-cm focal length lens, as shown in Figure 1.A.5, to study the effect of beam waist on the temperature profile. The temperature was also fairly uniform and was  $2150 \pm 30$  K within 9.1 cm of the length of the flame. The decrease is slower on both boundaries than that of the 30-cm focal length measurement. The temperature gradient in this case is 82 K/mm compared with 162 K/mm in the measurement with the 30-cm focal length lens. This is due to poorer spatial resolution from the longer interaction length and also more cold contribution in the 100-cm focal length measurement than the 30-cm focal length measurement. The temperature measurement results of the various lenses show that collinear CARS can be improved with smaller beam waist. A suitable beam waist at the focal point for a particular focusing lens can be obtained by proper expansion of the CARS laser beams. Further work is needed to test the suitability of the collinear CARS for DIAL test stand measurements.

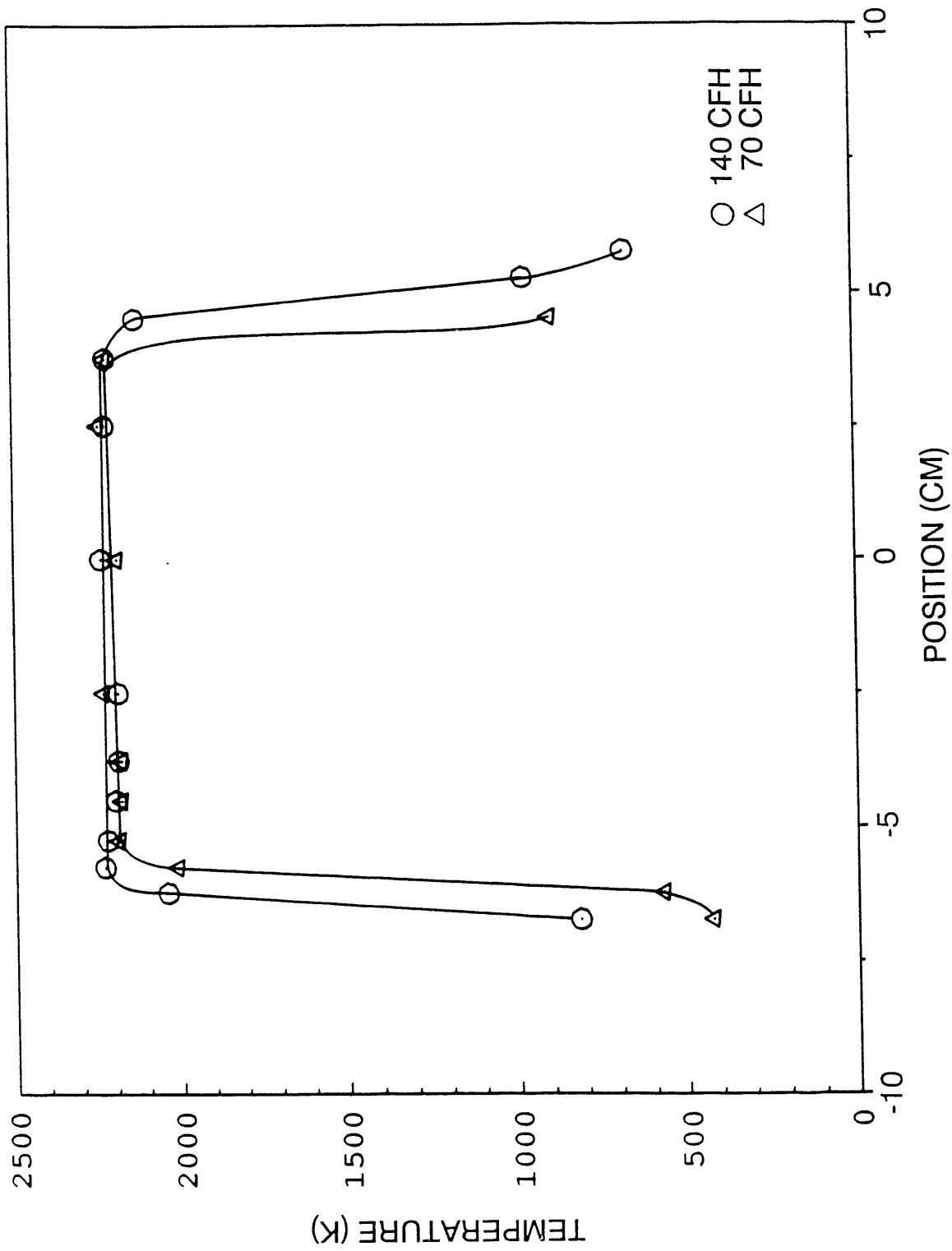


Figure 1.A.4. Temperature profile measured along the length of the burner with collinear CARS set up shown in Figure 1.A.2.

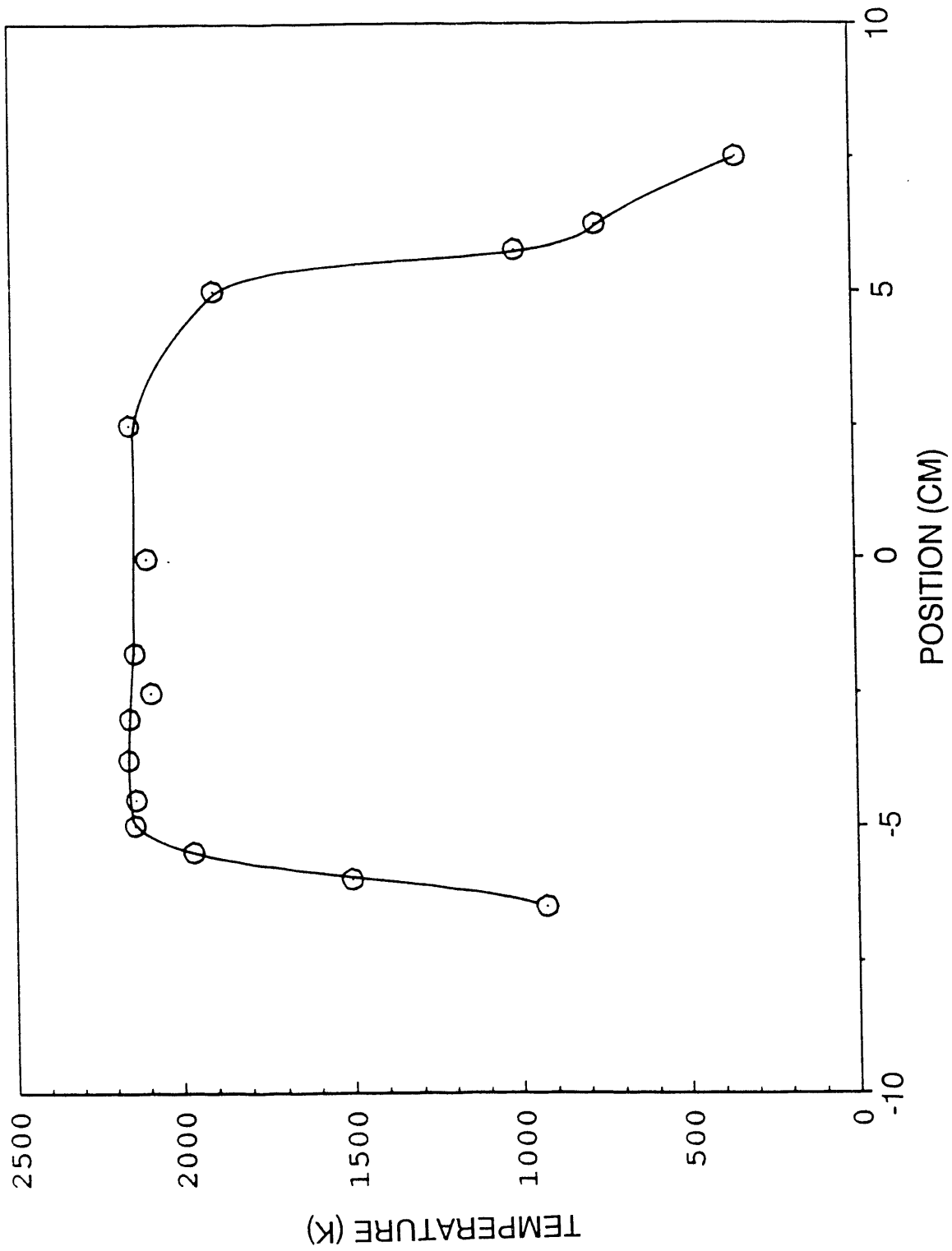


Figure 1.A.5. Temperature profile of the burner with collinear CARS with a 100-cm focal length lens.

Work to identify the new features observed over the 2 → 3 hot band transition of N<sub>2</sub> CARS in the LMF4-S test run at CFFF also continued. The controller box to control the lens traverse system and x-y-z fiber optics translator was redesigned to improve performance in the presence of the electrical noise. An amplifier has been incorporated in the controller box to increase the electrical pulse coming from the computer to overcome the electrical noise near the CFFF diffuser.

### Conclusions

The temperature measurements with collinear CARS in a CH<sub>4</sub>/air flame at 0.92 stoichiometry were made with various focusing lenses. To assure the accuracy of those measurements, the results were compared with the SLR and folded BOXCARS measurements. The measurements with a 30-cm focal length lens are in good agreement with the folded BOXCARS measurements. A lower inferred temperature was found with the collinear CARS measurements when the 100-cm focusing lens was used. The flame measurement results show collinear CARS, with a suitable beam waist at the focal point, can be used to measure the point temperature and also the temperature profile of a combustion environment.

### Work Forecast

The collinear CARS technique will be further tested on DIAL's test stand for temperature profile measurements. A computer model will be developed for analyzing the temperature profile data obtained from collinear CARS. The optics for the mobile CARS instrument will be modified for the forthcoming UTSI trip.

### References

1. Singh, J. P. and Yueh, F. Y. 1989. DIAL quarterly technical progress report FE-15601-39:12. Mississippi State University.
2. Alden, M. and Wallin, S. 1985. CARS experiment in a full-scale (10 m x 10 m) industrial coal furnace. *Appl. Opt.* 24:3434.
3. Hancock, R. D.; Hedman, P. O.; and Kramer, S. K. 1989. Coherent anti-Stokes Raman spectroscopy (CARS) temperature and species concentration measurement in coal-seeded flames. *Combustion and reaction engineering II: new experimental techniques*. AIChE annual meeting, San Francisco.

4. Singh, J. P. and Yueh, F. Y. 1989. DIAL quarterly technical progress report FE-15601-38:12. Mississippi State University.

## *B. Particle Size Distribution System (PSD)*

*J. D. Gassaway and W. Okhuysen*

### Work Performed

The data acquisition and operator interface software requirements for the field instrument were identified. The major additional requirement is the addition of features which will allow data collection to be synchronized with a facility's operating parameters. Several count histograms, each for a particular predefined set of facility operating conditions, can be accumulated concurrently. This will allow a statistically meaningful number of counts to be accumulated for each condition thus giving more useful information.

Histogramming hardware can be used to great advantage to reduce the complexity of the data acquisition software. Currently, histogramming is done in software and the control computer's resources are utilized inefficiently since the A/D converter must be polled to determine the end of a DMA acquisition cycle. The applicability of multichannel analyzers which are used for detection of pulses such as encountered in nuclear spectroscopy has been investigated. It may be feasible to modify one of these to suit our requirements.

The development of the signal processor for the field instrument has been resumed. The ripple filter/velocimeter and Log-IF amplifier PC boards will be routed and fabricated by a PC board vendor with three-layer capability. The remainder of the circuit boards will be laid out and fabricated in-house on two-layer boards. These consist of lower speed circuits which do not require a full ground plane.

Laboratory experiments were performed during this quarter. Scattering response patterns for the new optical configuration, folded receiver and optical transmission link, were mapped. Liquid cell and pinhole scattering experiments were performed.

### Conclusions

Data acquisition and instrument control software must be streamlined such that facility operating parameters may be correlated to particle measurements in a more systematic manner.

### Work Forecast

Efforts to improve acquisition and control software will continue. Building of the new signal processor will also continue.

### *C. Potassium Emission/Absorption System (PE/AS)*

*L. E. Bauman*

#### Work Performed

The line reversal analysis program was rewritten to calculate temperature and atomic densities from integrated line absorptivities. Constants for the alkali D-lines were added to the routine. This capability was necessary for support of the Faraday Rotation System development. Current rotation experiments are using cesium hydroxide as the seed and the cesium lines at 455 nm are weak and narrow, such that the D-line cannot be resolved for measurement of density through a profile analysis. The current routine is relatively slow but acceptable for the small amounts of data recorded in tandem with the Faraday Rotation System. The routine requires optimization if it is to be used for larger amounts of data, such as for a field test. The data taken on the CDIF nozzle without seed injection will provide a good test of the new integrated line absorptivity routine for atomic densities. The restoration and re-examination of CDIF and CFFF data is still underway at a slow pace due to a lack of manpower.

Further tests were performed in February on the DIAL test facility to look at potassium far wing profiles. These tests used an alternate combustor with oxygen enrichment in an attempt to study the profiles at higher temperatures. Preliminary analysis does not indicate that higher temperatures were achieved.

The PE/AS main calculation routine was rewritten to be more automatic prior to sending the field system to the CDIF in March.

The system still requires the addition of stepper motor control of slit width and replacement of the current stepper motor control of the wavelength drive which is unreliable.

#### Conclusions

The PE/AS is a field-ready instrument that is basically complete. The system is a powerful spectroscopic instrument with many capabilities and will continue to be improved as need arises and manpower is available. Problems with the non-Voigt profile on the potassium far wings that are evident in the

CFFF data of last May are being addressed with a study of the far wings on the DIAL facility. The laboratory system is being used in support of the development of the Faraday Rotation System.

Work Forecast

Work in the future will primarily concern modeling the potassium far wing profiles.

#### *D. Intrusive Multi-Probe System (IMPS)*

*L. R. Hester*

##### Work Performed

The analysis of the data taken in December 1989 with the intrusive lightpipe sensor, the wall-imbedded thermocouples and the MCP system on the special test section of the DIAL test stand was completed. The results show the intrusive lightpipe wall temperature measurements compare very favorably with the extrapolated thermocouple data, but the MCP data consistently indicated a higher wall temperature. After some modifications to the measurement techniques, additional tests were conducted during early March. The results of these tests indicate that lightpipe sensor distance from the wall and certain types of seeding affect the measurement values. Additional tests are planned to evaluate these effects and develop techniques to eliminate them.

The construction drawings for the intrusive SLR sensor's optics holder were completed and construction started. Major problems solved with the new holder include vibration and alignment problems. Considerable work was also accomplished on the faster data collection software for the intrusive SLR sensor to reduce the gas stream exposure time.

##### Conclusions

Additional tests with the intrusive lightpipe sensor using the special test section of the DIAL test stand are needed to refine the calibration of the sensor. These tests are primarily to evaluate and eliminate distance and seeding effects on the sensor measurements.

##### Work Forecast

Additional tests on the intrusive lightpipe sensor for calibration purposes are to be conducted. The intrusive lightpipe sensor and support system will be used to make surface temperature measurements on a special probe in the superheater section of the CFFF during the LMF4-T test. Procedures for these tests are to be developed during the next work phase. Also, plans are to complete construction of the intrusive SLR optics holder for some field tests during LMF4-T.

## *E. Faraday Rotation System (FRS)*

*L. E. Bauman*

### Work Performed

Further laboratory tests on cesium seeded flames have consistently yielded rotation angles of about 5°. Measurement of electron density in seeded flames is being done in tandem with the laboratory PE/AS and tests were halted when part of this system was taken with the field system to the CDIF.

Work on system characterization was delayed by the lack of a second polarizer which is required for determination of the laser and polarizer performance. A replacement far infrared grid polarizer was received late in this quarter and experiments to characterize the imperfection of the polarizer were completed. Experiments to measure the laser beam ellipticity indicate perfect polarization within the measurement precision. The ellipticity introduced into the laser beam by the waveguide remains to be studied. Software for system control, data acquisition and analysis on an IBM-compatible 386 computer is being written.

### Conclusions

Work on system characterization is proceeding.

### Work Forecast

The majority of work that needs to be completed shortly is switching the computer control, data acquisition, and analysis to a more reliable computer.

*F. Multi-Purpose Imaging System (MPIS)*

*R. Lengel and J. S. Lindner*

Work Performed

Preliminary studies on rubidium LIF continued. The large separation of the Rb doublet, 14.7 nm, allows the use of moderate dispersion wavelength discrimination to simultaneously image both rubidium lines. For these studies the fluorescence arising from an unexpanded laser beam (no cylindrical optics) was focused onto a 1200 groove-per-millimeter diffraction grating and then directed to the charge injection device (CID) camera. The grating provided a spectral dispersion of 0.36 nm-per-CID-pixel-element which is sufficient to provide fully resolved images of the two lines.

Figure 1.F.1 is an image captured when the laser was tuned to the 780-nm resonance line (the lower of the two bright areas); however, emission is also visible from the 794.7-nm resonance line. The two lines are tilted due to a rotation of the grating and are broadened by a combination of the intrinsic line widths of the emissions and the non-optimized geometry of the laboratory constructed grating monochromator. Assuming thermal equilibrium of the emitting levels, which are separated in energy by  $238 \text{ cm}^{-1}$  (354 K), the ratio of the intensities of these two images indicates a flame core temperature of 750 K. Since 1800 K would have been predicted, this low result could be caused by either an artificially low intensity of the 780-nm line or a high intensity at 794.7 (the intensity ratio,  $I(794.7)/I(780)$ , is predicted to be 0.54 for a 2000 K flame as opposed to the measured value of 0.8). An increase in the intensity at 794.7 nm seems unlikely since the response of the system should fall off at longer wavelengths due to the inherent characteristics of the intensifier and the CID elements of the camera. It is, however, quite possible that the higher energy  $5P_{3/2}$  state is destroyed by collisional energy transfer more rapidly than the lower  $5P_{1/2}$  state resulting in a lower than expected intensity at 780 nm. Regardless of the accuracy of the temperature determination the method will allow the determination of temperature gradients.

The paper "Laser Fluorescence Imaging of Potassium Atoms in Combustion Systems" was presented at the 28th AIAA Aerospace Sciences meeting in Reno, Nevada.<sup>1</sup> Abstracts entitled "The Use of Rubidium as a Surrogate for Potassium



Figure 1.F.1. Wavelength resolved rubidium fluorescence image of a seeded flame with the 780 nm emission being the lower image and the 795 nm the upper.

in Combustion System Imaging" and "Laser Induced Fluorescence Imaging of Rubidium in Combustion Systems" were accepted for the AIAA Plasmadynamics and Lasers conference and the 28th Symposium on Engineering Aspects of MHD meeting, respectively.

### Conclusions

The ability to image the two rubidium resonance lines will allow the determination of relative temperature gradient information.

### Work Forecast

Optimization of the laboratory constructed grating monochromator will permit further studies on the accuracy of the temperature determination and the question of the extent of collisional energy transfer.

### References

1. Lengel, R. K. and Lindner, J. S. 1990. Laser induced imaging of potassium atoms in combustion systems (AIAA 90-0348). Presented at AIAA 28th Aerospace Sciences Meeting, Jan. 8-11, 1990, Reno, Nevada.

## G. *Differential Absorption Laser Spectroscopy System (DALAS)*

*David L. Monts*

### Work Performed

Work began on the Differential Absorption Laser Spectroscopy (DALAS) System (see Figure 1.G.1) for measurement of line-of-sight-averaged species concentration. The main effort has been toward construction of the oscillator section of an alternating, two-wavelength dye laser based on the design of Hung and Brechignac.<sup>1</sup> The dye laser output power will ultimately need to be increased by addition of an amplifier section to the dye laser. But because proper operation of the dye laser's oscillator section is crucial to the success of DALAS and because dye laser amplification is rather straight-forward, effort for the present is concentrating on the oscillator section.

The optical components for the oscillator section have been mounted. An optical mount permitting independent selection of the dye laser's two wavelengths has been designed and constructed, as has a mount for the oscillator dye cell. The dye circulation system has been tested. Using spreadsheet computer software, theoretically ideal positions for the optical components have been determined for the Rhodamine 590 dye lasing region (552 - 580 nm). The dye laser is being set up using Rhodamine 590 as the laser dye because this dye produces the highest Nd:YAG-pumped dye laser power output and, hence, facilitates optimization of dye laser operating conditions. Alignment of the dye laser components to obtain lasing has begun. In order to simplify the laser system as much as possible to enhance the ease of obtaining lasing for the first time, the dye laser is being operated at a single wavelength. Once lasing has been achieved, development of the stepper motor system for producing the different wavelengths on alternate laser pulses will commence. Bid specifications for the computer and for the boxcar averager system have been written and are awaiting internal approval.

### Conclusions

Work on this project is progressing well.

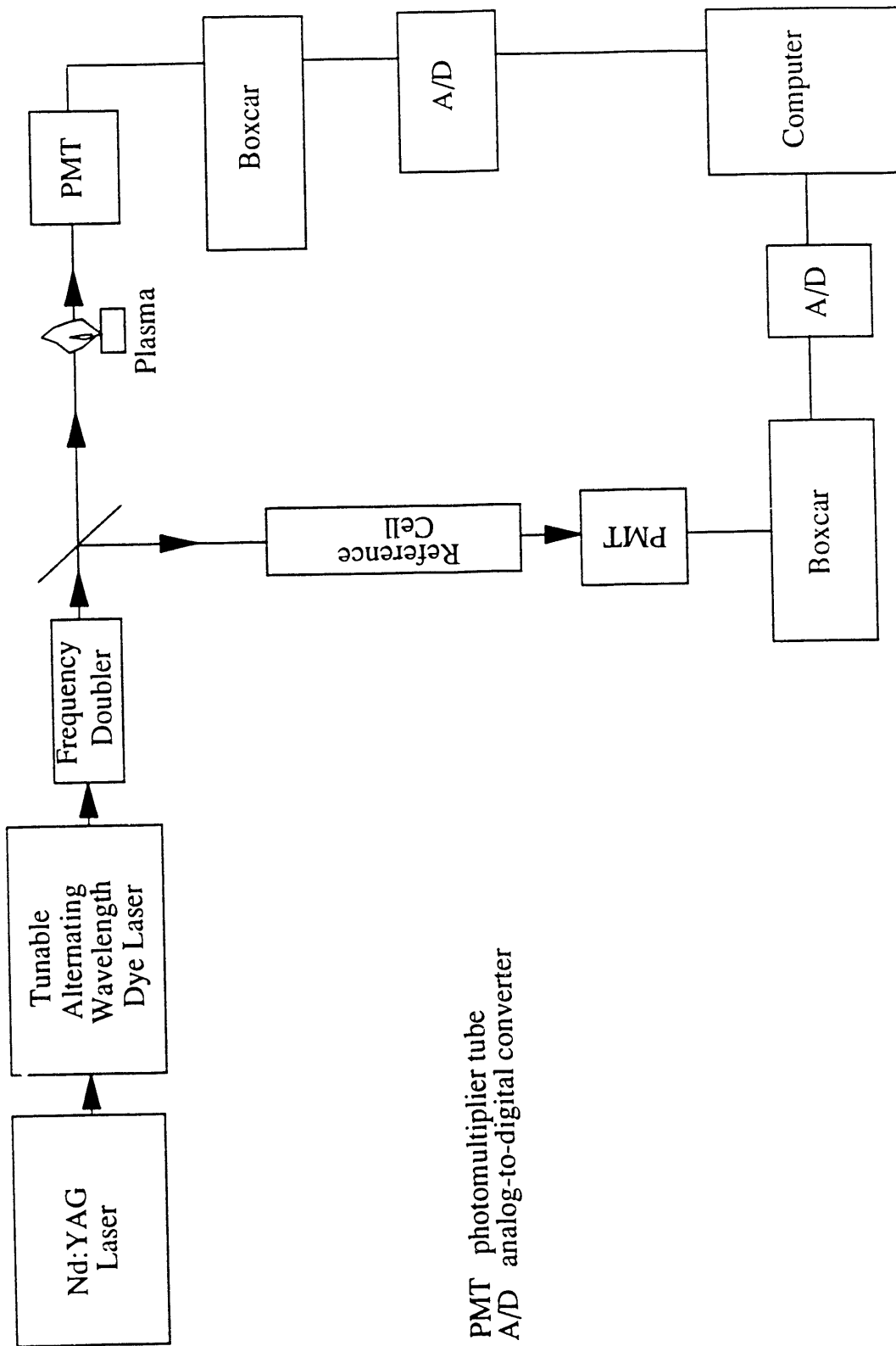


Figure 1.G.1. Differential Absorption Laser Spectroscopy System (DALAS).

### Work Forecast

During the next quarter, lasing from the dye laser oscillator section should be obtained, and characterization and optimization of its output should begin. The computer and other equipment should be received. In addition, design and construction of the detection system will begin, as well as design of the stepper motor system for alternating the wavelength of the dye laser.

### References

1. Hung, N. D., and Brechignac, P. 1988. Tunable alternate double-wavelength single grating dye laser for DIAL systems. *Appl. Opt.* 27:1906-1908.

## *H. Laser Optogalvanic Spectroscopy System (LOGS)*

*David L. Monts*

### Work Performed

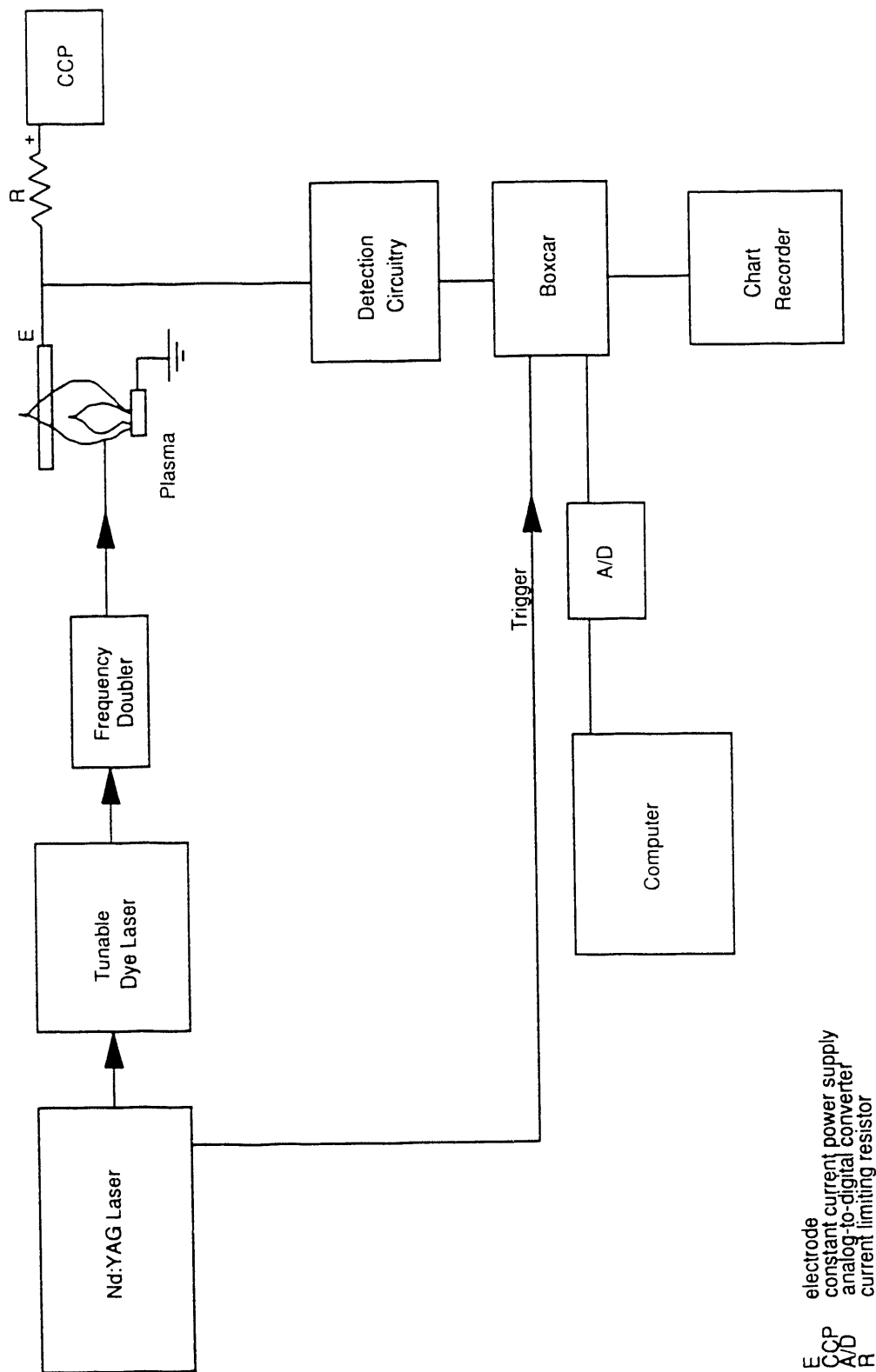
During the first quarter of 1990, work began on the Laser Optogalvanic Spectroscopy (LOGS) System (see Figure 1.H.1) for temperature determination and species identification. An electrode mount has been assembled that permits independent translation of the electrode vertically and horizontally through the flame of a homemade slot burner. A pre-amplifier for the LOGS signal, based on the design of Havrilla and Green, has been constructed and tested.<sup>1</sup> Using available equipment, the LOGS signals of argon in a hollow cathode spectroscopic lamp have been monitored on an oscilloscope.

Modification of existing software enables the wavelength of a commercial dye laser (Quanta-Ray PDL1) to be scanned under computer control of an available DEC computer. Attempts to use the DEC computer to record LOGS spectra have not been successful.

Using a slot burner, the LOGS signals of atomic species in their ground electronic state (sodium 589.0 and 589.6 nm transitions) and of atomic species in excited electronic states (potassium 581.3 and 583.2 nm transitions) have been observed on an oscilloscope; and LOGS spectra produced by scanning the dye laser wavelength have been recorded on a chart recorder (see Figure 1.H.2). Both species were introduced into the methane/air flame by aspirating aqueous salts into the slot burner. The LOGS signal of sodium solutions as dilute as 10 mg sodium/L of solution (10 ppm) has been observed.

At present, welding rods are being used as electrodes, since pure tungsten has the highest melting point of any of the elements and the welding rod alloy is primarily tungsten. The electrode "ages" due to reactions with flame species, especially oxygen. We have begun an investigation of how the electrode's composition, size, and "aging" affect the LOGS signal. The LOGS spectrum of a molecular species believed to be a tungsten oxide is observable whenever the dye laser beam grazes the electrode.

Bid specifications for the frequency-doubling system have been written and are awaiting internal approval.



E electrode  
 CCP constant current power supply  
 A/D analog-to-digital converter  
 R current limiting resistor

Figure 1.H.1. Laser Optogalvanic Spectroscopy System (LOGS).

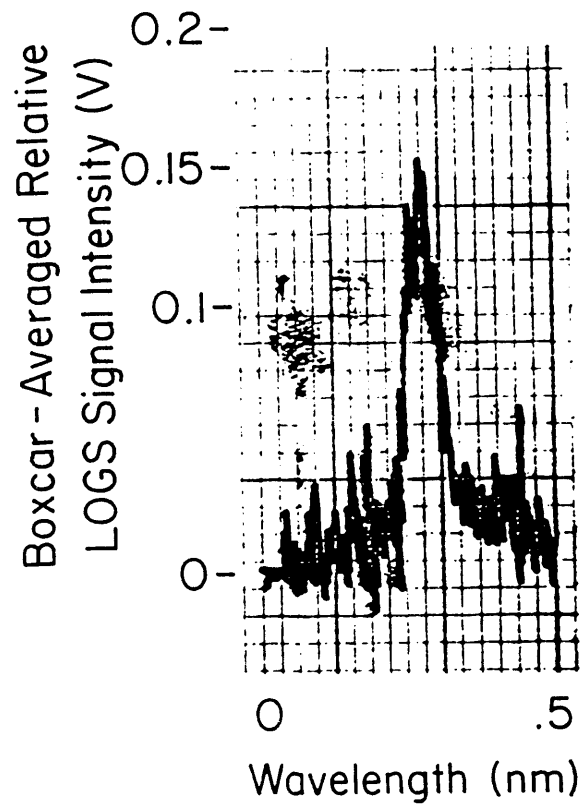


Figure 1.H.2. LOGS spectrum of potassium 581.3 nm transition.  
Scan extends from 581.0 nm to 581.5 nm.

## Conclusions

Work on this project is progressing well.

## Work Forecast

During the next quarter, investigation of the effect of electrode "aging", composition, and size on the LOGS signal will continue. Efforts to optimize the LOGS system and further enhance the signal-to-noise ratio will continue. The frequency-doubling system should be installed.

Because the DEC computer currently in use is about eight years old, it frequently needs repair. During the next quarter, delivery is expected of a PC-compatible computer system (to be shared with the DALAS system) that can be used not only to scan the dye laser, but also to collect data. Since the computer architecture of the DEC is very different from that of a PC, new computer software for the PC must be developed.

## References

1. Havrilla, G. J., and Green, R. B. 1981. Pre-Amplifier for Laser Enhanced Ionization Spectrometry. *Chem. Biomed. and Environ. Instrum.* 11:273-280.

## *I. Cross Correlation System (CCS)*

*O. P. Norton*

### Work Performed

The purchase of a personal computer with A/D board was postponed to evaluate other possible configurations such as a CAMAC (ANSI/IEEE 583) crate and transient digitizer connected to a PC with a GP-IB (IEEE 488) interface. Performance and price information was collected on these systems from several manufacturers and compared to the originally specified PC with an A/D board.

A CAMAC-based data acquisition system would be more expensive than buying an A/D board to fit into a PC. The CAMAC crate, controller, and a transient digitizer module adequate for the Cross Correlation System would cost at least \$9000. In addition, a PC would be needed to calculate the cross correlation functions. An A/D board and the PC to put it in could be purchased for less. Consequently, although the CAMAC system would offer some advantages, it represents a higher priced option than the PC with internal A/D board. Therefore, the equipment originally in the contract will be purchased.

A series of benchmarks were made using simulated data to determine the computation time for the cross correlation data reduction with different computers. The 80286 and 80386-based systems were tested with, and without, numerical coprocessors. The time required to compute the cross correlation function for different length data records on each computer was measured. Some preliminary test stand data were taken using a borrowed PC and A/D converter board.

### Conclusions

The benchmarks indicate that an 80386-based PC with an 80387 numeric coprocessor is highly desirable for computing cross correlation functions on the fly. A 25-MHz system should be purchased, as it represents a small price differential over slower systems. In contrast, a 33-MHz system represents a substantial price jump and is not justified.

Preliminary data taken on the test stand indicate that the Cross Correlation System measures a velocity which is very close to the centerline velocity measured with the LDV.

### Work Forecast

A 25-MHz, 80387-equipped, 80386-based PC with an internal A/D converter board will be purchased during the next quarter. Further data will be taken on the test stand and analyzed.

Task 2. Test Stand Operations: J. A. Etheridge

Work Performed

*A. Test Stand Modifications*

No modifications were made to the test stand.

*B. Test Stand Runs*

Nine test stand runs were completed during this quarter. Table 2.B.1 is a summary of all the test runs for this quarter. The total run time was approximately 91 hours. Three PE/AS test runs were done with oxygen enrichment. These were the first tests of this type to be done on this test stand. Oxygen was injected upstream of the combustor at a flow rate of 50 lbs/hr while combustion air flowrate was 400 lbs/hr. Air preheat was varied from 400 to 1050 K. The maximum temperature reached during these tests was approximately 2630 K. After these three test runs the combustor was removed for a visual inspection of the test stand. The only effect noted was that the ends of the port pipes that are inside the refractory lining had been burned away. This section of port pipe is used during construction of a test section as a form to mold the refractory around and does not contribute to the structural integrity of the test stand.

Table 2.B.1. Test stand runs, January - March, 1990.

RUN #	DATE	INSTRUMENTS	CONDITIONS	RUNTIME
1	1/25	SLR	Clean	8 hrs.
2	1/31	SLR/PEAS	Seed Injection	8 hrs.
3	2/6	CARS	Seed Injection	9 hrs.
4	2/14	CARS	Seed Injection	8 hrs.
5	2/22	PEAS	O <sub>2</sub> Injection	9 hrs.
6	2/27	PEAS	O <sub>2</sub> Injection	9 hrs.
7	3/1	PEAS	O <sub>2</sub> Injection	6 hrs.
8	3/6	SLR/PROBE	Clean	8 hrs.
9	3/27	CARS	Clean	6 hrs.

Task 3. Technical Support for National MHD Program: R. D. Benton

Work Performed

*A. Field Measurements*

A new device to remotely remove slag from the optical path was designed and fabricated. The PE/AS software was revised to allow data analysis with less operator intervention. Preparations were made for testing and the PE/AS system was taken to CDIF for temperature measurements at the nozzle exit.

Tests at CDIF and CFFF are scheduled for the next quarter. We anticipate PE/AS, LDV, and GAS measurements at CDIF. The TCLT, LDV, and IMPS systems are scheduled for the next CFFF test. We will continue to make measurements in support of testing at DOE facilities on request.

*B. Field Tests/Instrument Modifications*

The CARS and PSD systems will be used at the next CFFF test.

*C. Mobile Instrument Laboratory*

The Mobile Instrument Laboratory is available for field use.

#### Task 4. Project Management

This is an ongoing task considered up to date with the submission of this report.

Task 5. Technology Transfer

While mindful of the mission of this task, there is nothing to report for this quarter.

**END**

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