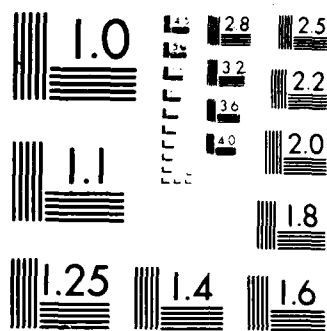| | | 1.0 | | | 2.8 | | 2.5 |
		1.1			3.2		2.2
					3.6		2.0
					4.0		1.8
		1.25			1.4		1.6

MICROCOPY RESOLUTION TEST CHART

COMPRESSION AND SHEAR WAVE PROPAGATION

IN PLAIN AND FILLED ELASTOMERS

Principal Investigator
Y.M. Gupta
Shock Dynamics Laboratory
Department of Physics
Washington State University
Pullman, WA 99164-2814

FINAL REPORT

12/1/82 - 5/31/86

Contract No. N00014-81-K-0840

September 30, 1986

WSU Contract #0106

DTIC
ELECTE
MAR 1 1 1987
E

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION	1b. RESTRICTIVE MARKINGS
UNCLASSIFIED	

2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT
N/A Since Unclassified	Approved for public release;
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	Distribution is unlimited.
N/A Since Unclassified	

4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S)
SDL - 0106 FTR	

6a. NAME OF PERFORMING ORGANIZATION	6b OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION
Washington State University Department of Physics, SDL		Office of Naval Research University of Washington

6c. ADDRESS (City, State, and ZIP Code)	7b. ADDRESS (City, State, and ZIP Code)
Pullman, WA 99164-2814	3710 Brooklyn Avenue, NE Unit No. 2 Seattle, WA 98195

8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
Office of Naval Research	ONR	N00014-81-K-0840

8c. ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS			
800 N Quincy Street Arlington, VA 22217-5000	PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

COMPRESSION AND SHEAR WAVE PROPAGATION IN PLAIN AND FILLED ELASTOMERS (UNCLASSIFIED)

12 PERSONAL AUTHOR(S)

Y.M. Gupta

13a. TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical	FROM 12/1/82 TO 5/31/86	September 30, 1986	30

16 SUPPLEMENTARY NOTATION

17	COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	ENERGETIC MATERIALS PHASE TRANSITION BAMO VISCOSITY
			HUGONIOT DATA DYNAMIC STRENGTH CdS COMPOSITES
			SHOCK RESPONSE SHEAR STRENGTH BAMO/THF ELASTOMERS

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Experimental results from several research tasks designed to address fundamental issues related to the shock response of energetic materials are summarized and discussed. Shock response of a recently synthesized energetic elastomer (BAMO/THF) and a composite (CdS/BAMO:THF) have been determined experimentally. Bulk and shear moduli, and viscosity of the elastomer were measured for different shock compressions. The elastomer behaves as a viscous fluid and no thermal decomposition was detected.

The composite results can be modeled using a simple mixture model. The experimental results show that the CdS particles experience a nearly hydrodynamic compression and no strength effects appear to be present. The measured end states are in agreement with the Wurtzite to rock salt transition observed in hydrostatically compressed CdS.

Experimental techniques have been developed to examine shock induced phase transformation in CdS single crystals. Preliminary results suggest that prior to transformation the CdS remains elastic.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	UNCLASSIFIED

22a NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Dr. Richard S. Miller	(202) 696-4406	ONR

A method to study the tension/recompression response of energetic materials has been developed and used to examine the response of a polycarbonate. Low damage experiments provide a stringent test of fracture models used to interpret the data. A research effort has recently been started to determine the P-V-T relation for shocked liquids. To date most of the effort has been spent on experimental design and assembly.

Accession For		
NTIS CRA&I	X	
DTIC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution/		
Availability Codes		
	Avail and/or	
Dist	Special	
A-1		

PREFACE

Table of Contents

I. INTRODUCTION

A. Objectives

In this report the results from several research tasks that were undertaken to address fundamental problems related to the high stress and strain-rate response of energetic materials are summarized. The present work was based on two main premises: (i) a crystalline hard material embedded in an elastomeric binder is representative of many energetic materials and (ii) model systems can be used to examine many fundamental issues important to understanding the shock response of energetic materials. Background discussion that justifies these premises and provides the rationale behind our work has been described in prior submissions to ONR. This discussion, in part, has also been presented in Reference 1.

The specific objectives of our work were as follows:

1. To determine the response of an energetic elastomer to large amplitude compression and shear waves.

2. To examine shock induced phase transformation in a material with high strength. This issue is important for understanding the role of material strength in shock induced chemical reactions.

3. To obtain experimental shock data on a composite (energetic elastomer and a hard material that undergoes a phase transformation) and to describe the experimental results in terms of the constituent response.

4. To develop new experimental methods and analyses for improved understanding of the shock response of energetic materials.

The last task is of considerable practical significance because shock characterization of propellants and explosives is a continuing need for Navy applications. Model systems are optimal for developing new experimental methods. Once developed, the methods may then be applied to propellants and composite explosives of interest.

The work described here examines the material response at the continuum level and is complimentary to the spectroscopy work designed to understand shock induced chemical reactions.[2]

B. Approach

We have chosen to examine the shock response of the materials of interest by conducting suitably instrumented plate impact experiments. The energetic elastomer we chose to study was a copolymer of 3,3-bis(azidomethyl) oxetane (BAMO) and tetrahydrofuran (THF) that has been recently synthesized by Manser.[3] Based on Manser's recommendation, a 50/50 mixture of BAMO/THF was selected for study. Experiments were conducted to examine the response of this elastomer to combined compression and shear waves. The experimental techniques are similar to those reported for solithane.[4] In Figure 1, we show a schematic view of the experimental method used to obtain time-resolved particle velocity measurements under combined compression and shear loading.[5] By varying the angle θ, the amounts of compression and shear motions imparted to the impact surface can be varied. The magnetic field can be rotated to the desired direction in the plane as shown. This method, utilizing embedded gauges, was also used for our experiments on composites.

To examine the influence of material strength on pressure induced phase transformation,[6] we elected to study CdS single crystals and to use CdS powders as a filler in the BAMO/THF elastomer. By obtaining and analyzing time-resolved measurements, we can determine the final states and the kinetics of the wurtzite to rock salt transition in shocked CdS (if this transition does occur in the shock experiments). By comparing the CdS response under two different conditions (single crystal with a large elastic limit, and powder suspended in an elastomer), we can examine the role of non-hydrostatic loading on the phase change.

Regarding the development of new experiments and analysis, we have concentrated on developing a method that permits time-resolved measurements during tension and recompaction; and examined the feasibility of developing a method to measure temperature in shocked liquids and elastomers. Both of these developments are expected to be of considerable value in characterizing and understanding the impact response of energetic materials.
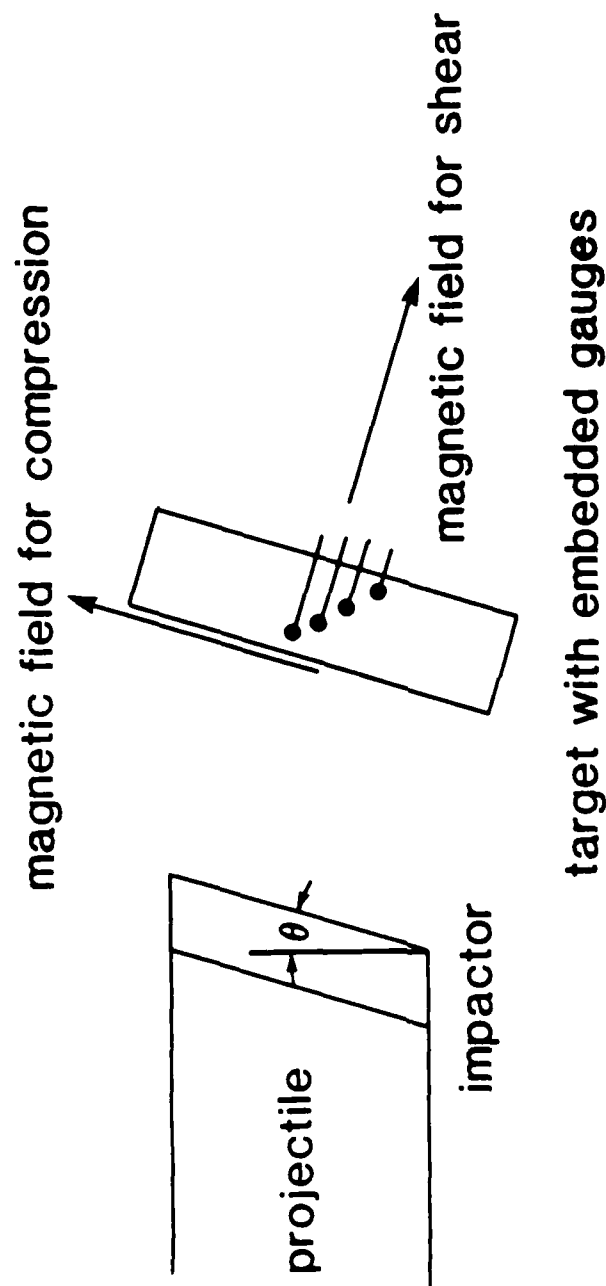
Fig. 1. Schematic view of the experimental arrangement for compression-release and shear measurements using electromagnetic gauges.

II. SUMMARY OF EXPERIMENTAL RESULTS AND DISCUSSION

The main findings of the present work are summarized and discussed in this section. Where applicable, the experimental method is described briefly. Because most of the experiments are the first of their kind, a considerable amount of effort was spent in developing experimental techniques and performing preliminary experiments. Detailed discussion of the experimental method and analysis, and further discussion of results, will be presented in journal articles.

A. Compression and Shear Wave Propagation in BAMO/THF

Results of quasi-static characterization of BAMO/THF (50/50) by Dr. R. Reed of NWC, China Lake, are indicated in Table I.

TABLE I: Quasi-Static Measurements*

	BAMO:THF	BAMO:THF + 54% CdS
Young's Modulus	176 PSI	612 PSI
Maximum Tensile Stress	63 PSI	273 PSI
Maximum Elongation	44%	70%

* Courtesy of Dr. R. Reed, NWC, China Lake, CA.

As is typical of elastomers, the material has a low modulus and strength under tension. The BAMO/THF used in our work was sent to us as monomers by Rocketdyne and polymerized in our laboratory using the procedure described by Manser.[3] Because of using materials from different batches and our learning of the procedures to cast samples with embedded gauges, the experimental scatter was higher than the scatter usually observed in shock wave data.

Several combined compression and shear wave experiments were conducted to measure compression and shear wave profiles at different depths in the sample interior. Two features of the profiles were

noteworthy: the compression wave profiles were nearly steady (at least within the experimental bounds) and the shear wave attenuation with propagation distance was extremely high. From a qualitative examination of the wave profiles, the material appeared to behave like a viscous fluid under shock loading.

Because the wave-profiles were nearly steady, the Rankine-Hugoniot jump conditions could be used to obtain the stress-volume compression curve. The results of nine such experiments (using different impactors and impact velocities) are shown in Figure 2. Along the x-axis, we have plotted the density compression ($\mu \equiv \rho/\rho_o - 1$). The two points far off the curve came from a batch that may not have been synthesized properly. Results of some tension measurements for this batch were also anomalous. The smooth curve drawn to fit the data is representative of a material that is initially very compressible.

By measuring the release (longitudinal) and shear wave velocities in the shocked state, we were able to determine the bulk, K, and shear, G, moduli in the shocked state. These results are shown in Figure 3. Several features are noteworthy. The bulk modulus increases nonlinearly with compression: the shear modulus is only measurable beyond about 15% compression; $G/K << 1$ over the entire range; there is considerable scatter in the data. The larger scatter, in contrast to crystalline materials, was also observed for solithane. The difficulty in positioning the gauges very accurately in such a compliant material is a possible source of the scatter.

Using the Hugoniot curve shown in Figure 2 and the initial slope of the release wave (isentrope), the Gruneisen constant Γ can be evaluated using the Hugoniot differential relation.[7] We have obtained a value of $G' \equiv \rho\Gamma = 5.6\pm0.6 \ gm/cm^3$ from our data. Using this value of G' and $C_v = 0.81 \ cal/gm^\circ C$, the calculated temperature rise along the isentroipe and the R-H curve is shown in Figure 4. The C_v value was derived using a Dulong-Petit law following Manser's suggestion. The temperature rise along the isentrope and the Hugoniot curve is nearly identical until $\mu \approx 0.15$. Then the temperature along the Hugoniot, as expected, increases. The large error bars reflect the uncertainty in the constants used to evaluate the temperature increase.

The decomposition temperature of this material at ambient pressure is approximately 200 $^\circ C$. Pac has reported a small increase in the decomposition temperature with confining pressure.[8] However, in the absence of kinetic effects, the temperature rise in our experiments is beyond the decomposition temperature expected from extrapolating Pac's results to the pressures in our experiments. The

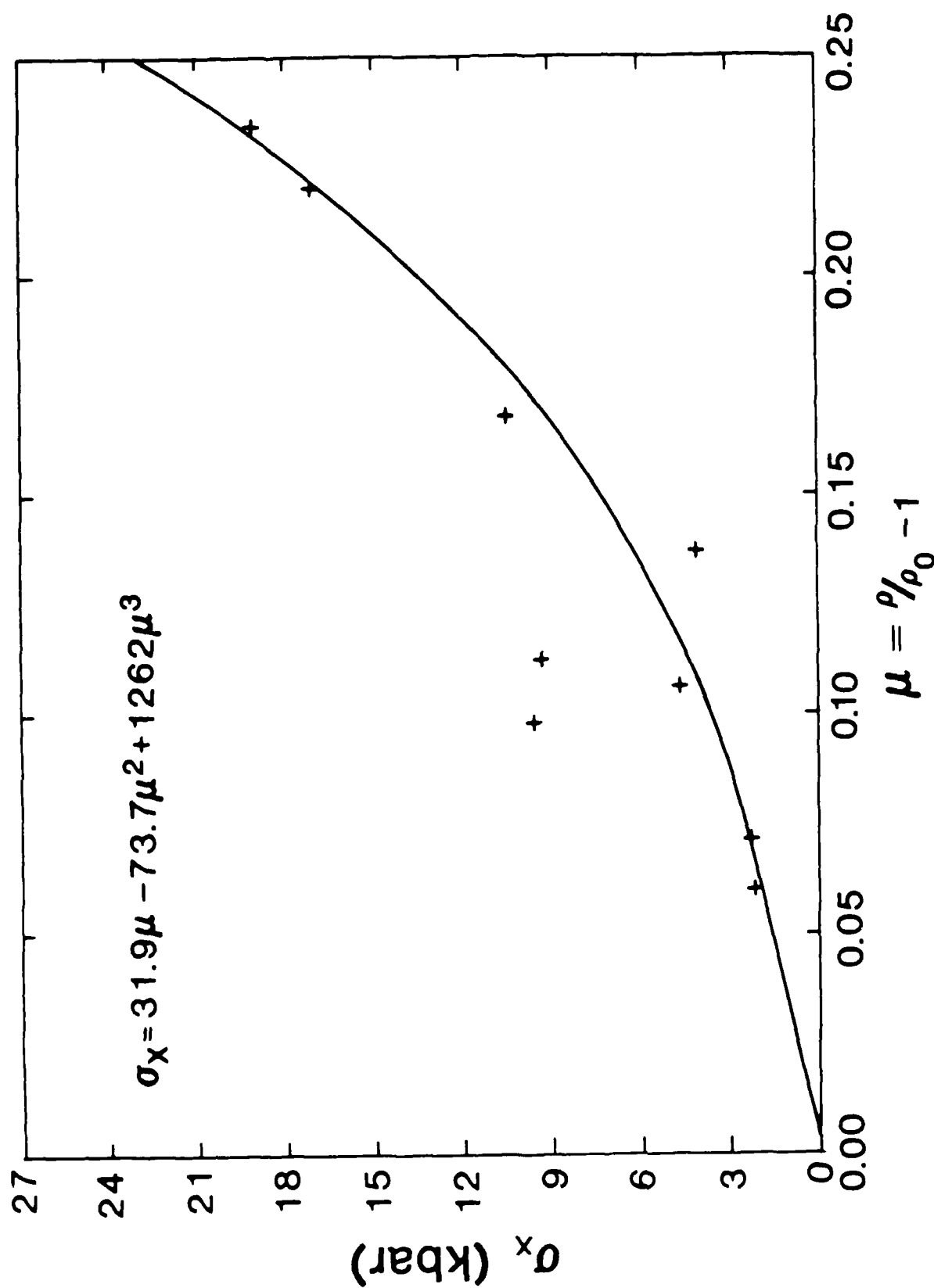$$\sigma_x = 31.9\mu - 73.7\mu^2 + 1262\mu^3$$

Fig. 2. Shock compression curve for BAMO/THF. The polynominal shown in the figure was used to fit the data.
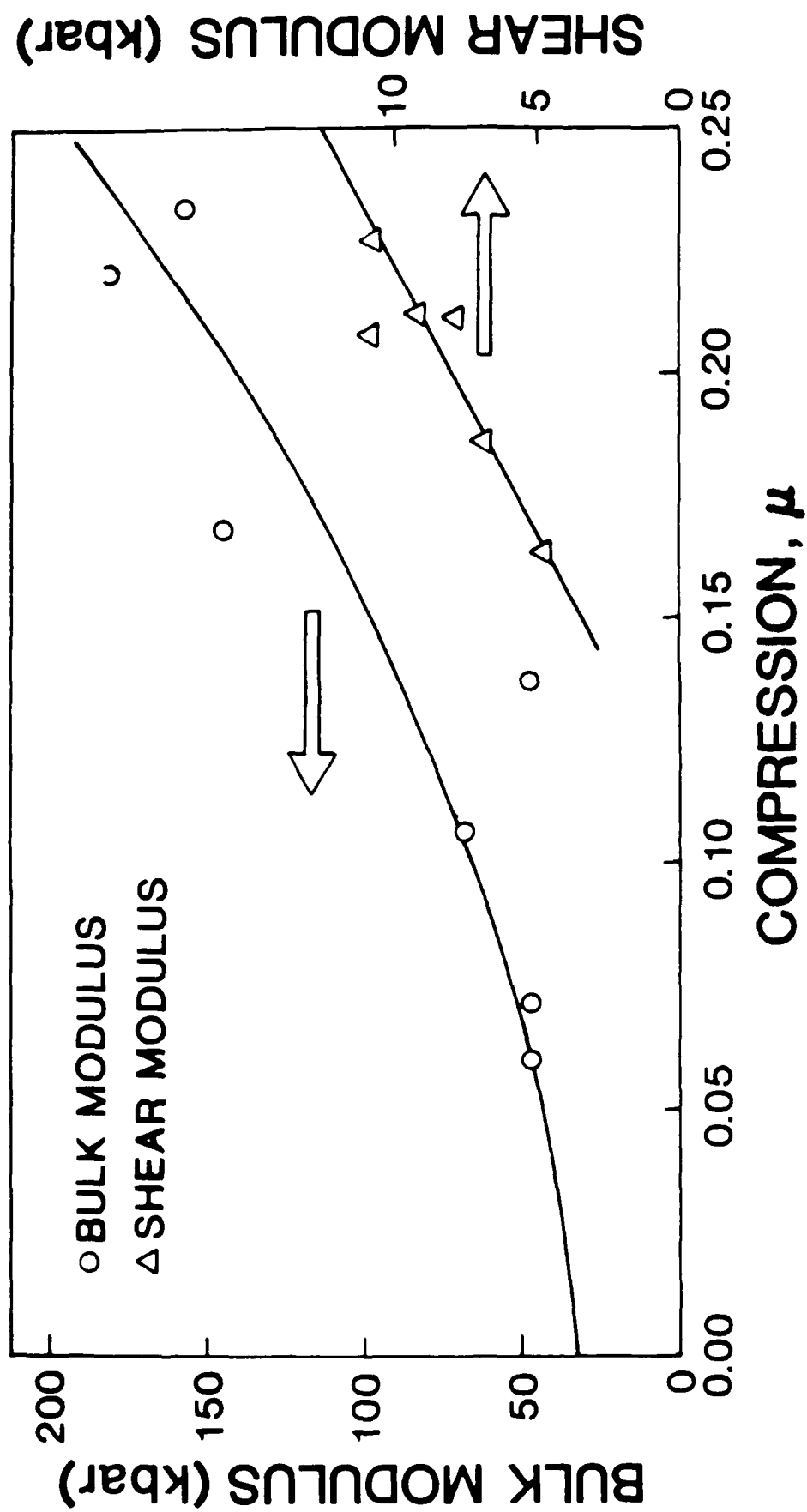
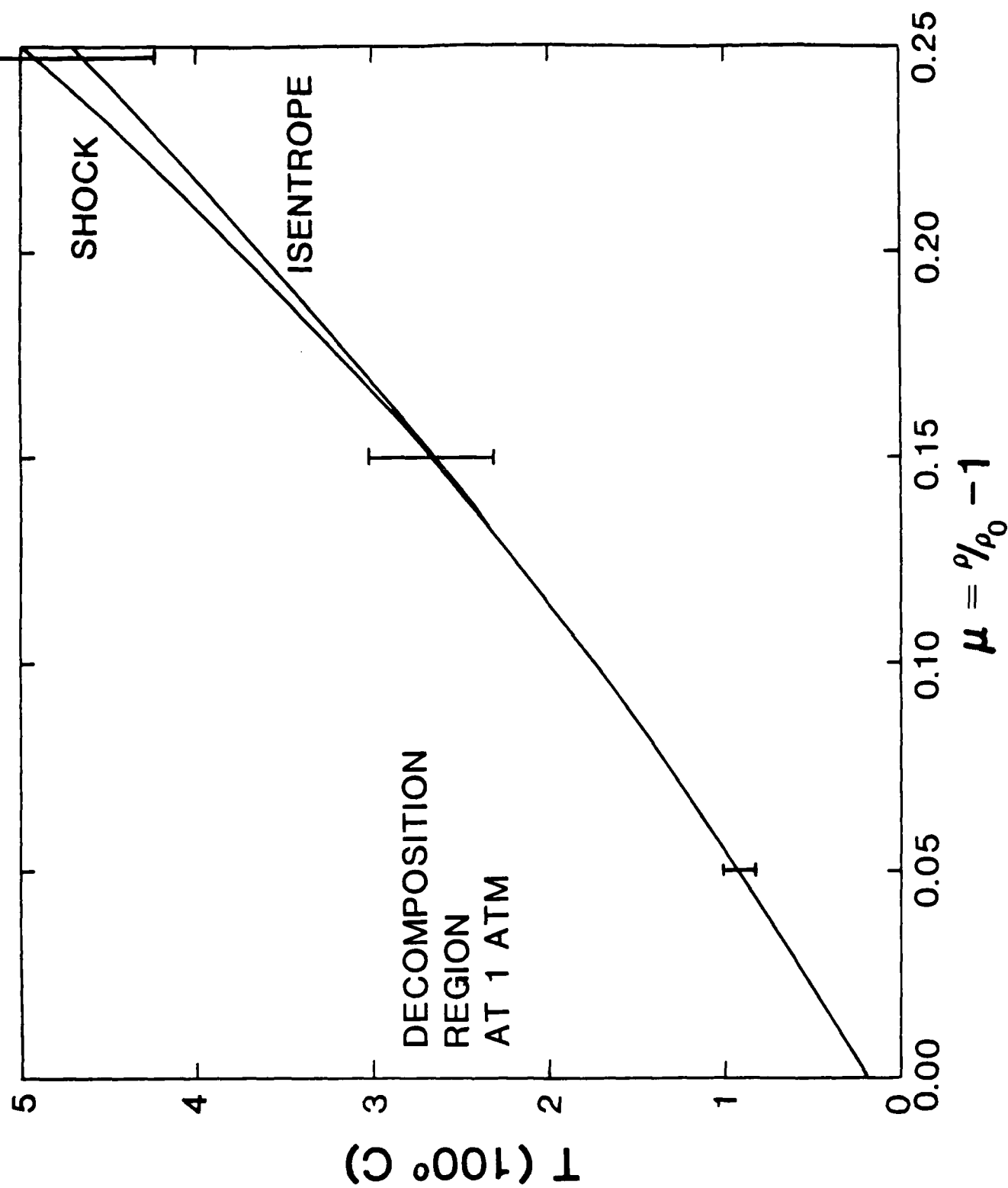Fig. 3. Bulk and shear moduli as a function of compression in shocked BAMO/THF.

Fig. 4. Calculated temperature rise along the isentrope and the Hugoniot in BAMO/THF.

absence of decomposition (as evidenced by the lack of increasing pressure) suggests that there is not sufficient time for decomposition. In the absence of temperature measurements, this conclusion must be considered tentative.

The observation of steady compression waves in the BAMO/THF coupled with $G/K < < 1$ allows us to treat BAMO/THF like a viscous fluid and use the steady wave analysis of Band and Duvall[9]. Using Duvall's procedure for analyzing the shock-front thickness, we have obtained viscosity as a function of compression. The measured values plotted in Figure 5 were fitted by a smooth curve. The viscosity measurements shown in Figure 5 are the first of their kind for elastomers and are expected to be valuable to "hot spot" calculations in propellants. Most such calculations to date have been hampered because good measurements of coefficients describing dissipative and transport properties are not available at high stresses and strain rates.

The results described have provided a comprehensive characterization of the elastomer and demonstrated an experimental approach that may be extended to other materials of interest.

B. Shock Response of CdS/BAMO:THF Composite*

This research effort had two main goals: (i) to determine the shock response of the composite and to model it in terms of its constituents, and (ii) to examine the effects of the elastomer matrix on the phase transition in CdS. The particle size of the CdS was in the 3-5 μm range and weight fraction of the CdS was 54%. This weight fraction (corresponding to a volume fraction of 22.63%) gave reproducible and pore-free samples. The initial densities of the BAMO:THF and CdS are 1.2 gm/cc and 4.83 gm/cc, respectively.

Using the multiple, embedded, particle-velocity gauges, a total of 6 experiments have been performed to date. Because the waves were unsteady but non-attenuating, the data were analyzed using the procedure described by Fowles and Williams[10]. The mass and momentum equations at a gauge location can be written as[3] :

Fig. 5. Viscosity as a function of compression in shocked BAMO/THF.

VISCOSITY (poise × 10^3)

$\mu = \rho/\rho_0 - 1$

$$d\sigma = \rho_o C_\sigma \, du \qquad (1)$$

$$dV = -\frac{du}{\rho_o C_*} \qquad (2)$$

Although $C_\sigma \neq C_*$ in general, we have used the approximation $C_* = C_\sigma$ and calculated the stress-strain paths using the above equations. The results are shown in Figure 6. The initial linear loading path followed by a decreasing slope is typical of a viscoelastic material. The dashed curve is the compression curve obtained by using a very simple mixture model.

$$V_m = f_1 V_1 + f_2 V_2 \qquad (3)$$

where V_m = specific volume of mixture

V_i = specific volume of ith constituent

f_i = volume fraction of constituent

At a given pressure P, the specific volume of the mixture is calculated using Eq. (3). The individual V_i values in Eq. (3) are calculated using the BAMO:THF results described in Section II.A and using the CdS results from the hydrostatic measurements of Samara and Giardiani.[11] The good agreement between the calculated mixture model and the experimental results (the peak state from each experiment) is quite remarkable. It appears that the CdS powder because of the low volume fraction experiences a nearly hydrodynamic compression due to the nearly fluid-like response of the BAMO:THF. Hence, the simple approach used here appears to work.

The shape of the $P-V$ curve (the locus of the end states) in Figure 6. explains why a two-wave structure is not observed in the gauge experiments despite the phase transition in the CdS. To observe a two-wave structure, either the volume fraction of the CdS needs to be increased substantially or a double shock experiment needs to be performed.

A considerable amount of effort was also spent in the past year in an attempt to develop new approaches or to refine existing methods for analyzing unsteady wave profiles (Lagrangian Analysis). Some success has been obtained and this work is continuing in conjunction with our experiments. Upon completion, we anticipate a publication describing the new developments for analyzing unsteady waves.
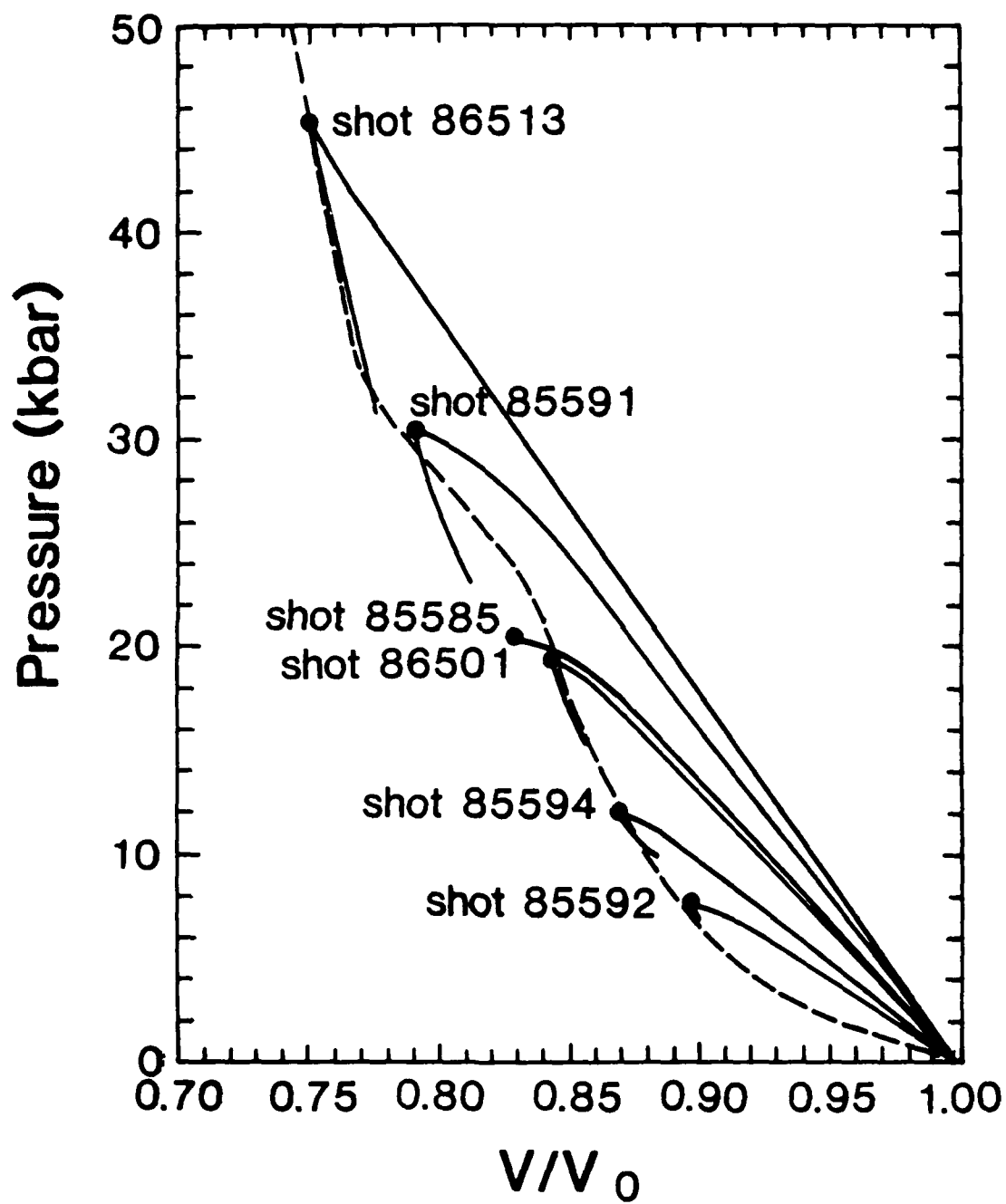
Fig. 6. Loading paths and end states in shock compressed CdS/BAMO:THF composite. The dashed curve is the calculated curve based on a simple mixture model.

In future work we will perform experiments to examine the composite response to double shocks and determine unloading wave profiles for single shock exeriments. Both of these are expected to confirm the transformation inferred from the $P-V$ curve shown in Figure 6.

C. Shock Induced Phase Transformation in CdS Single Crystals.

A useful precursor to understanding the role of material strength in chemical reactions would be to examine the effect of material strength on pressure induced phase transformations. As indicated in the review of Duvall and Graham,[12] most studies of shock induced phase transformation do not take into account the role of material strength; there is a strong need for experimental data. As suggested by Duvall, CdS single crystal is a natural candidate for studying this problem because it is a hard material (expected to have a large HEL) that undergoes a polymorphic phase transformation (Wurtzite → rock salt structure). This transition has been extensively examined in hydrostatic studies. Existing shock data consist of two experiments by Kennedy and Benedick[13] (one along the c-axis and one along the a-axis) that show an ill-defined two wave structure.

The intent of the present work was to develop an experimental method and then to use this method to establish the transformation and its kinetics under shock loading. In a subsequent effort, the effect of superposed shear on the transformation could then be examined. Because of the difficulty in interpreting the strongly time-dependent behavior at the CdS/Quartz gauge interface, only limited information can be obtained from an experiment of the type reported by Kennedy and Benedick.[13] We chose to augment these results by monitoring the stress-time (or particle velocity-time) profile at the interface between the elastic impactor and the CdS crystals. With these two types of measurements the following information can be obtained: amplitude and velocity of the first wave arriving at the CdS/Quartz interface, and time-resolved measurements of the initial and final states at the impact surface. These data can then be analyzed to determine if the two wave structure is indeed due to a phase transformation and to obtain information about the crystal lattice at the onset of transformation. In hard crystals, it is reasonable to conjecture that the phase transition may occur in the elastic state and, therefore, provide a mechanism for the collapse of the stress deviators.

The progress of this work was not as good as initially hoped for. This was, in part, due to a succession of experimental difficulties. These difficulties were compounded by the small size of crystals (typically 15 mm x 15 mm) and the very limited material availability. The overall experimental configuration used to date is shown in Figure 7. In these experiments, the wave profile transmitted
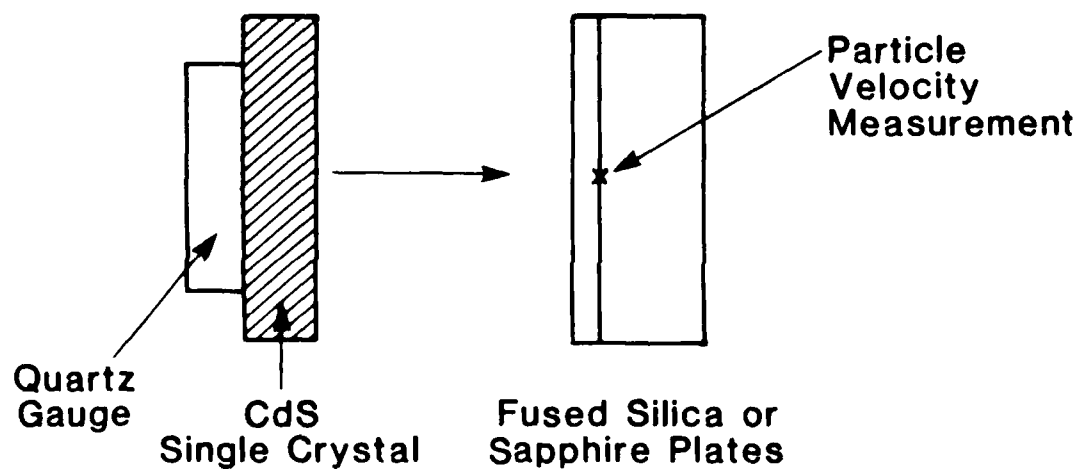
Fig. 7 Schematic view of the CdS single crystal experiments. Particle velocity measurement at the position indicated were made using electromagnetic gauges and laser interferometry (VISAR)

through the crystal is measured using the quartz gauge and the particle velocity profile is monitored at the impact surface. Initially, we had planned to use electromagnetic particle velocity gauges. However, the very strong polarization signal from the shocked CdS made it almost impossible to use this approach (The polarization signal from the uncoated CdS masked the rather large output of the rear surface quartz gauge). In subsequent experiments, the CdS crystals were completely encapsulated in a vapor-deposited metallic coating to obtain meaningful data from the quartz gauge.

The large electrical noise necessitated that an interferometric technique like the VISAR[14] be used to monitor the impact surface particle velocity profiles. The very small size of the samples (this causes interference from the light emission from the fused silica edges) coupled with the fact that these experiments were the first of their type in our laboratory resulted in considerable time and effort in implementing the experimental method. Although we did get some useful VISAR data, the strongly time-dependent response of the CdS above 35 kbar did not permit an unequivocal interpretation. The two PM tubes give different results, which though not completely surprising, makes it difficult to interpret the data.

We have now gone to a method where the impact surface profile will also be monitored using a quartz gauge. By using a sapphire buffer in front of the quartz gauge, we can record the CdS response well in excess of 40 kbar. Preliminary experiments to calibrate our shorted gauges in the experimental configuration of interest are underway.

To date, the following results have been obtained. Because of the limited number of experiments and the use of different techniques, these results should be treated as preliminary.

1. At an impact stress of 23 kbar, the CdS behaves like an elastic solid and a single wave is transmitted.

2. At elastic impact stresses (obtained by using an elastic impactor and assuming an elastic response of the CdS) above 40 kbar, the transmitted signal is similar to that observed by Kennedy and Benedick; that is, the first jump is followed by a decay to a plateau and then an increase to the final stress of the second wave.

3. Within the experimental error of these first experiments (3-4%), the amplitude of the first wave agrees with the elastic impact stress up to 42 kbar. At higher stresses, there are significant differences suggesting that the HEL is approximately 42 kbars.

4.   The plateau amplitude recorded by the quartz gauge (though difficult to interpret) remains con-
     stant even when the elastic impact stress is changed from 40 to 60 kbars.

The above results suggest that the transformation may be proceeding from an elastic state. If so, then
the region between 35 and 42 kbar needs to be examined carefully.

D. Development of Experimental Methods

Two experimental developments of potential significance to the shock response of energetic materials
have been examined in our work. These methods along with the progress to date are summarized
below.

1. Tension-Recompression Response of Shocked Solids[15]

In recent years there has been an increased interest in understanding tensile damage and its effects
on chemical reactions in energetic materials. The experimental method developed here was
motivated by the need to quantify the recompression response of the dynamically fractured material
on the microsecond time scale. The technique described here can also be used to detect a chemical
reaction that may result from the subsequent recompression pulse. As a part of the experimental
development we chose to examine the behavior of a polycarbonate (trade name Lexan) produced by
the General Electric Company because the tensile response of this material has been characterized at
SRI in a previous study.[16] More recently, the tension/recompression method has been extended to
examine a VRA propellant.[17]

The experimental configuration for the tension-recompression experiment is shown in Figure 8. The
usual configuration of the tension experiment is modified by incorporating a thin gap (of the order of
0.1 mm) followed by a recompression plate. In the usual tension experiment, the pulse amplitude
and duration are controlled by the impactor velocity and relative thickness of the impacting plates.
In this experiment, the gap width provides additional control on the tensile duration. The
recompression pulse amplitude can be varied by varying the recompression plate impedance.

An important aspect of the experiment is the ability to make time-resolved measurements at the front
surfaces of the sample and the recompression plate. In our experiments, we have chosen to use
electromagnetic particle velocity gauges. In many situations it may be advantageous to use laser
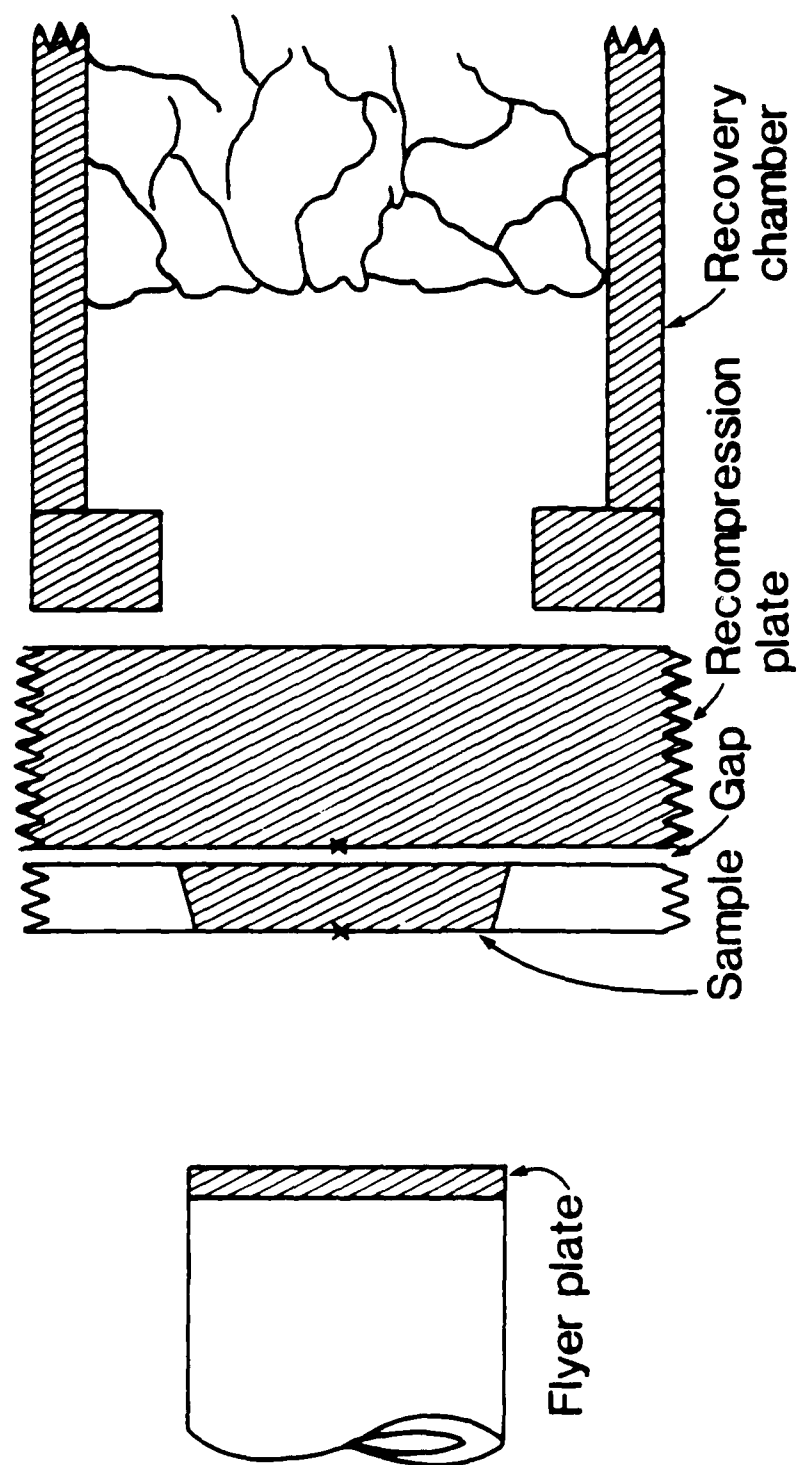
Fig. 8. Experimental arrangement for tension/recompression measurements. The crosses in the target locate the position of the particle velocity measurements.

interferometry to monitor the particle-velocity at the recompression plate surface. To see the significance of the experimental measurements, calculated particle velocity profiles for two idealized cases are shown in Figure 9 for a Lexan impactor and a Lexan target. The two bounds shown in Figure 9 demonstrate that time-resolved particle velocity measurements are central for understanding the material response.

The particle velocity profile at the recompression plate surface for an impact velocity of 0.302 mm μs is shown in Figure 10. In this experiment, the Lexan target plate spalled into two pieces. The calculated response shown in Figure 10 for this experiment was based on a model similar to that of Cochran and Banner.[18] During compression the material response was taken to be linear elastic; the tensile parameters for the calculations were obtained by iteratively matching several experiments.

Further experimental results and comparisons with two different types of tension models may be seen in Reference 15. The main findings of this developmental effort are as follows: the experimental method appears to be useful for examining the tension/recompression response under uniaxial strain loading; experiments performed at impact velocities close to the threshold provide a stringent check of the tension models. The complicated nature of the experiment requires a wave-propagation code for both design and interpretation of the experiments. It would be both interesting and useful to apply this technique to an explosive.

2. Temperature Measurements in Shocked Liquids

The inability to measure temperature in shocked materials is a major shortcoming in developing equations of state from shock wave experiments and in studying shock induced chemical reactions. Despite the assumptions of thermal equilibrium, accurate estimates of temperatures in shocked samples are difficult because of a lack of appropriate thermodynamic data under the conditions of interest. In recent years, optical emission methods have been attempted to infer shock temperatures at very high compressions. For chemical reaction studies, methods that are applicable to more modest compression (1-100 kbar) would be desirable. Because of the importance and difficulty of this problem, we have attempted a modest effort in this direction.

Our approach is to monitor the thermal resistivity of metallic foils/films in contact with shocked liquids. The choice of studying liquids in contrast to solids is a central aspect of our work because we avoid many of the problems that arise in studying shocked solids: strength effects, thermal bonding etc. Our work to date has been in two parts.
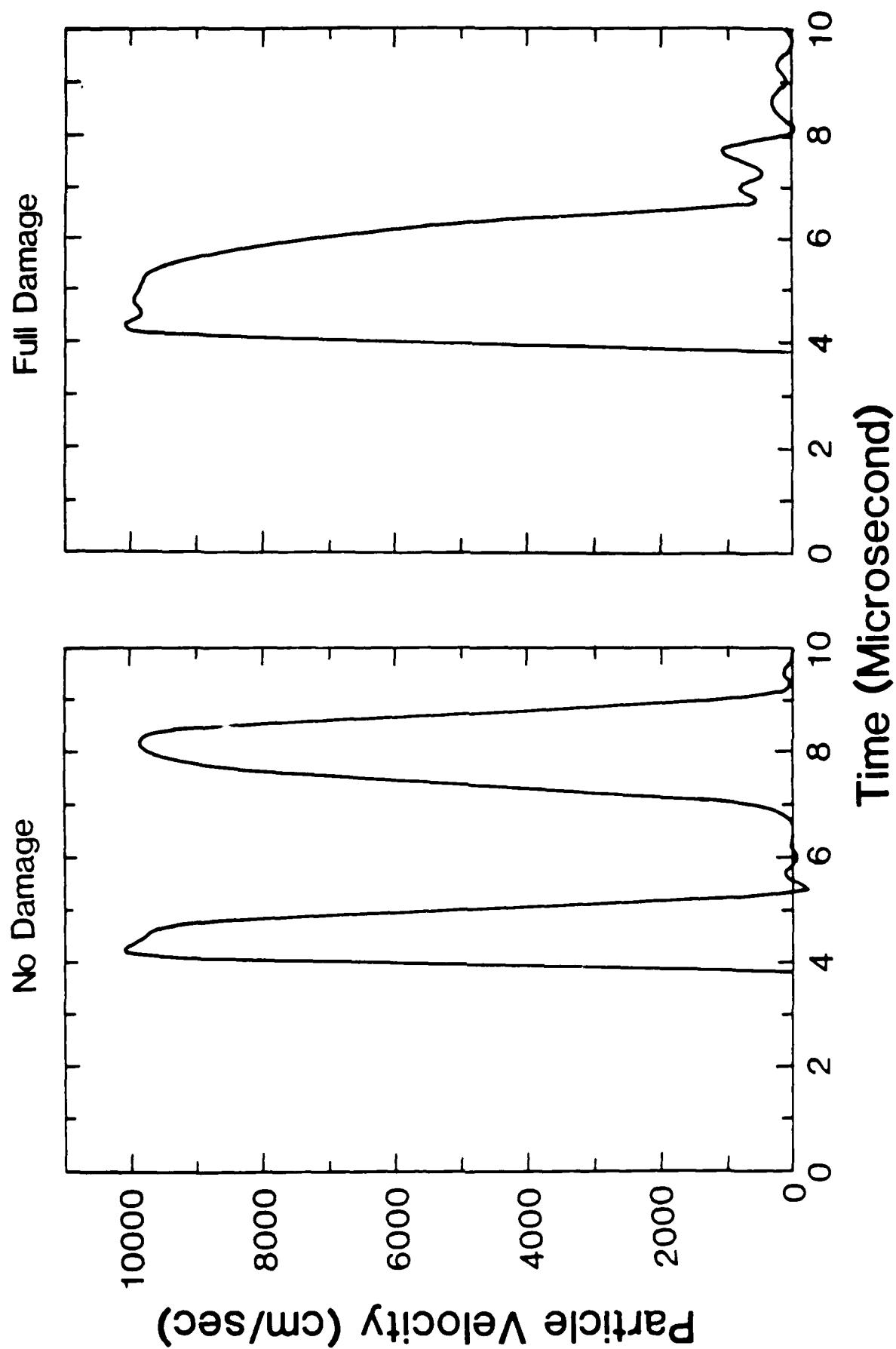
Fig. 9. Calculated waveforms at the recompression surface for the no-damage and the full spall case. Most realistic situations are bounded by these two extremes.
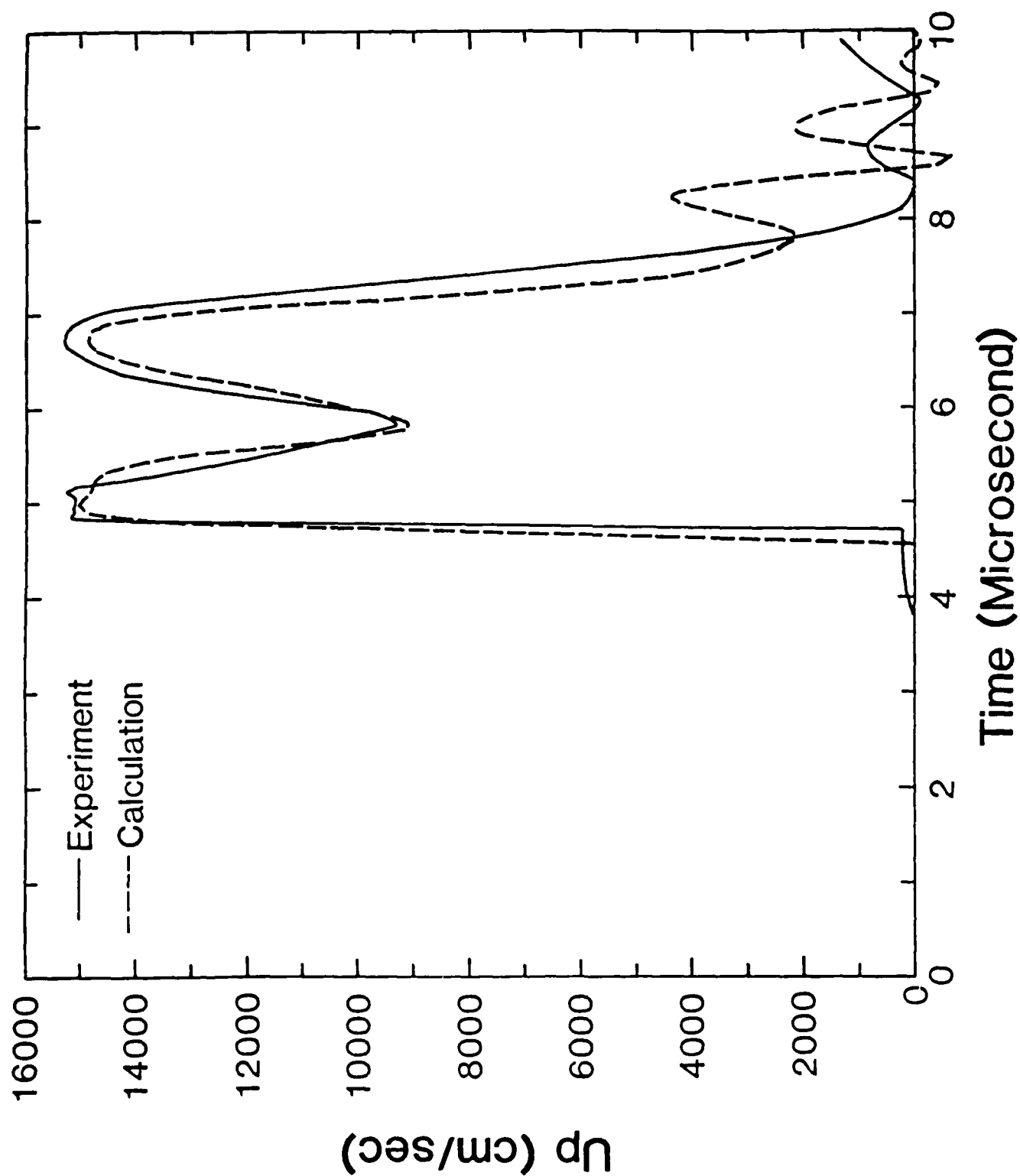
Fig. 10. Particle velocity-time profile at the recompression plate surface from the full spall experiment (impact velocity = 0.3 mm/μs). The calculated response is shown as the dashed curve.

In the first part, we monitored the resistance change of thin copper foils (~ 50 μm) suspended in liquids contained in appropriately designed cells. As expected, on the basis of heat conduction calculations, negligible changes were seen on the time scale (~ 1 μs) of our experiments. Essentially, the very low thermal conductivity of the liquid in contrast to the metallic foil does not permit heat flow into much of the foil. These experiments gave two important results: temperature measurement using this concept would require the use of very thin films (0.2 μm - 0.4 μm); experiments with foils can be used to monitor large changes in thermal conductivity in shocked liquids. Although we are not pursuing the latter result at the present, it is expected to be of considerable value to energetic material response at high strain rates. Knowledge of transport properties at high stresses and strain-rates is central to continuum modeling of "hot spot" formation and growth.

Because of our immediate interest in temperature measurements we have concentrated on developing an experimental method using very thin films. The target consists of a liquid in contact with a very thin metallic film (0.15 μm - 0.35 μm) deposited on an elastic substrate that has low thermal conductivity. Heat conduction calculations using this configuration and dimensions typical of our experiments suggest that the film will equilibrate (on the time scales of interest) to a significant fraction (30-40%) of the maximum liquid temperature.

The work to date has concentrated on defining the problem quantitatively, designing the experiments, determining experimental parameters using heat conduction calculations and performing a few preliminary experiments. To date, gauge survival remains as the major problem. Almost all of the effort has gone into experimental developments including methods to accurately monitor film thickness after deposition, to calibrate the temperature coefficient of gauge resistivity over the temperatures of interest, etc.

It should be emphasized that even if the experiment is successful, the measurement of shock temperatures will not be a routine measurement and will require considerable interpretation. However, the successful completion of the research effort described here will be a significant step towards solving an important problem in shock response of liquids and shock-induced chemical reactions.

Initially, we have concentrated on liquid CS_2 because of the parallel effort by Duvall and co-workers on both the optical spectroscopy and the EOS development.[2] If our experimental effort is successful, a central aspect of our work will be to ensure that we are indeed monitoring temperature. To this end, liquid CS_2 is a good candidate because of previous theoretical and experimental work.

III. PUBLICATIONS, PRESENTATIONS AND RESEARCH PERSONNEL

A. Publications

1. Y.M. Gupta, Invited Article on "Shock waves" in *Encyclopedia of Physics.* Third Edition (Van Nostrand Reinhold Company, New York, NY, 1985).

2. P. Majewski, Y.M. Gupta, and L. Seaman, "Tension-recompression response of shocked loaded polycarbonate", in *Shock Waves in Condensed Matter.* Editor, Y.M. Gupta (Plenum Publishing, New York, NY, 1986).

3. P.P. Majewski and Y.M. Gupta, "Shock wave response of an energetic elastomers", (paper to be submitted to J. Appl. Phys.).

4. Z.P. Tang and Y.M. Gupta, "Effect of an elastomeric matrix on shock induced phase transition in CdS", (manuscript under preparation for submission to J. Appl. Phys.).

5. Y.M. Gupta, Invited Article on "Shock waves in condensed matter", in *The Encyclopedia of Science and Technology.* (McGraw-Hill), in press.

B. Presentations

Invited Talks:

1. "Large amplitude compression and shear wave propagation in condensed materials", Acoustical Society of America Meeting, Minneapolis, MN (October 1985).

2. "Compression and shear wave propagation and shock reverberation experiments in condensed matter", Seminar at Graduate Aeronautical Laboratory, California Institute of Technology, Pasadena, CA (January 1985).

3.   "Shock waves in condensed matter", Presentation at the Symposium on Shock Wave Chemistry at the American Chemical Society Meeting, Chicago, IL (September 1985).

4.   "Summary of work on shock wave response of LiF single crystals", ONR Workshop on Relationship of Microstructure to Initiation Mechanisms in Energetic Materials, NSWC, Silver Spring, MD (January 1986).

Contributed Talks:

1.   "High strain-rate shear deformation of a polyurethane elastomer subjected to impact loading", Fourth Cleveland Symposium on Macromolecules: Irreversible Deformation of Polymers, Cleveland, OH (June 1983).

2.   "Dynamic shear properties of shocked liquid", Third APS Topical Conference on Shock Waves in Condensed Matter, Sante Fe, NM (July 1983).

3.   Coauthored with P. Majewski, "Response of an energetic elastomer to combined compression and shear loading", Third APS Topical Conference on Shock Waves in Condensed Matter, Sante Fe, NM (July 1983).

4.   Coauthored with R. Gustavsen, "Resistivity measurements of thin copper films (0.2 μm) to infer temperature in shocked liquids", Bull. Am. Phys. *30*, 1294 (1985).

5.   Coauthored with P. Majewski and L. Seaman, "Tension-recompression response in shock loaded polycarbonate", Bull. Am. Phys. Soc. *30*, 1304 (1985).

Participation in Workshops:

1.   "Shock compression chemistry in materials synthesis and processing", sponsored by the National Materials Advisory Board at the Battelle Center, Seattle, WA (March 1983).

2. "Relationship of microstructure to initiation mechanisms in energetic materials", sponsored by ONR at NSWS, Silver Spring, MD (January 1986).

C. Other Professional Activities

1. Chairman, Fourth APS Topical Conference on Shock Waves in Condensed Matter, Spokane, WA (July 1985).

2. Editor, *Shock Waves in Condensed Matter.* (Plenum Publishing, New York, NY, 1986).

D. Research Personnel Supported Under This Contract

1. P.M. Bellamy, Senior Research Engineer
2. P.P. Majewski, Postdoctoral Research Associate
3. Z.P. Tang, Visiting Scientist
4. R. Gustavsen, Graduate Student
5. B. Patyal, Graduate Student
6. J. Thompson, Engineering Technician

REFERENCES

1. W.J. Murri, Y.M. Gupta, and D.R. Curran, See Appendix in "Fracture and fragmentation of high energy propellant", SRI International Final Report to Lawrence Livermore Laboratory, Contract No. 112 under ERDA E(04-3) -115 (1979).

2. G.E. Duvall, "Optical spectroscopy of dynamically compressed liquids", Final Technical Report, for ONR Contract N00014-77-C-0232, June 30, 1986.

3. G. Manser, Work carried out under ONR Contract N00014-79-C-025, NR093-063 (1981).

4. Y.M. Gupta, Polymer Engineering and Science, *24*, 851 (1984).

5. Y.M. Gupta, Appl. Phys. Lett. *29*, 694 (1976).

6. G.E. Duvall, "Shock induced phase transitions in solids", in *Propagation of Shock Waves in Solids*. AMD, Vol. 17, pp. 97-114, Am. Soc. Mech. Engr. (1976).

7. G.E. Duvall and G.R. Fowles in *High Pressure Physics and Chemistry*. Eds. R.S Bradley (Academic Press, New York), 1963.

8. K.D. Pae, Presentation at ONR Review Meeting, Chestertown, MD (1985).

9. W. Band and G.E. Duvall, Am. J. Phys. *20*, 780 (1961); also unpublished work by G.E. Duvall.

10. R. Fowles and R.F. Williams, J. Appl. Phys. *41*, 360 (1970).

11. G.A. Samara and A.A. Giardiani, Phys. Rev. *140*, A388 (1965).

12. G.E. Duvall and R.A. Graham, Rev. of Modern Phys. *49*, 523 (1977).

13. J.D. Kennedy and W.B. Benedick, J. Phys. Chem. Solids. *27*, 125 (1966).

14. L.M. Barker and R.E. Hollenbach, J. Appl. Phys. *43*, 4669 (1972).

15. P. Majewski, Y.M. Gupta, and L. Seaman, "Tension-recompression response of shock loaded polycarbonate", in *Shock Waves in Condensed Matter* ˉ lited by Y.M. Gupta, (Plenum Publishing, New York, NY, 1986).

16. D.R. Curran, D.A. Shockey, and L. Seaman, J. Appl. Phys., *44*, 4025 (1973).

17. Y.M. Gupta and M.C. Cowperthwaite (unpublished).

18. S. Cochran and D. Banner, J. Appl. Phys., *48*, 2729 (1977).

END

4-87

DTIC