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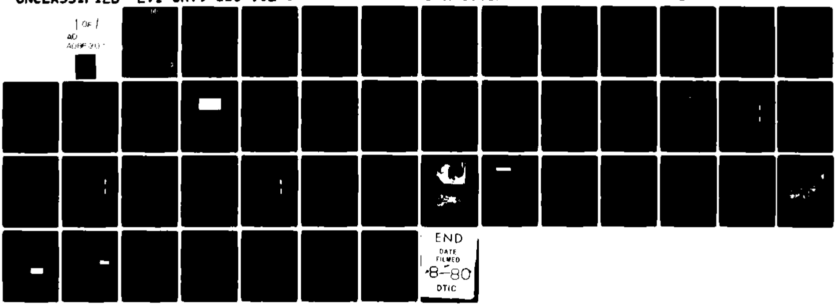

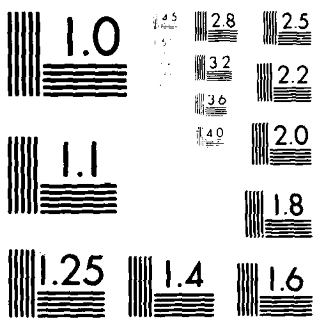

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TWCP ELECTRON BEAM TESTING PROGRAM

Volume III - Material Response Instrumentation for the Blackjack III Electron Beam Facility

Effects Technology, Inc.
5383 Hollister Avenue
Santa Barbara, California 93111

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F. A. Bick

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Impulse and Stress Generation	Electron Beam Diagnostics
Impulse Measurements	In-Situ Calorimetry

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Volume III of four volumes. This volume describes the instrumentation developed to characterize the Blackjack III pulsed electron beam facility environment, and to obtain impulse and stress generation data on FM5822A carbon phenolic, and 91-LD phenolic resin. The primary diagnostical contribution was the development of an in situ fluence measurement technique that significantly reduced experimental uncertainties. Impulse data were obtained using a translating Ronchi ruling and fiber optic light guide. Stress data

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Blackjack III Electron Beam Characterization
Depth-Dose Measurements

20. ABSTRACT (Continued)

were obtained simultaneously with the impulse measurements using a laser interferometer. This technique increased the amount of data obtained, and also provides a direct correlation between the impulse and stress data. These gages were all designed to operate in the intense radiation environment associated with a pulsed electron beam machine, and also in the magnetic field (25 kG) used to guide the electron beam.

PREFACE

This work was done for Effects Technology, Inc. (ETI) under the sponsorship and guidance of Mr. Donald Kohler of the Defense Nuclear Agency (DNA). Mr. M.J. Rosen was the ETI program manager. General program planning and execution were accomplished jointly with the participation of the following individuals and organizations:

D. R. Schallhorn, Harry Diamond Laboratories, (HDL)
M. J. Rosen, Effects Technology, Inc., (ETI)
C. D. Newlander, Air Force Weapons Laboratory, (AFWL)
D. A. Phelps, Maxwell Laboratories, Inc., (MLI)
N. H. Froula, Corrales Applied Physics Company, (CAPCo)

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This is the third volume of a four volume set describing the electron beam experimets in support of the TWCP Correlation Program. The four volumes are:

TWCP Electron Beam Testing Program:
Volume I - Summary

TWCP Electron Beam Testing Program:
Volume II - Preliminary Characterization of the Blackjack III Pulsed Electron Beam for Material Response Studies

TWCP Electron Beam Testing Program:
Volume III - Material Response Instrumentation for The Blackjack III Pulsed Electron Beam Facility

TWCP Electron Beam Testing Program:
Volume IV - Electron Beam Tests in Support of the TWCP Correlation Program

These volumes were compiled and edited by Effects Technology, Inc. (ETI). Volume I was written by ETI drawing upon the material in Volumes II, III and IV which were written by Corrales Applied Physics Company under contract to ETI.

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SECTION I

INTRODUCTION

This report describes the development of material response instrumentation for use on the Blackjack III pulsed electron accelerator. These experiments were conducted during three series of tests: Series II, 15 to 23 September 1977; Series III, 1 to 7 December 1977; and Series IV, 27 January 1978 through 2 February 1978.

Beam development and characterization data were gathered during these three series of tests and are discussed in Section II. The impulse gauge instrumentation developed for Blackjack III is discussed in Section III, and laser interferometry is discussed in Section IV. Table 1 summarizes the results in terms of instrumentation and beam development activities for each of the three test series.

Characterization of the Blackjack III beam for use in dynamic material response applications is discussed in reference 1. Application of the techniques discussed in the next three sections to several material response programs is described in references 2, 3, and 4.

Table 1

SUMMARY OF ACTIVITIES

Test Series	Shot No.	Beam Related Developments	Response Instrumentation Developments
II.	1700-1748	1. Attempts to improve gross beam uniformity.	1. Check inertial isolation scheme.
		2. Attempt to establish high fluence station.	2. Measure drift tube displacement.
		3. First encounter (last half of series) with serious diode flash-over on BJ III.	3. Check noise in photomultipliers.
			4. Proof test with prototype optical impulse gauge.
III.	1778-1808	1. Diode flash-over observed in 30% of tests.	1. Check effect of magnetic fields on laser.
		2. Peak diode voltage reduced to 850 kV for AFWL CP tests.	2. Debug dual impulse gauge.
			3. Set up instrumentation table.
IV.	1926-1942	1. 1 MV peak diode voltage achieved consistently with new diode insulator.	1. Interferometer check out shots.
		2. Detailed mapping of drift tube field.	2. Rebuild table.

SECTION II

BEAM DEVELOPMENT

Test Series II performed in September 1977 had two beam related objectives. First, several attempts were made to improve the gross beam uniformity and second, an attempt was made to establish a high fluence station (300-cal/cm^2). We were relatively unsuccessful in both these areas. The usual cathode shaping experiments including various edge curvatures, dish angles and cathode diameters were used, and the fluence was mapped in detail at the 65-cm location. Some experiments were done with the conducting guide cone in an attempt to improve the beam transport efficiency and thereby the uniformity. In spite of these attempts no significant improvement in uniformity was obtained over that observed and recorded for Test Series I in July 1977. The attempts to achieve and characterize a high fluence station were also unsuccessful in that when fluences above 200-cal/cm^2 were reached, the beam diameter was too small for most material response experimentation. At the high fluence (55-cm) axial location extremely high surface doses were indicated by the large number and manner of fracture of the calorimeter elements. This suggests a larger than anticipated increase in the relative coupling coefficient, and is discussed later in this section.

A total of 46 shots were fired during this series. During the first 23 pulses only one diode flash-over was noticed. However, during the last 22 pulses, 12 diode flash-overs were observed both early and late in time. Diode flashing was observed on nearly every shot on which the peak diode voltage was above 700-kV. So serious was the flashing problem that the diode impedance was reduced for the last 12 pulses in order to continue the instrumentation development and debugging. This amounted to a change in average impedance from about 1.7-ohms to about 1.1-ohms.

Test Series III consisted of 31 pulses in December 1977. These tests were performed just prior to TWCP impulse testing for the Air Force (ref. 4). Severe diode flash-over was observed in ten of these tests, and it was decided that a peak diode voltage of 1-MV was unachievable with the existing diode insulator. The impedance was again reduced at the end of the test series in preparation for the TWCP testing. The average peak diode voltage was thereby reduced to 850-kV.

Test Series IV was comprised of 16 tests performed over a three-day period beginning 31 January and ending 2 Feb 1978. Maxwell had installed a new diode insulator just prior to these tests, and its evaluation was one of the test objectives. Indeed, an average peak diode voltage of 1-MV was achieved in these 16 tests.

The axial magnetic guiding field is shown in Figure 1. Shown in this figure are the pretest estimate based on the calculated combination of fields from two solenoids and

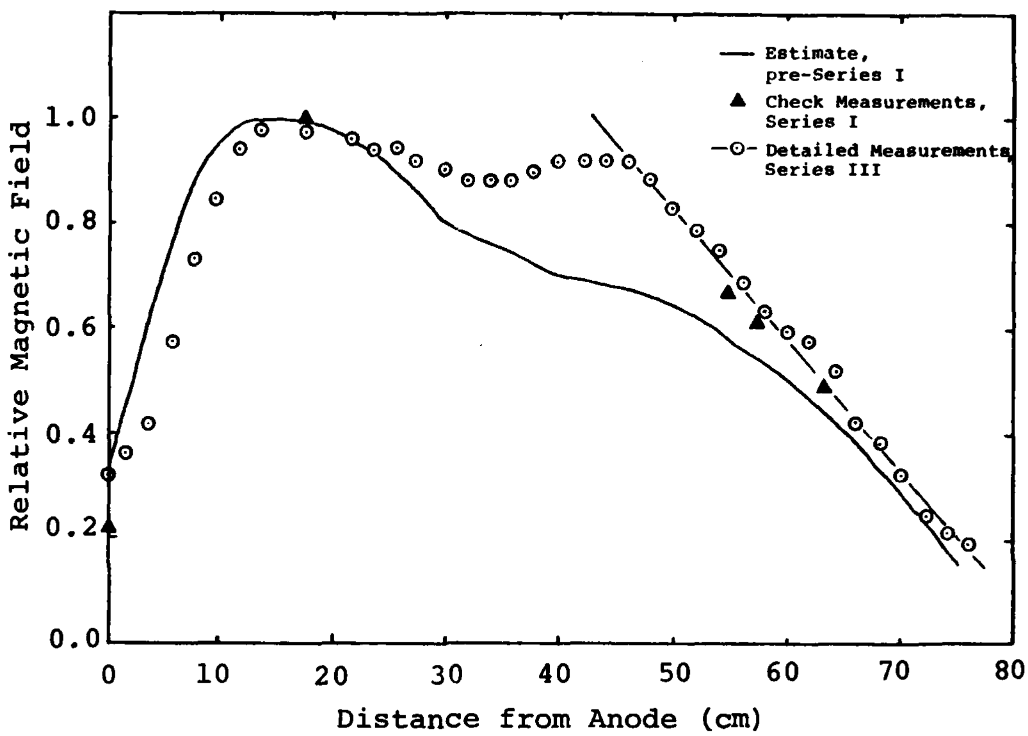


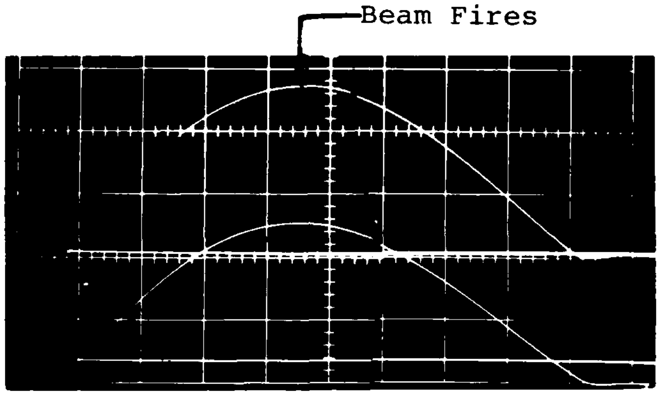
Figure 1. Electron Guiding Axial Magnetic Field

the estimated effect of eddy currents in the diode door. This estimation was spot checked during Series II (September 1977). The five measured data points are shown on Figure 1 and are in reasonable agreement with the estimation. However, anomalously high doses became apparent when the target-to-anode distance was less than 60-cm, and it was decided to map the field in detail. These results are also shown in the figure. Notice that, for distances less than about 55-cm, considerable deviation is obtained from the pretest estimate. The peak field existing at about 15-cm is 25-kilogauss. Figure 2 shows the field as a function of time. The electron beam is fired at the point of maximum field as indicated in the figure.

According to the adiabatic expansion theory of reference 5 the fluence should be proportional to the field; this is supported by the fluence data shown in Figure 3. The data points shown represent the average fluence compiled for the two test periods during which the diode was well behaved and the 1-MV peak beam was obtained routinely (July 1977 and January 1978). This theory also allows one to calculate the maximum electron angle as a function of field as:

$$\Theta_{max} = \sin^{-1}(B)^{1/2}$$

and, therefore, as a function of position as shown in Figure 4. Based on electron distribution assumptions at the cathode, the point of electron injection into the magnetic field, the mean electron angle can than be calculated as a function of



Upper Trace: Axial magnetic field probe.
2 msec/division.

Lower Trace: Solenoid current monitor.
2 msec/division.

Figure 2. Axial Magnetic Field as a Function of Time.

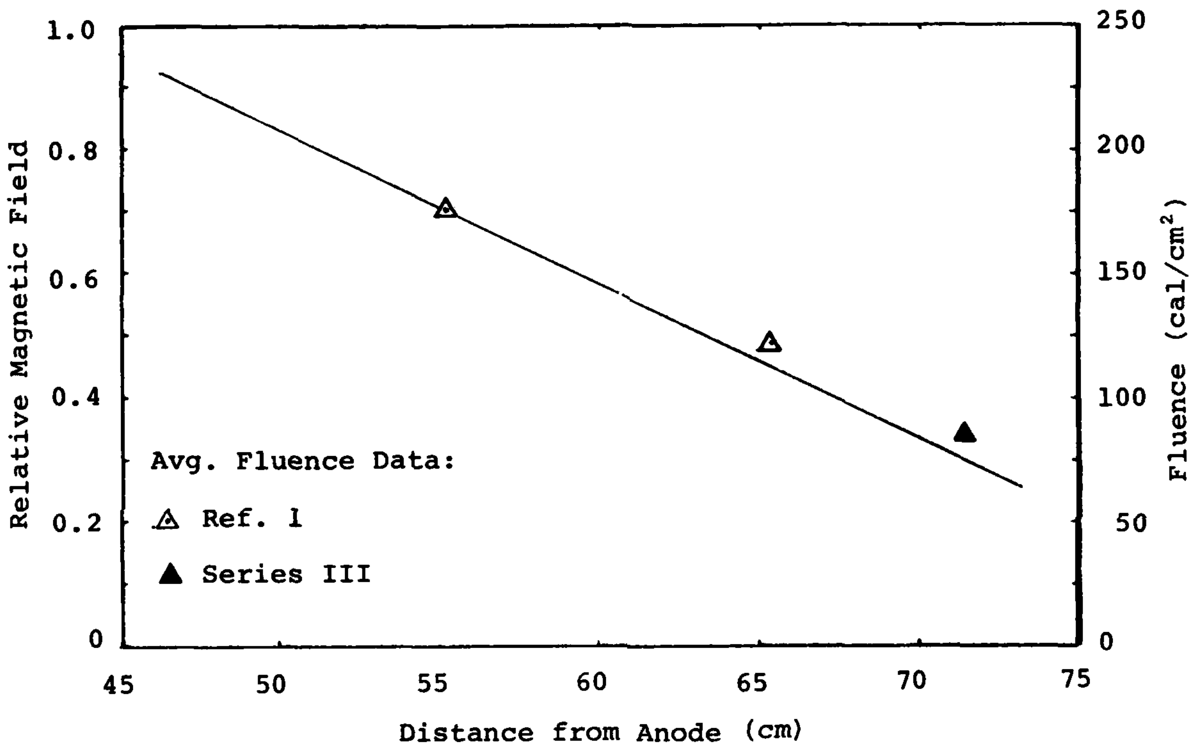


Figure 3. Correlation between Measured Field and Measured Fluence.

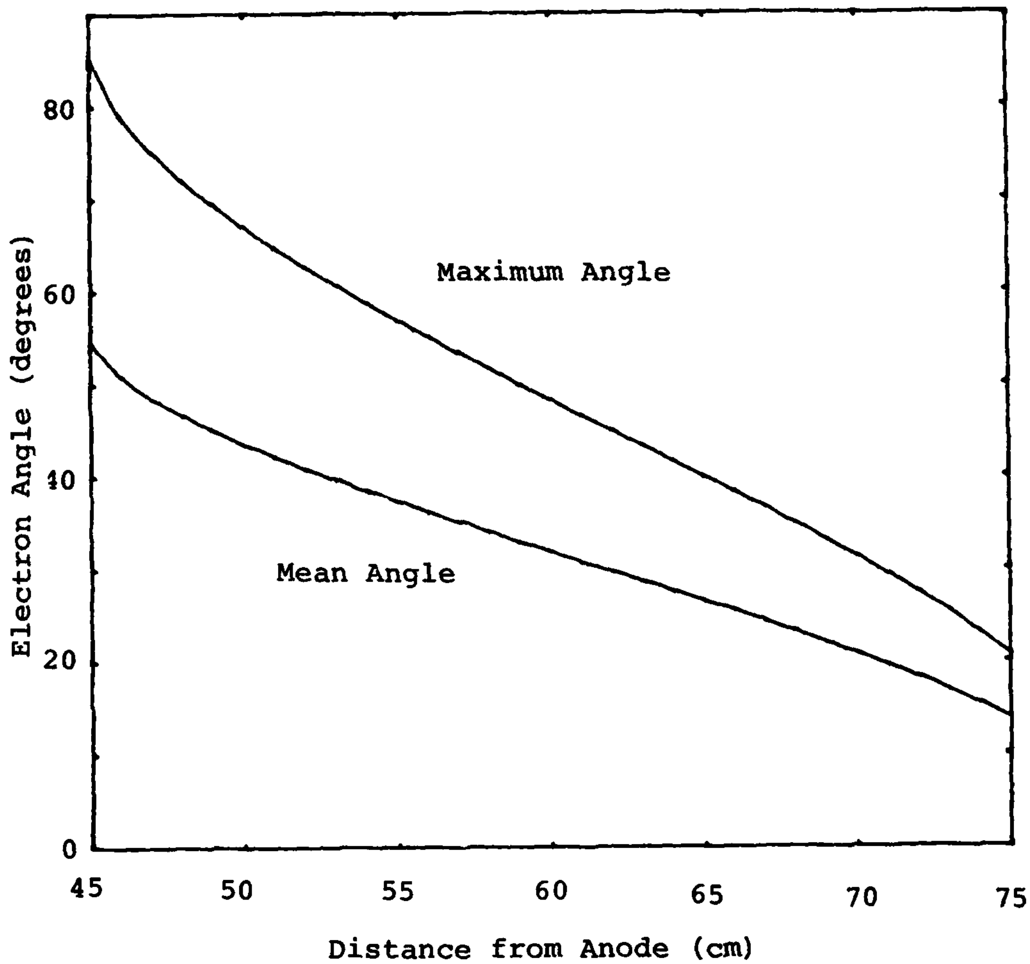


Figure 4. Calculated Electron Angles

position. This procedure is described in reference 4 where the procedure is substantiated by experimental data.

Knowledge of the mean electron angle allows one to calculate the peak relative dose for a given electron spectrum via a Monte Carlo transport code. This result, that is the peak relative dose versus position, is useful for pretest experimental design and is shown in Figure 5 for a typical 1-MV peak Blackjack III spectrum.

Alternate magnetic field configurations can be obtained by varying the current in, and the position of, the second solenoid as indicated by the dash lines in Figure 5. These alternate configurations have the potential advantage of reducing the dose-distance gradient, and hence, might improve the shot-to-shot dose repeatability. Note that plateau (zero gradient) regions can be created and may serve as well-defined experiment stations.

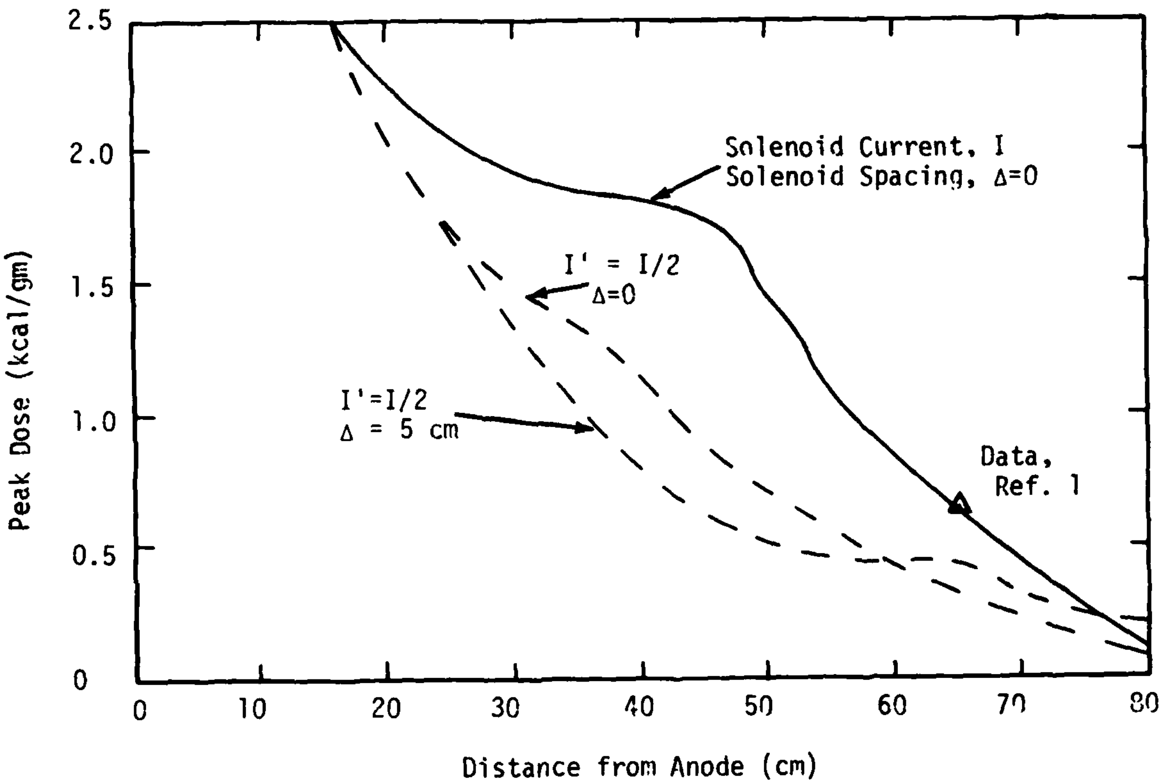


Figure 5. Peak Dose Versus Distance from Anode.

SECTION III

IMPULSE GAUGE DEVELOPMENT

In addition to the large pulsed electromagnetic fields normally associated with pulsed electron accelerator environments, two additional factors were considered in the design of the material response instrumentation for Blackjack III. First, the instrumentation is required to operate within the solenoid which provides the electron-guiding magnetic field; and second, the impulse gauge must be inertially isolated from the machine and drift chamber which are considerably displaced by the shock pulse originating at the water switches in the pulse line.

All materials used in construction of the momentum gauge were nonmagnetic, and the thickness of any conductors used was kept thin enough that no significant forces were induced by the 36-Hz, 25-kG magnetic field. (See Figures 1 and 2). This condition was verified by tests in which the field producing solenoid was pulsed without firing the Blackjack II machine.

Measurements of the relative displacement between the drift chamber and the concrete slab floor of the test cell were made. An optical displacement gauge was used during Test Series II with the results shown in Figure 6. The point of reference for this measurement was a massive magnetic and other experimental apparatus which rested on the floor

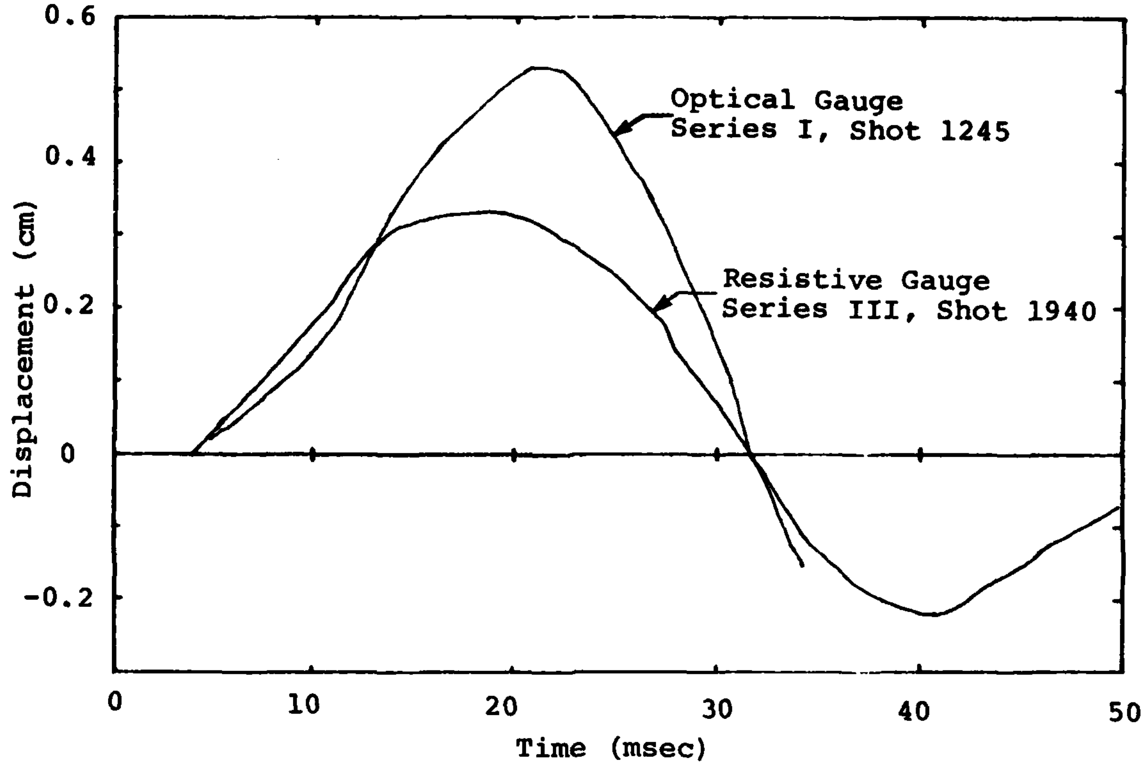


Figure 6. Drift Tube Displacement Data

of the test cell. This measurement was repeated with a CAPCo Model 130 resistive displacement gauge (ref. 4) during Test Series III. For this measurement the instrumentation table described in the next section was used as a point of reference. The results of these tests are in agreement and indicate a maximum displacement of about ± 0.5-cm with the peak displacement occurring at 20-msec. (See Fig. 6). The maximum acceleration occurs at about 30-msec and is about 100-m/sec^2 (10-g).

A shock isolated vacuum coupling was designed utilizing a special reentrant rubber boot. This experimental arrangement, shown in Figure 7, achieves inertial isolation of the impulse gauge, provides a quick disconnect vacuum flange, and allows several centimeters of relative axial displacement.

Three impulse gauges were developed, one during each of the three test periods. During Test Series II the gauge shown in Figure 8 was tested. In this design parallel 1/4-inch diameter glass-epoxy rods were constrained to move axially by two sets of parallel linear bearings. The target area for this configuration was 10-cm^2. The velocity of the moving assembly is measured by the modulation frequncy imposed on a light beam which is focused on a moving Ronchi ruling attached to the sample. This modulation is detected by a shielded photodiode and amplifier located in the impulse gauge support. (See Figure 7). After a series of tests to assure that the gauge was not affected by the pulsed magnetic

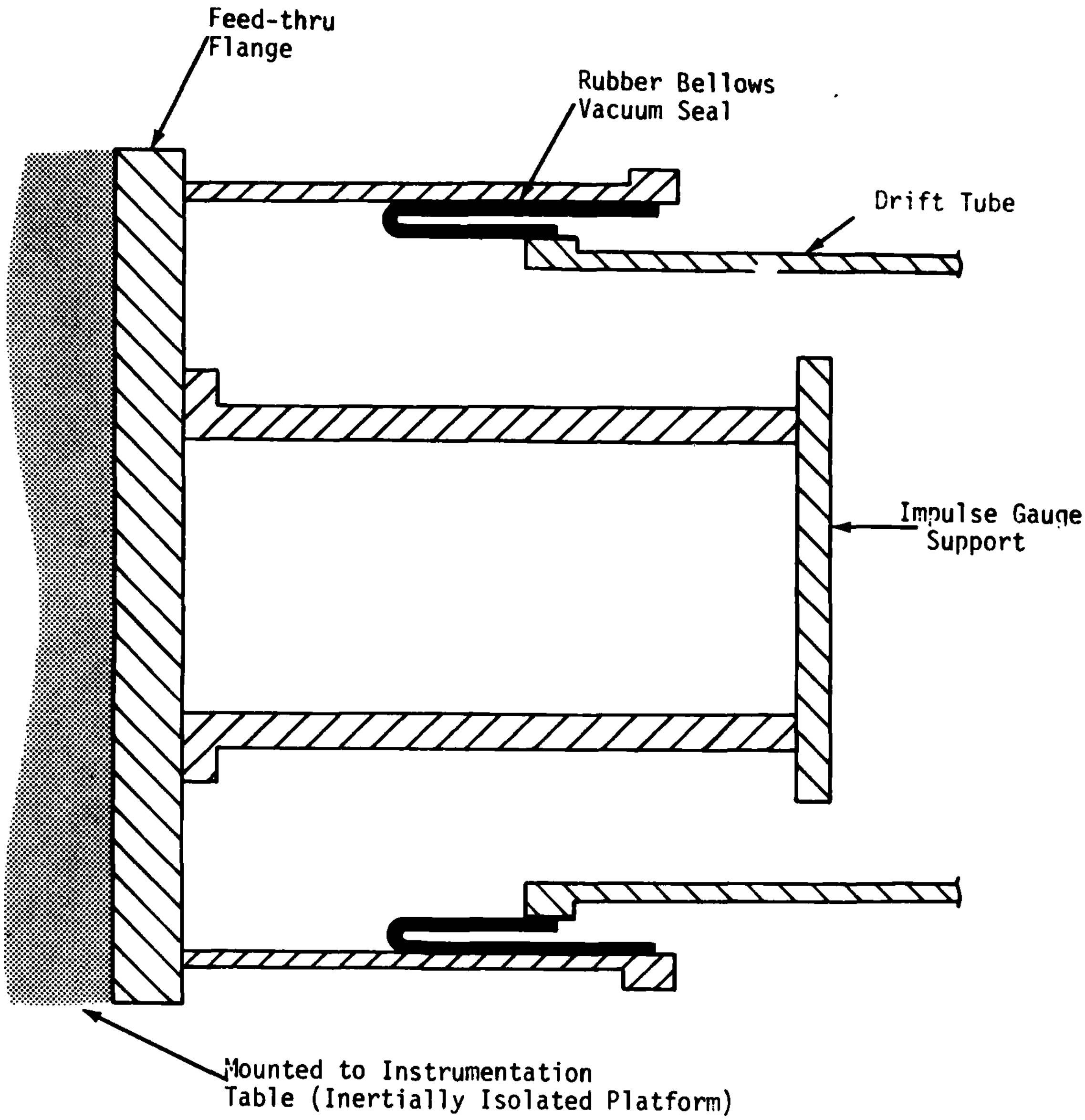


Figure 7. Shock Isolator

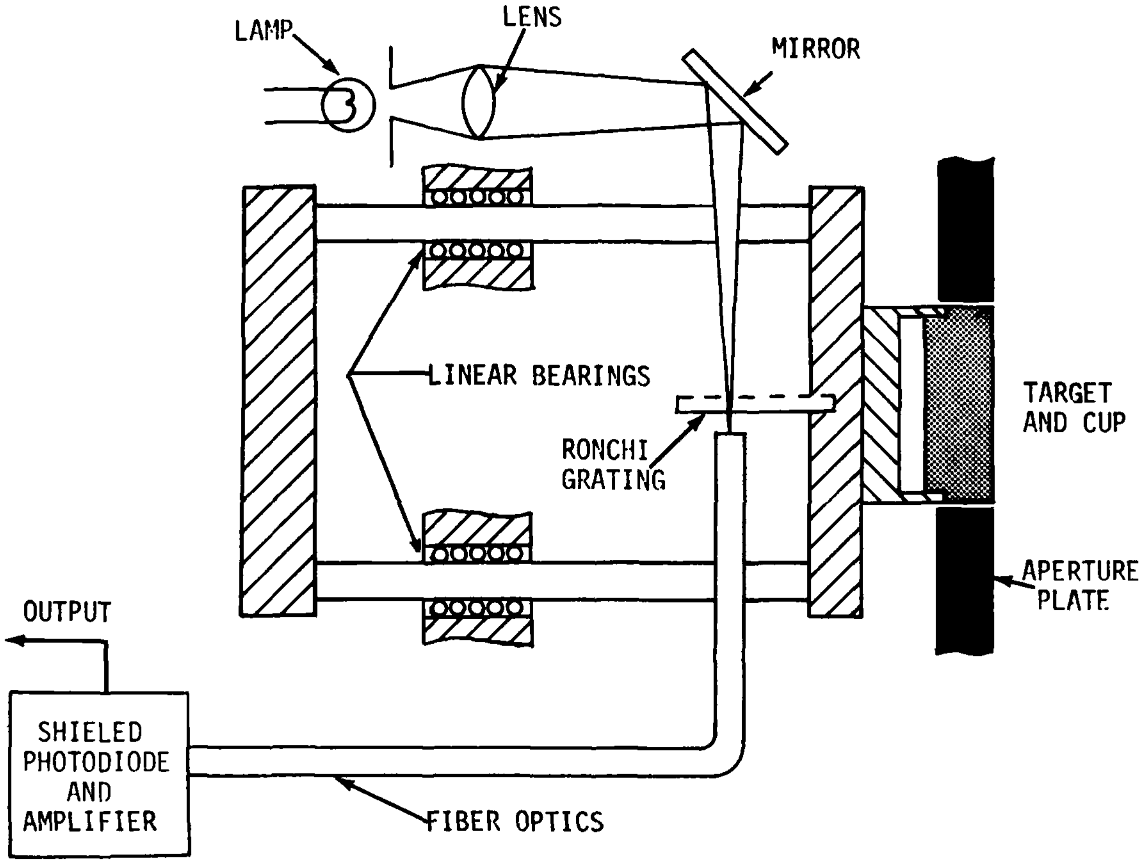


Figure 8. Impulse Gauge No. 1, 10-cm^2

field or machine shock effects described above, the gauge was tested on TWCP. Three types of TWCP were used in these tests in hopes of making impulse and post shot damage comparisons. The data are summarized in Table 2. Unfortunately, these impulse gauge debugging tests were done during a period of poor machine performance and extremely large shot to shot variations in fluence resulted so that no conclusions about the relative impulse generation for the several types of TWCP tested can be made. (No peripheral calorimetry was used).

A special dual impulse gauge shown in Figure 9 was developed and tested during Series III. Two of these 5.1-cm^2 gauges were placed side by side as indicated in Figure 10 and (with their associated peripheral calorimeters) used to make the impulse measurements presented in reference 4. In this dual gauge, as in the above gauge, velocity is determined by a moving Ronchi ruling, and a second photodiode and amplifier added in the support base. Representative data from the dual impulse gauge on two types of TWCP are given in Figure 11.

A third gauge design was developed and used in the TWCP correlation program as described in reference 4. This gauge is shown in Figure 12 and is similar in design to the parallel rod gauge shown in Figure 8 and tested in Series II. The parallel glass epoxy rods were replaced by stainless steel tubes, and the sample size was reduced to 8.5-cm^2 in order to bring peripheral calorimetry within the uniformly irradiated area as shown in Figure 13. Optical access for

Table 2

PRELIMINARY TWCP TEST DATA

Shot No.	Sample	Mean Energy (keV)	Diode Energy (kJ)	Deposition Time, FWHM (η sec)	Fluence (cal/cm^2)	Mass Loss (gm/cm^2)	Impulse (ktap)
1726	Fluence	710	21	53	62	--	--
1729	5055A S/N 4	730	27	59	--	.20	--
1730	5829A S/N 21	710	16	49	--	.12	--
1731	5832A S/N 10	710	15	41	--	.09	--
1739	Fluence	680	26	64	130	--	--
1742	5829A S/N 22	700	26	56	--	.24	10.2
1743	5055A S/N 5	770	20	48	--	.10	2.5
1744	5832A S/N 11	680	15	49	--	.11	1.6

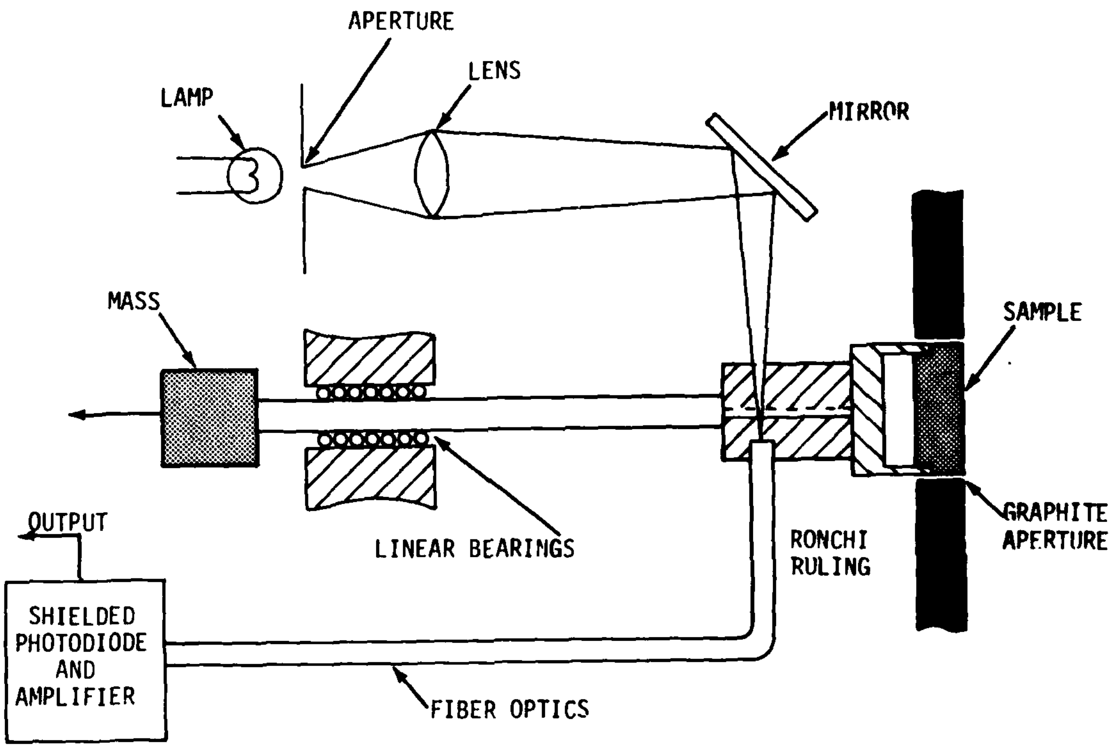


Figure 9. Impulse Gage No. 2, Dual, 5.1-cm^2

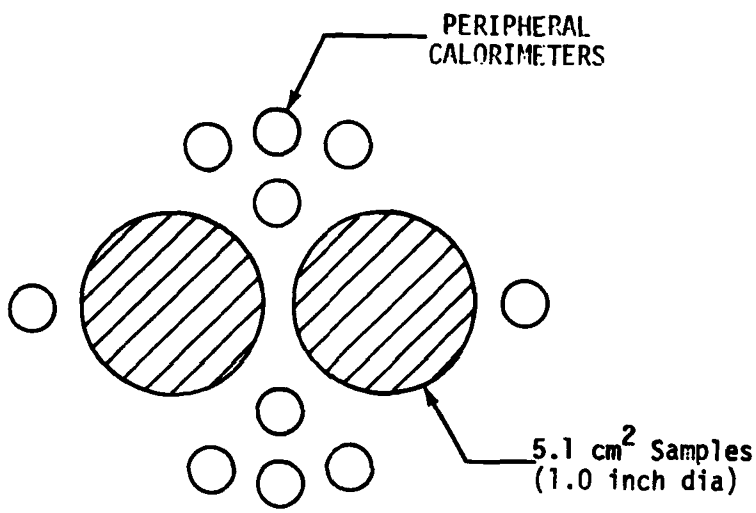


Figure 10. Peripheral Calorimetry Layout, Impulse Gauge No. 2.

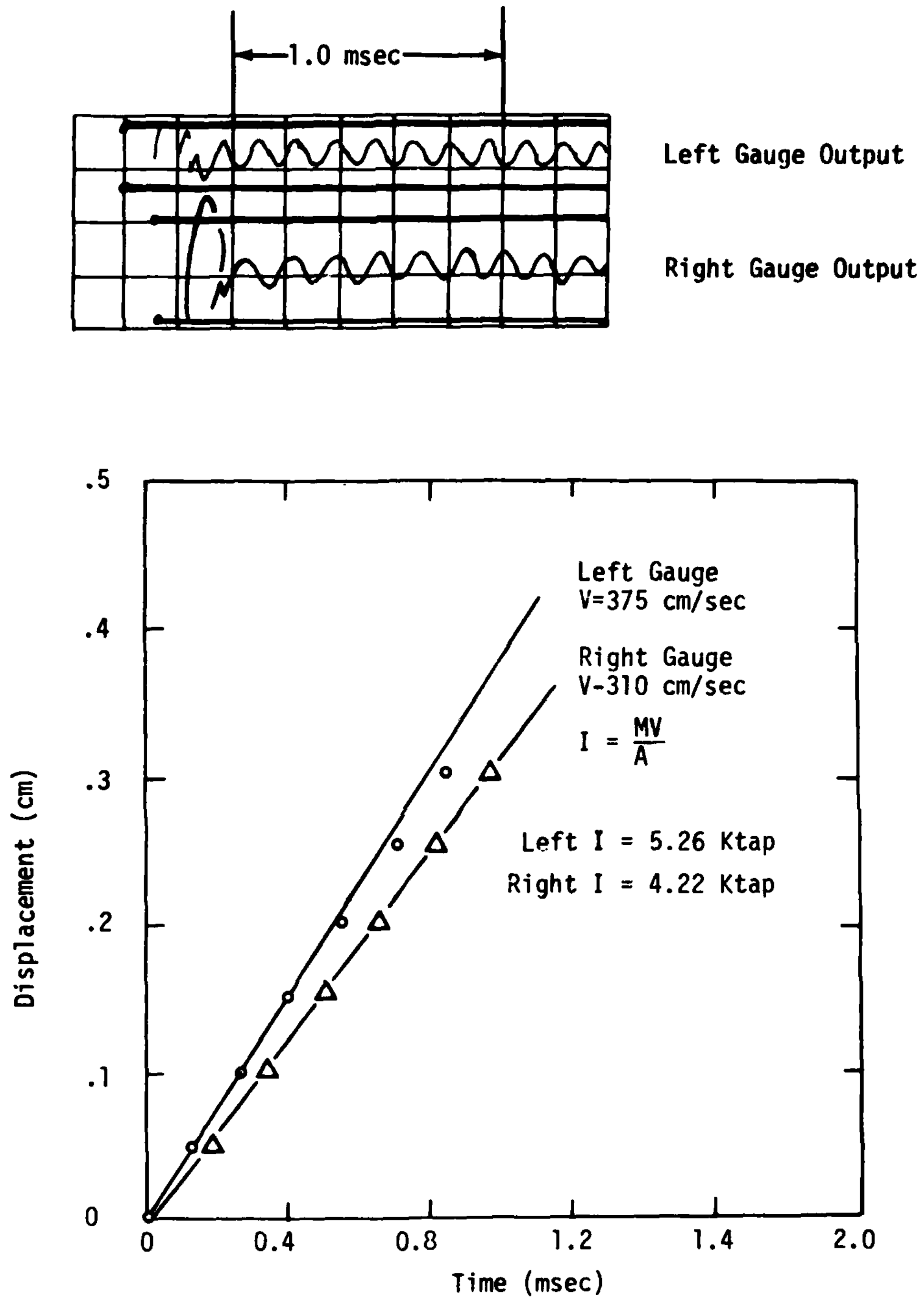


Figure 11. Representative Carbon Phenolic Data from Impulse Gauge No. 2

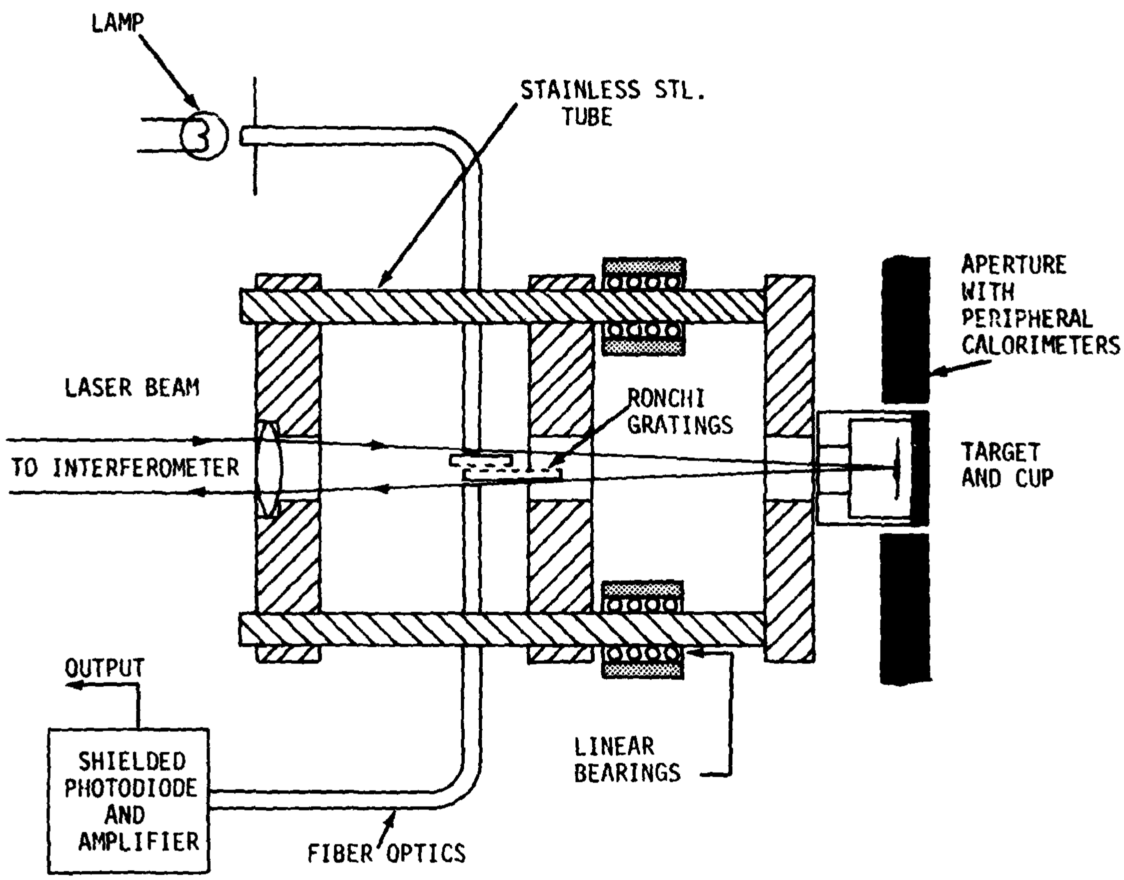


Figure 12. Impulse Gauge No. 3, 8.5-cm^2

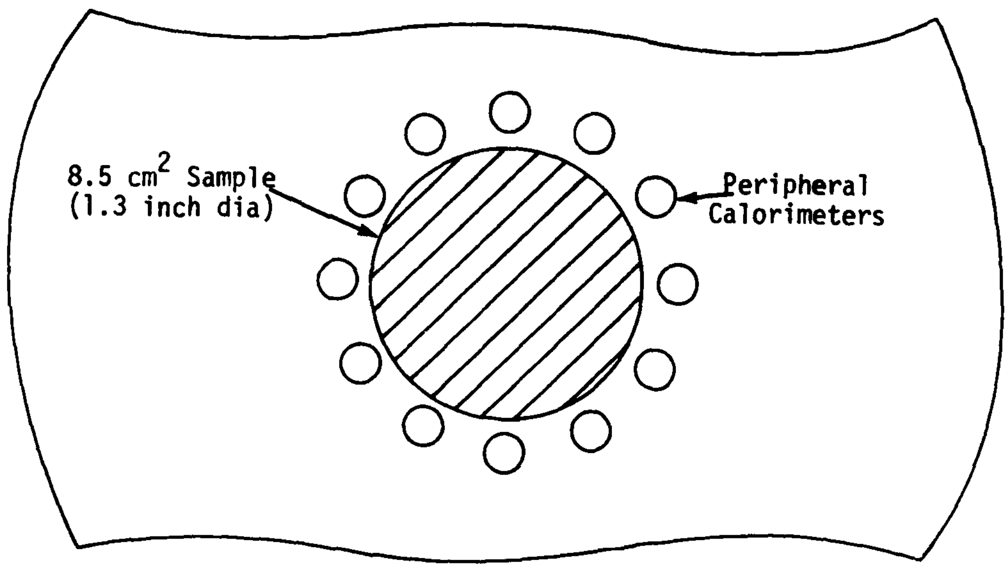


Figure 13. Peripheral Calorimetry Layout,
Impulse Gauge No. 3

the interferometer laser beam was provided by using fiber optic light guides to feed through the vacuum flange which allowed the light source and photodiode amplifier to be removed from the momentum gauge support base to a shielded area external to the drift chamber. In this gauge the light beam is modulated by the motion of one Ronchi ruling relative to a second Ronchi ruling eliminating the need for apertures and lenses. A photograph of this gauge is shown in Figure 14, and data representative of those obtained during tests under the TWCP Correlation Program (ref. 4) are shown in Figure 15.

This gauge was checked out prior to e-beam tests with the CAPCo 1/4-inch and 3/8-inch hose gas guns to a maximum momentum of 50-kdyne-sec. The agreement between projectile momentum and impulse gauge momentum was at least ± 5% for a careful experiment. At least half of this discrepancy is undoubtedly due to the projectile velocity measurement and is not attributable to the impulse gauge. The impact tests were most useful in discovering and removing vibrational resonances in the gauge which degrade the quality of the optical modulation signal.

The background impulse due to the impingement of anode debris on the gauge is a subject of considerable interest. Anode debris impulse measurements were made not only during the test series discussed here, but also during the initial test series conducted in July 1977 (ref. 1). In this case a crude passive gauge was used. Other measurements were made

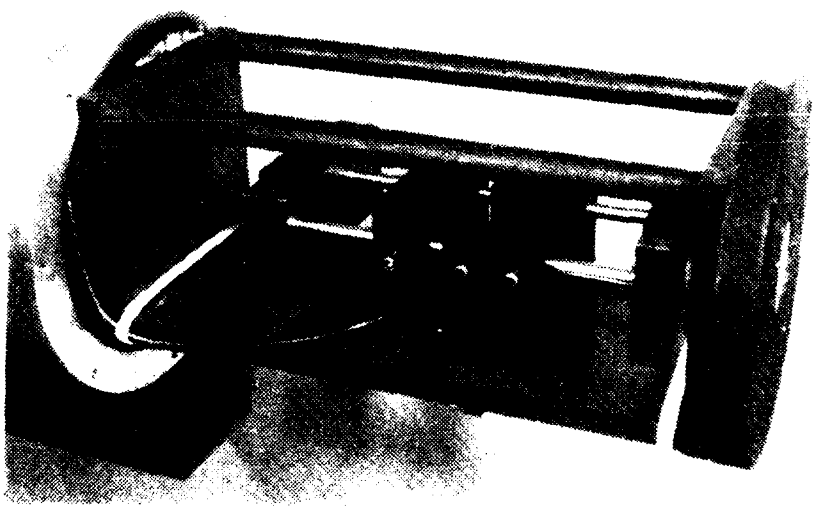


Figure 14. Impulse Gauge No. 3 with Peripheral Calorimeters and Shock Isolation Mount.

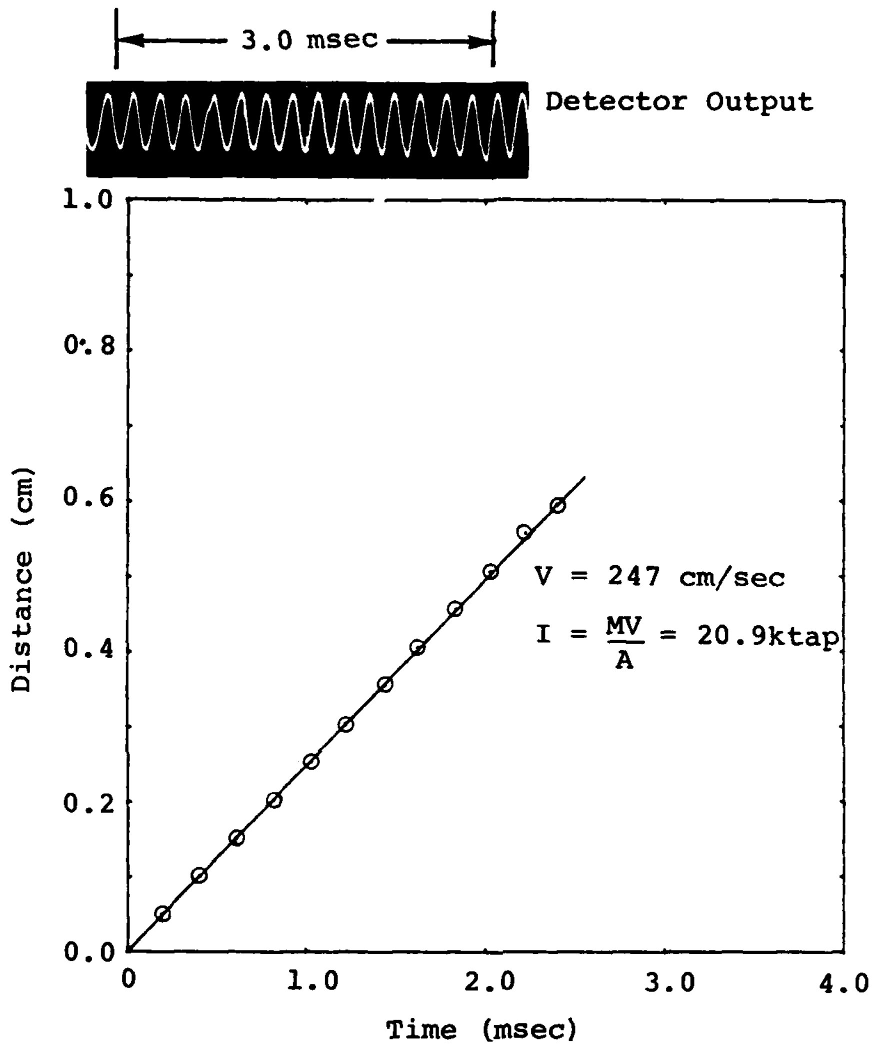


Figure 15. Representative 91-LD Resin Data from Impulse Gauge No. 3

and are reported in references 2, 3, and 4. A summary of all anode debris impulse measurements made on Blackjack III to this date is given in Table 3. Notice that introduction of the graphite scattering foil appears to reduce the anode debris impulse from about 400- to 100-taps.

Table 3

ANODE DEBRIS DATA SUMMARY

Shot No.	Filter* ?	Gauge Type**	Distance from Anode (cm)	Gauge Area (cm^2)	Impulse (ktap)	Reference
1632	No	0	65	10	(0.06)	Reference 1
1646	No	0	65	10	(0.07)	Reference 1
1740	No	1	65	10	0.40	This work, Series I
1829L	Yes	2	70	5	0.10	Reference 2
1829R	Yes	2	70	5	0.11	Reference 2
1841	Yes	2	65	5	0.09	Reference 2
2271	Yes	3	60	8.5	0.12	Reference 4
2296	Yes	3	60	8.5	0.13	Reference 3

Note: Anode is 1/4 mil mylar.

*0.025 gm/cm^2 graphite cloth.

**0, Passive indentor gauge, see reference 1.

1, See Figure 8.

2, See Figure 9

3, See Figure 12.

SECTION IV

INTERFEROMETER DEVELOPMENT

The CAPCo velocity/displacement interferometer was used to make particle velocity measurements in plexiglass and fused silica windows. Since this equipment was not developed under the subject program, only the Blackjack III setup will be discussed. The interested reader is referred to references 6 and 7 for a more complete description of interferometer systems.

During Test Series II and III experiments were done to assure that the interferometer system could be operated in the Blackjack III environment. The two major concerns were: (1) the adverse interaction of magnetic fields with the laser plasma, and (2) the proper location and shielding of the pulsed photomultiplier detectors. Noise tests were conducted during Series II and III. The photomultiplier detectors were finally located in the shielded instrumentation screen room located about sixty feet from where the laser beams from the interferometer pass through the blockhouse roof. The beams were directed to the detectors in the screen room by relay mirrors.

During Test Series III and Test Series IV work was done on the development and setup of a unique instrumentation support table. The table is mounted on linear bearings which allow it to slide parallel to the drift chamber on heavy steel shafting. The shafting is rigidly fixed to support pedestals. The entire test assembly including the impulse gauge, shock isolator support, and the CAPCo laser interferometer mount to the sliding table. This system allows the entire material response experiment to be set up and adjusted while the Maxwell technicians set up the diode. When set up for a shot, the impulse gauge and target extend into the drift chamber through the shock isolation section described previously. After the shot the entire impulse gauge and interferometer assembly is retracted from the drift chamber so that the diode door may be swung open for cleaning and anode replacement. The interferometer and table assembly are pictured in Figure 16.

During Test Series IV several interferometer test shots were done with plexiglass targets. The velocity and displacement interferometer signals and the reduced particle velocity data from one of these tests are shown in Figure 17. Notice the high resolution of the precursive part of the wave in the displacement interferometer data. Results representative of those obtained on TWCP for the TWCP Correlation Program are shown in Figure 18.

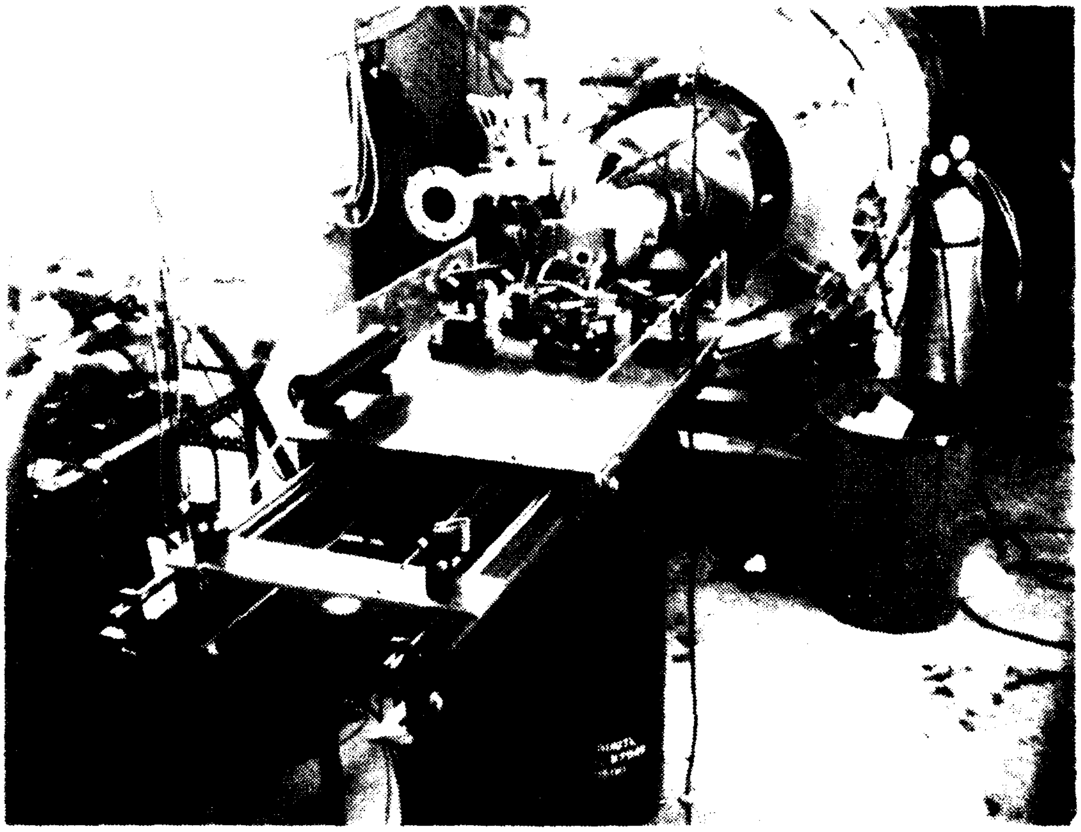


Figure 16. Laser Interferometer, Experiment Table, and Shock Isolator Coupling to Blackjack III Drift Tube

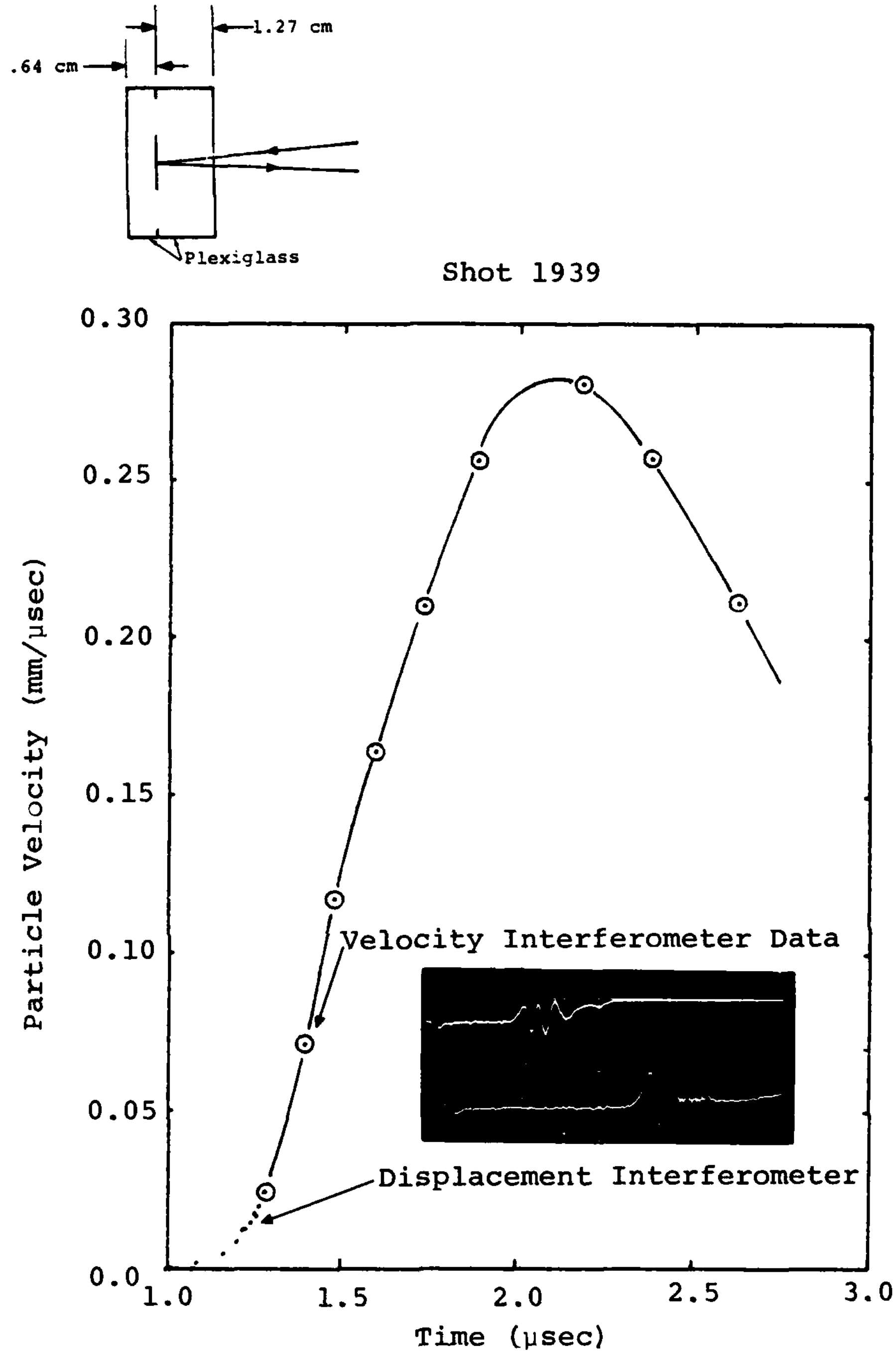
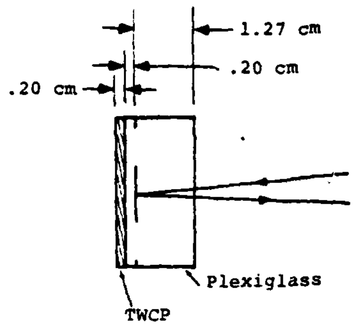


Figure 17. Interferometer Data on Plexiglass



Shot 2086

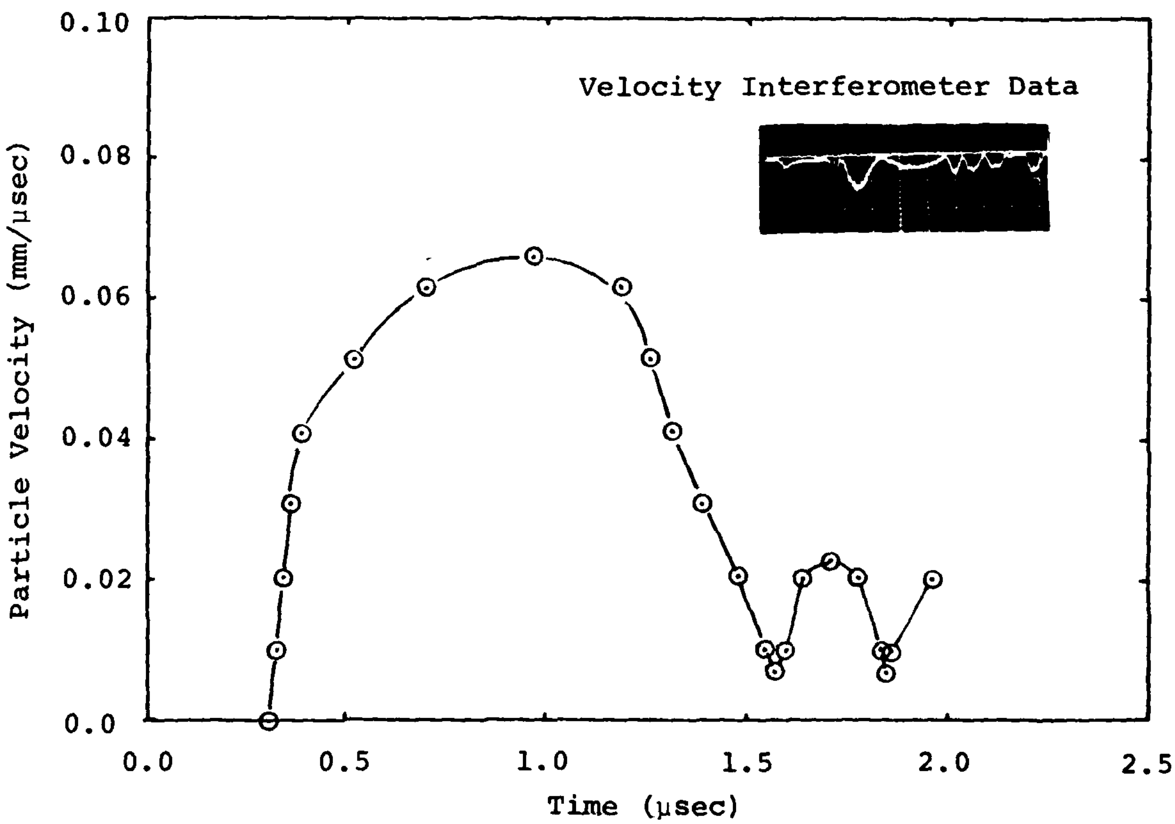


Figure 18. Representative Interferometer Data on Carbon Phenolic

SECTION V

CONCLUSIONS

A comprehensive material response instrumentation system was developed and tested. The system was designed expressly for the Blackjack III pulsed electron accelerator; however, with minor adaptations it is generally applicable to any accelerator and particularly suited to those with magnetic beam control, e.g., OWL II. The system is comprised of momentum gauges, a shock isolation system, and a sliding table which supports laser interferometry equipment. With this system impulse and particle velocity measurements can be made efficiently on the same test. Impulse measurements have been made in the range between 0.1- and 30-kilotaps and peak particle velocity measurements have been made in the range between 10^{-3} and 0.3-mm/μsec. Several materials response research programs have been accomplished with this equipment during the past year and are described in references 2, 3, and 4.

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