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NBS InterAgency Transducer Project
A Project Report

P. S. Lederer, J. S. Hilten, and Carol F. Vezzetti

Electronic Technology Division
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

June 27, 1975

Progress Report Covering Period October 1, 1974 to December 31, 1974

Prepared for
Naval Air Systems Command
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This is a progress report. The work is incomplete and is continuing. Results and conclusions are not necessarily those that will be included in a final report. Performance test data were obtained from one or two samples of several transducer types, and do not necessarily represent the characteristics of all transducers of a given type.

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Naval Air Systems Command
U.S. Navy and Transducer Committee
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Range Commanders Council

U.S. DEPARTMENT OF COMMERCE, Rogers C.B. Morton, Secretary

NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

ABSTRACT

The continuing development of a test method for evaluating the effects of short-duration, thermal radiant-energy transients on pressure transducer performance is described. The method consists of monitoring pressure transducer output as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. Precision of the method is to be at least adequate for the method to serve as an initial screening test. During this reporting period, the following three parameters were investigated for each of three radiation sources: (1) the amount of energy per unit area available as a function of distance from the source, (2) the response of a selected transducer as a function of distance from the source, and (3) flash duration. Repeatability of the method for each source was determined.

Work being performed for other agencies is also described briefly.

Key words: calibration; dynamic; electronic flash; photoflash bulb; pressure; pressure transducer response; thermal transient; transducer.

NBS Inter Agency Transducer Project

Progress Report No. 2 for the Period from
October 1, 1974 to December 31, 1974

to the

Naval Air Systems Command, U.S. Navy and
Transducer Committee, Telemetry Group, Range Commanders Council

NBS Project 4253434

Prepared by

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John S. Hilten
Carol F. Vezzetti

1. INTRODUCTION

A brief background for the NBS Inter Agency Transducer Project, including recent history and current objectives, was given in the preceding progress report [1].* The current task assigned to the Project by the Transducer Committee was also stated in detail. This task calls for the development of a test method for determining the effects of thermal transients on pressure-transducer performance. Precision of the method is to be at least adequate for the method to serve as an initial screening test. Other requirements are the following: the equipment should be inexpensive, simple to operate, and easy to construct; the method should be capable of generating thermal transients with durations greater than 1 ms, and of providing selectable, known, heat-flux inputs.

During the previous reporting period, apparatus was assembled, and an experimental test method was devised. The method consists of monitoring pressure transducer output as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash.

Because of the sponsor's requirement for a method using readily available and inexpensive components, simple radiation sources of relatively low energy output (and hence of low intensity) were used in the method development. The limitations in working distance imposed by these sources,

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*Figures in brackets indicate literature references, section 6.

including the limitation that the energy meter and the transducer under test must be separated in azimuth (i.e., that the angle formed by the axes energy meter-to-flash source and flash source-to-transducer cannot be small, and in fact for the sources selected and the transducer fixture developed, cannot be much less than $\pi/2$ rad), has been deemed acceptable by the sponsor for a method primarily intended to identify pressure transducers exhibiting appreciable changes in transducer performance in response to thermal radiant-energy transients.

2. EXPERIMENTAL DEVELOPMENT

During this reporting period, the following three parameters were investigated for each of three radiation sources: (1) the amount of energy per unit area available as a function of distance from the source, (2) the response of a selected transducer as a function of distance from the source, and (3) flash duration. Repeatability of the method for each source was also determined.

2.1 Description of Experimental Arrangement

The experimental arrangement is as follows (figure 1): The flashbulb or flashtube is mounted in a vertical position at the center of an optical bench. Mounted on the bench on opposite sides of the source are an energy meter and the transducer mounting fixture. The diaphragm of the mounted pressure transducer and the sensing element of the energy meter are aligned with, and equidistant from, the center of the flash unit. The energy meter and transducer may be moved along the bench to vary the respective distances between them and the flash unit, which is held fixed. Also fixed in position is a photodiode mounted at right angles 35 cm from the bench center line and used as a flash output monitor to check the operation of the energy meter. All four elements are adjusted in position vertically to be coplanar.

In a test, the quantities monitored are as follows: (1) the output of the pressure transducer displayed on an oscilloscope, (2) the digital reading of the energy meter (which displays the pulse energy in joules per unit sensor area), (3) the energy meter output displayed on an oscilloscope (peak amplitude is proportional to the energy input), and (4) the photodiode output also displayed on an oscilloscope.

2.1.1 Sources. Three sources were used in the investigations: an electronic flash at an energy setting of 150 J, No. 5 flashbulbs, and No. 22 flashbulbs. These sources are all intended to provide illumination for photography. Planned experiments with flood-flash FF-33 bulbs were postponed, as these bulbs were not available during the reporting period. The original plan of experiment also included the electronic flash at 50 J; however, these runs were dropped from the schedule because, even at the 150-J setting, the zero shift in the selected test transducer output in response to thermal radiant-energy transients from the electronic flash was small compared to the zero shifts resulting from the flashbulb source.

The flashbulb manufacturers provide the following information concerning light-output repeatability. Assuming that the specified excitation is supplied in each case, the population mean of measurements of the light output (measured with an integrating sphere or equivalent method) should fall within 10% of the manufacturer's published light-output value, with a confidence level of 95%.

A similar figure is not available for the flashtube used in the electronic flash. Flashtube light output depends on physical dimensions, on energy input, on the operating voltage, and on the xenon fill pressure. The manufacturer of the electronic flash unit does not publish an index of repeatability; however, a representative stated verbally that variations in flash-to-flash output under the operating conditions specified in the instruction manual should be significantly smaller than those which would adversely affect photographic results with available general-purpose films, including low-exposure-latitude color films. This statement is interpreted to mean that the flash-to-flash variation is no greater than ten percent, and probably less.

For the flashbulb sources, the spectral energy distribution closely approximates that predicted by the Wien Law over the wavelength range of approximately 350 to 650 nm, according to information supplied by the manufacturers. At wavelengths longer than about 650 nm, the spectral energy distribution curve for the flashbulbs diverges upward from the Wien-Law curve; information is not available for wavelengths shorter than 350 nm or longer than about 750 nm. Note: The exact spectral energy distribution for flashbulb sources depends on the combustible material, the oxygen fill pressure (most modern flashbulbs burn aluminum in pure oxygen), and the absorption characteristics of the envelope. The flame emission lines of aluminum are available in the literature; the other information is proprietary.

The spectral energy distribution for a flashtube depends on the operating voltage, as well as on the fill gas and envelope material. Typical manufacturer's data shows that the relative energy per 100 nm is approximately constant from 400 to 800 nm. At wavelengths greater than 800 nm, the operating voltage has a large effect, with a 500-V tube producing on the order of half again as much as a 2000-V tube. Specific spectral energy-distribution data for the flashtube used is not available from the manufacturer.

2.2 Investigation of Energy Available as a Function of Distance

The change in measured intensity (amount of energy per unit area) as a function of distance from the flash source was studied using the experimental arrangement described in 2.1. Three sources were used in the investigation: electronic flash at 150 J, No. 5 flashbulbs, and No. 22 flashbulbs.

Distance from the center plane of the flashbulb source to the energy meter sensor (and consequently the distance from the source to the test transducer diaphragm, for the investigation described in 2.3) was varied in 1-cm steps over the range of about 6 cm to 23 cm for runs with both No. 5 and No. 22 flashbulbs. The dimensions of the electronic flash head and the relatively low energy levels available even at the 150-J setting determined a smaller practical range of distances for runs with this unit. The minimum distance was limited to 7.5 cm; at 14.5 cm the test transducer zero shift (which was also measured, as described in 2.3) was about one-half of one percent of the full-scale output, and accordingly 14.5 cm was chosen as the upper limit for tests with the electronic flash. Steps of 0.5 cm were used in order to provide approximately the same number of data points as for tests with the flashbulb sources.

The results from this series of tests are shown plotted as energy meter reading ($mJ \cdot cm^{-2}$) vs separation (cm) in figure 2. Energy meter reading is plotted on a logarithmic scale. Separation refers to the distance from the center plane of the source to the energy meter sensor. The data-point plots A, B, and D fall along curves whose form is similar to that of an inverse-square relation; for comparison an arbitrary inverse-square plot is given in figure 2 (dashed curve C). The classical inverse-square relation of intensity vs distance for a point source of radiation does not strictly apply to the extended sources of these tests, particularly at the relatively short distances between the source and sensor. Small deviations of experimental points from the smooth curves probably result from variations both in source energy and in the performance of the energy meter. These deviations do not exceed 10% of the energy meter reading.

The maximum intensity levels were measured at the minimum source-sensor distances, which were limited by source dimensions for the flashbulb sources as well as for the electronic flash. Maximum levels of about 0.1, 0.8, and 2.2 $J \cdot cm^{-2}$ were measured for the electronic flash at 150 J, No. 5 flashbulbs, and No. 22 flashbulbs, respectively.

2.3 Investigation of Transducer Zero Shift as a Function of Distance

In the measured intensity-vs-distance tests described in 2.2, the zero shift of a pressure transducer located on the opposite side of the radiation source from the energy meter was monitored with an oscilloscope. For tests at ambient atmospheric pressure, any transducer output is regarded as zero shift. The transducer used in these tests is a semiconductor strain-gage pressure type and is designated in this report as transducer D. The results from this series of tests are shown plotted as transducer zero shift (% of full scale) vs separation (cm) in figure 3. Transducer zero shift is plotted on a logarithmic scale. Separation refers to the distance from the center plane of the source to the transducer diaphragm.

The data-point plots A, B, and D fall along curves whose form is similar to that of an inverse-square relation. An arbitrary inverse-square relation is again plotted (dashed curve C) for comparison. Test data for three distances is presented in table 1, as discussed in 2.6.

2.4 Investigation of Flash Source Duration and Waveform

As described in 2.1, a photodiode was used in conjunction with the energy meter to monitor the radiation emitted by the flash source. This photosensitive semiconductor component was actually a silicon phototransistor connected as a diode with a response time "better than 1 μs" over a wavelength range of 0.5 to 1.1 μm, according to the manufacturer. The output from the diode displayed on an oscilloscope screen provided the approximate shape of the radiant thermal transient as well as a measure of its amplitude.

Figure 4 consists of three photographs of oscilloscope traces of photodiode output in response to thermal radiant-energy transients from the electronic flash at 150 J, a No. 5 flashbulb, and a No. 22 flashbulb. The sweep time for each photograph was 50 ms, and the amplitude scale 2 V per division. Comparison of the photographs shows that the diode output waveform for the electronic flash source has a sharp rise time (less than 0.2 ms measured with the oscilloscope set to a fast sweep) and a slower decay of about 6 ms to drop to 10% of its peak amplitude. The transients generated by the two flashbulb types are more nearly symmetrical in rise and fall time. Rise times, from 10% of the peak amplitude to the peak,are about 9 ms for No. 5 flashbulbs and about 13 ms for No. 22 flashbulbs. Decay times are respectively 20 ms and 24 ms. The total duration of the thermal radiant-energy transients generated by these devices as measured by the diode is therefore roughly 6 ms for the electronic flash at 150 J, 29 ms for No. 5 flashbulbs, and 37 ms for No. 22 flashbulbs.

2.5 Investigation of Test Method Repeatability

A series of tests was carried out to determine the repeatability of the test method with transducer D as the test transducer. The results of these tests are plotted in figures 5, 6, and 7, which show the deviation in percent from a ten-shot average of transducer zero shift, energy meter response (digital reading), energy sensor output (analog signal available from the energy meter for which peak amplitude is proportional to energy input), and photodiode output for each of the three test sources.

As described in 2.1, the outputs of the photodiode, the energy sensor, and the transducer under test were displayed on an oscilloscope and measured; the digital output displayed by the energy meter was recorded. The pressure seen by the pressure transducer at the beginning of each run was atmospheric ambient.

The distance between the center plane of the flash source and the transducer diaphragm was 7.5 cm for the electronic flash, 10 cm for the No. 5 flashbulbs, and 12 cm for the No. 22 flashbulbs. These distances were not arbitrarily selected. The minimum source-transducer distance of 7.5 cm for the electronic flash was used because this source is relatively weak. The original intent was to use the same distance of 10 cm for the two flashbulb sources. However, the intensity of the No. 22 flashbulbs at 10 cm was at or above the energy meter's upper limit of 1 J $\cdot$ cm^{-2}, and the slightly greater distance of 12 cm was therefore used for this source. (An attenuating screen was available for use with the energy meter. Uncertainties of calibration associated with its use suggested that a direct measurement should be employed for the repeatability study.)

Table 2 presents a summary of the data given in the figures. Sample averages, maximum upper and lower percent deviations from the average, and sample standard deviations are given for energy meter readings, photodiode output, and transducer D zero shift.

2.6 Discussion of Experimental Results

Table 1 shows test transducer zero shift (mV) and energy meter reading ($mJ \cdot cm^{-2}$) for the three sources at three selected distances: 8, 10, and 14 cm. The table also includes the computed radiation sensitivity (defined as the ratio of the transducer zero shift to the energy meter reading, with units of $V \cdot cm^2 \cdot J^{-1}$) for the three sources at the three distances, for transducer D. The percentage variation in radiation sensitivity over the three distances is ±0.8%, ±2.9%, and ±1.7% for the electronic flash at 150 J, for No. 5 flashbulbs, and for No. 22 flashbulbs, respectively. Another measure, which permits direct comparison of zero shifts for transducers with differing full-scale outputs, is percent full-scale output radiation sensitivity ($\%FS \cdot cm^2 \cdot mJ^{-1}$). Using as a basis the average value of the radiation sensitivities for 8, 10, and 14 cm (0.123, 0.139, and 0.149 $V \cdot cm^2 \cdot J^{-1}$ for electronic flash at 150 J, for No. 5 flashbulbs, and for No. 22 flashbulbs, respectively) and the transducer D full-scale output of 500 mV, percent full-scale radiation sensitivities for the three sources are 0.025, 0.028, and 0.030 $\%FS \cdot cm^2 \cdot mJ^{-1}$, for transducer D.

As may be seen by examination of the data just presented, transducer D radiation sensitivity increases about 13% for the No. 5 flashbulb source as compared to the electronic flash; there is a further increase of about 7% for the No. 22 flashbulb source. An explanation of this situation may lie in the relative sizes of the light-emitting elements in each source. The diameter of the circular tube in which the capacitive discharge takes place in the electronic flash is about 2 cm; the diameter of the combustible filler in the flashbulbs is about 3.5 cm for the No. 5 flashbulbs and about 5 cm for the No. 22 flashbulbs. As the light-emitting element becomes large, an increasingly greater proportion of the energy radiating from the outer portions of the element will not reach the energy meter sensor but will be intercepted by the 2.2 cm-long collimating shroud which shields it; on the other hand, the transducer test fixture does not shield the pressure-sensitive element except for very large angles of incidence. Therefore, for sources with large light-emitting elements, the transducer sees more energy than the sensor.

Examination of the data presented in figures 6 and 7 for the flashbulb sources shows that the maximum deviations for the four quantities plotted fall within ±15% of the ten-shot average values. Examination of the data presented in figure 5 for the single electronic-flash source used shows that the maximum deviations for the four quantities plotted fall within ±5% of the ten-shot average values. Coefficients of variation* of the energy-meter readings based on ten shots are 2.3% for electronic flash at 150 J, 3.7% for No. 5 flashbulbs, and 6.5% for No. 22 flashbulbs. The corresponding coefficients of variation for measured transducer zero shift are 0.8%, 6.6%, and 5.2%. The shot-to-shot repeatability with a single electronic-flash

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*The coefficient of variation is defined as the ratio of the sample standard deviation to the sample mean, expressed as a percentage.

unit as the source is thus seen to be greater than that for flashbulb sources. One electronic-flash unit with one flashlamp was used in the tests; however, general experience with electronic flash for photography suggests that shot-to-shot repeatability for a properly designed single unit will almost always be superior to that for flashbulbs. In spite of the superior repeatability, use of an electronic-flash source at 150 J is not recommended because of the low output. Electronic-flash units with significantly greater output are produced commercially, especially to order, but their usefulness for the purposes of this test method is limited by considerations of size, availability, and cost.

A detailed comparison of the plots A, B, and C in figures 6 and 7 provides the basis for some tentative conclusions; no such basis results from examining figure 5, as the fluctuations do not correlate. The same remark applies to the plots of photodiode output, data points D. As expected, the plots of the digital reading of the energy meter (data points B) and the energy-meter output (data points C) are in reasonable agreement in both magnitude and direction of change.

A comparison of B or C with A of figure 6 shows agreement in the direction of change for test 2 to test 3, 3 to 4, 4 to 5, 5 to 6, 6 to 7, and 9 to 10. The same comparison with the plots of figure 7 shows similar agreement for 2 to 3, 4 to 5, 5 to 6, 6 to 7, 7 to 8, 8 to 9, and 9 to 10. A possible explanation for the discrepancies lies in the fact that the energy output from the source may vary in azimuth and hence the transducer under test and the energy meter may "see" comparatively different power levels for the same test run. The manufacturers have confirmed that a specific azimuthal variation in flashbulb output is known to exist because of the orientation of the igniter element. This information became available after the close of the reporting period.

An explanation for the lack of correlation of photodiode output with the energy-meter outputs or with transducer zero shift may lie in the spectral response characteristics. The energy-meter sensor is described by the manufacturer as having flat response over the wavelength range 300 nm to 20 μm, whereas the photodiode range is quoted as 500 nm to 1.1 μm. [Note: The percentage deviations in photodiode output from a ten-shot average are smaller for the electronic flash than for the flashbulbs; this aspect is in general agreement with the behavior of the energy-meter outputs and the transducer zero shift with respect to the two types of source. Coefficients of variation based on ten shots for photodiode output are 0.7 for the electronic flash at 150 J, 4.5% for No. 5 flashbulbs, and 3.9% for No. 22 flashbulbs.]

Figure 8 consists of three photographs of oscilloscope traces of transducer D zero shift in response to thermal radiant-energy transients from the three sources.

The source-to-transducer distance was 10 cm. In all cases, the duration of the transducer zero-shift response is much longer than that of the thermal-transient stimulus causing it. The zero-shift for electronic flash appears to reach a peak about 10 ms after the onset of the thermal radiant-energy transient. For the No. 5 and No. 22 flashbulbs, the transducer zero shift peaks after about 115 ms and 130 ms, respectively. Comparison of figures 4 and 8 shows that the form of the transducer D zero-shift response for the sources used is largely independent of the thermal radiant-energy transient waveshape.

3. PLANS FOR THE REPORTING PERIOD JANUARY 1, 1975 TO MARCH 31, 1975

The following tests are planned for the final reporting period for this project of January 1, 1975 to March 31, 1975.

(1) Measurements of the variation in intensity with distance from the source will be made, and the repeatability of the method will be determined for the long-duration flood-flash FF-33 lamps, which were not previously available.

(2) An investigation will be carried out to provide some measure of the gain in intensity that may be achieved by means of the use of reflectors in conjunction with the flash source.

(3) The zero shifts of selected pressure transducers will be determined at two or more distances from the source and with two or more sources of thermal radiant-energy transients. Transducer types to be represented will include semiconductor strain gage, unbonded strain gage, thin-film strain gage, and quartz crystal.

(4) The zero shift of selected transducers will be measured in response to energy incident on the transducer diaphragm at angles other than normal to the surface.

(5) The output of selected transducers will be measured with the transducer itself measuring full-scale pressure.

(6) The output of selected transducers will be measured with the transducer itself measuring vacuum pressure.

(7) The effect on beam intensity of glass inserted into the beam of radiant energy will be investigated for at least one source.

(8) The effect on beam intensity of different apertures inserted into the beam of radiant energy will be investigated for at least one source.

(9) The effect of line-voltage variation on electronic-flash energy level will be measured.

(10) The effect of battery-voltage variation on electronic-flash energy level will be measured.

4. OTHER-AGENCY WORK

Two tasks outside the NBS Inter Agency Transducer Project are in progress for other Government agencies. Since the objectives of those tasks fall within the area of the NBS Inter Agency Transducer Project, an abstract or brief report is given as appropriate:

4.1 Development of a Dynamic Pressure Calibration Method*

Vezzetti, C.F., Hilten, J.S., and Lederer, P.S., Development of a Dynamic Pressure Calibration Technique — Progress Report for the Period February 15, 1974 to August 15, 1974, NBSIR 75-708 (June 5, 1975).

Work continues on the development of a method of producing sinusoidally varying pressures of at least 35 kPa zero-to-peak with amplitude variations within ±5% up to 2 kHz for the dynamic calibration of pressure transducers.

Sinusoidally varying pressures of 34 kPa zero-to-peak have been produced, to data, between 40 Hz and 750 Hz by vibrating a 10-cm column of a dimethyl siloxane liquid at 36 g_n zero-to-peak. Damping of the liquid column was accomplished by packing the fixture tube with a number of smaller diameter tubes (revised abstract).

4.2 Space Shuttle Pogo Pressure Measuring System**

In support of the experimental work carried out by the transducer project staff, a theoretical investigation was undertaken by the Mathematical Analysis Section of NBS. This resulted in the publication of NBS Technical Note 856 [Kraft, Richard, Note on a Vibratory Phenomenon Arising in Transducer Calibration, NBS Technical Note 856 (February 1975)]. An abstract follows:

By making appropriate physical approximations and idealizations a theoretical explanation is found for a vibratory phenomenon observed in calibrating pressure transducers inside thin liquid-filled cylinders. The theoretical explanation requires proving the equivalence of two boundary initial problems which define the vibratory phenomenon. A short, general and complete proof of this equivalence is given.

Since June, 1974, a new windmill calibrator has been designed and constructed. Considerable delays were experienced in the manufacturers' delivery of major components, in turn delaying completion of the calibrator. When the device was ready for checkout, higher priority tasks necessitated postponement of further work until after the beginning of 1975.

5. TRANSDUCER-RELATED NBS PUBLICATIONS

A variety of activities at NBS related to transducers and to their calibration results in publications. In order to enhance the dissemination of this information, the following reference and abstract is presented:

Payne, B.F., An Automated System for Precision Calibration of Acceleroemters, NBSIR 74-482 (April 1974).

The report describes an automated system for accelerometer calibration under real-time control by a small, dedicated digital computer. The hardware

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*The sponsor of this work is NASA Langley Research Center.
**The sponsor of this work is NASA Marshall Space Flight Center.

components of the system are described and the software programs are given. The software automatically regulates the rate and amount of data collected based on analysis of input data. Print-outs of the frequency response of test accelerometers is on a teletypewriter, and also the response can be stored on a magnetic tape. Manual operation of the system is also described.

6. REFERENCES

[1] P.S. Lederer and J.S. Hilten, NBS Inter Agency Transducer Project — Progress Report covering Period July 1, 1974 to September 30, 1974, NBSIR 75-654 (February 1975).

TABLE 1

TRANSDUCER D ZERO SHIFT IN RESPONSE TO THERMAL RADIANT-ENERGY TRANSIENTS

Source of Transient	Electronic Flash at 150 J			No. 5 Flashbulb			No. 22 Flashbulb		
Distance from Center Line of Energy Source to Transducer Diaphragm (cm)	Transducer Zero Shift* (mV)	Energy Meter Reading ($mJ \cdot cm^{-2}$)	Radiation Sensitivity ($V \cdot cm^2 \cdot J^{-1}$)	Transducer Zero Shift* (mV)	Energy Meter Reading ($mJ \cdot cm^{-2}$)	Radiation Sensitivity ($V \cdot cm^2 \cdot J^{-1}$)	Transducer Zero Shift* (mV)	Energy Meter Reading ($mJ \cdot cm^{-2}$)	Radiation Sensitivity ($V \cdot cm^2 \cdot J^{-1}$)
8	11.3	91	0.124	63	442	0.143	240	1631	0.149
10	7.2	59	0.122	41	293	0.140	140	930	0.151
14	3.5	28	0.123	19	137	0.135	76	520	0.146

*Full-scale output for transducer D is 500 mV, corresponding to 340 kPa (50 psig). All measurements were taken with transducer D at ambient atmospheric pressure and with constant electrical excitation.

TABLE 2

TEN-SHOT REPEATABILITY OF THERMAL-TRANSIENT SOURCE AND TRANSDUCER D ZERO SHIFT*

	Energy-Meter Readings			Photodiode Output**			Transducer D Zero Shift		
	Sample Average ($mJ \cdot cm^{-2}$)	Maximum Deviation from Average (%)	Sample Standard Deviation ($mJ \cdot cm^{-2}$) [1S%]	Sample Average (V)	Maximum Deviation from Average (%)	Sample Standard Deviation (V) [1S%]	Sample Average (mV)	Maximum Deviation from Average (%)	Sample Standard Deviation (mV) [1S%]
Electronic Flash at 150 J	101.0	-4.0, +3.4	2.3 [2.3]	8.0	-1.5, +1.0	0.1 [1.2]	12.8	-2.0, +1.1	0.1 [0.8]
5 Flashbulb	297	-5.1, +4.7	11 [3.7]	4.4	-7, +10	0.2 [4.5]	38.6	-11.1, +10.5	2.5 [6.5]
22 Flashbulb	764	-10, +12	50 [6.5]	12.8	-6, +4	0.5 [3.9]	98.6	-10.3, +6.9	5.1 [5.2]

*All measurements were taken at ambient atmospheric pressure; the transducer diaphragm was 7.5 cm, 10 cm, and 12 cm from the center plane of the electronic flashtube, the No. 5 flashbulb source, and the No. 22 flashbulb source, respectively.

**The photodiode output is given in peak volts and, unlike the energy meter readings, does not represent a measure of the total energy available in the transient.

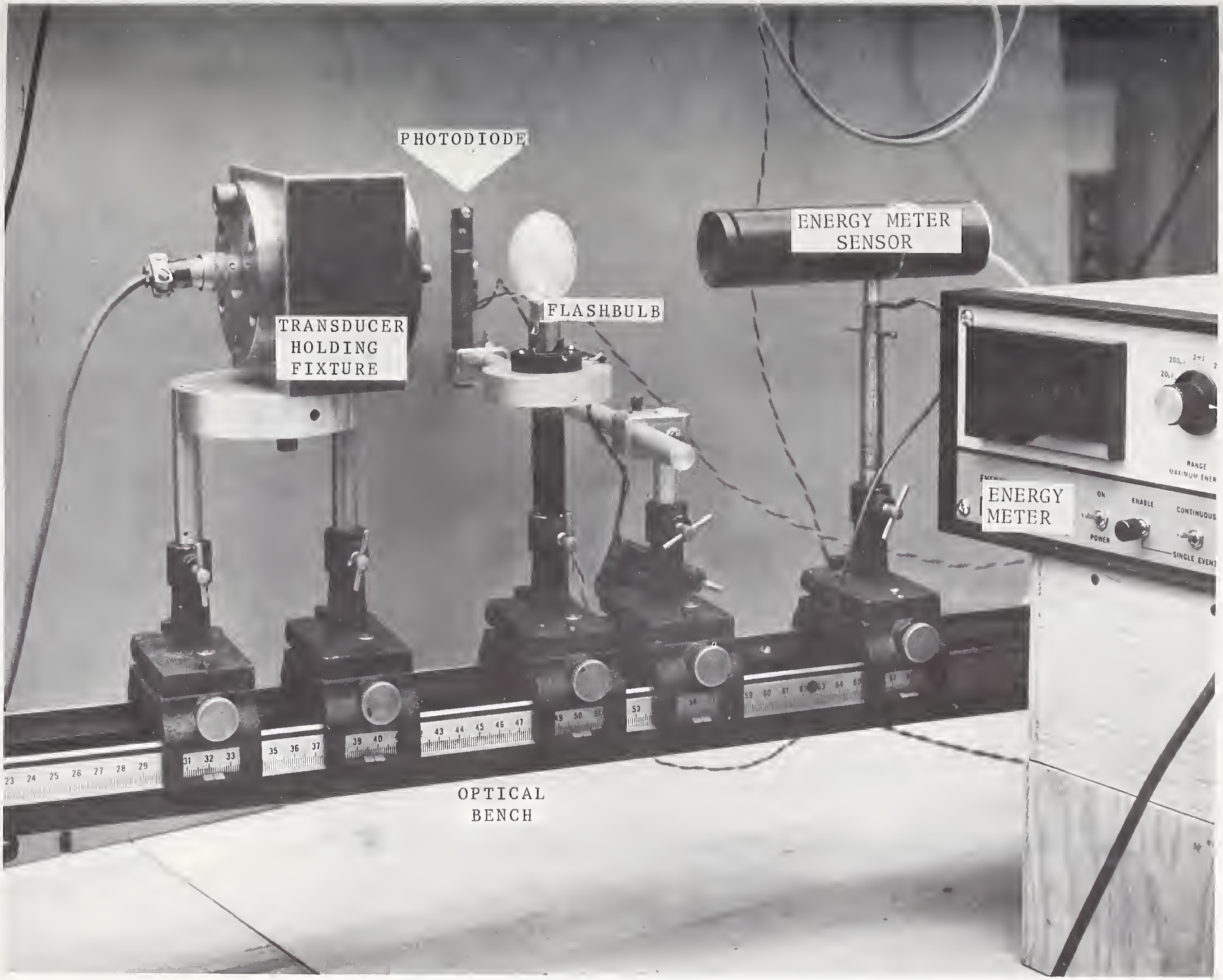

Figure 1: Overall view of experimental apparatus with transducer holding fixture, flashbulb source, photodiode, and energy meter sensor supported by holders mounted on an optical bench. The energy meter instrument is at the right.

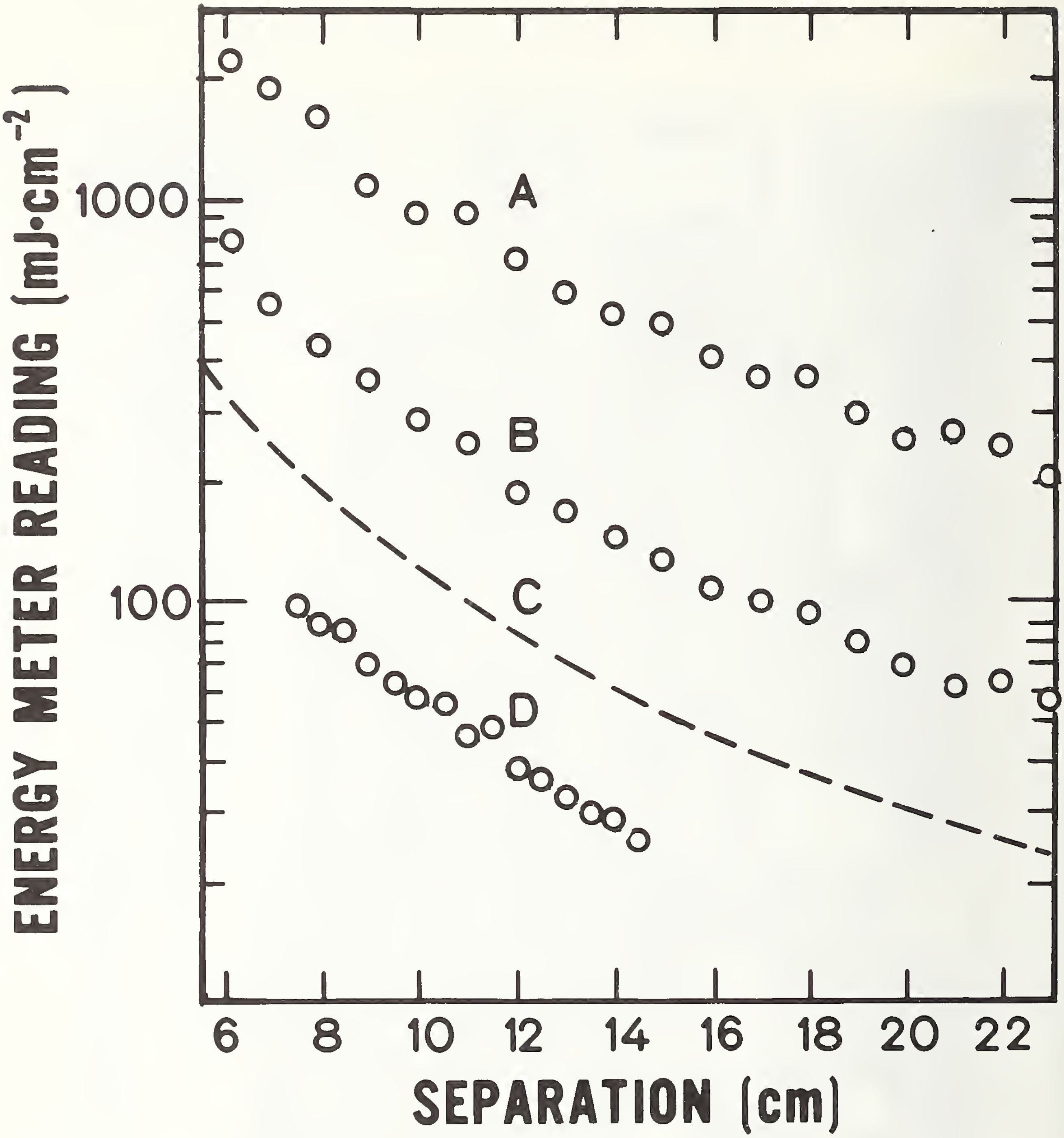

Figure 2: Energy meter reading as a function of separation, i.e., distance from the center plane of the source to the energy meter sensor. Energy meter reading is plotted on a logarithmic scale. Data points A refer to No. 22 flashbulbs, data points B refer to No. 5 flashbulbs, and data points D refer to the electronic flash at 150 J. Curve C is a plot of an arbitrary inverse-square relation for comparison.

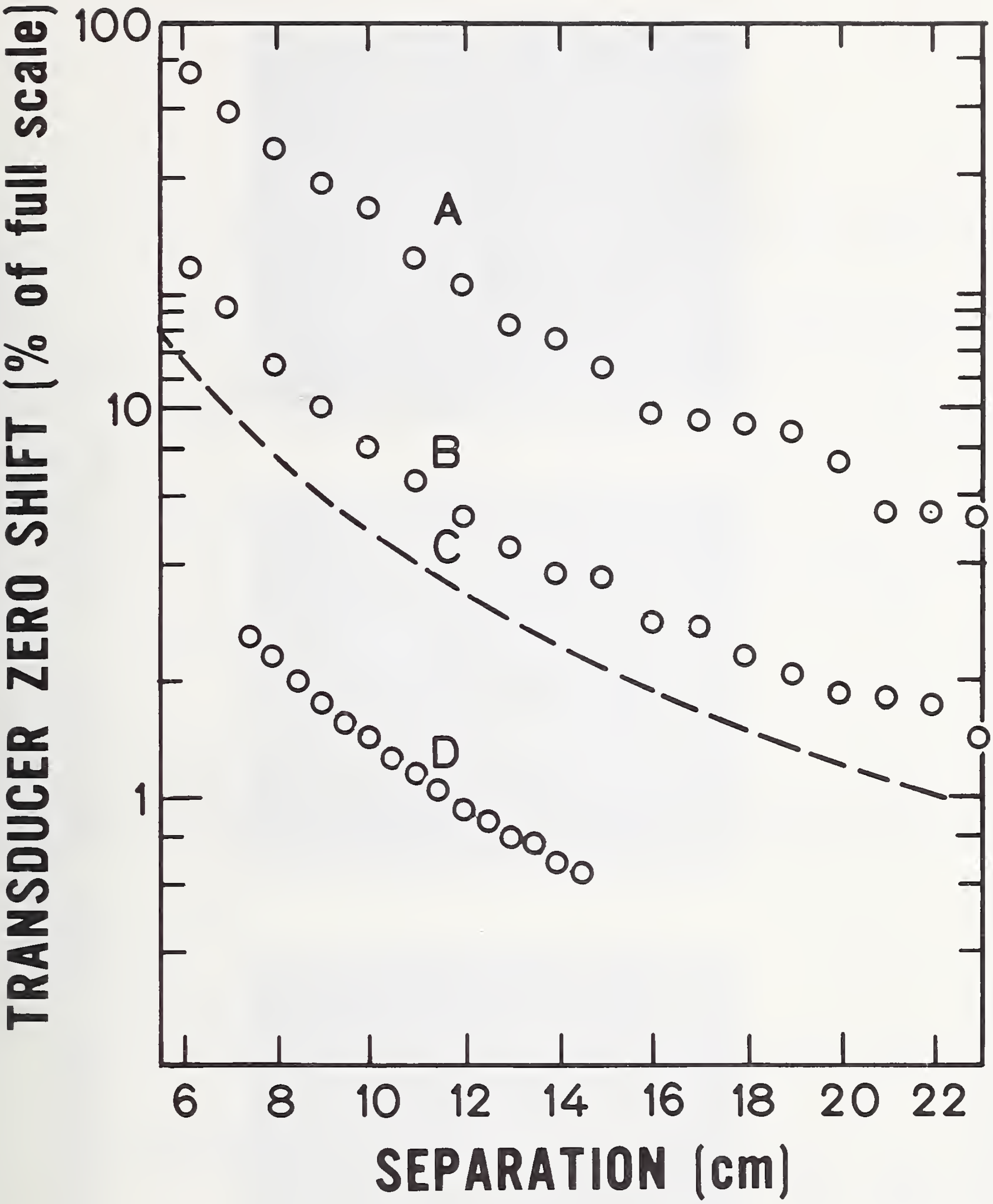

FIGURE 3: TRANSDUCER D ZERO SHIFT EXPRESSED AS PERCENT OF THE FULL-SCALE READING AS A FUNCTION OF SEPARATION, I.E., DISTANCE FROM THE CENTER PLANE OF THE SOURCE TO THE ENERGY METER SENSOR. TRANSDUCER ZERO SHIFT IS PLOTTED ON A LOGARITHMIC SCALE. DATA POINTS A REFER TO NO. 22 FLASHBULBS, DATA POINTS B REFER TO NO. 5 FLASHBULBS, AND DATA POINTS D REFER TO THE ELECTRONIC FLASH AT 150 J. CURVE C IS A PLOT OF AN ARBITRARY INVERSE-SQUARE RELATION FOR COMPARISON.

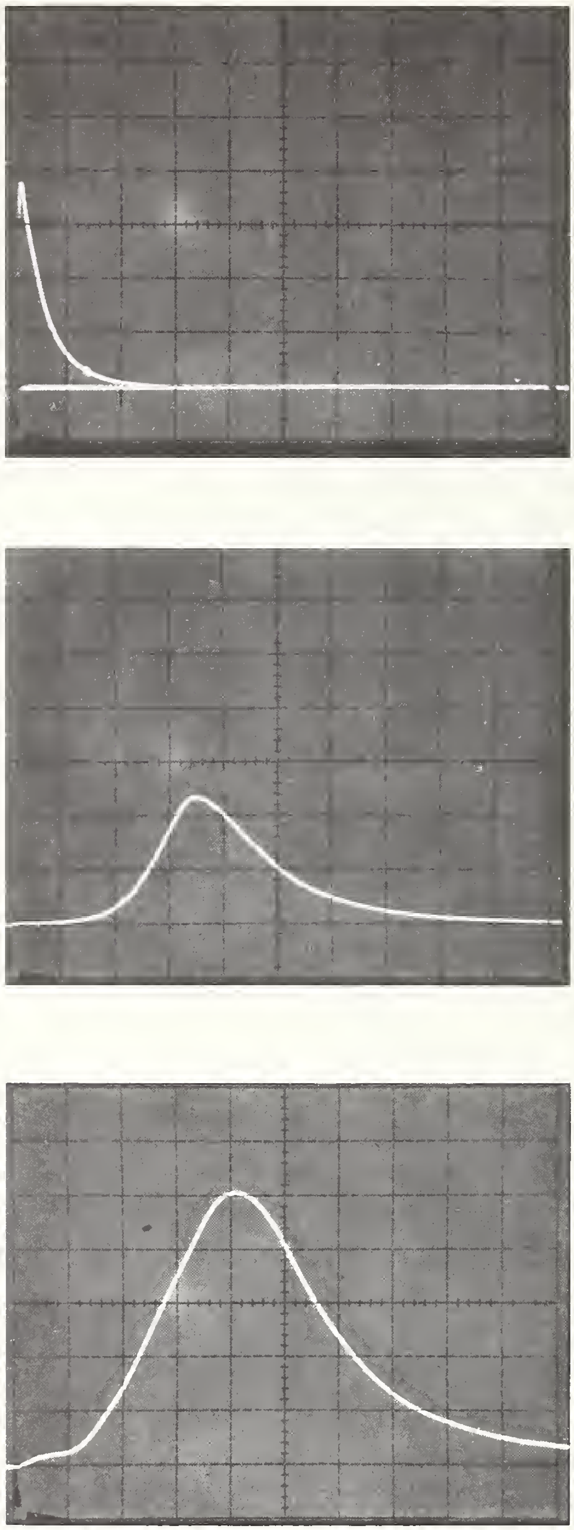

Figure 4: Oscilloscope traces showing photodiode output in response to thermal radiant-energy transients from (top) the electronic flash at 150 J, (center) a No. 5 flashbulb, and (bottom) a No. 22 flashbulb. The sweep time for each photograph was 50 ms, and the amplitude scale, 2 V per division.

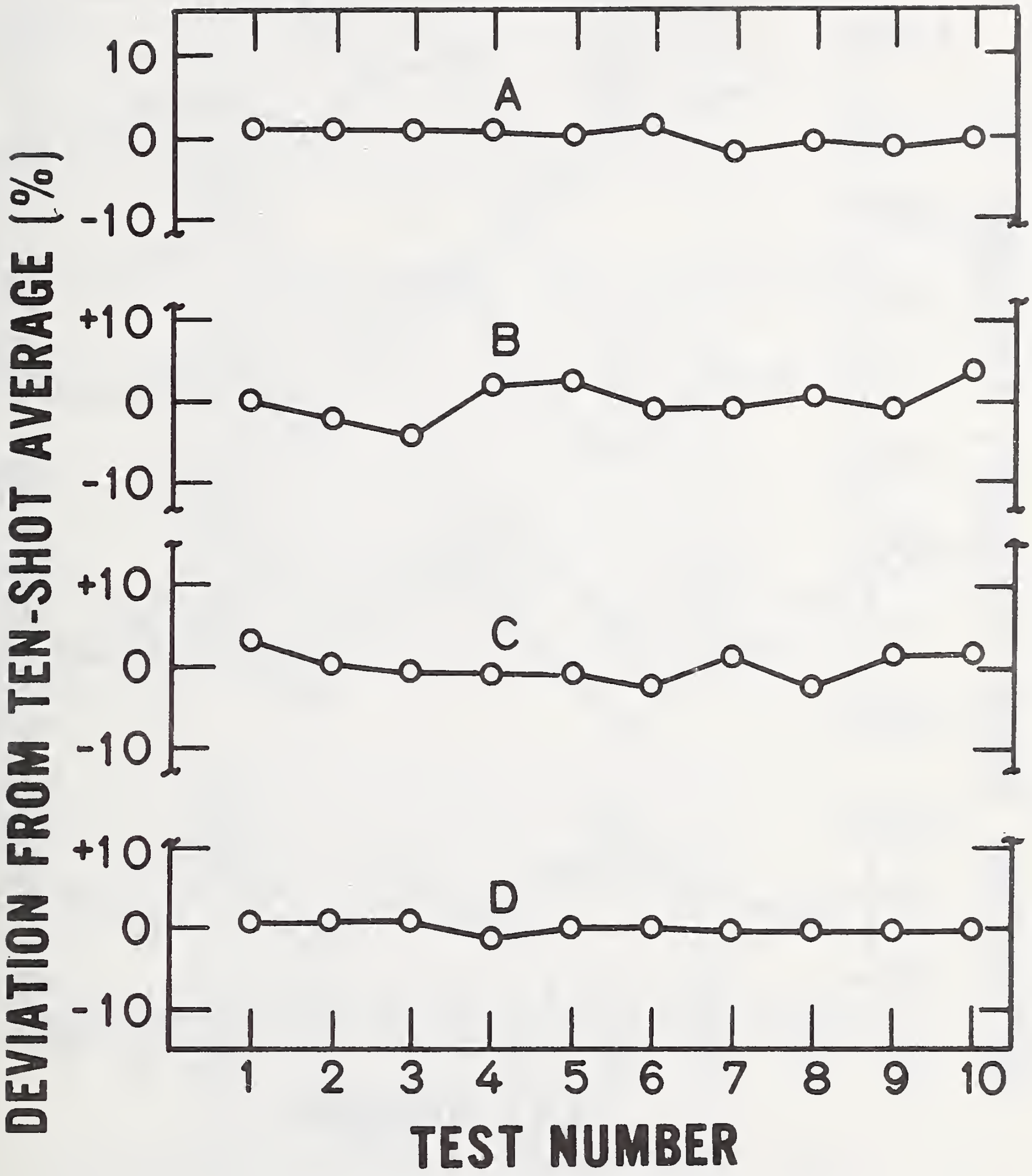

FIGURE 5: PERCENT DEVIATION FROM A TEN-SHOT AVERAGE FOR THE QUANTITIES (A) TRANSDUCER X ZERO SHIFT, (B) ENERGY METER RESPONSE, (C) ENERGY SENSOR OUTPUT, AND (D) PHOTODIODE OUTPUT; THE SOURCE WAS THE ELECTRONIC FLASH AT 150 J. THE DISTANCE BETWEEN THE CENTER PLANE OF THE FLASH SOURCE AND THE TRANSDUCER DIAPHRAGM WAS 7.5 CM.

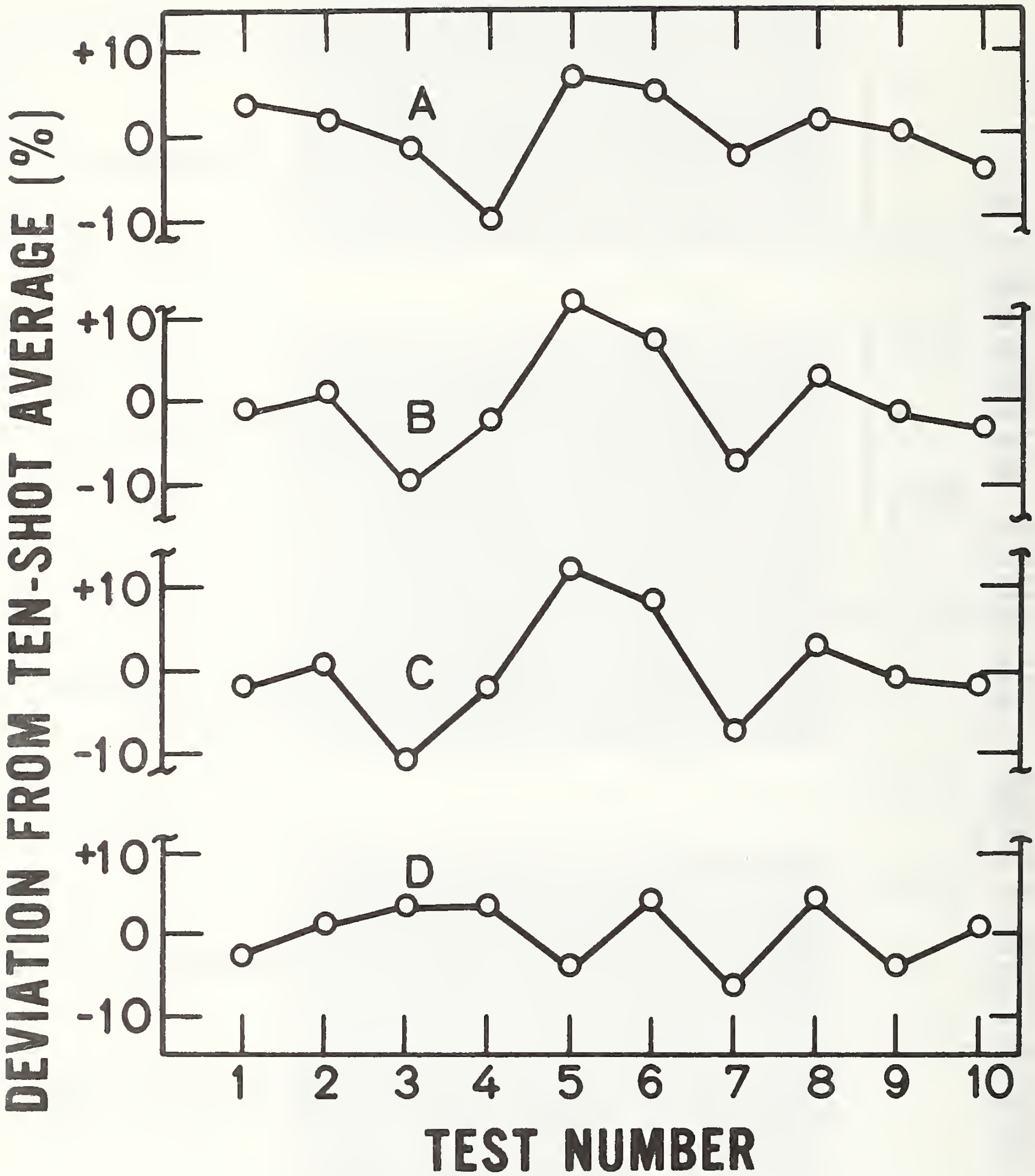

FIGURE 6: PERCENT DEVIATION FROM A TEN-SHOT AVERAGE FOR THE QUANTITIES (A) TRANSDUCER X ZERO SHIFT, (B) ENERGY METER RESPONSE, (C) ENERGY SENSOR OUTPUT, AND (D) PHOTODIODE OUTPUT; THE SOURCE WAS NO. 5 FLASHBULBS. THE DISTANCE BETWEEN THE CENTER PLANE OF THE FLASH SOURCE AND THE TRANSDUCER DIAPHRAGM WAS 10 CM.

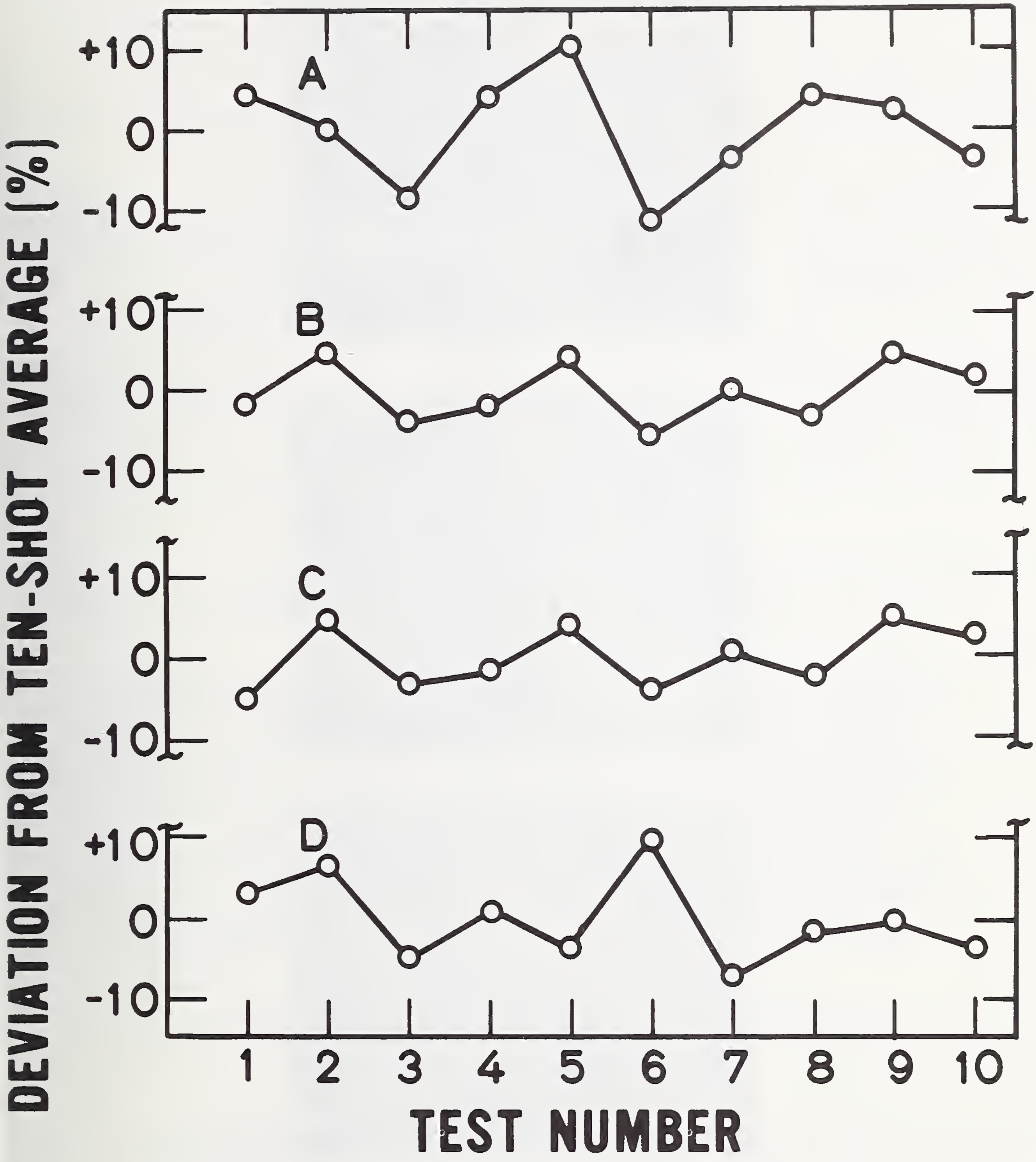

Figure 7: Percent deviation from a ten-shot average for the quantities (A) transducer X zero shift, (B) energy meter response, (C) energy sensor output, and (D) photodiode output; the source was No. 22 flash-bulbs. The distance between the center plane of the flash source and the transducer diaphragm was 12 cm.

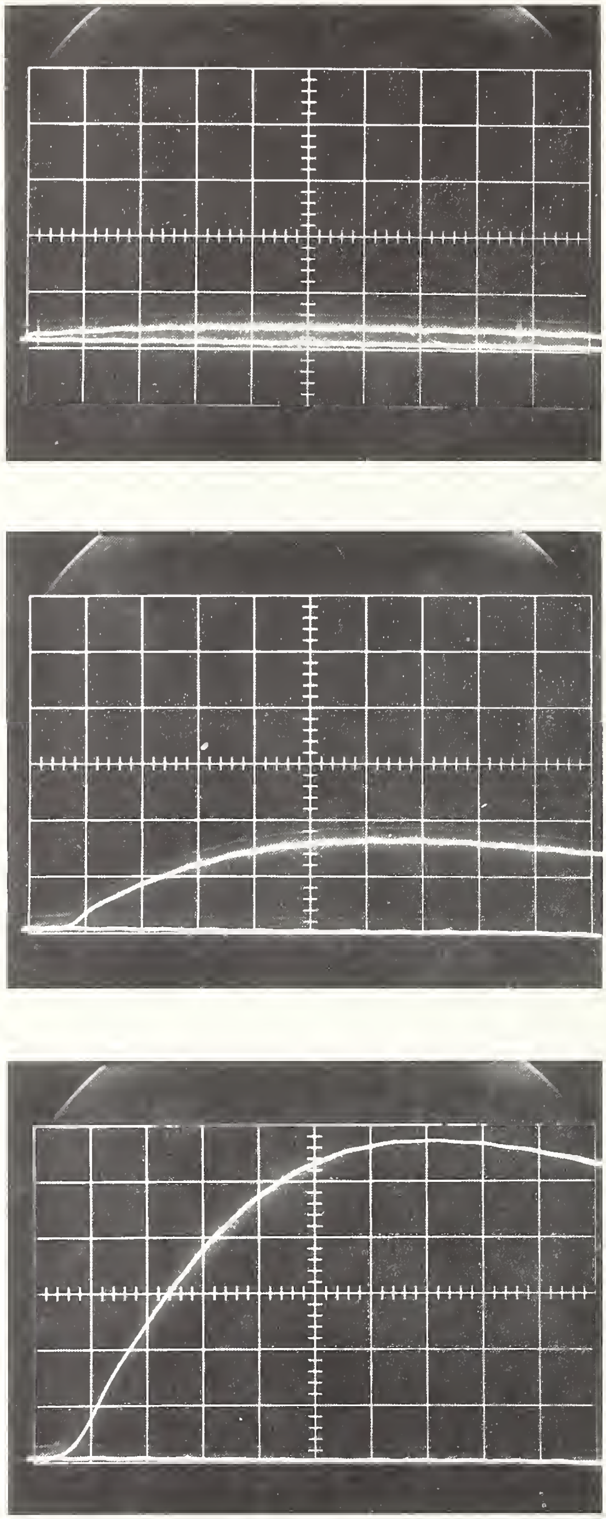

Figure 8: Oscilloscope traces showing transducer D zero shift in response to thermal radiant-energy transients from (top) the electronic flash at 150 J, (center) a No. 5 flashbulb, and (bottom) a No. 22 flashbulb. The source-to-transducer distance was 10 cm. The sweep time for each photograph was 200 ms, and the amplitude scale, 25 mV per division (corresponding to 5% of the full-scale output per division).

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The continuing development of a test method for evaluating the effects of short-duration thermal radiant-energy transients on pressure transducer performance is described. The method consists of monitoring pressure transducer output as the transducer is exposed to radiation resulting from the ignition of a photographic flashbulb or from the discharge of an electronic flash. Precision of the method is to be at least adequate for the method to serve as a first-cut screening test. During this reporting period, the following three parameters were investigated for each of three radiation sources: (1) the amount of energy per unit area available as a function of distance from the source, (2) the response of a selected transducer as a function of distance from the source, and (3) flash duration. Repeatability of the method for each source was determined.

Work being performed for other agencies is also described briefly.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Calibration; dynamic, electronic flash; photoflash bulb; pressure; pressure transducer response; thermal transient; transducer.

18. AVAILABILITY

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