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Displacement Measurements in Kiwi TNT

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Pin Technique for

Displacement Measurements in Kiwi TNT

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ABSTRACT

A pin technique used to measure relatively small, early outward displacements of the TNT reactor core and reflector cylinder components during the Kiwi Transient Nuclear Test is described. Considerations necessary to adapt this method to the environment of the reactor transient and the results are presented. An experiment to determine the times of closing of selected propellant passages using coaxial wires is also given.

It was of interest to determine, among other measurements, displacement versus time of a modified Kiwi reactor core and reflector components through a small distance during reactor expansion induced by a nuclear transient. These data were assimilated with other measurements and used to verify theoretical predictions. A method for obtaining the velocity of rapidly moving objects under difficult environmental conditions is the "pin technique." Although the first recorded use of the pin technique was at the Los Alamos Scientific Laboratory in 1944, the concept is still relatively unknown. Therefore, a description of pins and the considerations necessary to adapt the technique to the environmental conditions of the Kiwi Transient Nuclear Test are of interest.

In very general terms, the "pin technique" is a method of obtaining discrete position data related to time from the sequential closure of a series of electrical switches whose locations in space are precisely known. An elementary concept is illustrated in Figure 1.
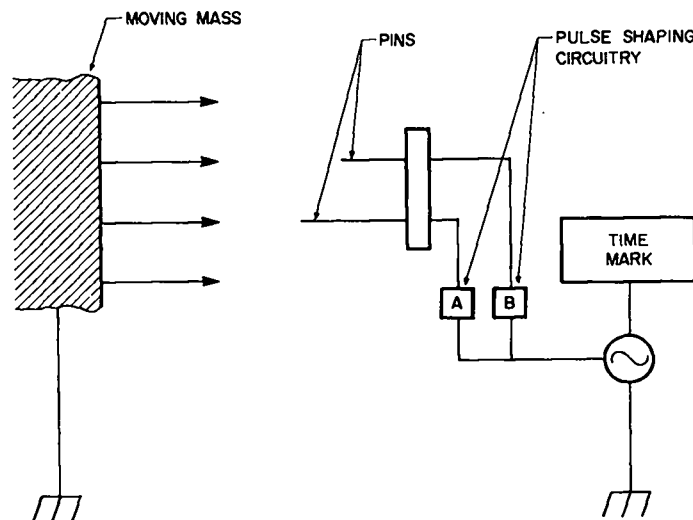

Figure 1.

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The pin assembly, on the right side of the figure, consists of electrically conducting wires oriented toward a moving object that is also conducting. Boxes A and B are pulse shaping networks containing capacitors, resistors, and a power supply. Their outputs are mixed on a common signal line and transmitted to a recording device, usually an oscilloscope or magnetic tape. As the moving mass contacts the lead pin, circuit "A" is closed, and its capacitor discharge pulse is recorded. The discharge of circuit "B" is similarly recorded at a later time. Since the position of the second pin in space is known relative to the first, the measurement of the time separation between closures gives the average velocity of the mass. If instrumentation of sufficient sensitivity and response is used, extremely high velocities may be measured. Velocity measurements of 2 to 10 millimeters per microsecond with an accuracy of ± 0.01 microsecond are common.

It is often more convenient to construct the pin coaxially so that the outer and inner conductors form the two elements of the circuit, thus eliminating the necessity of grounding the object under study during its movement. For high velocity experiments, and if the object is nonconducting or environmental shielding is required, a closure is obtained by driving a metallic cap into contact with the inner conductor. Such a pin in cross section is shown in Figure 2.
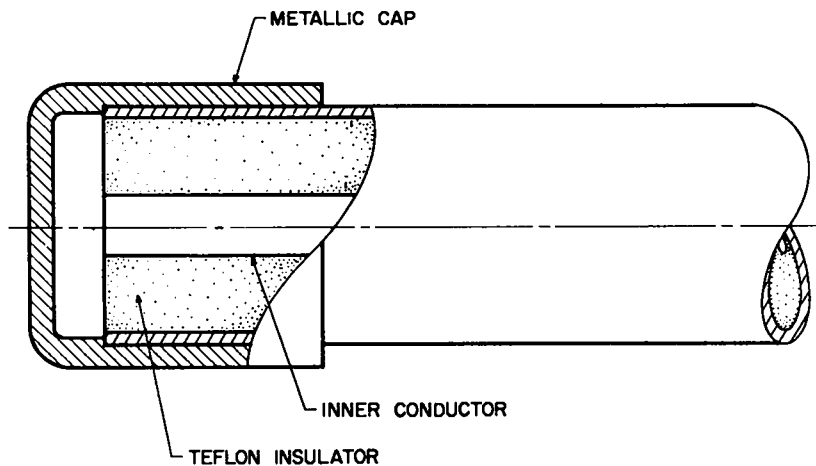

Figure 2.

For reasons of instrumentation economy and accuracy of data presentation, it is desirable that the signals of several pins be mixed into a single channel and that the channel or channels have common timing with other measurements. A convenient number has been found to be seven per channel. Therefore, coding of the pulses is necessary to identify the pin closure with its pulse. Figure 3 is a basic circuit commonly used for this purpose.
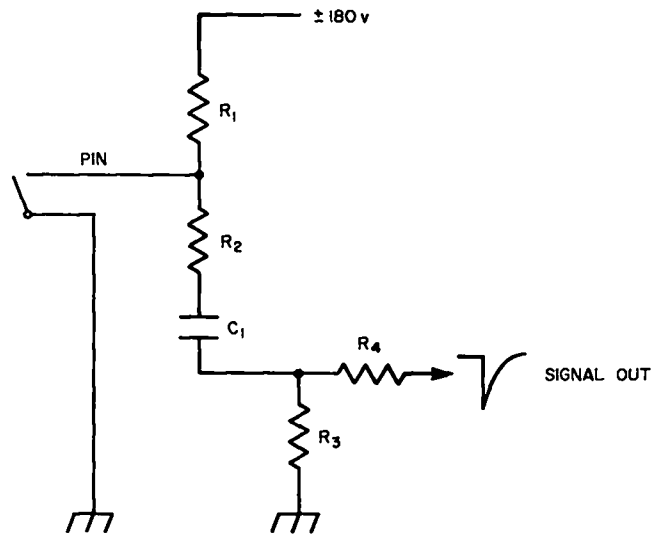
Figure 3.

R_1 is a current limiting resistor which allows C_1 to be charged to 180 volts. R_2 and C_1 are selected values that shape the decay of the discharge of C_1 according to their time constant. R_3 and R_4 match the output to the characteristics of the transmission line. The charging voltage polarity is alternated for successive pins to form the prime identification characteristic.

The data recording system must have sufficient recording time to span the event and yet have resolution consistent with the desired accuracy of the measurement and pulse recognition. Oscilloscopes with raster presentation have been found suitable for recording many experiments.

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In the TNT test, data were to be acquired close to the peak power level; thus the pins and electronics were adapted to resist the effects of the extreme radiation environment and to be capable of closure at very low velocities.

The low velocity, predicted to be in hundreds of feet per second rather than the usual millimeters per microsecond, precluded the use of a shielded pin with a metallic cap. At low velocities the pressure generated at impact is not sufficient to close the gap before the shock transmitted to the pin body via the outer portions of the cap perturbs the position of the inner conductor. Therefore, a capless configuration in which the impacting material formed the electrical path between the inner and outer conductors was used. During the event, the air around the reactor was expected to be very highly ionized which would tend to cause premature shorting. Therefore, a coating was found which would insulate the pin from ionization closure but would still allow closure when impacted.

The gamma dose was predicted to attain a level at a high enough rate where its heating effects would melt all known materials. Therefore, the materials of pin construction were selected to withstand the highest temperatures possible consistent with the requirement of data acquisition at reasonable cost. Properties affecting the selection of materials were the melting point, specific heat, and coefficients of expansion.

The Compton current was also an important consideration in that its polarity and magnitude would affect the noise level and the character of the closure pulse.

Consideration of these factors resulted in a pin construction as shown in Figure 4.

The pin fabrication is a variation of standard thermocouple practice in which magnesium oxide preforms are crushed to maximum density by swaging the stainless steel sheath around the inner conductor. This coaxial assembly was estimated to be able to withstand temperatures in excess of 1400°C.

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ASTROCERAM CERAMIC CEMENT   STAINLESS STEEL CONDUCTORS
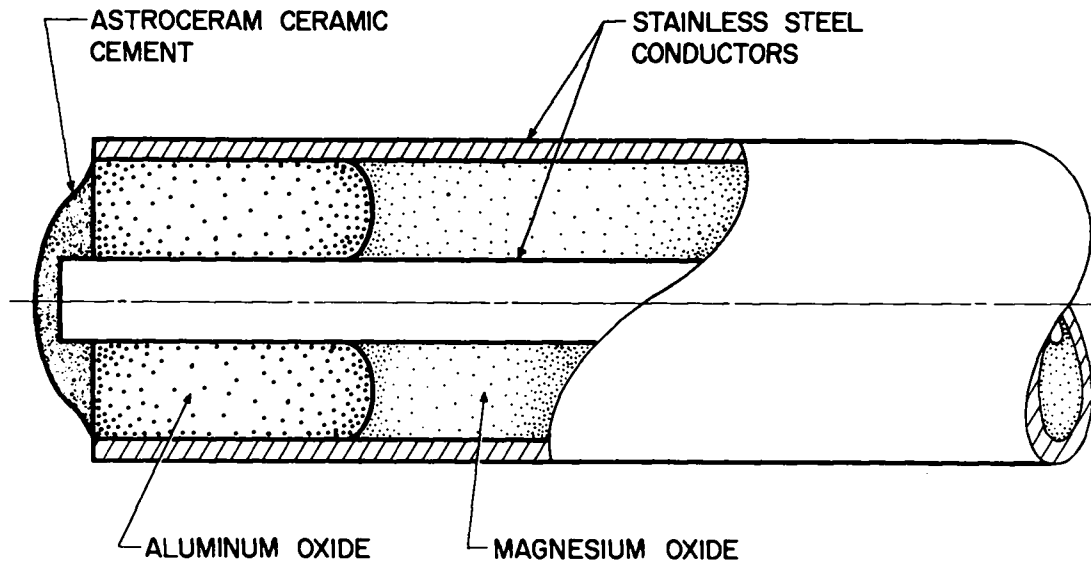
ALUMINUM OXIDE   MAGNESIUM OXIDE

Figure 4.

Because of the hygroscopic characteristic of magnesium oxide, the pins were hermetically sealed. Unfortunately, the Astroceram ceramic cement, since it is water thinned, could not be used as both the hermetic and frangible seals. A plug of aluminum oxide was sprayed onto the end of the pin by the Rokide process and subsequently ground to expose the center conductor. The aluminum oxide plug also provided support to the assembly when the steel was close to its melting point. The extension of the inner conductor into the Astroceram was found necessary to ensure closure upon impact. It provided an area of high unit loading which punched through the Astroceram material. Continued motion of the impacting core material then swept away the remaining Astroceram to make contact with the outer conductor. Astroceram is a product of the American Thermocatalytic Corporation. It is fragile until cured at high temperatures, but the electrical properties are satisfactory in the uncured state. However, the coaxial assemblies were baked at 600°F to ensure removal of the water of hydration. One sample was crudely tested for resistivity loss as a function of temperature by measuring the inner to outer conductor resistance while heating the coaxial assembly with an

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oxyacetelyene torch. Approximately 700 ohms remained at the point of
sheath melting (approximately 1415°C). Room temperature insulation
resistance was over 10^{10} ohms.

Theoretical estimates of the pin's sensitivity to gamma induced
Compton currents were combined with the results of a literature search
to arrive at an order-of-magnitude value for electronic design purposes.
Compensation with a considerable factor of safety was introduced in the
electronic design to account for this imprecision.
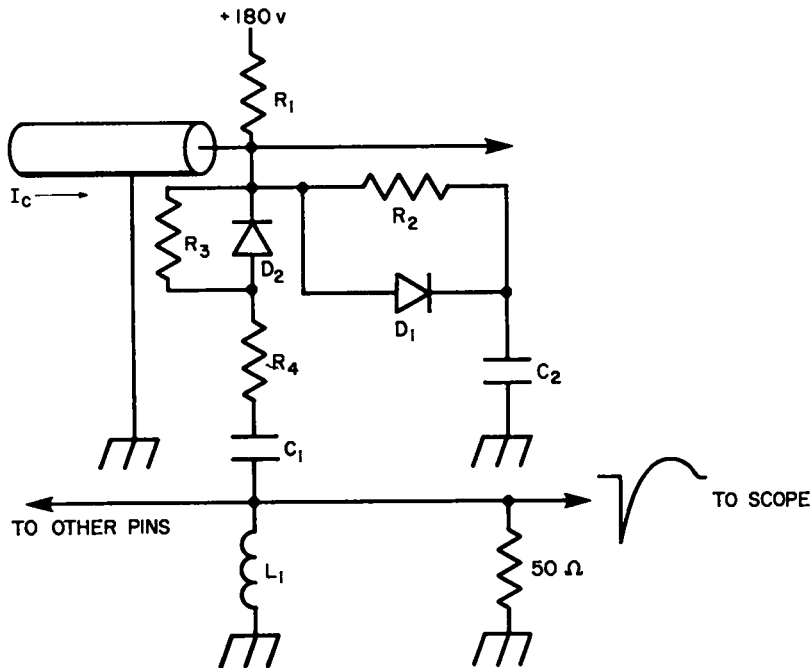
The pin pulse shaping circuit is shown in Figure 5.

Figure 5.

As in the basic circuit shown earlier, R_1 is a current limiting
resistor which allows C_1 and C_2 to charge to 180 volts. When a pin
closure or simulated closure occurs, C_1 discharges through R_4 +50 ohms
shunted by some inductance L_1. This RLC network provides additional
pin coding other than the RC time constant by varying the ringing
frequency and the resistive damping factor. A typical pulse is shown
in the figure. The circuit arm R_2, D_1, and C_2 is employed to provide a

charge sink for the Compton current I_c which was considered to be probably of positive polarity. (The preponderance of data examined indicated this to be true for constructions closely approximating the size and material of the pin cable.) C_2 is large compared to C_1 and aids in maintaining a more stable voltage across C_1. D_1 provides a low impedance path for I_c charging while R_2 limits pin cable recharge in case of multiple contacts or "chatter." D_2 and R_3 isolate the closed and unclosed pins. The components C_1 and L_1 together compose a high pass filter which shunts the untoward Compton current. A high pass filter was selected because it was anticipated that Compton current noise and resistive loss would follow the power curve of the reactor. The resulting low frequency activity would be attenuated while the high frequency capacitor discharge initiated at pin closure would be passed by the high pass filter.

Seven such circuits comprised one mixer card and one data channel with three of the pulse shaping circuit outputs inverted by a pulse transformer. The charging voltage was supplied by batteries integrated into the mixer package. The simulator connection leads to a silicon-controlled rectifier circuit which functions as a switch to simulate a closure upon command. This circuit enabled dry run tests of the mixer and pin circuitry to occur either repetitively for setup purposes or singularly upon command of a simulated trigger pulse. Figure 6 shows, from left to right, the pin mixer box assembly, the pin simulator, and the simulator power supply.

To prevent spurious apparent closures due to ionization at connections, the pin coaxial construction was made continuous from the point of contact at the reactor to termination at the mixer. Sharp bends and deformation of the outer conductors were avoided insofar as practical. The mixer was placed in a box and immersed in DC-200 silicone fluid. External connections from the mixer to the simulator were filled with silicone grease and capped off prior to the hot run.
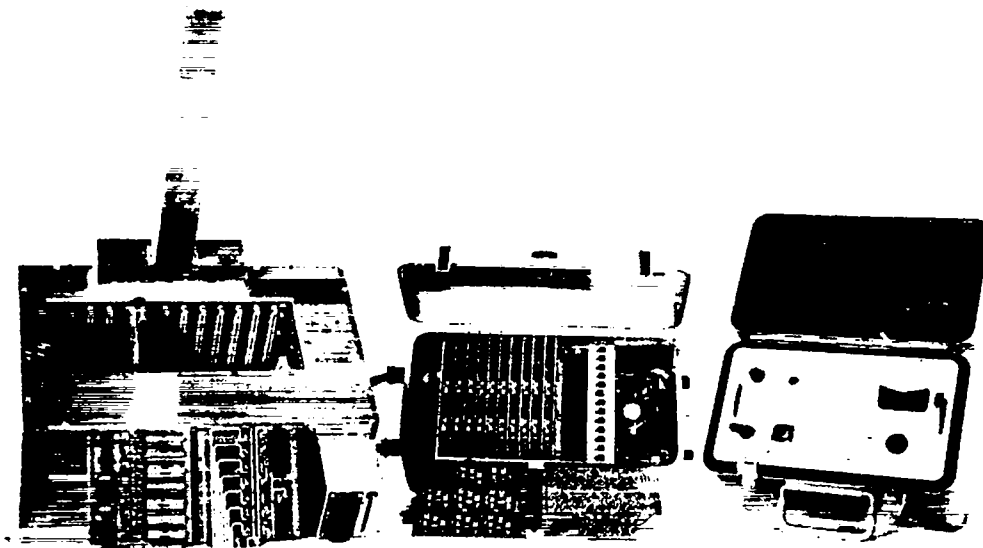
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Figure 6.

The mixer box was shielded with 6 inches of lead and 12 inches of borax for gamma and neutron attenuation. An aluminum box contained the mixer and shielding material. The pins were arranged in groups of seven in a holder as shown in Figure 7.
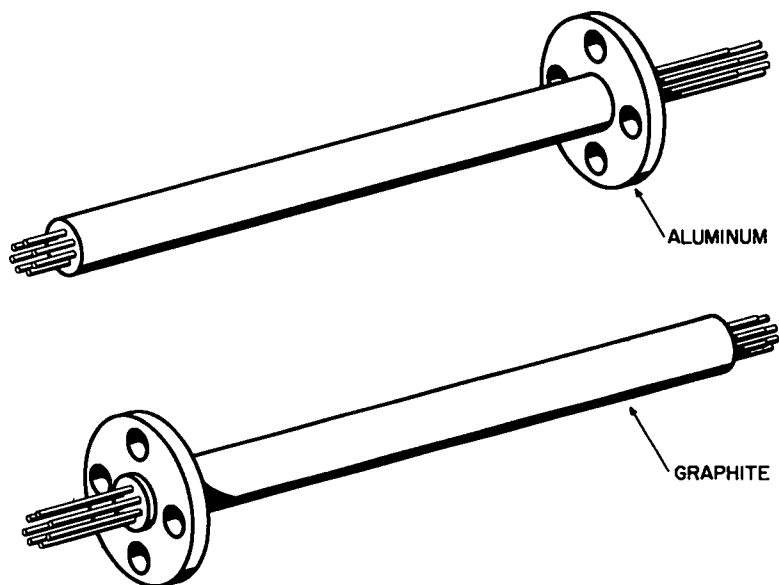

Figure 7.

The barrel of the assembly was made of ATJ grade graphite selected for its high temperature characteristics and neutronic similarity to the reactor material. The pins were locked in place in a specific and carefully measured position relative to each other and to the flange. Dimensions from pin to pin were gaged to within ±0.003 inch and from pin to flange within ±0.004 inch. The pin holder penetrated a precisely known distance into the reactor and was secured by bolting the flange to a spotfaced area on the pressure vessel surface. Other pin groups of similar configuration were mounted to a bracket crossing the end of the pressure vessel. A total of ten pin groups monitored the early expansion of the reactor.

Figure 8 shows the position of the groups monitoring the core and reflector cylinder expansions and the location of the mixer circuitry. The LVDT's shown in the photograph were used to continuously monitor for position shifts of two single points near the top of the core and reflector cylinder during final systems setup and checkout. These sensors were removed and replaced by pin assemblies for the test.

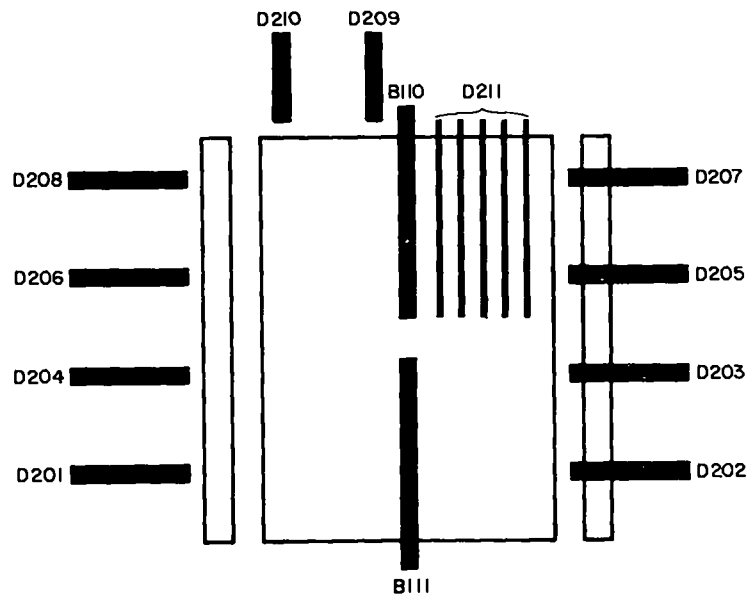Figure 9 schematically indicates the location of all pin groups.
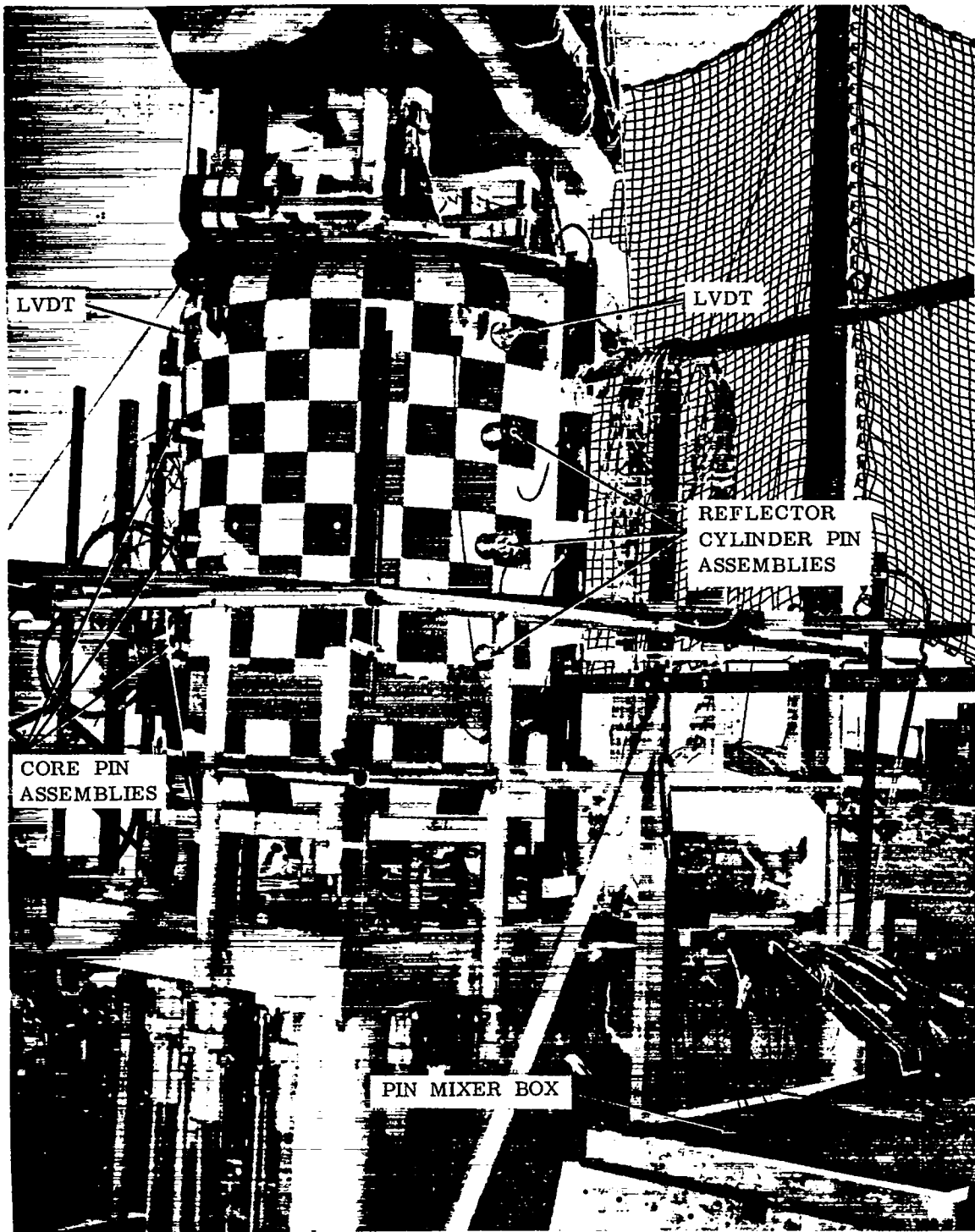

Figure 9.

Figure 8. Reactor External View.

In addition to the ten pin groups monitoring early outward expansions, 21 coaxial wires similar to the pins were inserted to varying penetrations into selected propellant passages in the core. This was an experiment to determine the time of closing of these passages from the collapse or shorting of the coaxial wires. These coaxial wires had Mullite sleeves spaced over the length inserted in the core to keep the stainless steel sheathing from contacting the hot core surfaces and thereby delaying the reduction in insulation resistivity due to temperature rise which would be present in the core surrounding the probe. Insulation resistivity decrease would produce a shunting effect similar to collapse but would be a lower frequency disturbance.

Figure 10 is a block diagram of a typical pin data acquisition channel. Thirteen signal cables of RG-58 were terminated at the mixer in the oil-filled cavity. These coaxial cables carried the pin group signals 700 feet to conditioning and primary recording equipment located in a shielded building. Each of these signals was connected to one channel of a dual beam oscilloscope and to a mixer-line driver. Ten-kilocycle time pips from the range time system were mixed with each pin group signal in the oscilloscopes and in the mixer-line drivers. The two group signal display on each oscilloscope was photographed by Dynafax cameras modified to operate as streak cameras. Seven scope-camera units were used for primary recording of the 13 signals. This system provided 8 milliseconds writing time with 2-microsecond resolution. A firing chassis at the control point provided signals to apply camera power at minus 60 seconds, to open camera shutters at minus 2 seconds, and to close camera shutters at plus 1 second. Local confirm circuits monitored camera speeds, camera shutters, time pips, and pin power to provide confirmation signals to the control point and a GO/NO-GO signal to the firing chassis. A trigger signal corresponding to a power level of 10^{15} fissions per second was used to intensify the oscilloscope beams and was also mixed with each pin group signal and 10-kilocycle time pips in the mixer-line driver. Oscilloscope intensities were triggered at

Figure 10. Block Diagram Typical Pin Data Channel.

fixed times after the power level trigger as determined by theoretical predictions and measurement location. The local control provided for system checkout and dry run operations. The signals from the 13 mixer-line driver units were transmitted over 13 triplets to the control point for backup and time tie recording on 13 channels of magnetic tape. The time pips and the power level trigger served as common events to tie all pin data together and to tie pin data to other recorded information. Most of the data were reduced from magnetic tape since motions occurred slightly later than predicted causing the primary recording system to produce incomplete records during the fixed and limited recording interval. Reducible records were obtained following the test by playing the magnetic tape signals directly into one unit of the primary oscilloscope-Dynafax system just described. This presentation provided 2-microsecond resolution with waveform degradation and loss in signal-to-noise ratio over the primary system.

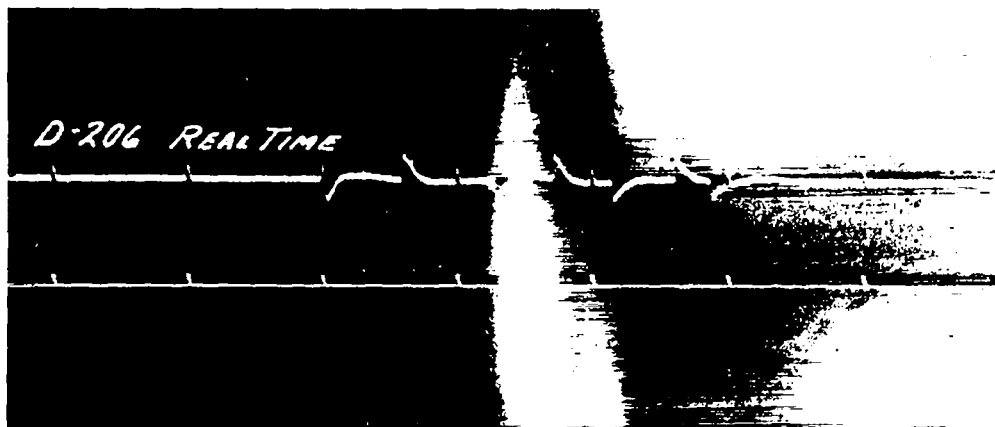Figure 11 shows the primary (real time) recording of channel D-206.

Figure 11.

The lack of noise and low frequency transients on this and all other traces indicates that the system performed as expected.

Of the 13 pin groups, 12 transmitted data, eight channels were easily interpreted with good confidence, two had a low confidence level,

and two were very difficult to interpret owing to greatly attenuated pulse waveforms. These last two groups and the group which transmitted no data were the in-core experiment to determine the coolant passage collapses. Attenuation of these in-core events was not unexpected owing to predicted signal shunting from decreasing insulation resistivity and increasing pin circuit resistance with increasing temperatures. It is of interest to note that this performance was attained in an environment where the total fissions were about two orders of magnitude greater than in any known rapid, deliberate, or accidental reactor excursion. The TNT maximum reciprocal period was about 1630 seconds^{-1}.

On the two in-core groups which produced attenuated waveforms it was indicated that passage collapses occurred earliest in the bottom half of the core, 280 to 50 microseconds before peak power, and 20 to 80 microseconds following peak power in the top half of the core. Other evidence tends to confirm this order of collapse. Waveform attenuation prevented more detailed identification of these collapses.

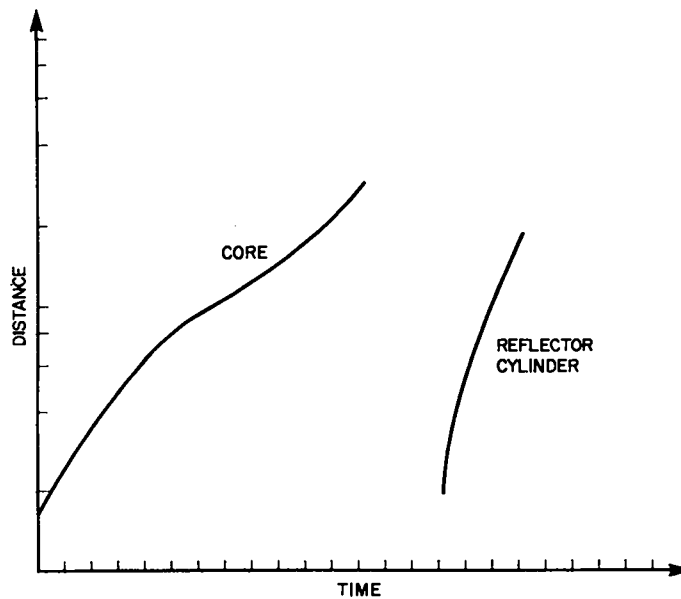Figure 12 shows typical displacements versus time which were measured.

Figure 12.

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Figure 13 shows a summary of all displacement measurements.

In considering the overall behavior of all the channels, it appears that the reference against which we were measuring displacement (the pressure vessel) underwent a general outward and upward displacement at about 12.2 milliseconds. (See points on Channels D-202, 205, 207, 208, 209, and 210 taken after this time.) Channel D-204 appears to be an exception to this in that it shows a discontinuity after 11.4 milliseconds. At 50-percent height the core attained a velocity of about 1700 centimeters per second at the end of the data-taking interval. At 75-percent height reflector cylinder velocities of 1150 centimeters per second were observed with early motions, and 1800 centimeters per second was attained at later times.

Figure 14 is an expansion chart showing core and reflector cylinder contours at 100-microsecond intervals.
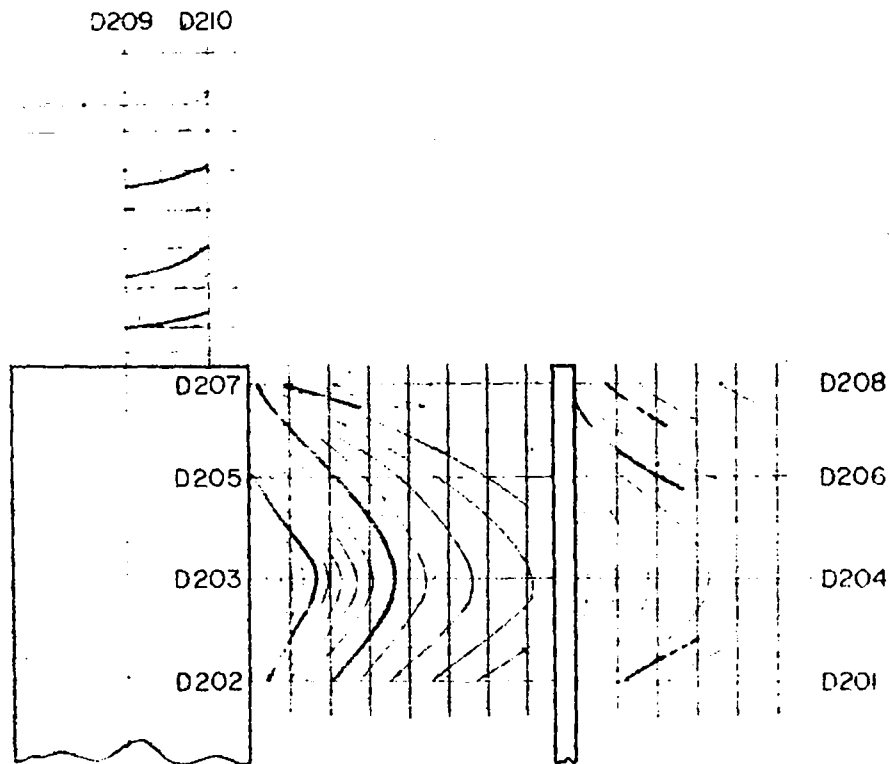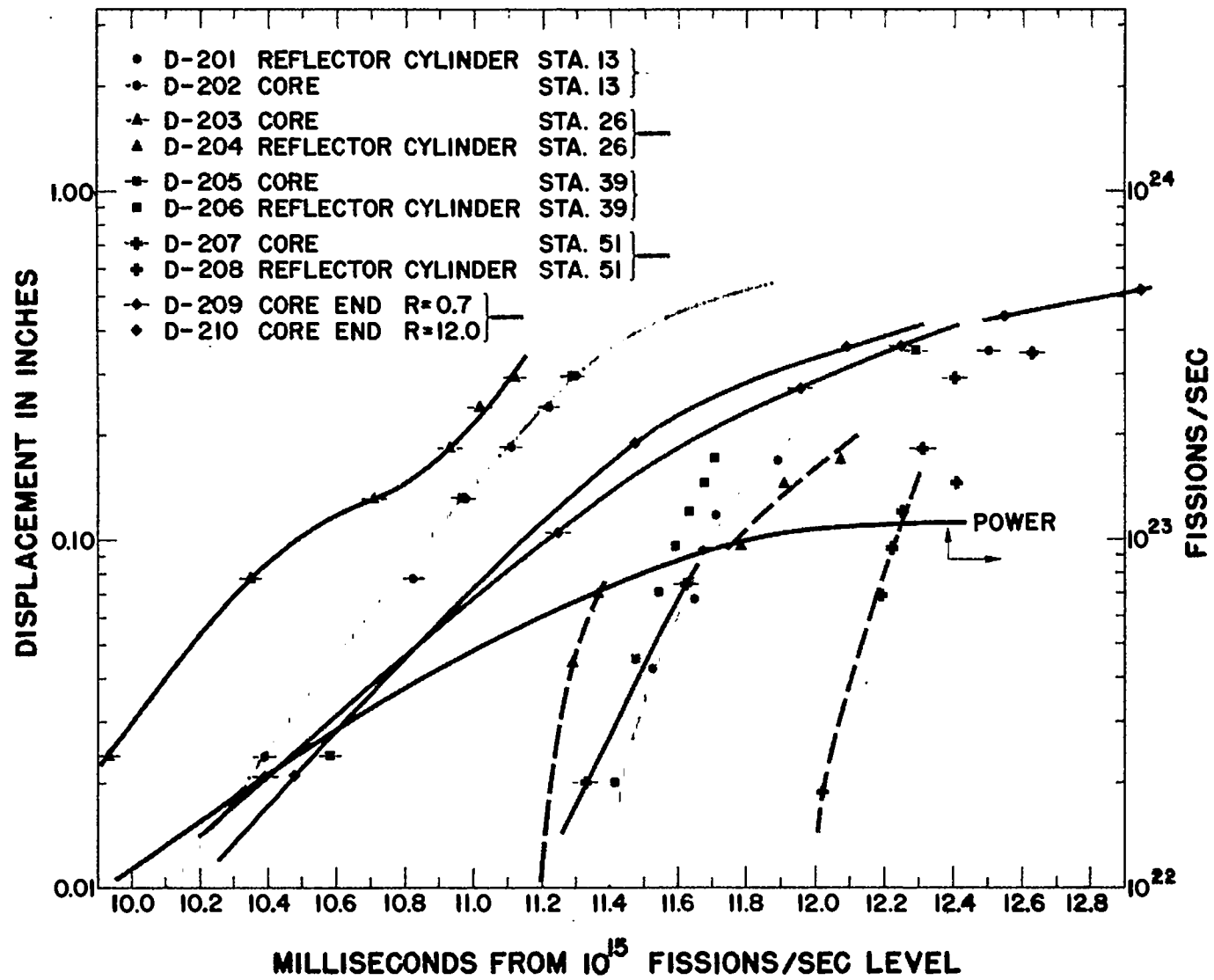

Figure 14.

Figure 13. Summary of all displacement measurements.

The data show that early motions appear to begin centrally. There is some indication that the activity center later moves downward in that the motions at 75-percent height start after those at 25-percent height. The in-core collapse measurements also tended to indicate this.