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MEASUREMENT OF THE TRANSIENT CONTROL ROD MOTION AND ITS EFFECT ON THE AFRRI-TRIGA REACTOR PULSE

ARMED FORCES RADIOBIOLOGY RESEARCH INSTITUTE
Defense Atomic Support Agency
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MEASUREMENT OF THE TRANSIENT CONTROL ROD MOTION AND ITS EFFECT ON THE AFRRI-TRIGA REACTOR PULSE

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FOREWORD
(Nontechnical summary)

The TRIGA nuclear reactor is presently the primary source of radiation for the radiobiology studies being conducted at the Armed Forces Radiobiology Research Institute. Much of the research is done with the pulsed radiation bursts from the reactor. Pneumatic ejection of a transient control rod from the fuel region of the reactor places the reactor in a highly supercritical state and results in an inherently safe self-controlled nuclear excursion which produces a large burst of neutrons and gamma rays. Reported here is the design of a system to study the finite travel time of this transient control rod and the measurement of the effect of the control rod motion on the behavior of the reactor.

With the pneumatic ejection pressure of 72 psi, the rod has been found to move outward with a nearly constant acceleration of 2.5 g's. It is also found that the rod momentum causes an initial depression of the shock absorbing anvil by about 1.1 centimeters above its final equilibrium position. For pulses on the order of prompt critical ($1.00 reactivity insertion), major effects are produced in the magnitude and shape of the "prompt jump" region of the pulse. For reactivity insertions above $2.80, a coupling between the outward travel time of the rod and the time of occurrence of the pulse peak has been observed. If lower air pressures are used for the ejection of the rod, the pulse peak can be caused to occur before the rod reaches the anvil. If the rod bounce produced by initial depression of the anvil occurs at nearly the time of the peak, distortions in the peak are observed with a corresponding effect on the total radiation produced in the burst.

ABSTRACT

The design of a system for the measurement of the transient control rod motion of the AFRRI-TRIGA pulse reactor is presented. Data on the transient rod motion and its effect on the reactor pulse are presented and discussed. It is found that the finite travel time of the rod has an effect on the time of the pulse peak and the magnitude and shape of the pulses above $3.00. For pulses on the order of $1.00, the beginning of the power transient has been found to be sensitive to the transient rod bounce.

I. INTRODUCTION

At the Armed Forces Radiobiology Research Institute (AFRRI), a large portion of the radiobiology research utilizes the TRIGA reactor as the radiation source. For this reason, it is desired that the nature and degree of reproducibility of the gamma ray and neutron fields from the reactor be known to high precision. A majority of the experiments is conducted with the pulsed radiation fields (bursts) that may be produced with the reactor. These bursts occur with a time duration on the order of milliseconds and produce drastically changing radiation intensities during this time. An extensive study of the AFRRI-TRIGA reactor radiation pulse has been undertaken to provide an understanding of how the properties of the radiation fields vary with time during and immediately following the pulse. This paper reports the design of a system to study the effect of the finite travel time of the transient control rod on the size and shape of the pulse of radiation.

The transient rod, which enables rapid insertion of large amounts of reactivity, is made of borated graphite in aluminum cladding. It is located on the vertical axis of the 20 percent enriched uranium, zirconium hydride and water moderated core which is suspended from a movable dolly into a water pool to a depth of approximately 15 feet. This water provides radiation shielding, neutron moderation, and cooling for the reactor core. The transient rod is driven out of the core pneumatically by a piston within a movable air cylinder located on the dolly. The amount of rod removed is predetermined by the positioning of the air cylinder and shock absorber (anvil) remotely from the control console. The shock absorber, at the upper end of the air cylinder, consists of a spring and hydraulic deceleration system. Such a system has an inherent bounce characteristic when the piston reaches the top of the air cylinder. This has been indicated by high-speed photography.

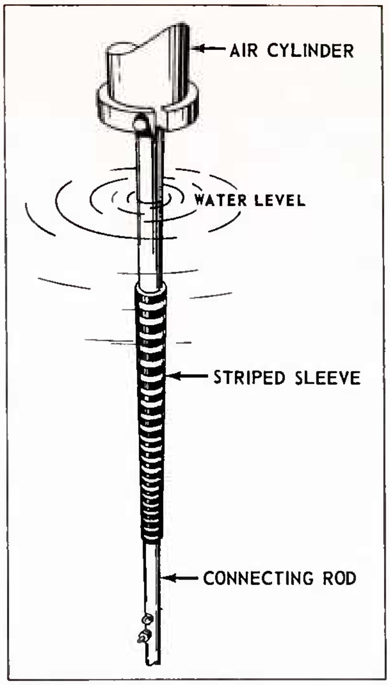
To determine the transient rod effects on the pulse, a system was required to accurately correlate the displacement of the transient rod and the reactor power as a function of time during a pulse. The criteria for this system were that it be inexpensive to build, be capable of response times on the order of milliseconds, be durable enough to enable repetitive rod displacement measurements on a routine basis, provide immediate readout of data, and not affect the normal rod motion.

High-speed underwater movies, resistance wire systems and other methods were considered but were discarded for not satisfying one or more of the above criteria. The system finally developed was a simple light source--photodiode system.

II. DESCRIPTION OF TRANSIENT ROD MOTION SYSTEM

The transient rod motion system developed indicates the transient rod displacement through its entire 15 inches of motion. A 1.0 inch i.d., 20 inches long stainless steel tube was machined to a wall thickness of 0.130 inch and polished. The tube was then painted with stripes of black acrylic paint 1 centimeter in width and spaced 1 centimeter apart. The connecting rod between the transient rod and the pneumatic piston on the core dolly was then disconnected and this striped stainless steel sleeve was fitted snugly onto the rod (Figure 1) and pinned into place. It was necessary to place the top of the sleeve at least 15 inches below the bottom of the pneumatic cylinder to permit this amount of the connecting rod to travel into the cylinder as the piston moves up. Thus the sleeve had to be placed under the surface of the water. Therefore, the photodiode sensor was also required to be under the water.

Figure 1. Striped sleeve and connecting rod



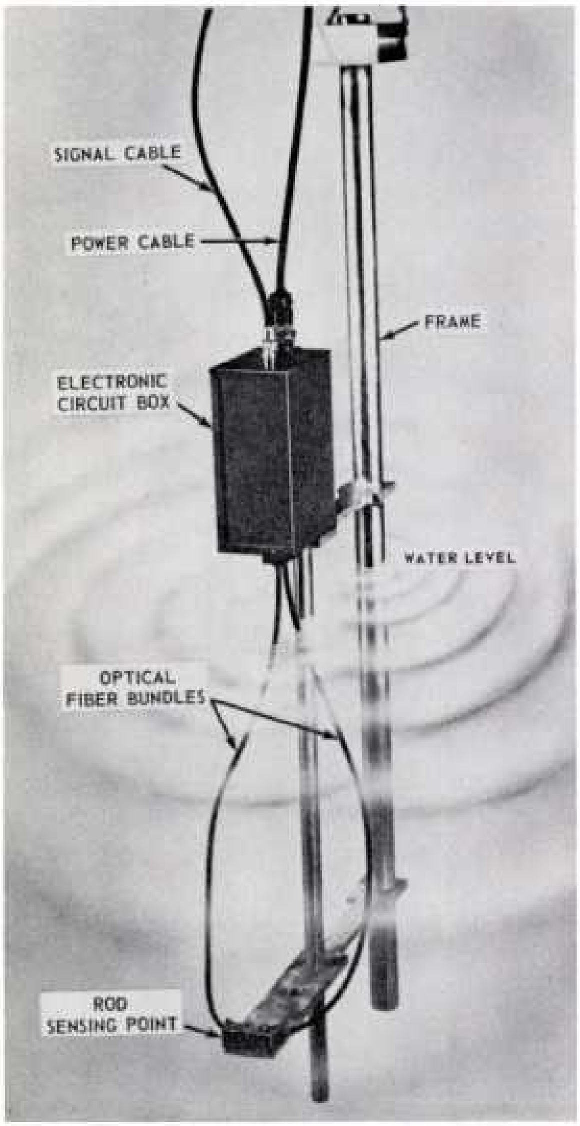


Figure 2. Frame and mounted components

To accomplish this, two 1/8-inch diameter optical fiber bundles were mounted on a frame with the electronic circuitry box mounted at the top (Figure 2). One optical fiber bundle provides a light path for the light source from the circuit box to the face of the striped sleeve and the other provides a light path for the reflected light from the sleeve to a photodiode sensor located in the circuit box. Figure 3 provides a schematic diagram of the sensing circuit. A Texas Instruments, Inc. type 1N2175, N-P-N diffused silicon photo-duo-diode was selected for its fast rise time (~2 μsec) and high sensitivity. The preamplifier has a voltage amplification of 30 dB and response of ± 1 dB from 10 Hz to 10^4 Hz. The single stage amplifier serves to increase the rate of charge of the 0.47 μF capacitor. The 2N1306 serves as a cathode follower to match the input requirement of a Model 1012, Minneapolis-Honeywell Visicorder Oscillograph.

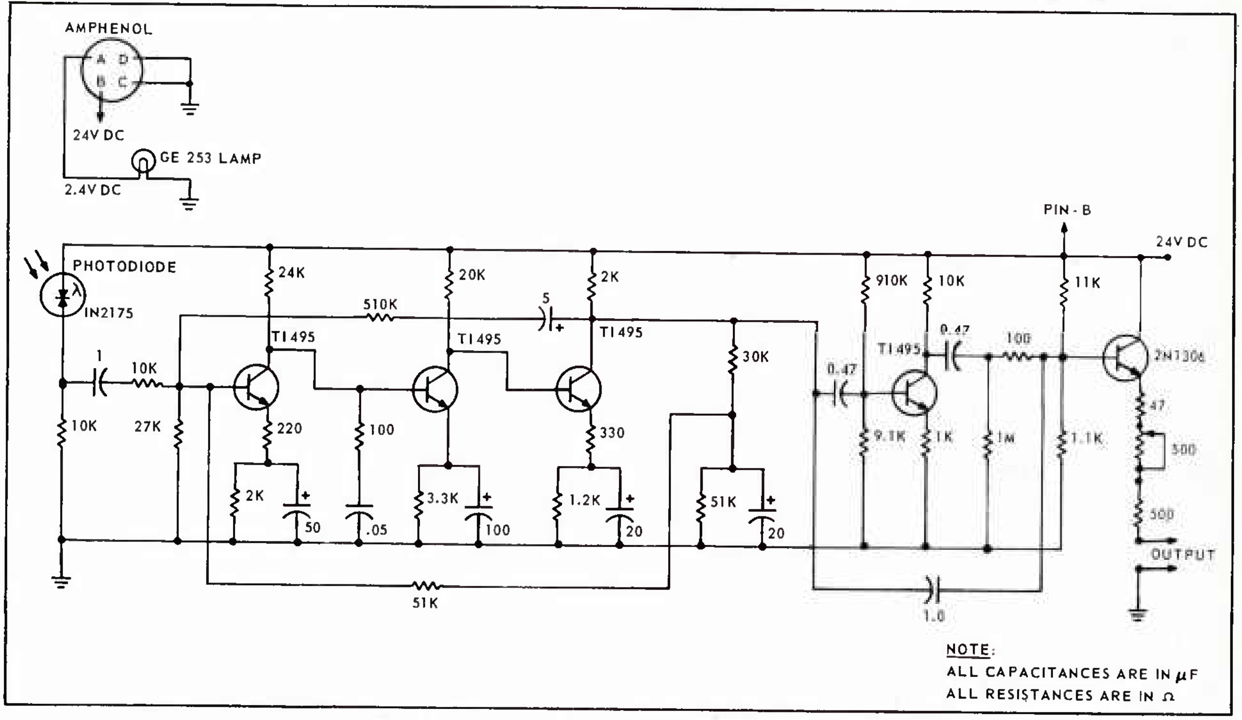


Figure 3. Photodiode sensing circuit

The circuit diagram of the power supply for the photodiode circuit and the G.E. 253 lamp light source is shown in Figure 4. The power supply provides 24 volts dc to the photodiode circuit and either 2.4 volts dc (for operation) or 6.3 volts ac (for alignment test) to the lamp.

An overall block diagram of the system is shown in Figure 5.

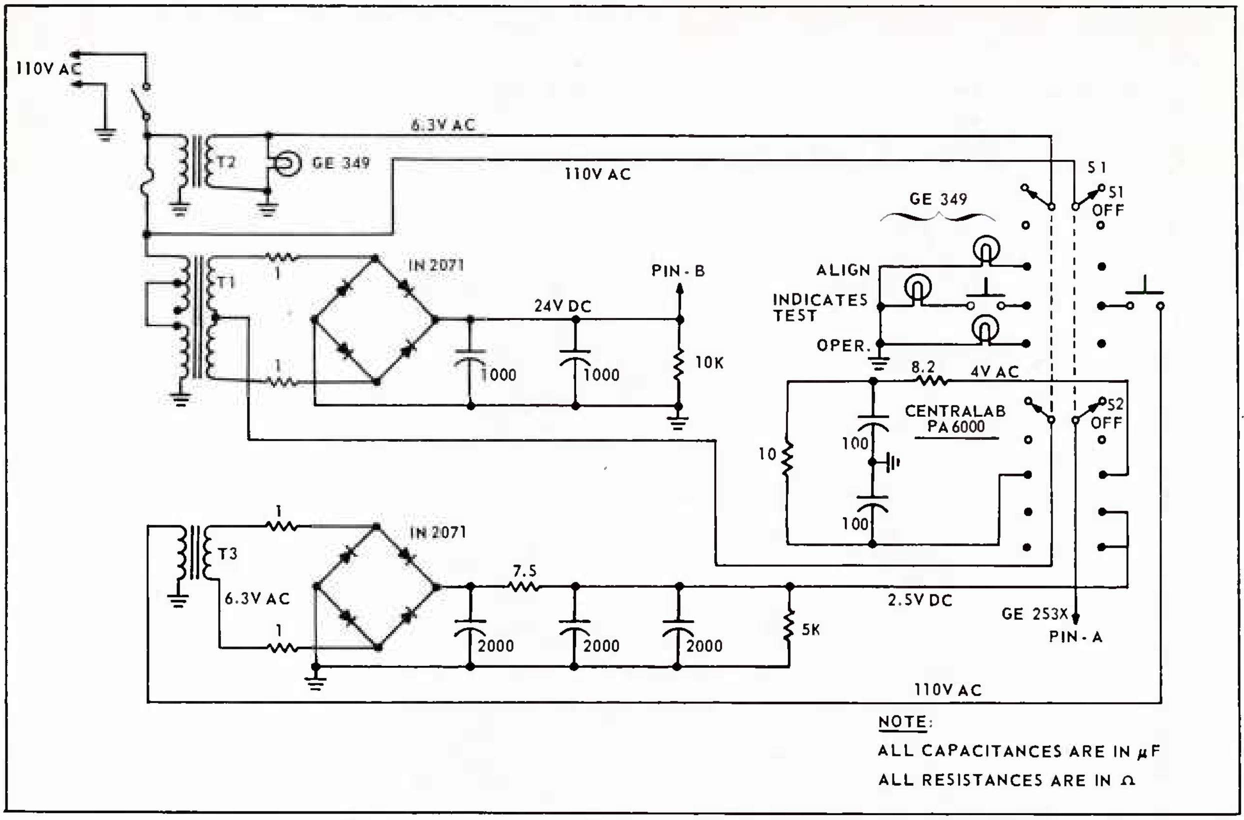


Figure 4. Power supply circuit

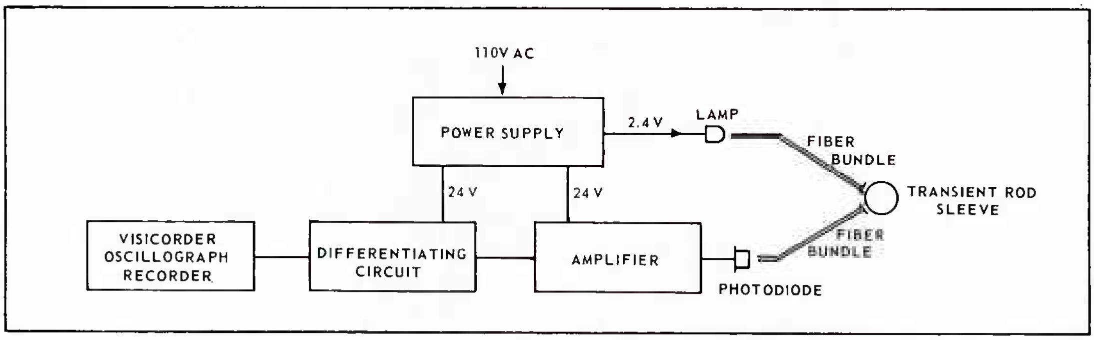


Figure 5. Block diagram -- transient rod displacement system

III. PERFORMANCE OF THE SYSTEM

Figure 6 provides output traces on the Minneapolis-Honeywell Oscillograph for the motion of the transient rod as a function of time after the air solenoid is de-energized for a $2.83 reactivity insertion. The output is a series of positive and negative pulses resulting from differentiating the photodiode current as the polished and black striped stainless steel sleeve sections pass in front of the light source--photodiode face. Each positive pulse sharply denotes the point in time of passage of the sleeve from polished to black striped surface. Each negative pulse denotes the point in time of passage of the sleeve from black striped to polished surface. Thus each 1 centimeter displacement of the rod is recorded. The position of the rod as it

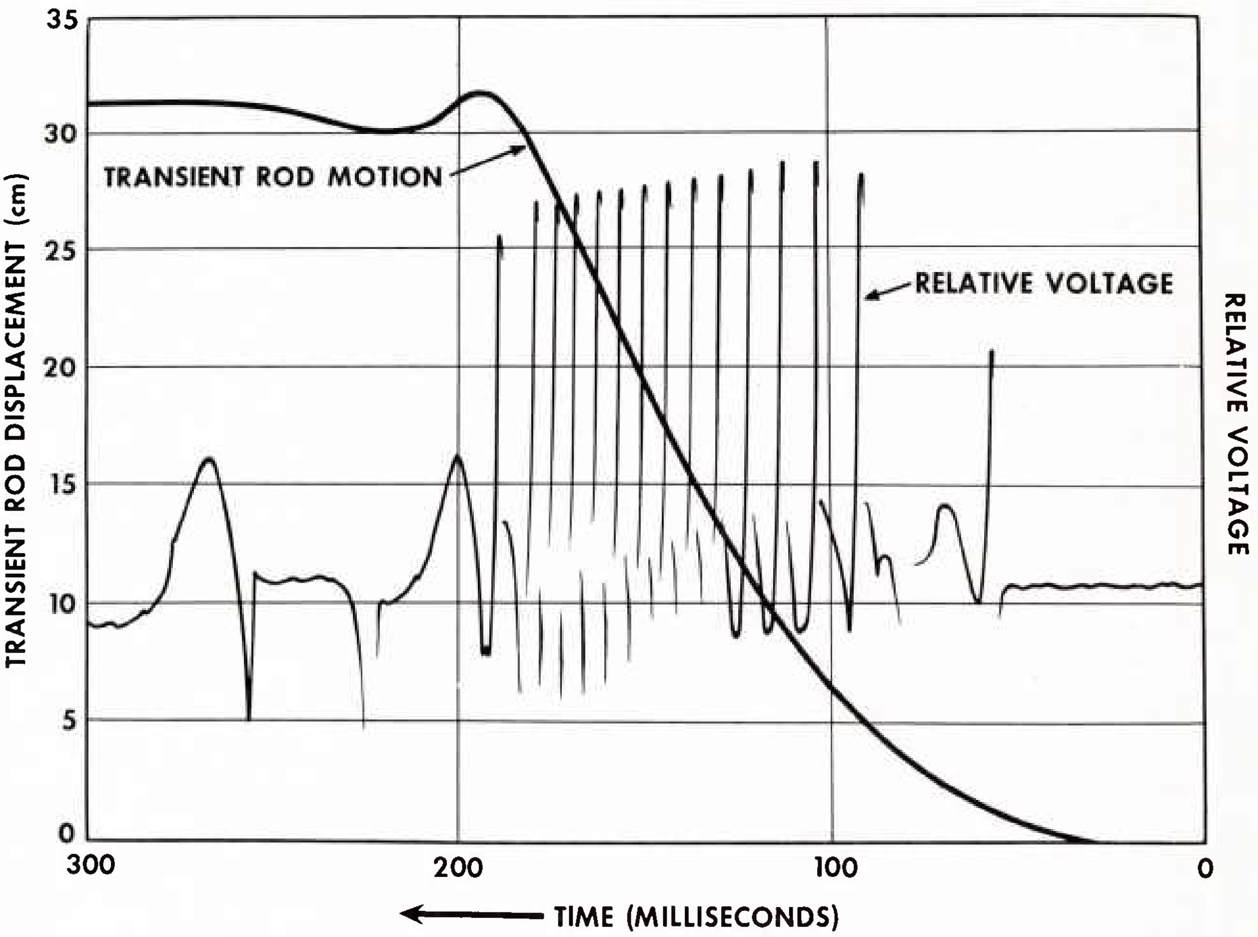


Figure 6. Output traces of oscillograph

passes each centimeter mark is known to within ± 0.05 centimeter. This precision is dependent upon factors such as amplifier gain, fiber bundle diameter, lamp intensity, etc.

Problems were experienced in positioning the rod sensing point (see Figure 2) to provide adequate light to the photodiode. However, when the sensing point was optimally positioned, at least a 50-milliampere peak output was observed and full scale deflection of the Visicorder trace was obtained using an M-1000 fluid damped subminiature galvanometer with the Visicorder.

IV. RESULTS AND DISCUSSION OF TRANSIENT ROD MOTION MEASUREMENTS

With the system described above, transient rod motion measurements have been made simultaneously with measurements of the TRIGA reactor power pulse. It has been found that the rod has a nearly constant acceleration for 72 psi air pressure of approximately 2.4×10^3 cm/s^2 (2.5 g's) until it makes contact with the upper shock absorber (anvil). It is found that the rod momentum then depresses the anvil about 1.1 centimeters above a final equilibrium position. The rod motion is, however, highly damped and only oscillates through slightly greater than one-half cycle before reaching its final position. This has been indicated by high-speed photography.

The characteristics of the reactor power transient during and immediately after the extraction of the rod have been examined to see what effect the finite travel time and bounce of the rod have on the pulse. For the larger pulses the reactor power exhibits little response to the transient rod other than from the "prompt jump" effect until the positive reactivity exceeds the prompt critical value of $1.00. For times much shorter than the shortest half-life fission product delayed neutron emitter, this is to be expected. Figure 7 shows the rod displacement and beginning of the power transient for a \$2.83 pulse as a function of time after the air solenoid valve is de-energized. The time at which \$1.00 of reactivity has been inserted is indicated.

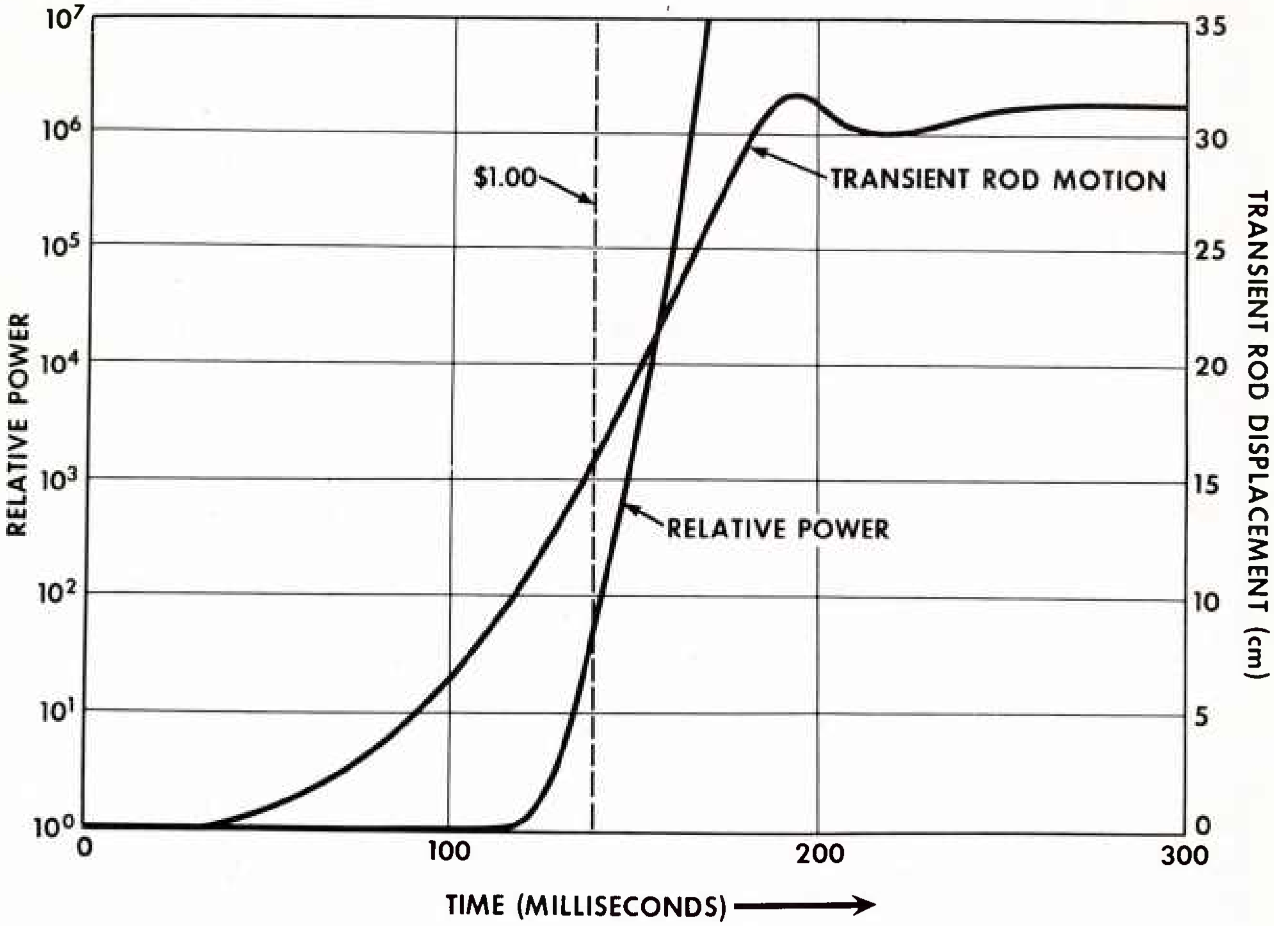


Figure 7. Rod displacement and relative power for \$2.83 pulse

The difference between the time required for the rod to achieve its "full out" position (taken to be the maximum point of travel with the anvil depressed) and the time for the peak of the reactor power excursion to occur decreases as the amount of reactivity is increased. This is due to two factors. It requires greater time for the rod to travel further and, for the larger reactivity insertions, the rate of power rise is greater. Figure 8 provides plots of the reactor power excursion resulting from reactivity insertions of \$2.83 and \$1.50 and the time dependence of the transient rod displacement producing these power excursions. The peak of the pulse occurs simultaneously with the rod reaching its "full out" position for a \$2.83 pulse. It can be inferred from the results for the \$2.83 pulse that the time of the peak for larger pulses will be governed by the finite travel time of the transient rod. This is more clearly demonstrated in Figure 9 showing curves of time to rod "full out" and time to pulse peak. Thus, in the region of the peak, the pulse behaves as if an accelerated reactivity insertion was made for the large pulses and only for the smaller reactivity insertions does it behave as if a step insertion was made.

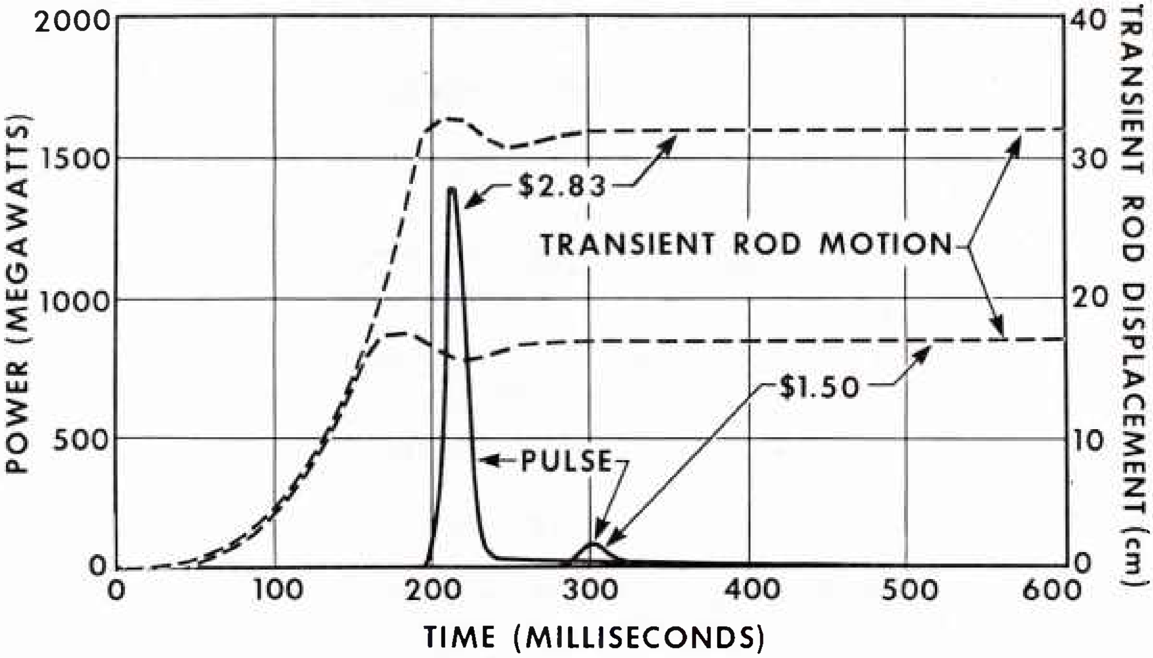


Figure 8. \$2.83 and \$1.50 pulse

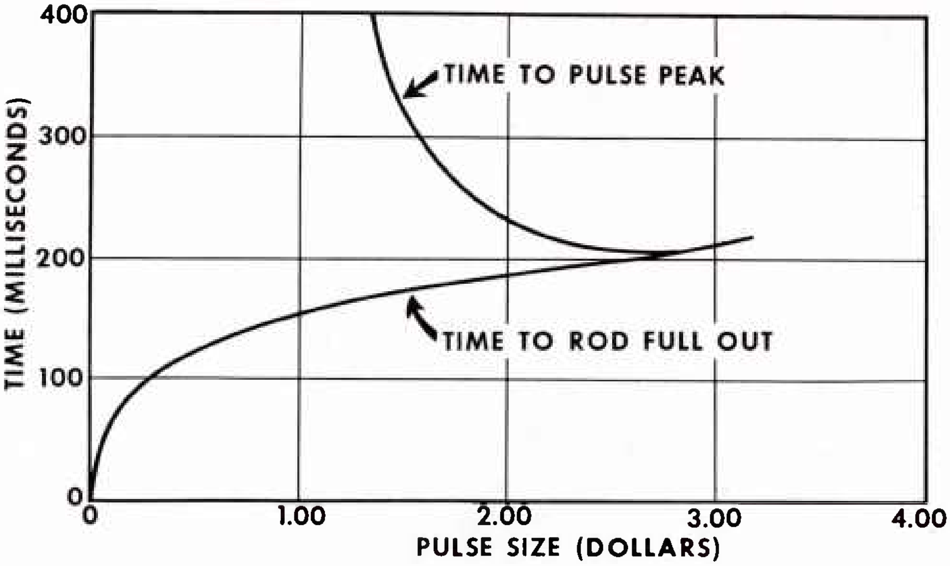


Figure 9. Time to rod "full out" and to pulse peak

The effect of the finite travel time and bounce of the rod at the termination of the travel has been studied by measurements in the reactivity range from \$2.83 to \$3.14. These rod motion effects have been accentuated by decreasing the air pressure to the piston and thus increasing the travel time of the rod. Table I provides data of rod travel time to bounce (the point of maximum inward motion after the rod has reached "full out"), time to pulse peak power and peak power in megawatts. Among the points to be noted is the relatively constant peak pulse size for all \$3.14 insertions except for that at 50 psi. In the 50 psi case, the rod bounce reduces the value of the peak power by about 6 percent. From these data it appears that the rod bounce only causes significant effects on the magnitude of the power peak when the bounce occurs near the time of the peak.

Table I. Effect of Variation of Air Solenoid Pressure on Pulse

Pressure (psi)	Pulse size (dollars)	Time to bounce* (milliseconds)	Time to peak* (milliseconds)	Peak power (megawatts)
76	2.83	128	129	1480
	3.00	131	133	1750
	3.14	129	139	1970
65	2.83	144	161	1528
	3.00	155	160	1812
	3.14	164	160	1968
60	2.83	150	166	1540
	3.00	164	170	1690
	3.14	176	170	1940
50	2.83	170	187	1500
	3.00	180	184	1760
	3.14	188	185	1848
45	2.83	182	208	1510
	3.00	199	209	1770
	3,14	216	210	1990

* The times given here are based on t=0 at the time the transient rod begins movement at the bottom of the piston. The time base for the figures is the time the air solenoid valve is de-energized. The difference is a function of pressure and is 80 milliseconds at 76 psi pressure.

It is also seen for low rod accelerations (45 and 50 psi) that the reactor power achieves a sufficiently high level that the pulse is turned over by temperature effects before the rod reaches "full out".

The unit of "dollar" is commonly used for reactivity since for values of reactivity below $1.00, a reactor excursion must rely upon delayed neutrons which are emitted from the fission products fractions of a second to seconds after fission occurs. The effect of reactivity insertions in the region of $1.00 is extremely critical to small uncertainties and perturbations in reactivity. This is especially true during the first few decades of the pulse due to the "prompt jump" effect caused by these delayed neutrons. Figure 10 shows the theoretical "prompt jump" region of the pulse for idealized "step function" reactivity insertions ranging from $0.70 to $1.40 for the

TRIGA reactor. Figure 11 provides experimental measurement of this time region for actual reactivity insertions of similar total magnitude.

Considerable difference in both the shape and the magnitude of the power in the "prompt jump" region is observed in Figures 10 and 11. This is primarily due to two factors. The power traces in Figure 11 coincide during the rod ejection period for all the insertions and this is because an accelerated reactivity insertion is being experienced rather than an instantaneous insertion. Secondly, the nonmonotonic behavior is

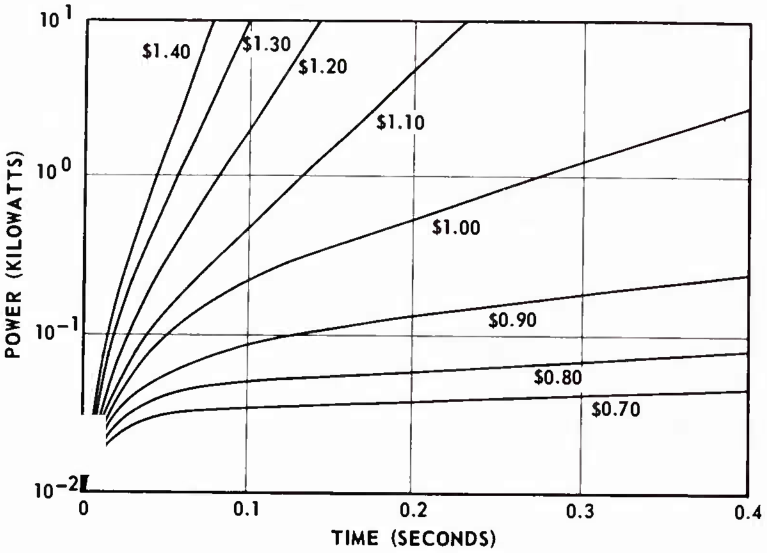
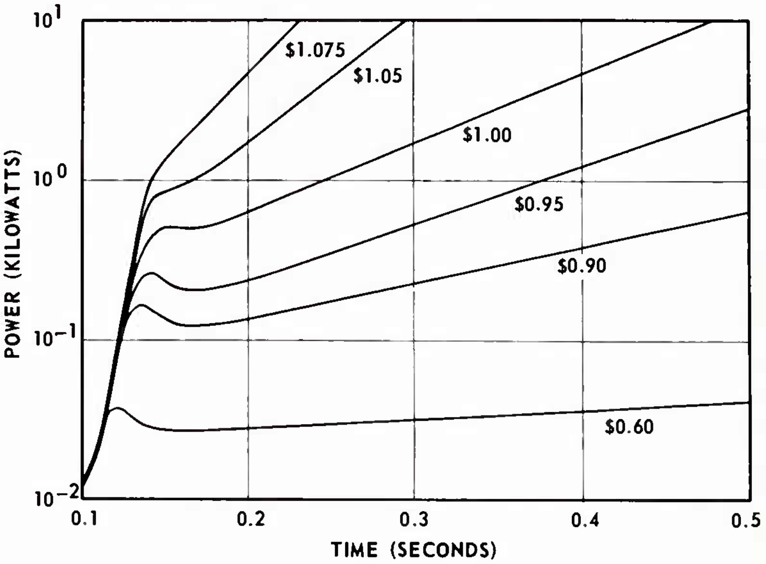


Figure 10. Theoretical prompt jump region

Figure 11. Experimental prompt jump region



caused by the inward bounce of the rod and is due to the sensitivity of a supercritical nuclear reactor to small but sudden decreases in reactivity.[1,2]

For initial power levels on the order of watts, these twc effects in the "prompt jump" region have negligible effect on the pulse peak for pulses on the order of $1.00 since they occur far below the peak power levels which are on the order of megawatts.

The differences in the asymptotic regions of the power traces for the same reactivity insertions are attributed to dynamic reactivity effects reported earlier.[1]

V. SUMMARY

The design of a system for the measurement of the transient control rod motion of the AFRRI-TRIGA reactor has been presented. Data on the transient rod motion and its effect on the reactor pulse are presented and discussed. It is shown that the finite travel time of the rod has an effect on the time of the pulse peak and possibly the magnitude for pulses above $3.00. For pulses on the order of $1.00, the rod bounce affects the beginning of the power transient in the "prompt jump" region. It is also found that the rod bounce has an effect on the magnitude of the peak of the pulse when the bounce occurs at the time of peak. Both observations point out the sensitivity to minor but sudden insertions of negative reactivity.

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The design of a system for the measurement of the transient control rod motion of the AFRRI-TRIGA pulse reactor is presented. Data on the transient rod motion and its effect on the reactor pulse are presented and discussed. It is found that the finite travel time of the rod has an effect on the time of the pulse peak and the magnitude and shape of the pulses above \$3.00. For pulses on the order of \$1.00, the beginning of the power transient has been found to be sensitive to the transient rod bounce.

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