GEAP-4018

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PHYSICS

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GENERAL ELECTRIC
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SAN JOSE, CALIFORNIA

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ABSTRACT

The diffusion length of thermal neutrons in light water was measured as a function of temperature in the range 20°C to 90°C for both pure water and poison solutions. Various concentrations of three poisons - H_3BO_3, $CdSO_4$, and Gd $(NO_3)_3$ - were used in this experiment. The thermal neutron source was the thermal column of the General Electric Nuclear Test Reactor. The "Water Gun" apparatus was utilized for the measurements.

INTRODUCTION

Various experimental techniques have been used to measure the diffusion length of thermal neutrons in water. These techniques fall into three distinct groups based upon the source of thermal neutrons.

(1) Thermal neutrons from a thermal column[1-4].

(2) A point source of low energy neutrons such as the 25 Kev neutrons from an Sb^{124}-Be source[5-8].

(3) The pulsed neutron source[9-14].

The technique chosen for this experiment falls into the first group, i.e., the thermal column of the General Electric Nuclear Test Reactor (hereinafter referred to as the NTR) is used as a source of thermal neutrons.

The experiment described here was designed to measure the thermal diffusion length, L, for water as a function of both temperature and poison concentration. The measurement was undertaken to evaluate calculational models for the thermal neutron current into a strongly absorbing material in a reactor. The diffusion length is usually inferred from an experimental determination of the relaxation length of thermal neutrons. This experimentally determined number must then be corrected for geometry in order to obtain the diffusion length.

The value of the relaxation length measured in the "Water Gun" apparatus is identical to the value which would be obtained in a medium extending to infinity in the direction perpendicular to the face of the thermal column. The finite extent of the water gun in this direction is compensated by lining the boundary of the gun with cadmium to the extent of blackness for thermal neutrons. By this means the shape of the log of the flux vs. distance curve remains the same near the cadmium boundary regardless of the extent of the diffusing medium. The slope of the log of the flux vs. distance curve thus is the same measured in the water gun as it is in a medium of infinite extent, and the slope of this curve determines the relaxation length and hence the diffusion length in the medium.

EXPERIMENTAL ARRANGEMENT

The Water Gun is positioned at the face of NTR's thermal column with its control and instrumentation located in the NTR control room (Figure 1). The Water Gun consists of three main regions: graphite extension of NTR thermal column, water buffer section, and variable length water column (more detailed description is given under "Description of Apparatus").

The Water system is comprised of three independent loops: the primary, the secondary, and the heat exchanger loops (Figure 2). The primary loop consists of the water buffer compartment, between graphite matching section and variable water column, centrifugal pump, surge tank and heat exchanger. These components are all interconnected by 1/2 inch I.D. aluminum piping with swage lock fittings. A 1/4 inch tube with a valve at the top of the buffer compartment serves as an air bleed line for this loop. The air line is opened during initial filling of the system, thus insuring a plenum.

The secondary loop is comprized of the water column compartment which contains the movable piston, the supply tank with heaters and calibrated sight glass and a centrifugal pump. All components of this loop are connected by 3/4 inches I.D. aluminum tubing with swage lock fittings. Two 1/4 inch tubes with valves at the top of the variable length water column housing serve as air bleed lines for this loop. Proper selection of five valves in the secondary loop allows the water to be circulated either through the Water Gun or the "mixing loop". The latter is used when salt of the element under investigation is being dissolved. Another combination of valve settings allows the secondary loop to be drained through Tygon tubing and conduit into the NTR cell hold-up tank where it is retained until the induced activity allows it to be discarded.

The heat exchanger in the primary loop maintains the temperature constant in the water buffer region and the temperature of the secondary loop is controlled by a "Precision Micro Set Thermometer" positioned in the supply tank. This thermometer intermittently actuates an immersion type quartz heater through a control circuit (Figure 3) thus maintaining the

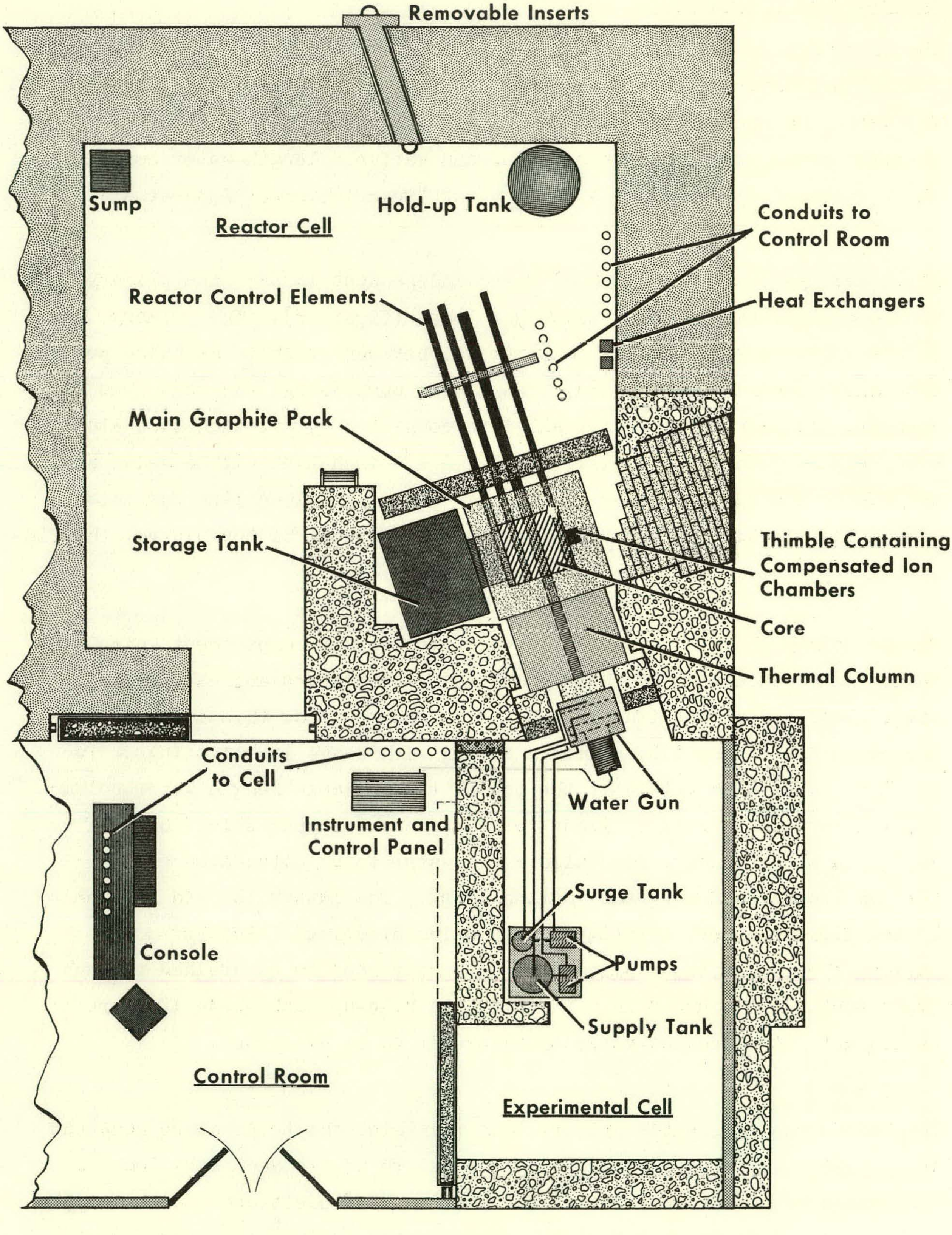

Figure 1. NUCLEAR TEST REACTOR EXPERIMENTAL FACILITIES

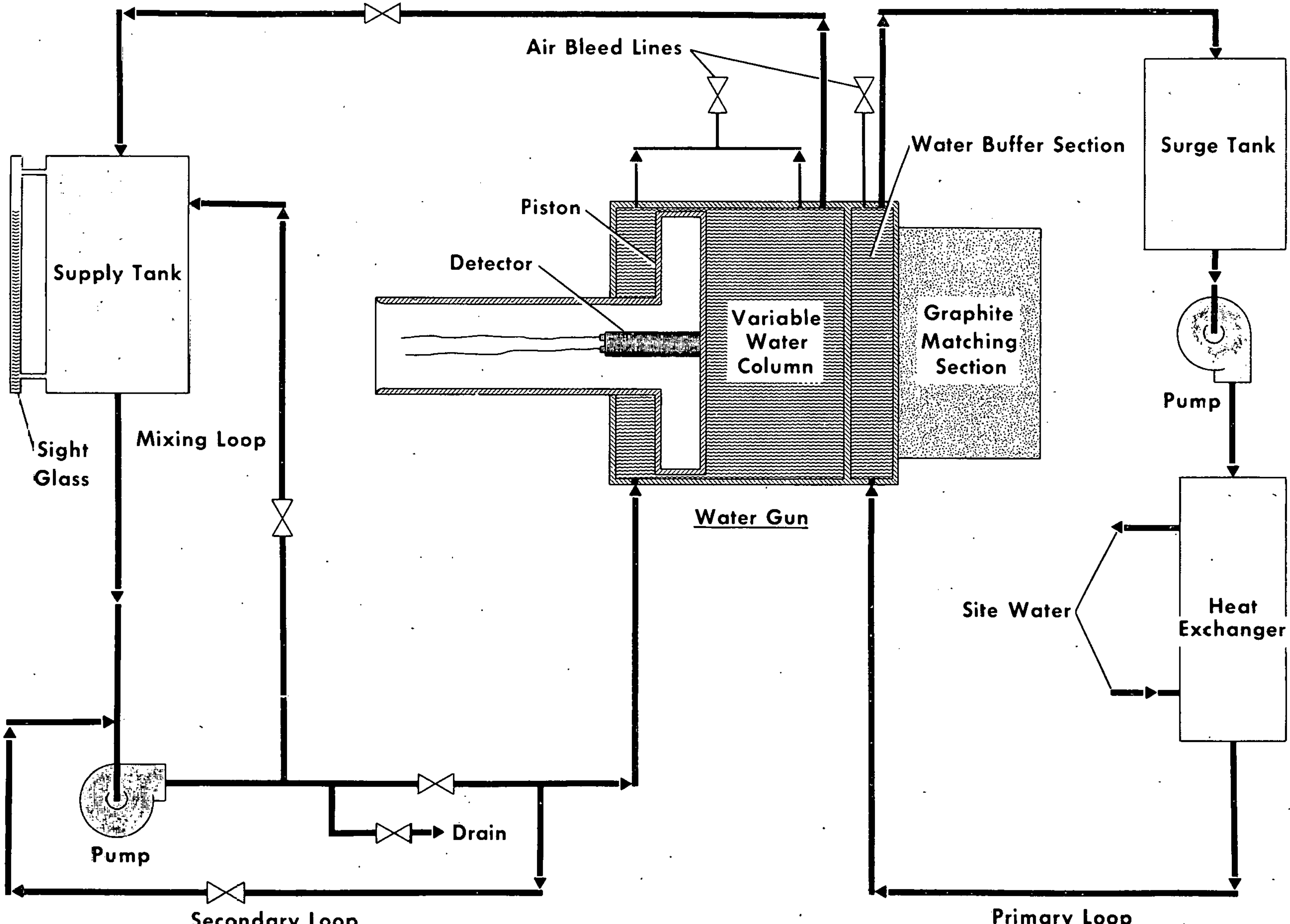

Figure 2. WATER FLOW DIAGRAM

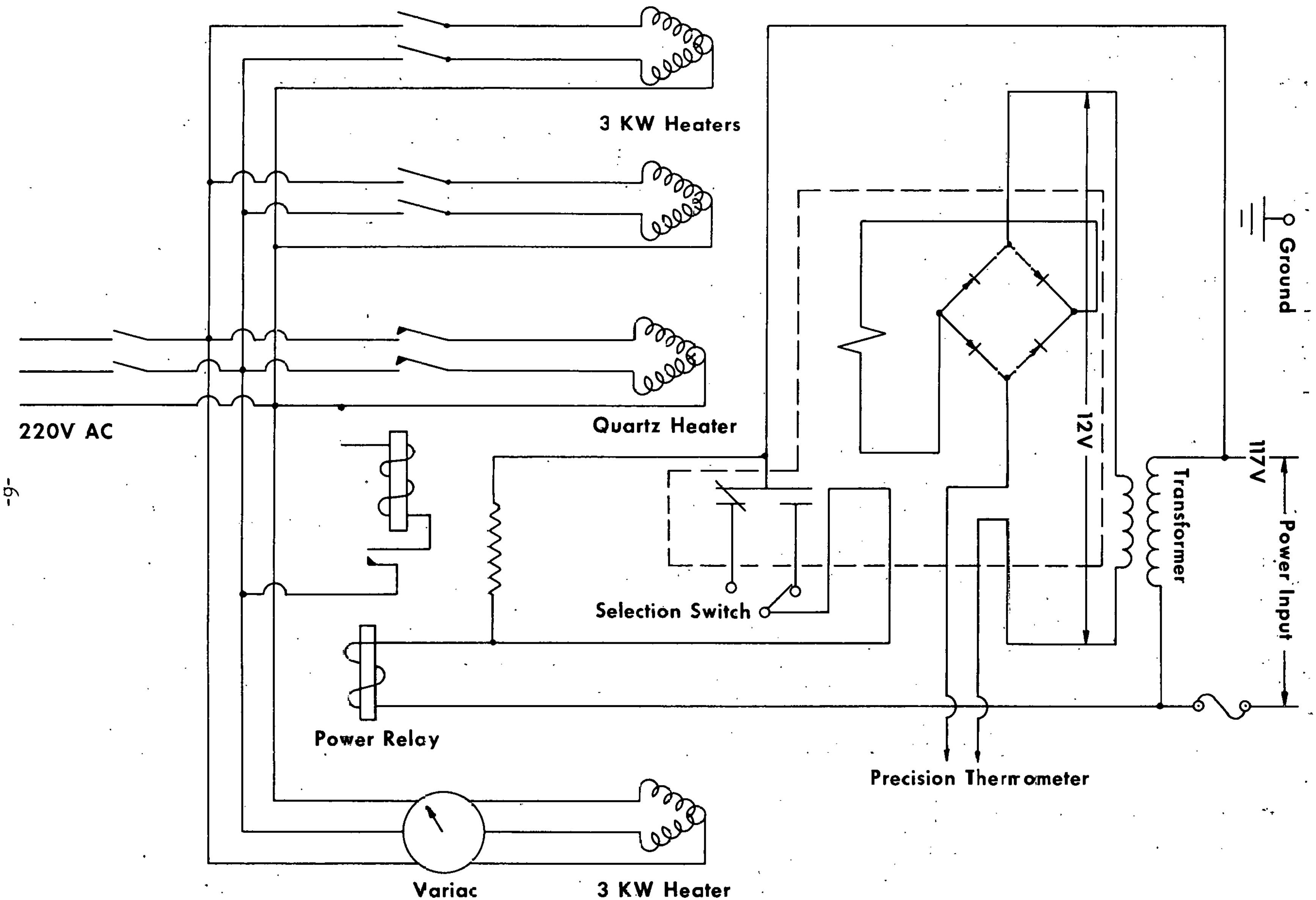

Figure 3. TEMPERATURE CONTROL CIRCUIT

temperature constant to within ± 0.5°C. For runs above 40°C the solution is preheated by three 3 KW heaters in the supply tank and maintained by one of these heaters along with the quartz heater. Five immersion type thermocouples in the loops and one inside the piston next to the detector monitor the temperature of the system. This information is continuously recorded by a six point temperature recorder. The temperature of the detector inside the piston is kept constant by circulating cold water through an aluminum annulus around the photomultiplier tube and crystal mount.

The movement of the piston in the Water Gun is initiated from the control room by actuating a reversible motor which is coupled through a gear reduction unit by a chain to the lead screw. The lead screw is rigidly attached to the bottom side of the piston sleeve. As the piston advances toward the insulating membrane of the buffer section the length of the water column in front of it decreases. The actual volume of water in the whole compartment remains constant. The extent of piston travel is controlled by two microswitches at the two extreme positions. The location of the piston face and that of the detector is indicated on the control panel in the control room. The coarse position readout is obtained from a selsyn arrangement. The generator is mounted on the piston sleeve coupled through a set of precision gears to a stationary rack, and the motor is mounted on the control panel with a dial indicator. The fine position readout is obtained from the dial indication of a caliper mounted on top of piston sleeve and piston housing. The fine readout is observed through a pair of field glasses and a combination of mirrors on top of and behind an 8 ft. shielding wall which separates the control room from the experimental area.

The power level of the NTR is kept at 10 KW to within 0.05%. This stability is accomplished by means of an electronic arrangement used primarily for the "Absorber Burn-up" experiment (GEAP-3617 interim report): A γ-compensated ion chamber positioned in NTR's "thimble" (Figure 4) supplies a signal to a micro-microammeter. A large portion of this signal is bucked out by a solid state current source connected through a stable voltage divider. The difference between the output of the ion chamber and the constant DC bucking current is amplified and recorded. In order

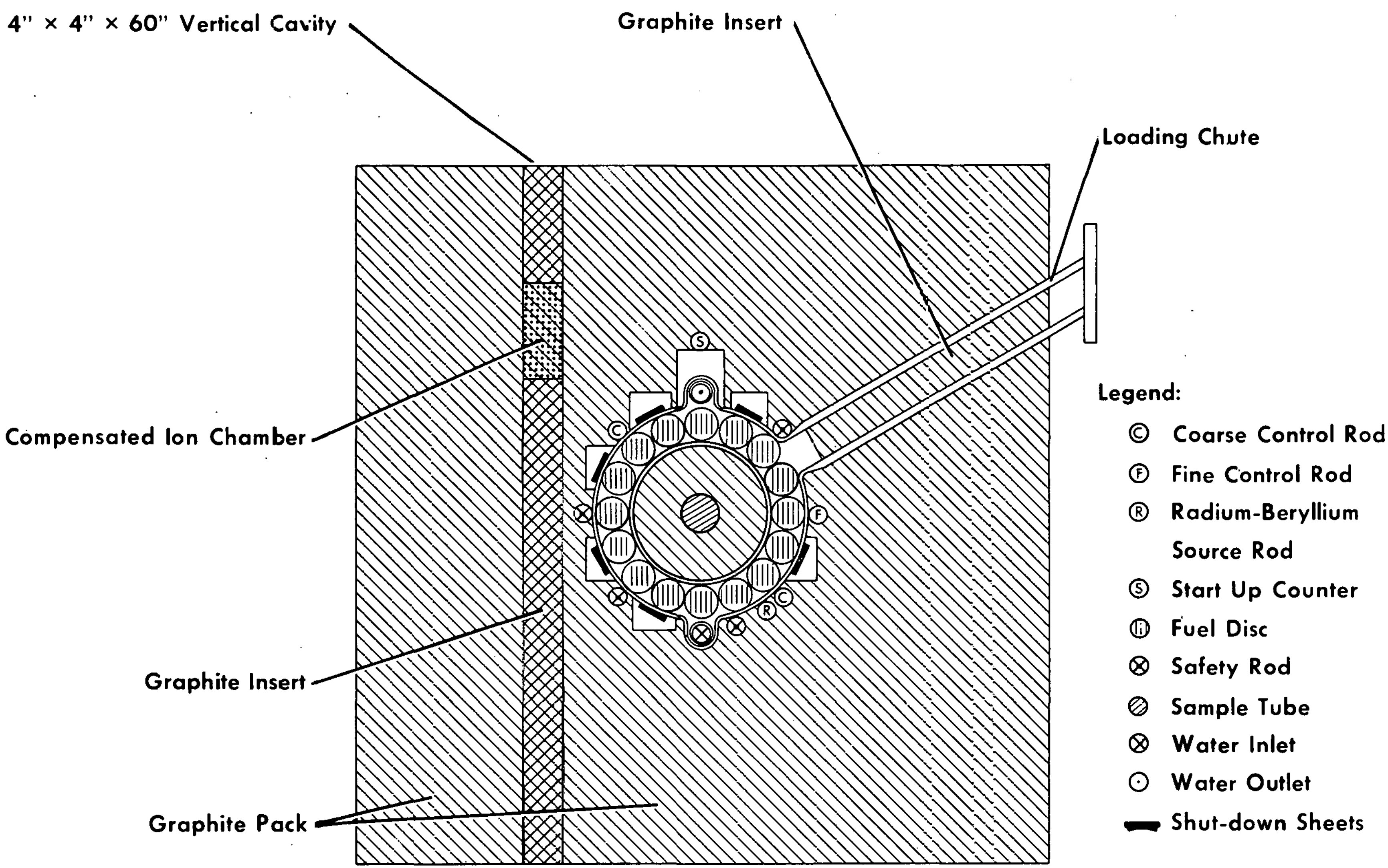

Figure 4. CORE ARRANGEMENT

to maintain constant power, any drift shown by the micro-microammeter is compensated for by adjustment of the NTR's fine control rod.

The detector consists of a B^{10} - Zn S(Ag), thin scintillator attached to a 10 stage photomultiplier tube. Following the photomultiplier is a current sensitive solid state preamplifier - emitter follower. The rest of the instrumentation consists of double differentiation type linear pulse amplifier with base line discrimination and a crystal controlled oscillator - scaler arrangement.

DESCRIPTION OF APPARATUS

The water gun consists of three main right circular cylindrical regions: graphite, water buffer, and variable length water column. A detailed drawing is given in Figure 5. The graphite region is 23.0 inches in diameter and 12 inches long, composed of six slabs of graphite supported by a cradle in front of the water buffer region. Immediately following the graphite is a 0.1 inch air gap into which a 30 mil cadmium sheet is inserted for "background" measurements. Following this air gap is the water buffer region 24.0 inches in diameter and 1.187 inches thick. The front and back aluminum covers of this compartment are straight and parallel. To insure rigidity of this compartment, 32 plexiglass spacers are uniformly arrayed in three concentric circles around the central axis of the water gun. The spacers are 1.287 inches long and 9/16 inch overall diameter, held in place by aluminum screws. An air space, formed by a Bakelite ring, 0.093 inch long, 25.0 inches O.D., 24.0 inches I.D., between the two water regions, serves as a thermal insulator. The water column region following the thermal insulator section is 24.0 inches in diameter and contains a movable piston whose maximum distance of travel is 9.8 inches.

The difference in diameters of graphite and water regions compensates for the different extrapolation lengths of flux in the two media.

The water buffer section's rear cover and the water column section's front cover are 0.062 inch thick aluminum; both partitions have a 5.0 inch diameter recess at the center reducing their thicknesses to 0.016 inches. To reinforce this area and at the same time reduce thermal conduction, 8 quartz discs 0.250 inches in diameter and 0.185 inches thick are uniformly arrayed in two concentric circles.

The piston face is 23.75 inches in diameter, covered by 0.032 inch cadmium sheet. The cadmium is bonded to the aluminum piston face with a mixture of EPON 828 VERSAMID 140, weight proportion of 100:60, and it is also coated with the same epoxy resin for protection. The piston is

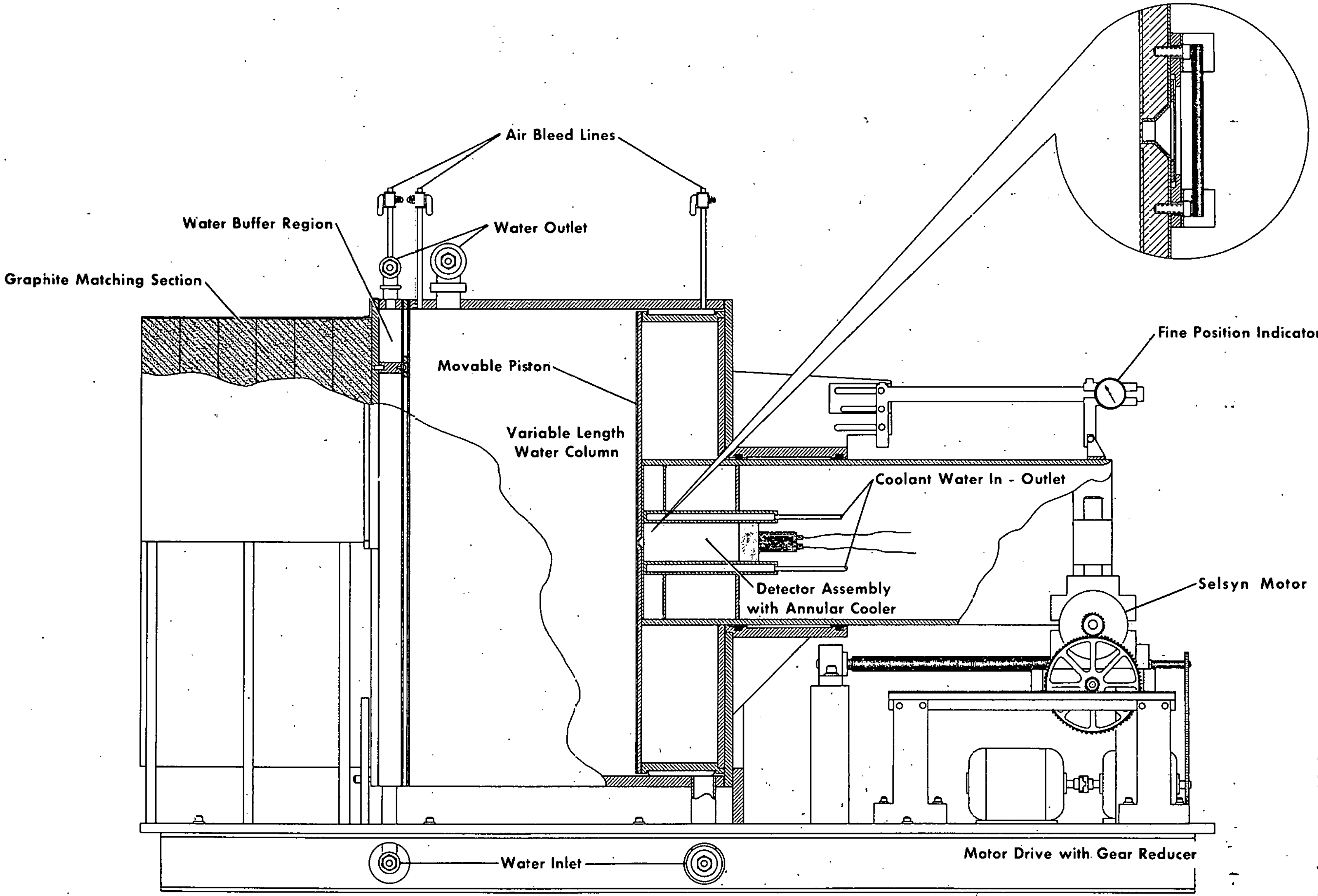

Figure 5. WATER GUN

4.0 inches long and has four 3-3/8 x 3/8 x 3/8 inches nylon runners mounted on the periphery spaced 90° apart. These runners protrude beyond the piston circumference by 3/16 inches, thus insuring smooth motion of the piston and also providing space for the water to flow around the piston when it is moved. A 0.5 inch diameter hole in the center of the cadmium sheet followed by a 0.010 inch aluminum membrane provides an unobstructed path for neutrons to the detector firmly positioned behind this membrane inside the piston. A thermocouple attached to the surface of piston cover monitors the temperature of detector environment. The 3/8 inch aluminum piston cover is counterbored to a depth of 3/16 inches at a 45° angle from the detector's side and the remaining 3/16 inches is reduced to 0.010 inches with a 0.250 inch diameter. The back face of the piston cover excluding the counterbored portion is lined with 0.020 inches cadmium, covering an area of 7.81 inches in diameter concentric with the water gun axis. The length of the piston sleeve, as measured from the face of the cover, is 26-1/8 inches long with an O.D. of 8.497 inches and is lined with 1/32 inches cadmium. With the detector in position two cadmium lined circular inserts are placed at the end of the sleeve thus eliminating the backscattering effect.

The piston housing, which includes the back plate of the water column volume, is made of stainless steel; it covers the piston sleeve for a length of 6 inches and contains two rubber O-Rings. The entire water gun (except the piston housing) is made out of 6061-T6 aluminum, covered with 1/32 inch cadmium and is supported by a plate 55-7/8 x 26-1/2 x 1/2 inches which rests on an adjustable height dolly.

A reversible motor mounted on the base plate is used to move the piston through a 5:1 gear reduction by a chain coupling attached to a lead screw which is also rigidly mounted to the base plate. The motion of the lead screw is transmitted to the piston through a nylon nut positioned inside a nut housing rigidly attached to the under side of the piston sleeve.

EXPERIMENTAL PROCEDURES

The procedures employed are straightforward and consist of four runs per measurement. A run is a series of count rates taken at different positions over the travel range of the piston from the full "in" to the full "out" positions. The direction of travel is reversed and another series of counting rates versus position are obtained. The 0.030 in. cadmium sheet is inserted and the count rate versus position is again determined in both directions. These latter runs serve to establish the background for the measurement. Figure 6 is a plot of typical experimental points after the background is subtracted. The ratio of total counts to background counts with the piston in the full "in" position is about 80 in a typical case.

The water temperature in both loops is measured and recorded throughout each run and is held constant to within ± 0.5°C.

The power level of the NTR is 10 KW during a run and does not vary by more than 0.05%. The thermal neutron flux in the center of the face of the thermal column is 10^5 nv/cm^2-sec-watt.

For the poisoned measurements, weighed amounts of the salt of the element under investigation are dissolved in the mixing loop of the secondary system which contains the movable piston. Aliquots of these solutions are removed before and after each run and analyzed both qualitatively and quantitatively.

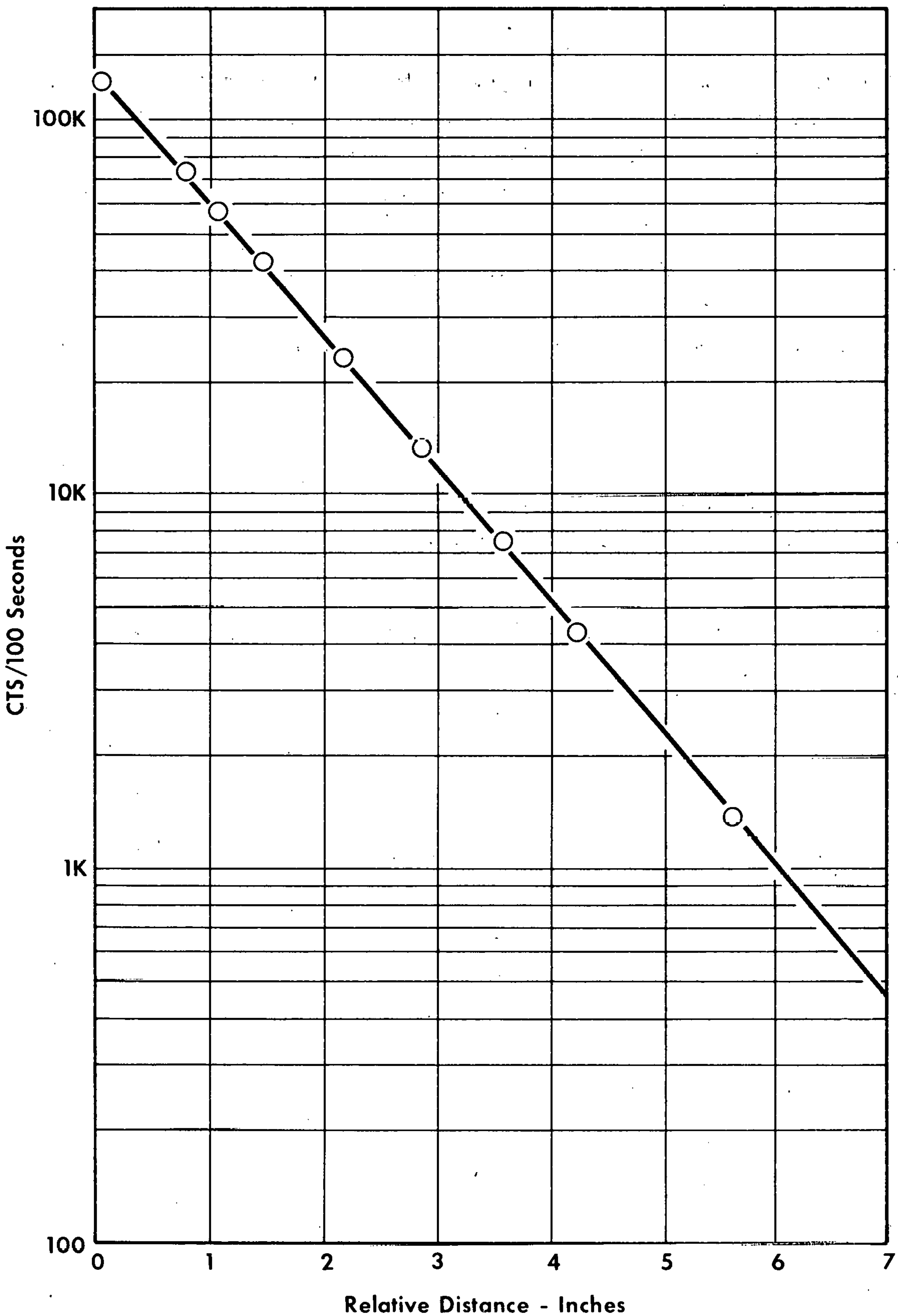

Figure 6. TYPICAL PLOT OF EXPERIMENTAL POINTS

RESULTS

The reported results are determined in the following manner: The total counts versus position for each "in" and "out" run are corrected for background and analyzed by the method of least squares using a matrix inversion technique. Each point is given a weight of

$$W_i = \frac{(Y_i - B_i)^2}{(Y_i + B_i)} \tag{1}$$

where Y_i represents the total i^{th} count and B_i represents the background at that point.

This analysis results in the relaxation length which has to be corrected for geometry. The correction factor used is determined by the assumption that the extrapolated flux is zero at the radius of the cylinder plus $0.71\ \lambda_{tr}$. The diffusion length is then computed using the relation

$$L = \frac{L\ \text{measured}}{\sqrt{1 - L^2_{\text{meas.}} \left(\frac{2.405}{R + 0.71\ \lambda_{tr}} \right)^2}} \tag{2}$$

where L measured is the relaxation distance. The result is further corrected for density.

An estimator for the standard deviation of the slope is computed from the matrix and provides an upper limit for the standard deviation of each run. The data shown in Figures 7 and 8 are the average of L values obtained in moving the piston in and out. The error bars shown are the square root of the sum of the squares of the standard deviation for each "in" and "out" run which corresponds to twice the standard deviation of the average L.

Random errors such as timing errors (one part in 2500) and positioning errors (one part in 1000) are not included due to their small effect on the diffusion length. The results of this experiment are tabulated on the following page for the various temperatures and poison concentrations investigated.

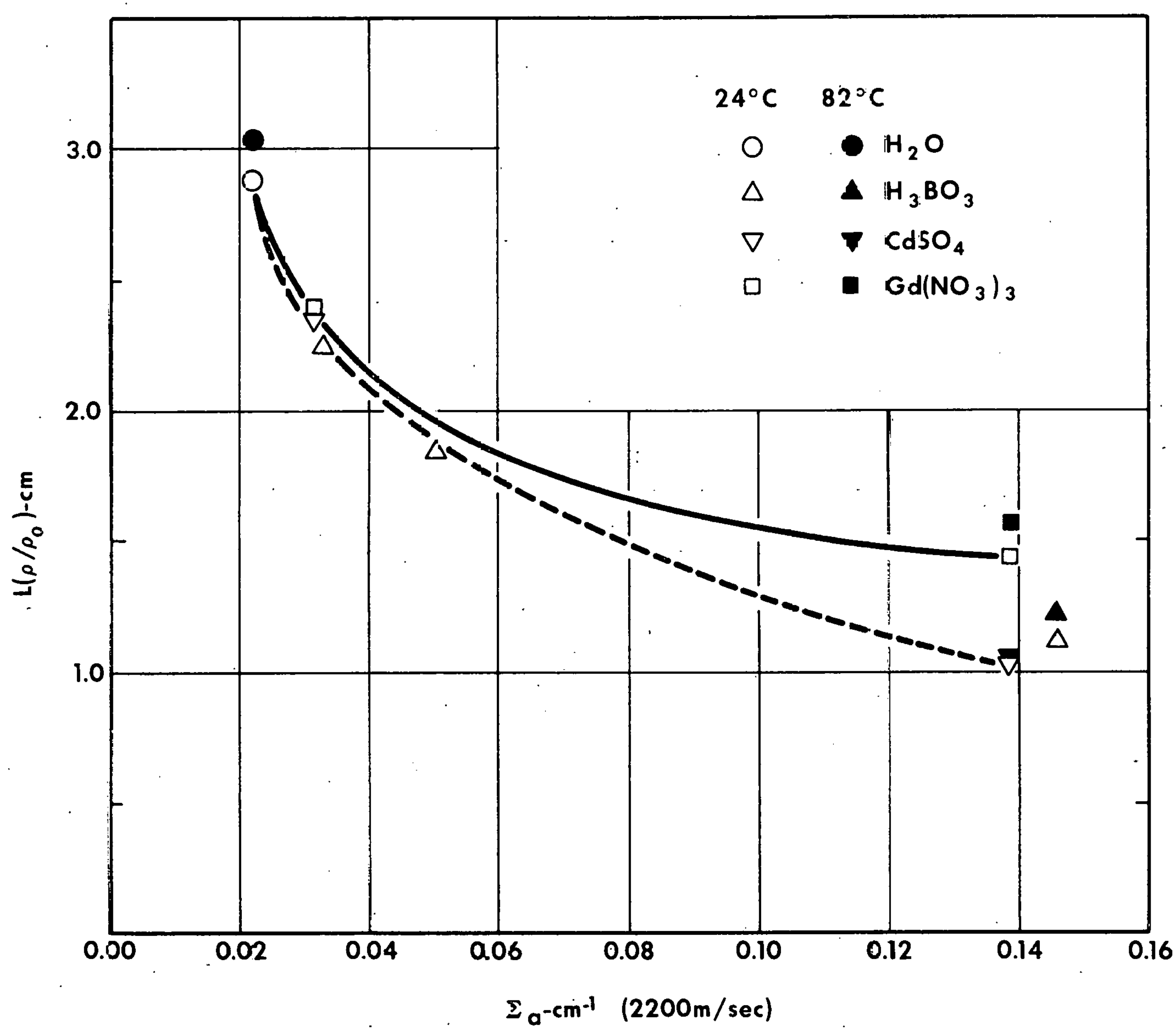

Figure 7. DIFFUSION LENGTH VERSUS CROSS SECTION

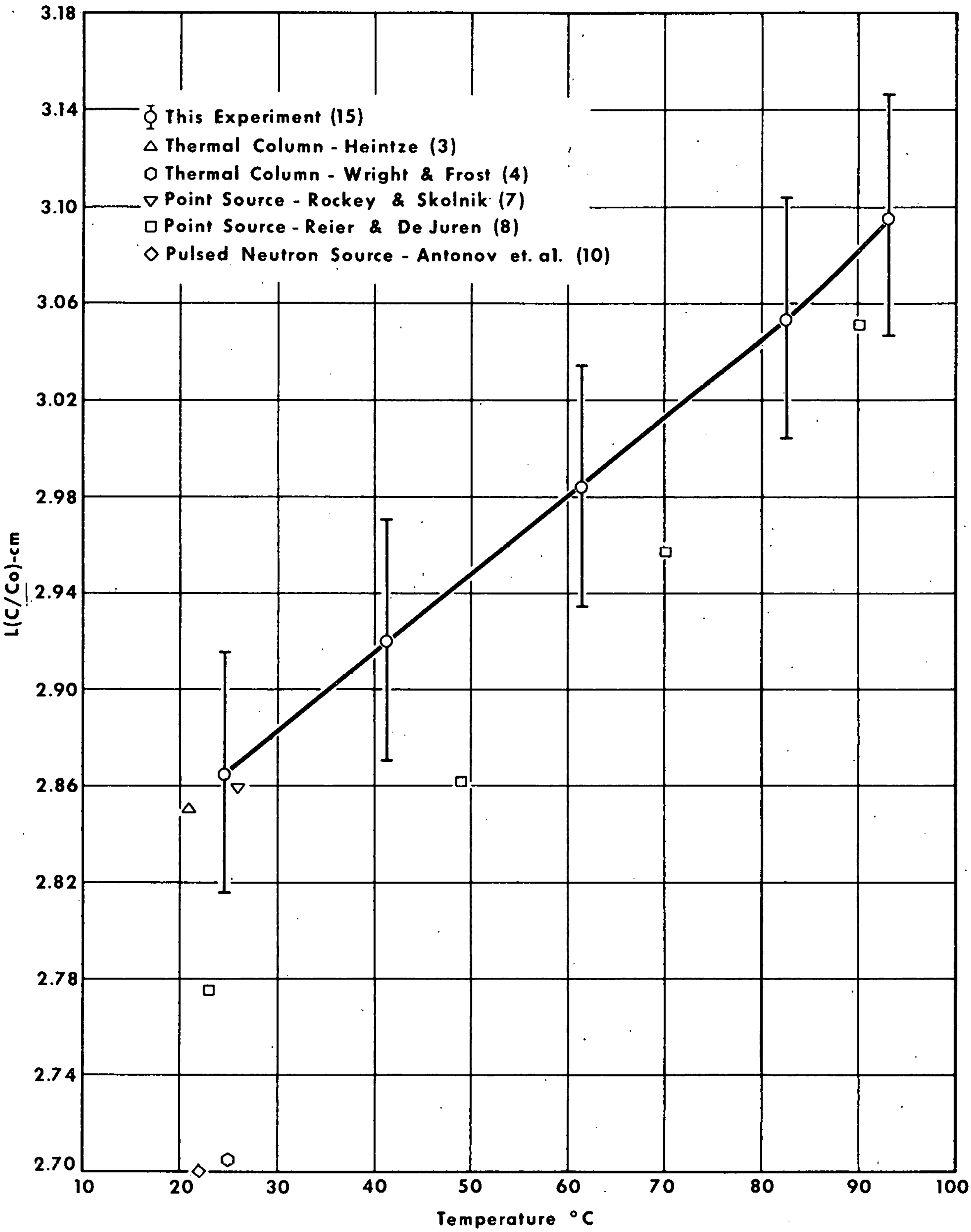

Figure 8. DIFFUSION LENGTH VERSUS TEMPERATURE

RESULTS

Poison	Conc. gm/liter	$T^{o}C$	Σa cm^{-1}	$\rho\ H_2O$ gm/cm^3	L meas. cm	L corr. cm	$L(\rho/\rho_0)$ cm
None	-	24.55	0.022	0.997183	2.804	2.873	2.865 ± .05
None	-	41.25	0.022	0.991762	2.870	2.944	2.920 ± .05
None	-	61.29	0.022	0.982556	2.956	3.037	2.984 ± .05
None	-	82.37	0.022	0.970323	3.056	3.146	3.053 ± .05
None	-	92.86	0.022	0.963876	3.115	3.210	3.094 ± .05
H_3BO_3	15.83	24.35	0.146	0.997232	1.158	1.163	1.160 ± .05
H_3BO_3	15.83	82.01	0.142	0.970552	1.259	1.265	1.288 ± .05
$Cd\ SO_4$	1.312	23.72	0.0317	0.997387	2.368	2.409	2.403 ± .05
$Cd\ SO_4$	15.79	24.00	0.138	0.99732	1.097	1.101	1.098 ± .05
$Cd\ SO_4$	15.79	83.91	0.134	0.96935	1.060	1.064	1.031 ± .05
$Gd\ (NO_3)_3$	0.154	24.57	0.0316	0.99718	2.410	2.453	2.446 ± .05
$Gd\ (NO_3)_3$	1.858	24.64	0.139	0.99717	1.417	1.426	1.422 ± .05
$Gd\ (NO_3)_3$	1.858	82.26	0.135	0.97040	1.620	1.633	1.585 ± .05

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W. C. Ballowe died on March 14, 1962, prior to completion of this report.