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INTERIM REPORT

PRODUCTION TEST 105-589-A

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SUBCRITICAL NEUTRON FLUX MONITOR
INTERIM REPORT
PRODUCTION TEST 105-589-A

By

D. C. Pound

Physics Development Unit
Pile Engineering Sub-Section

February 29, 1956

HANFORD ATOMIC PRODUCTS OPERATION
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SUBCRITICAL NEUTRON FLUX MONITOR
INTERIM REPORT
PRODUCTION TEST 105-589-A

INTRODUCTION

Considerations of nuclear safety in reactor operations dictate the requirement for instrumentation capable of directly indicating the neutron density during all phases of reactor operations, including the subcritical full shutdown condition, with an electrical signal sufficient to reliably activate the safety circuit at any time. The most sensitive neutron detection instrumentation employed at Hanford up to this time are the BF_3 neutron proportional counter systems which are not capable of reliably indicating the low neutron densities present in the highly subcritical Hanford reactor in the presence of the intense gamma background, nor are they capable of reliably activating the safety circuit trips until well after criticality has been attained. In addition to the inherently high susceptibility to gamma radiation, the proportional counter systems are not stable and are prone to maladjustment which leads to erroneous information.

Production Test 105-589-A[i] was initiated to obtain in-pile performance data from U-235 fission counters in the low density neutron monitoring application; fission counters provide a high degree of discrimination against gamma radiation, hence are more sensitive in this application, and provide a greater degree of operating reliability and stability than previous systems. This report describes the U-235 fission counters, their application to the safe reactor startup problem, and the in-pile performance of the initial installation at DR pile.

SUMMARY

The first subcritical monitor or fission counter was installed in C test hole of DR pile on November 18, 1954. The system was a prototype for a final operational instrument, and consisted of a fission counter, mechanical positioner, preamplifier, linear amplifier, logarithmic counting rate meter, and a recorder. The neutron induced counting rate was 20 counts per second when all safety and control rods were in the reactor at the end of a normal outage; this signal is a full decade above the minimum statistically acceptable for recording purposes. Reactivity information during startups was accurate to within 20 inhours when obtained from initial control rod withdrawal and within 10 inhours when obtained from the last 80 inhour approach to critical. The performance of the system indicated that suitable neutron transient and power level information would be obtained during "hot" startups, i.e., startups made shortly after a scram has occurred. The stability and reliability of the electronic portion was excellent during the testing interval of three and a half months, and suitable design changes have been made to overcome the one fault found which was water condensation in the mechanical positioning mechanism.

DISCUSSION

A. Background

The neutron flux existing during a shutdown of a Hanford production reactor is primarily due to photoneutrons produced by fission product gamma radiation absorbed in the natural deuterium present in the cooling water. This reaction has a threshold energy of 2.2 mev. The primary fission products having gammas of sufficient energy and effective half lives long enough to outlive the longest delayed neutron groups include Rh^{106}, Pr^{144}, La^{140}, Te^{131}, I^{135}, Rb^{88}, and I^{134}. Some of these isotopes are of rather short half life but are present over extended intervals because of a longer half life parent isotope. Figure 1 is a calculated curve of the relative neutron flux as a function of time in the vicinity of a process tube operated at 500 kilowatts after a 1500 inhour scram. The magnitude of the flux will necessarily vary from point to point within the reactor, depending upon the previous tube powers, the location of the safety and control rods, the amount and location of metal discharges, and the various coefficient and poison transients. The predominant feature of this neutron flux transient is the wide range (in excess of 10^{10}) of neutron fluxes encountered in the normal operation of the Hanford reactors.

The reactor safety and control instrumentation system must be able to adequately monitor the entire flux range if the approach to full power is to be accomplished with a high degree of safety. The lack of proper instrument coverage in the very low flux ranges could lead to failure to recognize changes in the reactivity status of the reactor until well after criticality had been obtained. The present neutron instrumentation systems in use at the Hanford reactors cannot adequately monitor the entire range of neutron flux which is experienced.

Typical Hanford reactor instrument ranges prior to a cold startup are shown in bar form to the right of Figure 1; the dotted portions indicate to a degree the possible variations. The safety circuit Beckman amplifiers and control galvanometers obtain their signal from neutron sensitive ion chambers which produce a current proportional to the total ionization occurring within the chamber. The Beckmans are the neutron sensitive, power level trips in the safety circuit, and, when range switched, constitute the first safety circuit trip to be reached at the present time during a startup. The range of ion chamber current type systems is limited in that the residual background current caused by the gamma activity of the ion chamber and its surroundings is directly dependent upon radioactivity induced by the local neutron flux during prior operation. The ion chamber installations at Hanford contain a quantity of structural steel, the radioactivity of which places an upper limit of about 10^5 on the range of the ion

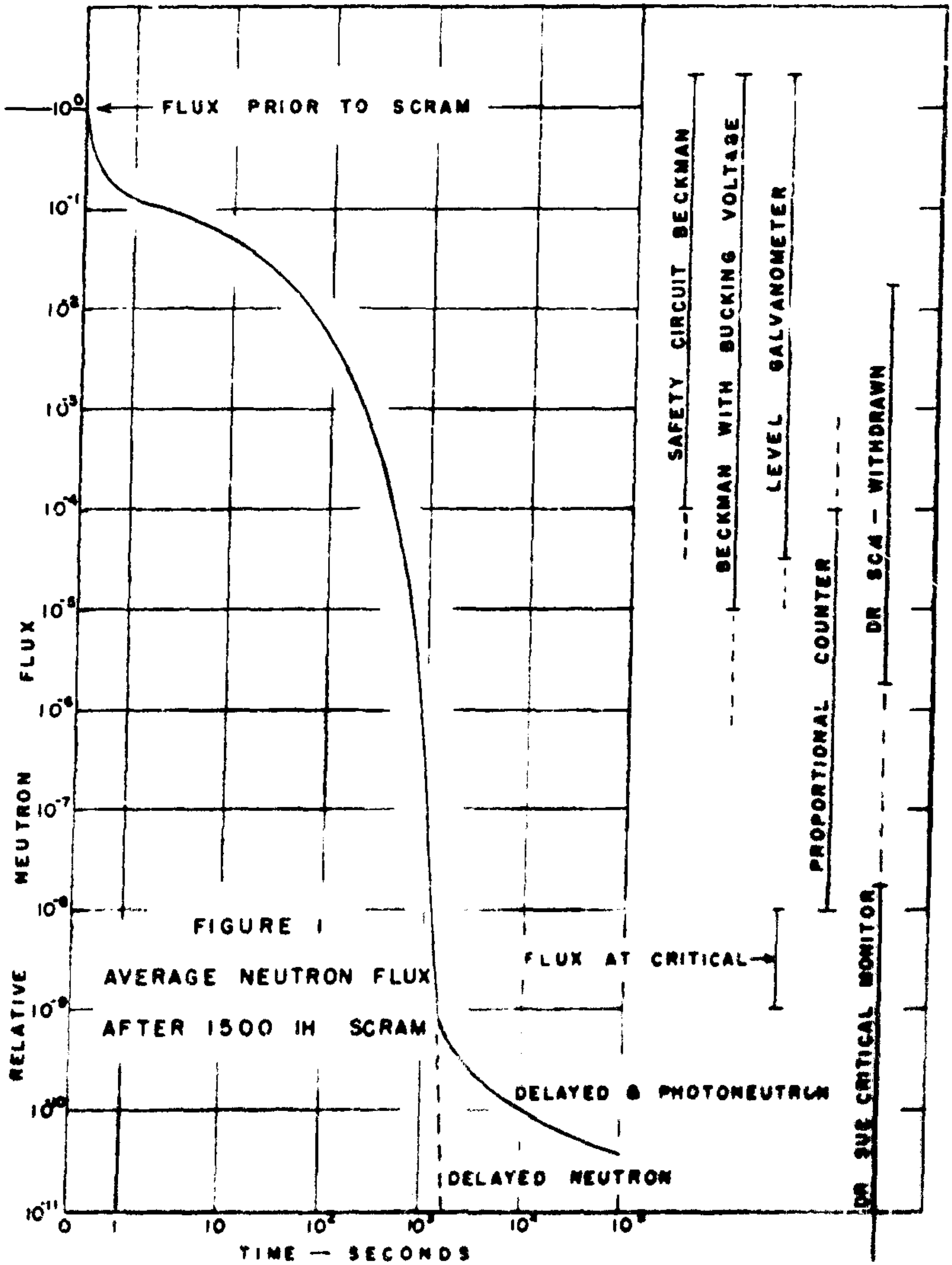

FIGURE I

AVERAGE NEUTRON FLUX AFTER 1500 IH SCRAM current. An additional one to two decades of range is obtained by "bucking" out a portion of the gamma induced current manually with an opposite and approximately equal current (the so-called bucking voltage system) or automatically with a special gamma compensation volume in the ion chamber.

Boron trifluoride neutron proportional counters (the so-called "PC's") are capable of detecting neutrons in a gamma radiation field of about 100 R per hour maximum. This limits the possible locations of this type of detector to those positions where the neutron flux is too low to adequately measure and record during a reactor outage because the gamma radiation in the reactor shield becomes limiting before a region of adequate neutron flux is attained. Proportional counters have the two additional detrimental factors of the lack of evidence, due to very low counting rates, of proper functioning until after reactor criticality has been established and the possibility of unknown damage or loss through misuse of the system. The counting life of boron trifluoride proportional counters is limited to about 10^9 total counts, a value which can be exceeded with ease if the system is not shut off immediately after use during a reactor startup. This limited life is due to the fact that the BF_3 gas molecules are destroyed in the counting action releasing free fluorine atoms[(2)] which are detrimental. The fluorine in a damaged counter that has rested in a low flux region, such as during a reactor shutdown, will combine to form F_2 molecules, which are not detrimental to proportional counter action. As the reactor startup proceeds, the neutron flux, hence counting rate, increases, and the F_2 molecules are broken down to nacent fluorine which forms heavy negative ions. The result of this action is a progressive decrease in the effective sensitivity of the counter as the counting rate increases. The damage becomes significant in three progressive forms. First, the reactor periods obtained from the damaged counter will be considerably longer than the true periods; secondly, the system may give completely misleading information at high counting rates, and thirdly, the counter will become totally useless through loss of all suitable counting characteristics. Either or both of the first two forms may not be observed in cases of severe misuse or damage.

The subcritical neutron flux monitor, or subcritical monitor, is based upon the use of a fission counter, a type of fast ionization chamber. This counter employs a thin coating of U-235 as the neutron detecting element. The U-235 undergoes fission upon the capture of a thermal neutron, and one of the fission fragments escapes from the U-235 coating and ionizes the gas atmosphere within the counter. This primary ionization is then collected as a pulse to be utilized in the associated electronics as required. A fission counter is capable of reliably detecting fluxes of the order of 10 to 100 neutrons per cm^2 per second in the presence of a 10^5 R per hour gamma field.[3, 4, 5] This is possible because the ionization pulses caused by the fission fragments are very large in comparison with the pulses due to gamma radiation. The fission pulses are even further favored through the geometry of the counter design and the faster pulse shaping that is possible in the associated electronics used with this type of detector. The counting life of a fission counter is essentially unlimited as the filling atmosphere is argon, a noble gas, which is not broken down in the counting action.

The use of fission counters in this application at Hanford was brought about through a consideration of the available information [3, 4, 5] and calculations of the expected conditions within the Hanford reactors. Two fission counter electrodes were obtained from ORNL. These electrodes were designed for a counter used at ORNL and were of a small enough diameter to be useful in the proposed Hanford installations. Initial calculations indicated that a counter based upon this electrode would be

[redacted]

capable of detecting a flux of 100 neutrons per square centimeter per second in the presence of a 10^5 R/hr gamma field; this is the minimum sensitivity that would permit the use of a fission counter inside of a Hanford reactor during a regular shutdown. Laboratory tests of the fission counter employed indicate a neutron flux sensitivity which is 7% of that of the older brass BF_3 counters and 1.2% of that of the aluminum BF_3 counters currently employed in the PC systems. The sensitivity of the fission counter is 0.05 counts per neutron per cm^2 per second. This low efficiency is, however, far overbalanced by the ability of the fission counter to operate in intense gamma radiation fields.

The fission counter, then, offers the ability to satisfy the requirements for neutron flux monitoring in a shutdown reactor while the problem of damage from the basic counting action is avoided. The associated electronics for fission counter usage are fairly well proven through several years of laboratory usage at many sites. Suitable circuits are available to transmit the small, fast pulses from the counter over distances of several hundred feet as encountered at the reactors. The primary electronic problem then is one of creating a system that is easy to operate and free of extraneous influences such as electrical noise. The use of the counter within the reactor proper requires that some mechanism be provided to remove the counter to a protected location in the reactor shield while the reactor is at power so as to avoid burnout of the U-235 by the very high neutron fluxes.

B. Prototype Installation

The first prototype on-pile installation of the subcritical monitor was installed in C test hole at 105-DR on November 18, 1954. The design[6] is such that, after the reactor is shut down, the counter may be moved into a position between two process tubes in the outermost column of tubes (See Figure 2) by means of a motorized system. The counter is then able to easily detect the shutdown neutron flux. The counter must be retracted

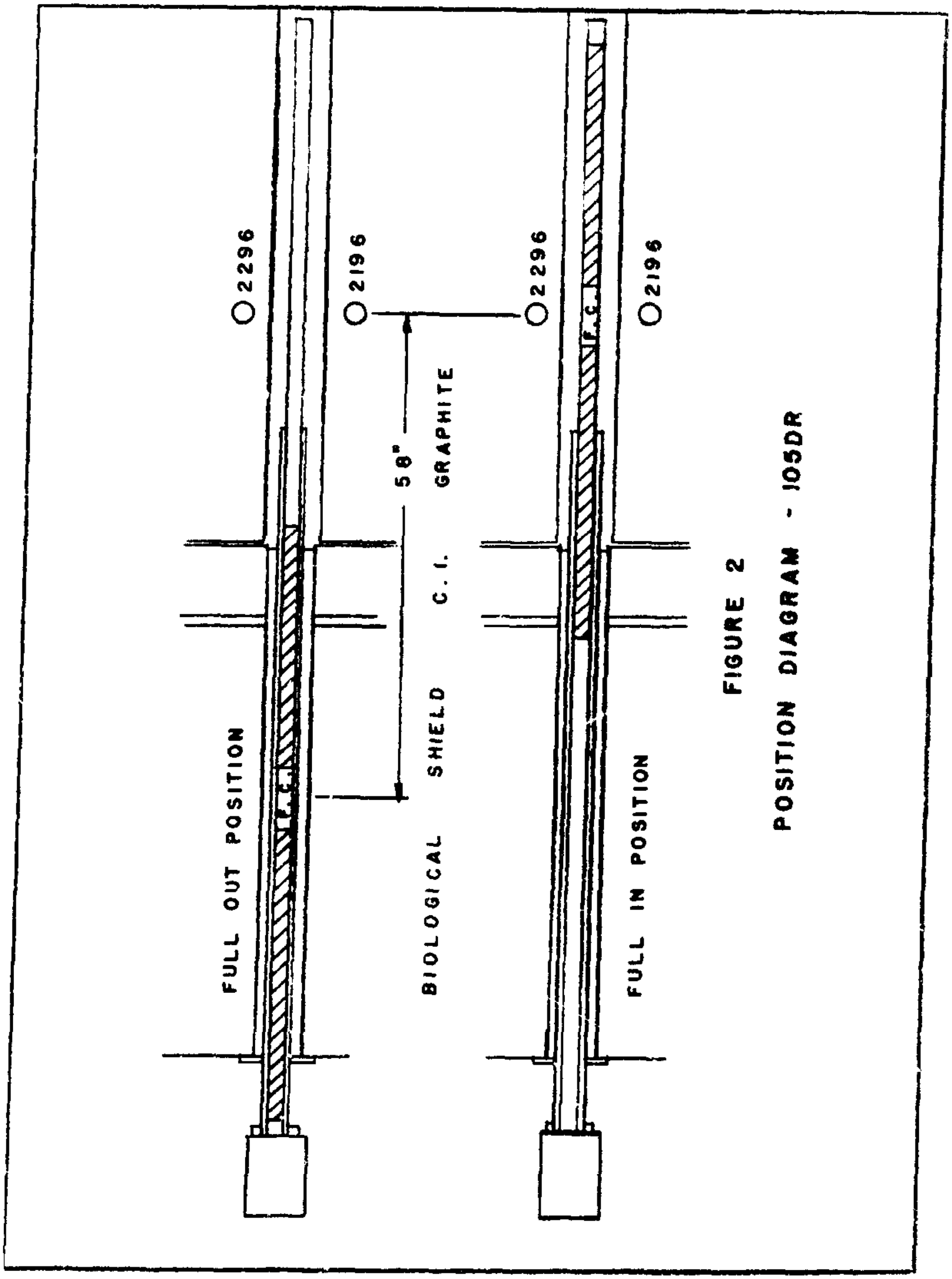

FIGURE 2
POSITION DIAGRAM - 105DR

by the motor when the reactor is brought up to operating power as the neutron flux would burn out the U-235 in the counter and could cause radiation damage in some of the components, notably the signal cable. The actual withdrawal may be done in several steps so as to utilize the range of the counter to the fullest extent. The withdrawal places the counter in a protected position within the reactor shield and causes shielding plug trains on each end of the counter to completely fill the hole through the biological shield to prevent radiation beams.

The fission counter (Figure 3) employed in the first installation is based upon an available electrode made originally for the Oak Ridge National Laboratory model Q-1092-2 counter. This electrode is a nickel sleeve three inches long and one inch in diameter. It has an internal area of 57 cm^2 which is coated with one milligram per cm^2 of $U_3{}^{235}O_8$. The predominant material of construction employed is 2S aluminum so as to minimize the internal radioactivity of the counter. The insulators supporting the pulse collecting anode are made of Alsinag 222, a machinable ceramic composed of magnesium silicate. The chamber is sealed after assembly by soldering with pure tin. The final evacuation, outgassing and filling is done through the hollow stem of the kovar seal. The filling used is one atmosphere of dry, commercial argon gas. The finished counter was calibrated in the Hanford Standard Pile; the sensitivity being 0.05 total counts per neutron per cm^2, which is within 5 per cent of the calculated figures.

The pulses from the fission counter are fed into an electronic system which is a rather conventional lineup (Figure 4) of preamplifier, amplifier, logarithmic counting rate meter, recorder, and a positioning motor control circuit. This system, with the exception of the preamplifier and motor circuit, consists of modified commercial equipment. All components are of a reliable, proven design employing premium parts.

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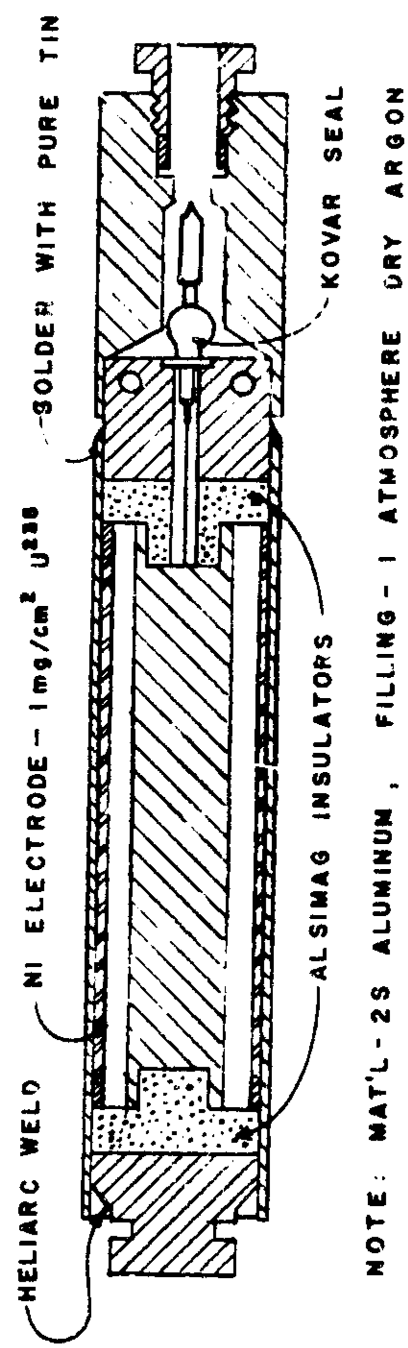

FIGURE 3

FISSION COUNTER FOR SUBCRITICAL MONITOR

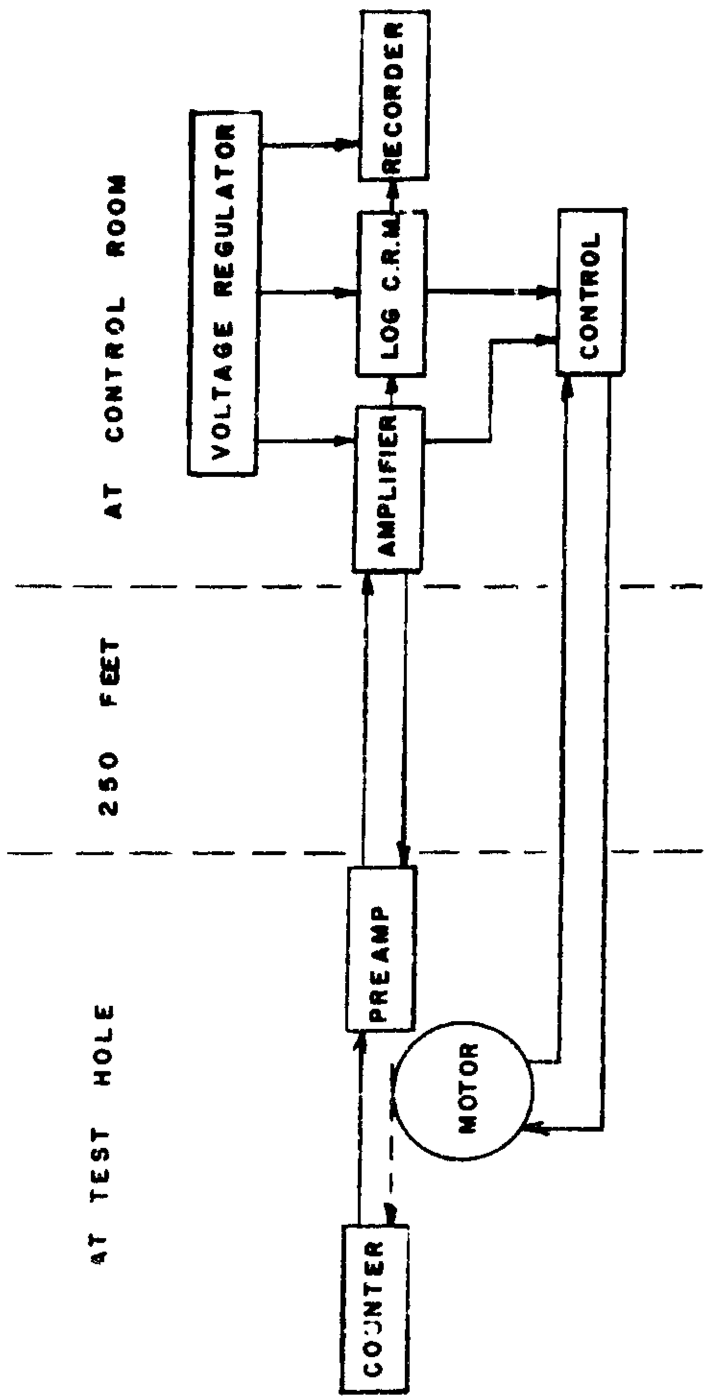

FIGURE 4
SUB CRITICAL MONITOR SYSTEM DIAGRAM— 105 DR

C. Performance

The subcritical neutron flux monitor installation was operated for a period of three and a half months during which seven startups were observed. Difficulty was encountered in operating the system two times during this interval, however, the trouble both times was in a temporary a-c power regulator which was then replaced. Satisfactory operation was easily achieved on every startup monitored, and no adjustment of the system was required in this interval.

The neutron detection characteristics of the fission counter were verified after installation by taking the discriminator curves in Figure 5. The relative densities of neutrons and gammas to which the counter was exposed were controlled by placing the counter at varying positions in the shutdown reactor. Curve 1 was taken at 58 inches out from the last metal column; this placed the counter in the middle of the reactor shield, and the principal source of radiation was the alpha particles from the U-235 in the counter. Curve 2 was taken at 18 inches out from the last metal column, which places the counter in the graphite reflector. The radiation at this point consists of the same internal alphas as Curve 1 with an estimated 10^3 R per hour of gamma and about 215 neutrons per cm^2 per second. Curves 1 and 2 are typical of the laboratory tests made at less than 1 R/hr of gamma radiation and indicate that 10^3 R/hr has no observable influence upon the neutron detection ability of the fission counter, i.e., the gamma pulses are completely biased out. Curve 3 was made with the counter at 0 inches, that is, positioned immediately between two fuel bearing process tubes. The radiation in this case consists of the internal alphas, about 10^5 R per hour of gamma, and 550 neutrons per cm^2 per second. A suitable operating point still exists between 20 and 25 on the discriminator, 25 being the operating point, and the knee in the neutron induced portion of the curve is set at the same point as on Curve 2, which indicates that the neutron detection ability is unimpaired in spite of the high gamma activity. Curve 4 is the gamma

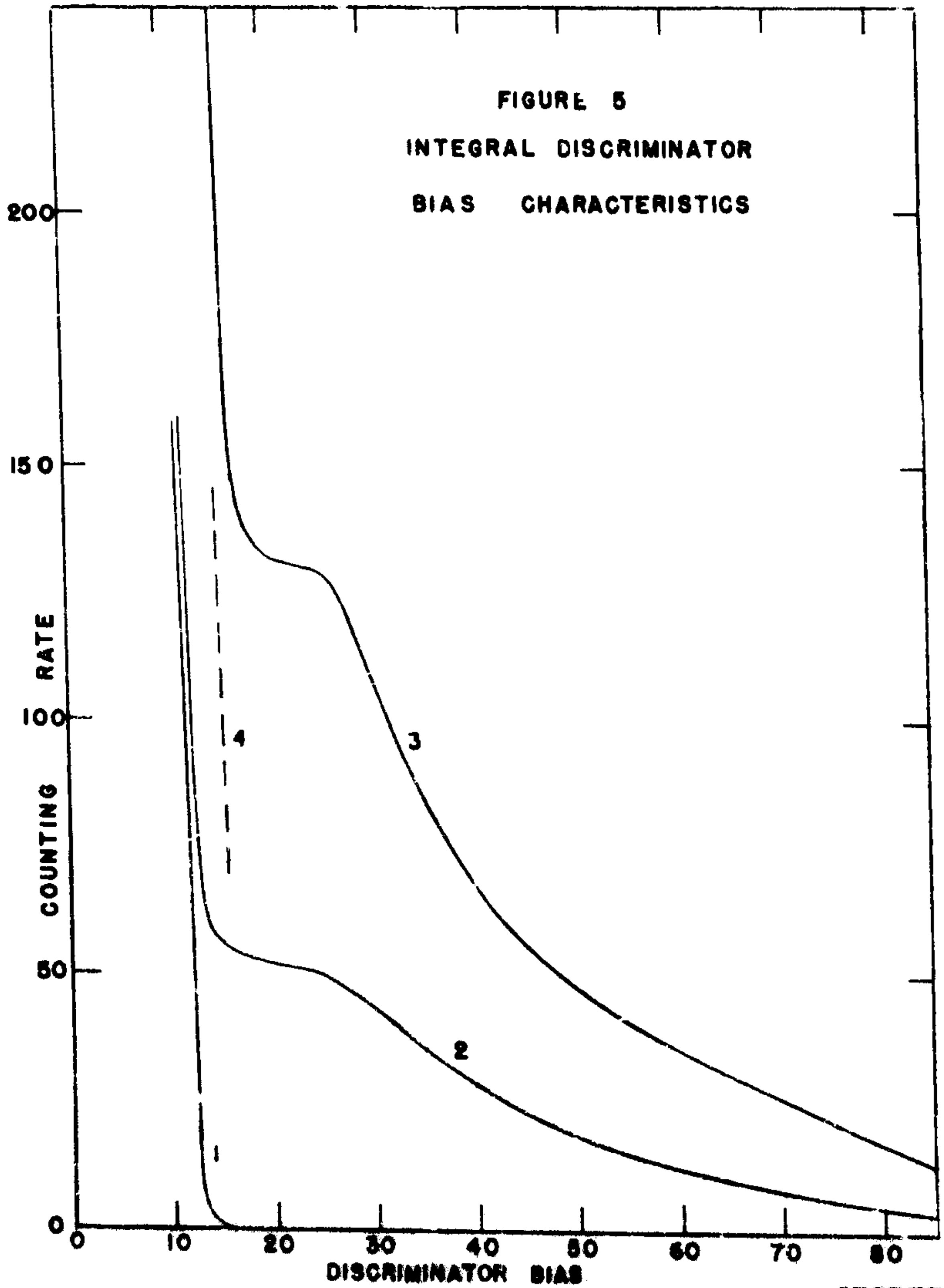

FIGURE 5
INTEGRAL DISCRIMINATOR
BIAS CHARACTERISTICS

and alpha contribution in Curve 3 after the neutron induced portion has been subtracted off.

Recorder charts obtained on two of the reactor startups are presented in Figures 6 and 7. They are typical of all startups observed; the only variations are in the manner in which reactor criticality was obtained, and in the arbitrary counter positions employed in the later stages of the rise in reactor power. Time increases from right to left on the chart with a speed of two minutes per inch or forty seconds per division. The counting rate or neutron flux increases from bottom to top varying through four decades from one count per second to 10,000 counts per second. The power levels noted are derived from the existing reactor instrumentation during the periodic special instrument calibration startups. The power level calibration remained accurate within a factor of 2 and the minimum statistically acceptable (one count per second) sensitivity was 0.001 watt of neutron flux. The best sensitivity realized with the present BF_3 systems on a comparable basis, that is, at counting rates capable of being recorded on a logarithmic count rate meter system, has been in the 1 to 10 watt range of neutron flux and has varied by orders of magnitude depending upon the status of the equipment and control settings during the various startups. The high sensitivity of the subcritical monitor assured at all times, even when all safety and control rods were still inserted at the end of an outage, at least a full decade of useful neutron induced signal above the minimum capable of being presented on the four decade recorder system. This ability to detect and record the neutron flux at all times provides ample assurance that the system is functioning properly and that it will perform the reactor safety and control functions expected of it when called upon to do so.

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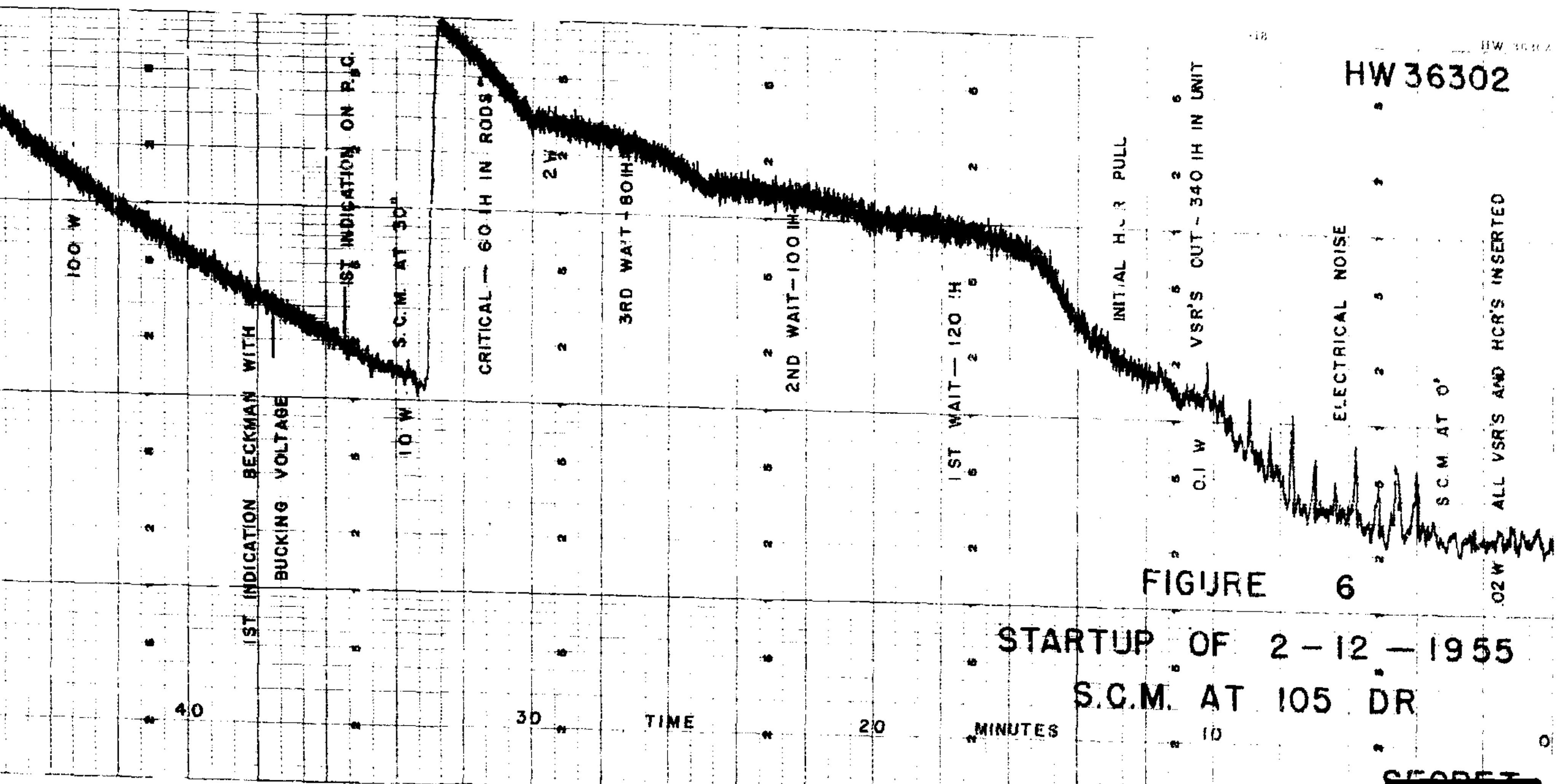


FIGURE 6

STARTUP OF 2 – 12 – 1955
S.C.M. AT 105 DR

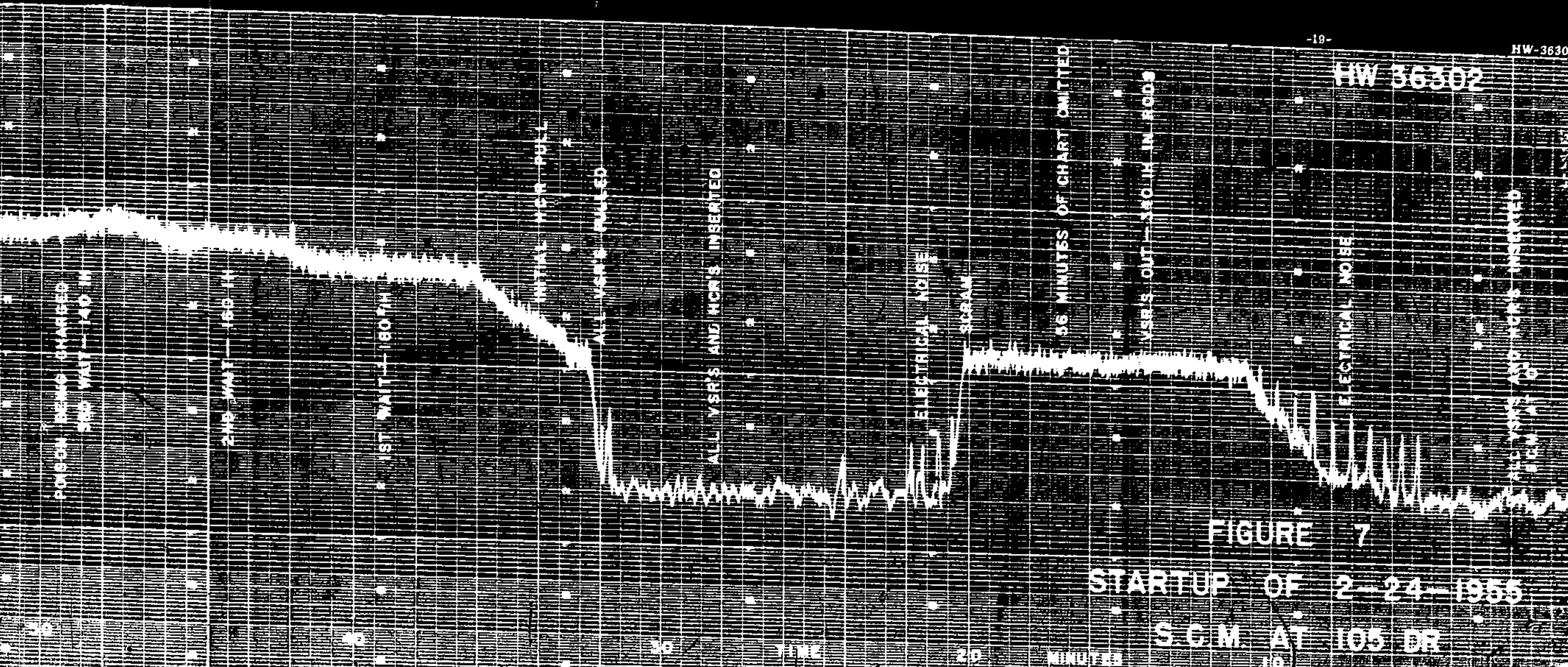
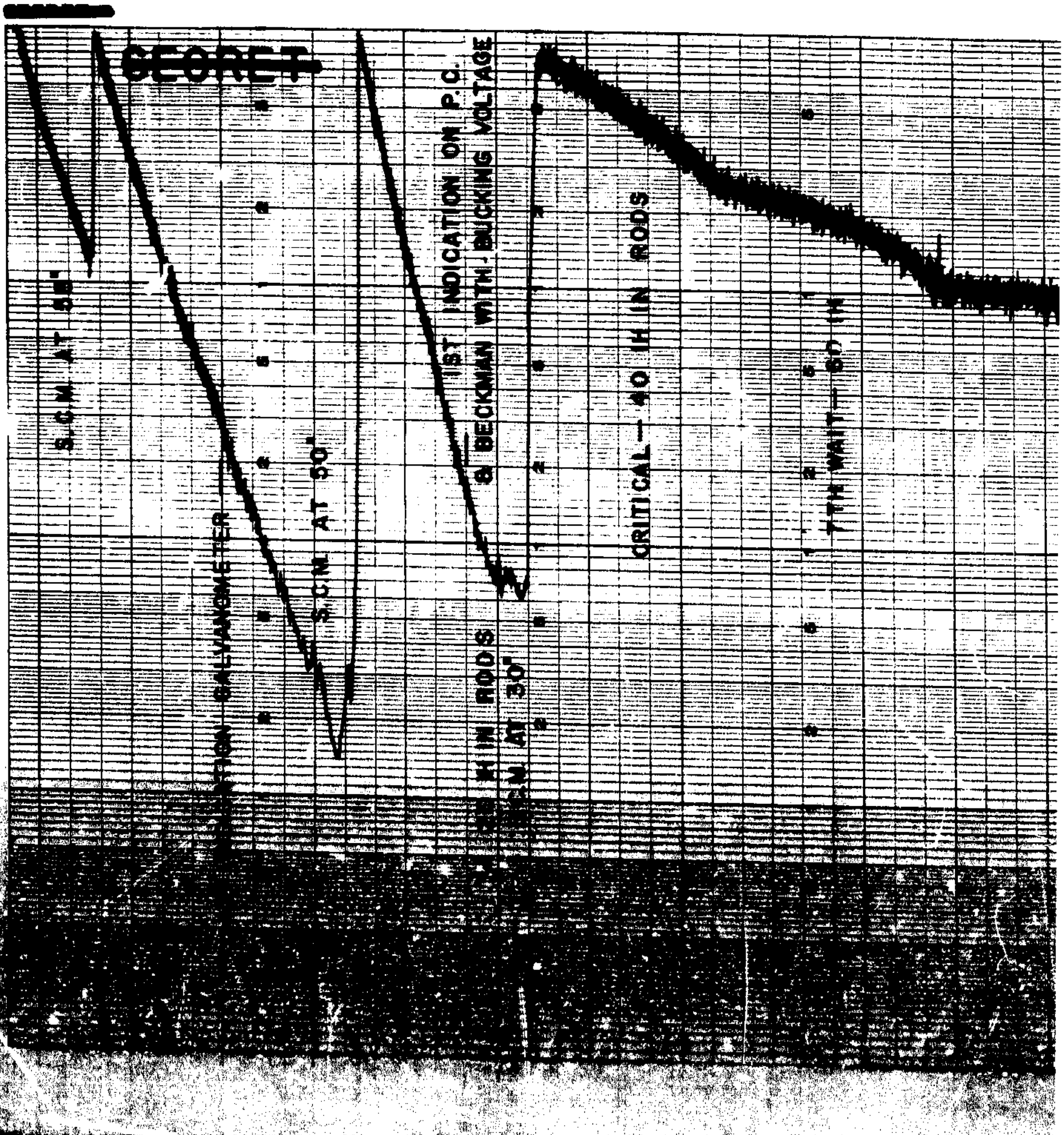


FIGURE 7

STARTUP OF 2—24—1955

S.C.M. AT 105 DR


SECRET
S.C.M. AT 50"
GALVANOMETER
S.C.N AT 50"
IH IN RODS
AT 30"
1ST INDICATION ON P.C.
& BECKMAN WITH BUCKING VOLTAGE
CRITICAL — 40 IH IN RODS
7TH WAIT — 60 IH

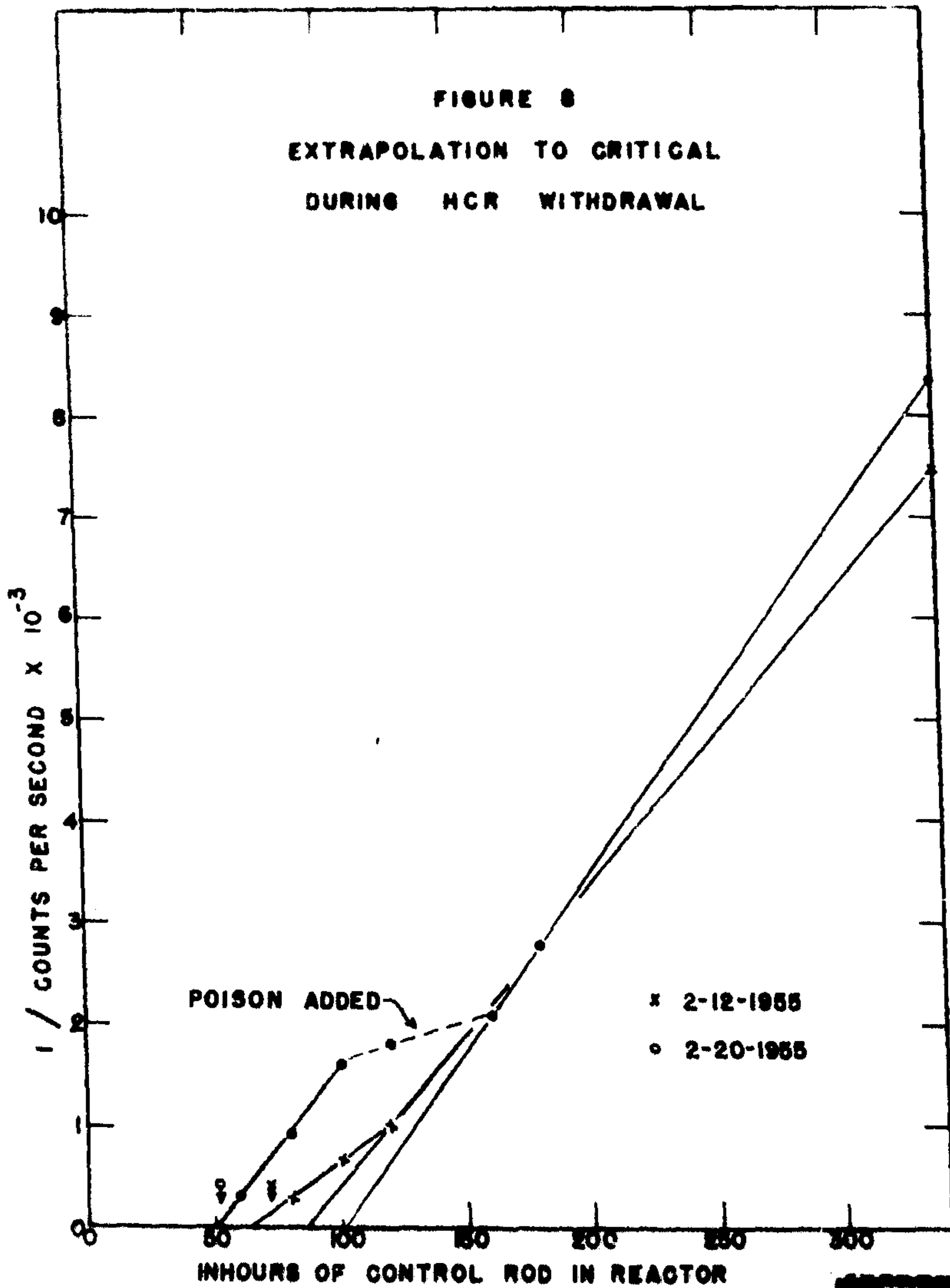
The various vertical safety and horizontal control rod pulls are noted on the charts along with the inhours of rod remaining in the reactor at each time. The spikes which appear during the safety rod withdrawals are caused by electrical noise induced in the system. This noise should be minimized by some redesign of the cabling and filtering of the counter system.

The startup of February 12, 1955 is shown in Figure 6. This was a fairly normal startup with the exception of the long (260 second) rising period, which was used for instrument calibration. The increase in the rate of rise on this period is due to xenon decay; a value of 24 inhours per hour is derived from this startup.

The startup of February 24, 1955 is shown in Figure 7. This chart demonstrates, to a degree, the ability to detect abnormal reactivity conditions. The decrease in counting rate after the second five minute wait in the control rod withdrawal indicated that something out of the ordinary was occurring. An investigation revealed that ball valve tubes were being charged with poison during the rod withdrawals; this activity was stopped, and the startup proceeded in a normal manner.

The steady state neutron flux in a subcritical reactor is directly proportional to the neutron source strength (photoneutron primarily) and inversely proportional to the inhours below critical. The neutron source strength in a particular reactor is a function of the previous operating history and the length of time since shutdown. Fortunately, the neutron source at the time of a cold startup is relatively constant. This is because the short half life gammas causing photoneutrons are gone, and only the longer half life gammas, which are representative of the average reactor power level for a considerable time prior to the shutdown, are producing the photoneutrons. With a nearly constant neutron source prior to a cold startup, any large variations in neutron flux may be attributed to changing the reactivity status of the reactor. A variation of an order of magnitude in the subcritical reactivity will result in a decade change in neutron flux, or counting rate. Stated slightly differently, if 90 per cent of the control strength holding a reactor in a subcritical condition is removed, then the steady state neutron flux will increase by a factor of 10. This relationship of neutron flux and reactivity may be used to estimate when the reactor will become critical. It should be borne in mind that the fission counter, being a single, small detector, is sampling only a region of the reactor and is subject to some flux shift or control rod shadowing effects. This means that inhour values derived from the flux-reactivity relationship are relative to the effect of the varying control strength upon the region being monitored. These effects are not serious and can be minimized by employing a fixed control rod withdrawal order. While the reactivity values obtained with the subcritical monitor are somewhat dependent upon regions within the reactor, the establishment of reactor criticality and the values of rising periods of neutron flux or power are not confined to regions and quickly assume equal influence throughout the reactor, and any condition of flux transients detected by the subcritical monitor is representative of the entire reactor.

The actual point at which criticality will be obtained may be predicted in a quick manner as shown in Figure 8. The reciprocal of the counting rate at a particular time is plotted versus the calculated value of the control rods in the reactor at that time. Critical is estimated as the inhour value at which the inverse of the steady state subcritical neutron density extrapolates to zero. Care must be exercised in visually estimating the counting rate in the regions within 40 inhours of critical as the value to be used is the equilibrium, or steady state value, which is not always obtained because of the "sluggishness" of the reactor as critical is closely approached. This results from the time required for the longer



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lived delayed neutrons to attain equilibrium. The estimate of criticality, obtained from the initial rapid withdrawal of the control rods during all the startups observed at DR reactor, was, in general, within one rod pull or 20 inhours of the correct value and appeared to be a reliable rule of operation.

The break in the plot for February 20 is due to the poison column charging during the startup. The arrows indicate the actual points where critical was obtained. No effort has been made to correct the approach to critical data for the xenon decay during the rod pulls as it does not alter the prediction greatly and unncessarily complicates the process. Some degree of success has been experienced in estimating critical from the change in subcritical multiplication during the vertical safety rod withdrawal; however, there is not sufficient data available yet to estimate the inaccuracies inherent in this method.

The opportunity to adequately test the performance of the system during a hot startup was not available because of a policy limiting these outages to very short times early in 1955. During one hot startup, the instrument was placed in operation as the reactor passed the 1 MW region, and one decade of information was obtained along with the rising period of the reactor. This small bit of operation of the system appeared to be quite normal. There is, in addition, no reason to doubt the operation of the systems during a hot startup as there is a sufficient reserve of ability to detect neutrons under the adverse gamma radiation fields in a freshly scrammed reactor.

A calibration has been obtained (Figure 9) of the relative sensitivity of the chamber at various positions in its range of travel. The optimum method of operation has been to use the same fixed positions with known sensitivity ratios during every startup so that the power level is fairly well established at any one time. The positions used in the initial

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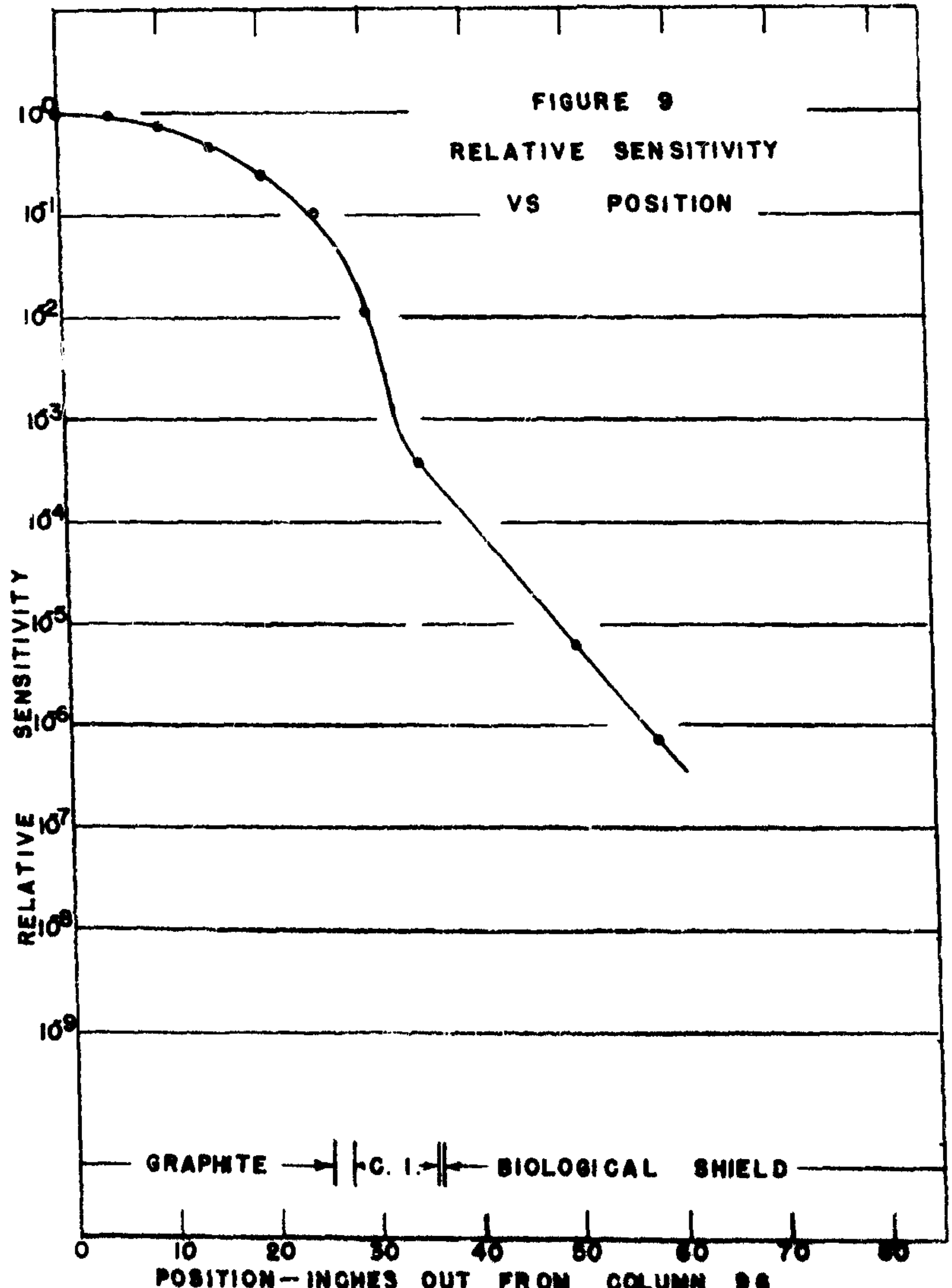

FIGURE 9

RELATIVE SENSITIVITY VS POSITION

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installation at DR were 0, 30, 50 and 58 inches. It is hoped that by increasing the travel slightly and not inserting the chamber quite so deep in the full in position that a sensitivity suitable for full power operation can be obtained in the full out position. The system, as installed at DR, monitored the flux up to a 10 MW power level.

The system failed in April, 1955 through water condensation in the mechanism housing, which had a large hole which permitted the breathing of moist air. A new mechanism(7) has been designed in which the effect of water condensation should be very small and a totally sealed enclosure has been provided, and the improved system is being installed in a process tube on the front face of D reactor.

D. C. Pound

DCP:ms

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ABSTRACT

The neutron flux in a highly subcritical Hanford reactor has been successfully monitored with a prototype fission counter system suited to process usage. Performance data is included in the form of reactor startup flux transients and the prediction of criticality and reactivity. The problem of monitoring subcritical flux levels is outlined along with the limitations of the instrumentation used up to the present.