DUQUESNE LIGHT COMPANY
Nuclear Safety and Licensing Department

Beaver Valley Power Station, Unit No. 1

ANALOG ROD POSITION INDICATION SYSTEM

Special Report

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Abstract

This report discusses the history and operational aspects of the Analog Rod Position Indication System (ARPIS) installed at Beaver Valley Power Station Unit No. 1. Testing and observation of the ARPIS during the period from initial startup through operation during the third cycle has revealed a number of phenomena which affect the ability of this system to accurately determine the position of control rods during operations involving withdrawn rods in Modes 1 through 5. These phenomena appear to be as follows:

1) Steady state nonlinearity of the ARPIS
2) Transient inaccuracy due to rod motion
3) Calibration shift due to power level
4) Calibration shift due to operation below normal operating temperature

These inaccuracies in the ARPIS are measurable and repeatable but the magnitude of these inaccuracies varies from rod to rod. While steps such as "custom made" meter scales, limited use of "soak times" and special calibration techniques are in use to operate the system within the accuracy requirements of the Technical Specifications, testing and plant operation within these accuracy requirements requires excessive operator attention and could result in an inadvertant violation of a Limiting Condition for Operation.

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Analog Rod Position Indication System
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I. Introduction

This special report of the operational performance of the analog rod position indication system (ARPIS) was prepared to respond to an NRC staff request for information set forth in the Safety Evaluation to Amendment No. 52 of the facility license, as modified during a meeting with the NRC staff conducted on July 13, 1982. This special report examines those aspects of the performance of the ARPIS which were observed during testing and operation of the system. A companion report, prepared by Westinghouse Electric Corporation, covers the design and out-of-core testing and analysis performed by Westinghouse as well as Westinghouse's evaluation of plant data obtained from Duquesne Light Company.

II. Background

During the pre-startup testing phase, prior to the initial operation of Beaver Valley, difficulties were encountered during the initial calibration of the ARPIS. These difficulties appeared at the time to exhibit two characteristics, namely: nonlinearity and drift. The nonlinearity in the actual rod position versus indicated analog position was accomodated within the $\pm$ 12 step accuracy limit established by the core safety analysis. The NSSS vendor was consulted during the pre-startup testing phase concerning the drift problem and station personnel were advised that time should be allowed during calibration to allow the ARPIS to stabilize prior to recording data or making calibration adjustments. Based upon these recommendations, the initial calibration of the ARPIS was considered to be successful and plant startup commenced.

Operation during Cycle 1 revealed certain anomalies in the operation of the ARPIS which were unquantified at that time. These were:

- Variations in ARPIS output with Reactor Coolant System average temperature
- Variations in ARPIS output with reactor power level
- The magnitude of the variation was different for individual analog rod position indicators

Operators noted that drift after rod motion continued to occur with the reactor at power but, based upon the earlier advice from the NSSS vendor that a stabilization period was required, this was not considered to be a concern at the time. Calibration shift due to reactor power level did not appear to be a concern at that time either because the shape of the nonlinear calibration curve for the ARPIS provided substantial margin near full scale, the normal operating range of the rods. There is no documentation to establish whether or not additional adjustments were made to the ARPIS during Cycle 1 operation.

During the Cycle 1 - Cycle 2 refueling outage, the NRC Resident Inspector expressed concern that operation of the reactor with known drift due to rod motion could be considered a violation of a limiting condition for operation if that drift caused the ARPIS indication to fall outside the ± 12 step band allowed by the plant Technical Specifications. Under this interpretation of the Technical Specifications, no stabilization period was allowed. During the Cycle 2 startup testing, difficulty was encountered calibrating the ARPIS due to nonlinearities in the system. A calibration technique was devised to attempt to envelop these nonlinearities within the allowed accuracy limits. In addition, extensive testing was conducted during the Cycle 2 preoperational and startup period to:

- Quantify the time-dependent drift in the individual ARPIS calibrations due to rod motion, and
- Quantify the relationship between ARPIS calibration shift and reactor power level.

It was observed during this testing that the primary detector voltage was less sensitive to drift and calibration shift problems than was the secondary output voltage from the detectors.

Westinghouse Electric Corporation was consulted during this testing period and observed some of the testing and reviewed the data obtained from the ARPIS testing. The Westinghouse representative hypothesized that the effects which we observed during the testing of the ARPIS were thermal phenomena associated mainly with the temperature of the control rod lead screw which serves as a movable transformer core within the ARPIS detectors. This hypothesis appeared to be reasonable since every effect which was measured was related to an apparent change in lead screw temperature and that the apparent magnitude and direction of the change in ARPIS calibration was consistent with this hypothesis. There is no accurate means to determine the actual lead screw temperature by either direct measurement or by thermal hydraulic analysis in the relatively complex thermal system which comprises the environment for the lead screw; therefore, no direct way to prove this hypothesis was available using installed plant components.

Technical Specifications (Amendment 35) were developed, submitted and approved which recognized many of the characteristics of the ARPIS which were quantified during the Cycle 2 pre-startup testing period. The main features of these revised technical specifications were as follows:

1. A one-hour stabilization period was allowed during which time reliance would be placed upon the use of comparisons between measured primary detector voltages and a calibration graph of primary detector voltage versus actual rod position (as inferred from the group demand counters).

2. Use of primary detector voltage measurements was allowed for up to three rods per group.

A permanent solution to this problem was to be developed later. The NRC safety evaluation for Amendment 35 stated that the NRC staff plans "to discuss the matter further with Westinghouse to determine what long-term fixes may be needed".

Duquesne Light Company, realizing the limitations of Amendment 35 and the complex nature of the phenomena affecting the accuracy of the ARPIS, decided to pursue a reanalysis of the physics restrictions related to rod misalignment in an effort to increase the allowable misalignment band. This effort was directed toward limiting those instances where the use of primary detector voltages would be required to meet the limiting conditions for operation of the technical specifications. This approach has obvious advantages from a human factors standpoint in that a large amount of operator attention was being directed to the Rod Position Indication System. Duquesne Light Company contracted with Westinghouse Electric Corporation to perform a reanalysis of the rod misalignment situation to meet the licensing requirements for the facility. This reanalysis was performed and assumed a total single rod misalignment of ± 32 steps; 16 steps for instrument inaccuracy and 16 steps for allowed misalignment. This Westinghouse study was submitted along with a request for amendment to the facility license to the NRC and was approved, for Cycle 2 only, as Amendment 42. Duquesne Light Company assumed that the limitation of applicability to Cycle 2 was due to the cycle-dependent nature of the Westinghouse safety analysis, upon which this Amendment was based.

Based upon reasonably satisfactory operation of the ARPIS during Cycle 2, the Company contracted with Westinghouse to perform a core safety analysis for Cycle 3 assuming ± 16 step rod deviation (± 32 steps including instrument inaccuracy). During the same time period, Westinghouse devised and submitted to its customers and the NRC a model technical specification which assumed ± 12 step rod deviation but placed reliance upon the group demand counters when the rods were within a defined mid-span band. This new Westinghouse proposed model technical specification was based upon the latest model technical specifications published in NUREG 0452, Rev. 4, which were more restrictive than the existing technical specifications for Beaver Valley, particularly in the area of accuracy requirements at reduced temperature as set forth in Technical Specification 3.1.3.3. Duquesne Light Company reviewed these proposed model technical specifications and concluded that these specifications represented an escalation of requirements and did not fully envelop the transient effects which we had observed.

According to Atomic Energy Clearinghouse Report, Volume 28, No. 31, the Tennessee Valley Authority (Sequoyah Nuclear Plant) was cited on February 17, 1982 in Inspection 82-04 for violation of Specification 3.1.3.3 in that TVA was unable to maintain one analog rod position indicator operable at a reactor coolant system temperature below normal operating temperature. During a conference call between TVA and NRC-NRR held on February 18, 1982, it was reported that NRR was aware of the temperature effects on ARPIS accuracy. TVA avoided this conflict with Specification 3.1.3.3 by maintaining the reactor trip breakers open while in Modes 3, 4 and 5. Duquesne elected not to pursue this corrective action since it reduces the operator's ability to cope with a dilution incident.

On February 23, 1982, Duquesne Light Company submitted an application for amendment to the technical specifications which sought to retain the Cycle 2 technical specifications for rod position indication systems, including the ± 16 step misalignment tolerance, for Cycle 3 and beyond. The concept of continuation of the use of the Cycle 2 technical specifications for the ARPIS was rejected by NRR-CPB. NRR-CPB requested an analysis of multiple rod misalignment to support the ± 16 step request. Duquesne Light Company then reexamined and modified the model technical specifications prepared by Westinghouse. These were submitted to the NRC on April 21, 1982. Westinghouse had stated that these model technical specifications had been presented to the NRC and had received a favorable informal review from the NRC - Core Performance Branch. Neither the February 23, 1982 application nor the April 21, 1982 submittal contained ARPIS accuracy requirements during Modes 3, 4 and 5. The NRC expressed concern about the ability to accurately determine the position of a stuck or dropped rod outside the band of required accuracy as set forth in the Westinghouse proposed model technical specifications. This approach was subsequently rejected by the NRC.

On May 5, 1982, the Company withdrew previous applications for technical specification change related to the ARPIS and submitted a new request for amendment to the technical specifications. The May 5, 1982 application proposed the use of "custom made" ARPIS meter scales and a one hour "soak time" during which reliance would be placed upon the group demand indicators to determine rod position. The May 5, 1982 application also proposed the use of primary detector voltages as a backup means of determining rod position. This proposed specification was developed from the original Cycle 2 specification and retained the original format and many of its basic features. The NRC staff posed additional questions which were responded to in the Company's letter dated May 26, 1982.

During the NRC review process, the NRC staff substantially revised our May 5, 1982 application and returned this revised draft to the Company. This revised draft maintained the basic concepts of the Company's May 5, 1982 application, as supplemented by the Company's May 26, 1982 letter, but represented a major change in format and contained some provisions new to Beaver Valley, drawn from the model technical specifications contained in NUREG 0452, Rev. 4. One of these changes proposed was the imposition of accuracy requirements on the ARPIS in Modes 3, 4 and 5. The Company agreed to the technical specifications in order to return the unit to service and, on June 10, 1982, submitted formal application for amendment to the technical specifications using the NRC staff proposal with a few minor changes.

On June 11, 1982, the Company sought a further amendment to the technical specifications to remove the ARPIS accuracy requirements below an average reactor coolant system temperature of 547F. In addition, the June 11, 1982 revision sought to modify the method of reporting entries into the ACTION statement 3.1.3.2(d). Despite the NRC staff experience concerning Sequoyah on February 18, 1982, the staff believed that operation of the ARPIS within the ± 12 step accuracy requirements was feasible at reduced temperature. The Company proposed and conducted a test on June 12 through 14, 1982 which established the degree to which the accuracy of the ARPIS was affected by temperature and confirmed the accuracy of the information transmitted to the NRC staff related to the Company's June 11, 1982 request for amendment. The NRC subsequently granted a temporary waiver of the accuracy requirements imposed upon the ARPIS during Modes 3, 4 and 5 pending further discussions on the matter with the Company. A permanent change to specification 3.1.3.3 was approved by the NRC on September 3, 1982.

The NRC staff requested that the Company make a presentation of the results of its ARPIS calibration and testing program as well as a technical discussion by Westinghouse related to their theoretical analysis and operational experience with ARPIS. This meeting was held on July 13, 1982 in Bethesda.

Beaver Valley has operated as a base loaded station near full power with all control rods fully withdrawn. In this configuration, the ARPIS typically indicates off-scale - high. During plant maneuvering, during startups and shutdowns, the ARPIS has generally remained within its accuracy limits, with the exception of rod F-10. Rod F-10 appears to be particularly sensitive to thermal effects. In addition, the primary voltage for this rod is higher than for the other rods which initially led to the conclusion that a high resistance connection may be developing in the primary detector circuit. Electrical measurements were made to the circuitry of the ARPIS for Rod F-10 during a recent shutdown. These measurements did not reveal any circuit faults nor degraded components.

Due to a greatly reduced industrial load in the Pittsburgh area, it is expected that the plant will be required to be operated in a load following mode. This method of operation will involve some rod motion and we expect to encounter some RPI calibration problems.

III. Description Of The ARPIS

The Analog Rod Position Indication System (ARPIS) consists of a detector mounted on each control rod, a signal conditioner for each detector and an analog voltmeter (calibrated in terms of control rod "steps") for each signal conditioner. Various other output signals are available and used (i.e. rod bottom bistables and computer signals).

The ARPIS detector is a linear variable transformer consisting of primary and secondary coils alternately stacked on a stainless steel coil form. Each coil was custom wound by the manufacturer to provide linear response based upon shop tests conducted at ambient temperature. The detector is mounted over the control rod drive line pressure housing and is not in direct contact with primary coolant. Both the primary and secondary coils are connected in series and terminate in a top plate mounted connector. The moveable core of the detector consists of the drive shaft connected to the Rod Cluster Control Assemblies (RCCA) and is contained within the pressure housing. As the RCCA is withdrawn, the drive shaft moves up into the detector assembly and links more and more flux between the primary and secondary detector coils, thus increasing the detector output voltage. The primary coil itself acts as a variable reluctance during rod motion. The detector assemblies are cooled by the shroud cooling system, consisting of three fans which circulate air past the control rod drive mechanism coils and then upward past the ARPIS detector coils.

The primary detector coils are series connected with a fixed 500 ohm resistor which is driven by a 120V 60 Hz A.C. Sola transformer. The effect of the series connection on the fixed resistor and primary detector coil is that approximately 18 volts appears across the detector with the control rod fully inserted and approximately 26 volts appears across the detector with the rod fully withdrawn at plant operating temperature. The purpose of the 500 ohm resistor in the primary circuit is to provide some measure of isolation from one detector circuit to another, to limit fault current and to act as a pseudo current source. Refer to Figures 1 and 2 for a schematic representation of the primary detector circuit.

The secondary coils on the ARPIS detectors are wound to provide a turns ratio of approximately 46 to 37. When the drive line moves into the detector, more and more flux is linked between the primary and secondary coils. This produces an A.C. voltage in the secondary coils which varies from about 8 VAC with the rods fully inserted to about 12 VAC with the rods fully withdrawn at ambient temperature.

Each detector secondary circuit has its own signal conditioner where the secondary A.C. voltage is rectified and filtered to produce a D.C. voltage proportional to the drive line position. The signal conditioners are also connected to the power supply regulator output to provide some compensation for variations in regulator output. The signal conditioners provide a "zero" and "span" adjustment in the input network with a D.C. "null" voltage referenced to the individual detector primary voltage. The input network design is such that the "zero" and "span" adjustments are somewhat interactive. The signal conditioners utilize an operational amplifier to provide power to operate the analog indicator. This operational amplifier also has "zero" and "span" adjustments for meter calibration which are independent of the "zero" and "span" adjustments on the input circuitry. Calibration of the system is normally performed by manipulation of the "zero" and "span" adjustments on the input circuitry. The signal conditioner provides signals to the rod bottom bistables and the plant computer. Capability exists to input a test signal for calibration purposes and jacks are installed to read the D.C. rod position signal and the primary detector voltage. Figure 3 schematically shows the signal conditioner.

The analog indicators are vertically mounted, slide rule type plug-in D.C. voltmeters which are calibrated in terms of "steps". The meters travel from zero to full scale upon application of a 0 to 3.45 VDC signal, or 15 mV per step. A mechanical "zero" adjustment is provided on the side of the meter.

The power supply for the system is derived from 120 Volt AC distribution panels fed from 480 volt emergency buses E-9 and E-10 through a step-down transformer.

The computer receives a signal from each ARPIS signal conditioner as well as from the group demand indicators for the purpose of calculating and alarming an apparent rod deviation. The computation of rod deviation involves the comparison of each analog rod position signal with its associated group demand indicator to determine if a deviation of greater than 12 steps exists. The ability to properly perform this calculation and alarm function depends heavily upon the accurate representation of the analog rod position versus actual rod position function within the computer. The computer can use up to a fifth order equation to represent this calibration curve.

IV. Test And Calibration Program And Test Results

1980 Test Program

The test program conducted in the fall of 1980 for the startup of Cycle 2 concentrated on quantifying three effects, namely:

1) Determination of the steady state calibration curve

2) Determination of the magnitude and duration of the time related shift in the ARPIS calibration curves due to rod motion

3) Determination of the magnitude of the steady state shift in calibration of the ARPIS due to increasing reactor power level

Testing associated with Items 1 and 2 above was performed at an average Reactor Coolant System (RCS) temperature of approximately 547F in Mode 3. Testing associated with Item 3 above was performed in Mode 1 (power operation). When in Mode 1, average RCS temperature increases with power level. No data was obtained with the nominal average RCS temperature below 547F.

Tests associated with the determination of the relationship between the steady state rod position and ARPIS indication were performed by withdrawing rods by groups in increments to the fully withdrawn position and allowing the detectors to thermally stabilize at each increment. Primary detector voltage. secondary detector voltage, group demand position and ARPIS indication were recorded at each increment after thermal stabilization was achieved. The shape of the typical resulting calibration curves is shown in Figure 4*.

*Note that the ordinate of Figures 4 through 7 is expressed in terms of signal conditioner output voltage (i.e. 0.015 VDC equals 1 step of the ARPIS indicator) to avoid confusion with indicator readings obtained in later testing with nonlinear scales. Signal conditioner output voltage was never directly recorded during the 1980 testing period.

Figure 4 shows a pronounced steady state nonlinearity in the calibration curve for the ARPIS detectors. This nonlinearity was attributed to the presence of a "search" coil within the detector assembly (resulting in "low end" nonlinearity) and to the finite length of the detector coil and drive line (resulting in "high end" nonlinearity). The degree of nonlinearity was unique to each rod. All circuit parameters consistently showed the same relationship between actual rod position and signal, indicating that the nonlinearity observed originated in the detector. Despire the nonlinearity observed, each rod was calibrated to fit within the ± 12 step acceptance criteria.

To quantify the effect of rod motion on calibration curve shift, a testing sequence was devised involving alternate rod withdrawals and insertions with circuit data recorded during the thermal transients resulting from the rod motion. Figure 5 shows the typical envelope of calibration shifts recorded during this test. The phenomenon observed has the characteristic that the ARPIS indicator always "leads" the actual rod position, whether during rod withdrawal or insertion. Rod withdrawal caused a much greater shift in calibration than did rod insertion and the observed transient effects were greater near the fully withdrawn positions. Withdrawing deeply inserted rods caused a much greater shift in calibration than did rod withdrawals over shorter distances. The typical maximum shift in the calibration curve was about 24 steps due to this transient thermal phenomenon. The thermal transient stabilized to the original calibration curve in less than one hour in all cases. No correlation was found between thermal sensitivity and core position, leading to the conclusion that the variations in thermal sensitivity were due mainly to variations in detector construction and materials from rod to rod.

It should be noted that, because of the nonlinear nature of the steady state calibration curve, the 24 step accuracy margin was met with rods near the fully withdrawn position. With rods more deeply inserted, calibration shifts due to rod motion become of greater concern due to the reduced margin to the + 12 step limit. This reduced margin to the +12 step limit did not represent a severe operating impediment since the plant was operated most of the time at base load with rods fully withdrawn.

During testing involving the study of the transient effects on the calibration of the ARPIS, it was noted that the transient shift in calibration was less pronounced when measurements were made on the detector primary coil as when measurements were made on the secondary. This result appears reasonable since thermal changes affecting the permeability of the drive line will have a smaller effect on the primary coil acting as a variable reluctance as opposed to these same changes of permeability will have on the detector acting as a variable transformer. The relative insensitivity of the detector primary voltage to transient thermal effects as opposed to secondary voltage output appeared to be in the range of 2 or 3 to 1, depending on the rod involved. This led to the conclusion that the use of primary detector voltage curves represented a viable alternative to the use of the analog indicators.

During initial operation of Cycle 2, additional data was obtained to quantify the shift in calibration due to increases in reactor power. Figure 6 illustrates a typical calibration curve showing this power related calibration shift. The actual data obtained was for Control Bank D toward its upper range of travel and data above 200 steps was used to extrapolate the approximate shape of the 100 percent power curve below 200 steps shown in Figure 6. The magnitude of the power related shift in calibration appears to be in the range of from 4 to 6 steps for all but one rod. This rod (F-10) appears to be significantly more sensitive to thermal phenomena than the other rods.

1982 Test Program

During the plant heatup preceeding the startup of Cycle 3, data was collected at reduced RCS average temperatures to evaluate the effect of reduced temperatures on ARPIS calibrations. Data was taken at plant Tave temperatures of 320F, 400F, 500F and 547F. At 320F, the ARPIS indicated from approximately 170 to 200 steps for fully withdrawn rods, depending on the rod. As plant temperature increased, ARPIS indicated rod position increased, finally achieving the nominal calibration (within 12 steps) at 547F. Figure 7 illustrates the envelope of the ARPIS indicator readings at various plant temperatures. This data is particularly important in conjunction with the new accuracy requirements imposed by Technical Specification 3.1.3.3 in the latest issue of the Standard Technical Specifications. This data clearly shows that the ARPIS does not maintain its accuracy at temperatures below the range for which the system was designed and calibrated.

During this testing period, two other checks were made. The first, to evaluate the effect of changes in cooling air to the detectors and the second, to evaluate the effect of magnetic cross coupling between the rods. To evaluate the effect of changes in cooling air to the detectors, one of the three shroud cooling fans was shut down for one hour while the plant was at elevated temperature. No change in ARPIS indication was observed under reduced cooling conditions (rods were maintained fully withdrawn). We believe that the only effect that reduced detector cooling air flow will have will be to lengthen time to reach thermal stabilization after rod motion. We have not conducted tests to demonstrate this hypothesis, however.

To evaluate the effect of magnetic cross coupling, one rod group was maintained fully withdrawn while a second group was tripped to the fully inserted position. If magnetic cross coupling was a significant effect, one would expect that the ARPIS indications for the rods maintained fully withdrawn would decrease when the remaining rod group was tripped. Observation, however, showed that the ARPIS indications of the rods maintained fully withdrawn increased slightly (1 or 2 steps) when the remaining rods were tripped. This effect was attributed to a slight unloading of the ARPIS power supply when the magnetic material was removed from the detector coils of the tripped rods. We believe that this effect has no significance.

Prior to the startup for Cycle 3, two steps were taken to improve the performance of the ARPIS. First "custom made" meter scales were installed on the ARPIS indicators to compensate for the nonlinear nature of the detector calibration curves and higher order equations were used by the plant computer to compensate for this same nonlinear effect. It was believed that by compensating for this major nonlinearity of the system, the allowed accuracy margins permitted by the safety analysis would envelop all other thermal effects.

The new "custom made" ARPIS meter scales were produced by programming a stand-alone microprocessor with a graphics output to produce the meter scales. The calibration data for each rod obtained during the Cycle 2 startup testing period was input to the computer and a curve fitting program was used to obtain polynomial coefficients (see Figure 8). The resulting polynomial equation was then used to compute the position of the relative meter marking in five step increments in such a way that the distance between the "zero" indication and the "230 step" indication would be the same for each scale and would equal the range of motion exhibited by the meter when spanned from zero to 3.45 VDC. The resulting scales were then fastened over the existing meter scales within the meter face to glass space. Each indicator was calibrated as a channel according to a new procedure which minimized stabilization times by recognizing the minimum rod motion induced by thermal transient when the rod is calibrated using insertion motion only. The resulting calibrations very closely matched the actual rod positions. The polynomial coefficients were also inserted into the plant computer. After Cycle 3 startup, Control Bank D rods were recalibrated using test signals to reduce the ARPIS indications closer to the -12 step limit in order to gain additional margin during operation. This was necessary and justified because every significant thermal phenomenon had the effect of increasing ARPIS indicator output.

Operation during Cycle 3 has been at base load (except during startup and shutdown evolutions) with rods fully withdrawn and there has been little opportunity to observe ARPIS performance over a wide range. Based upon our observation to date in Cycle 3, we believe that the current Technical Specifications are too restrictive to permit the plant to perform the evolutions that it was designed to perform without exceeding a Limiting Condition for Operation in the Rod Position Indication portion of the Technical Specifications.

V. Conclusion

We believe that the testing program which has been conducted at Beaver Valley has provided a good quantitative insight into the significant phenomena affecting the accuracy of the ARPIS.

While substantial progress has been made in drafting technical specifications which protect the safety of the reactor, the existing specifications limit the operational capabilities of the system and cause an excessive amount of operator attention to use the system within these specifications. Duquesne Light Company intends to continue to pursue an appropriate solution to this problem.

SIMPLIFIED ANALOG ROD POSITION DETECTOR

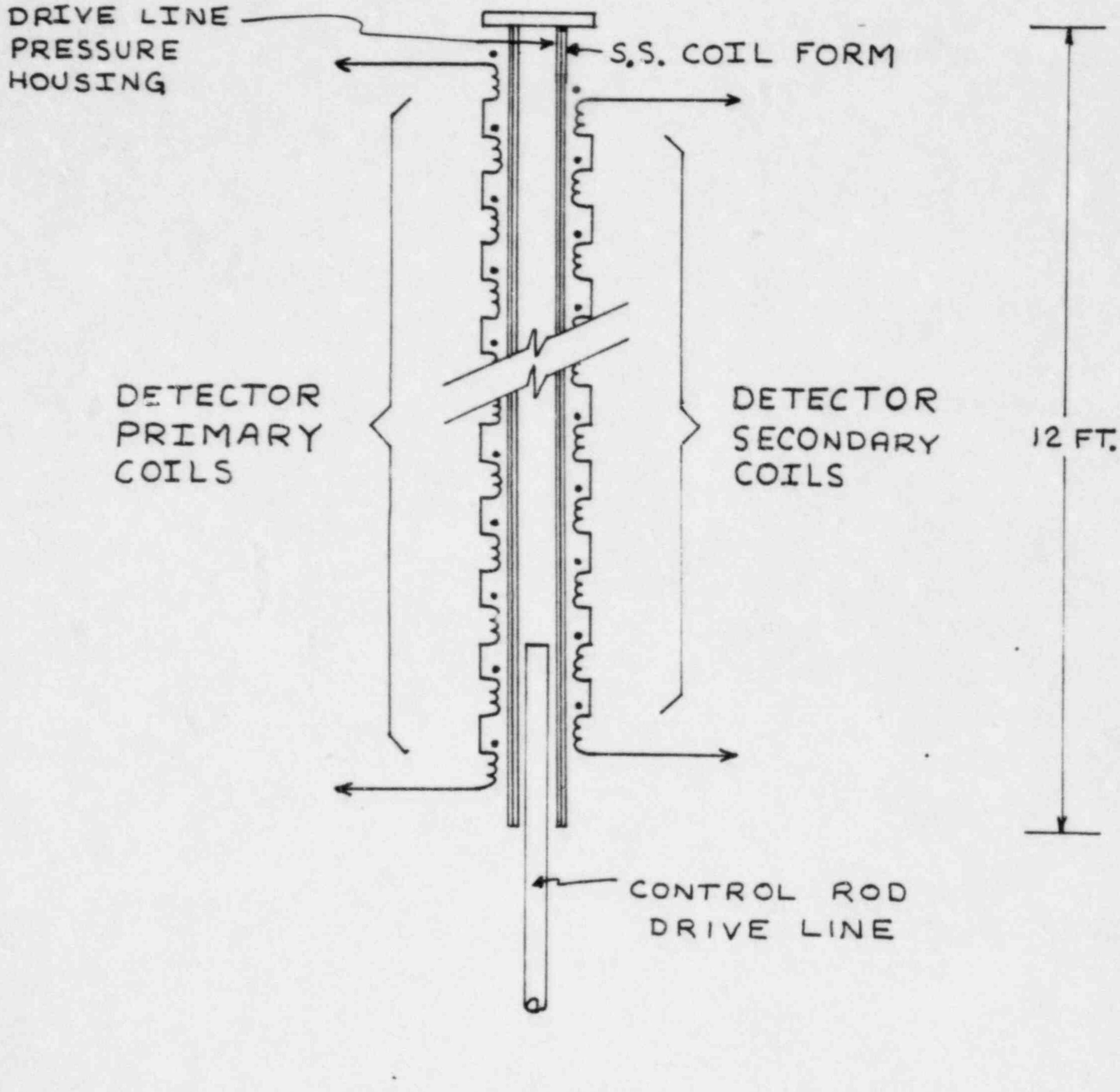


FIG. 1

TYPICAL
PRIMARY WIRING

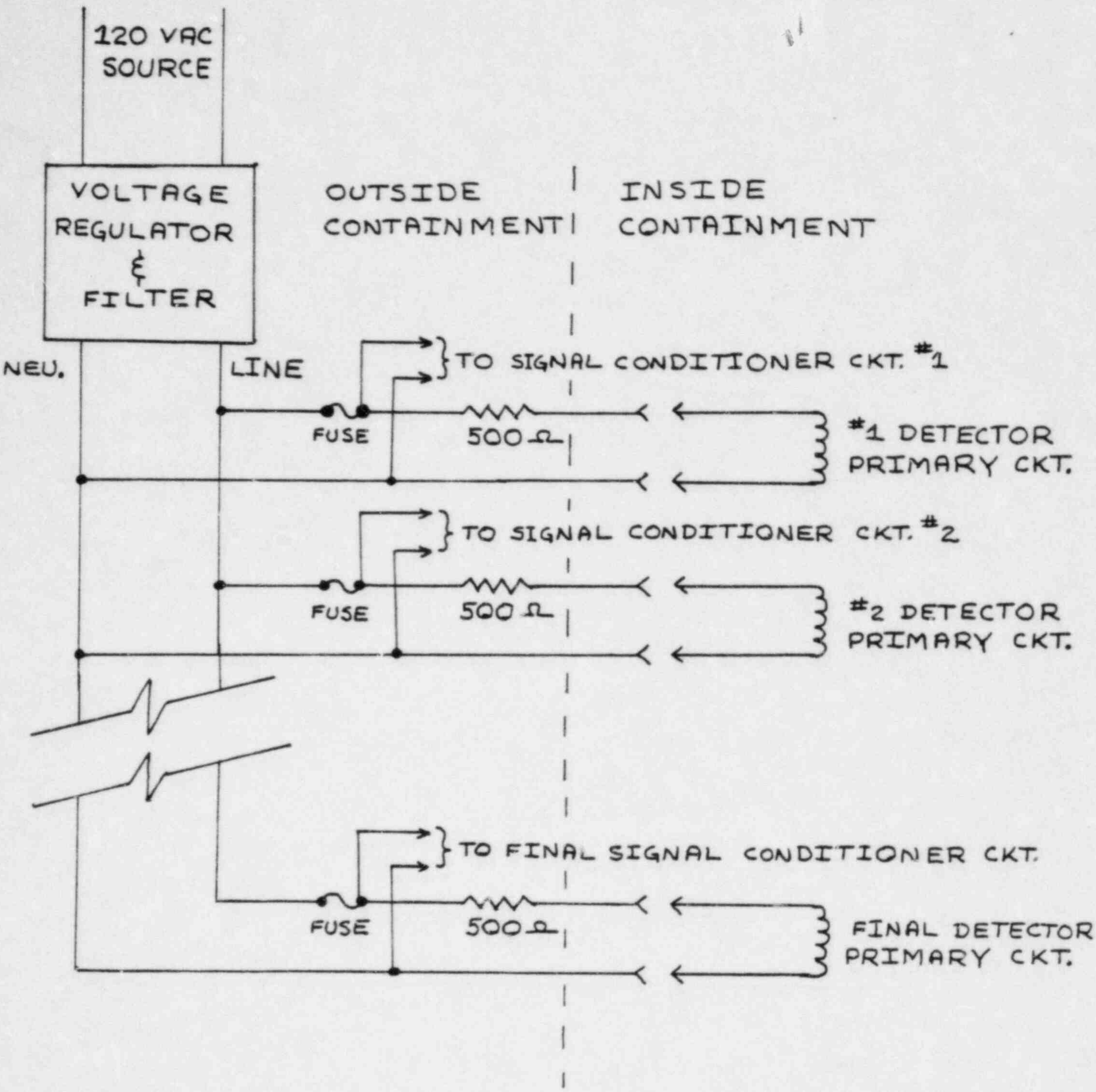


FIG. 2

TYPICAL DETECTOR
SECONDARY CIRCUIT

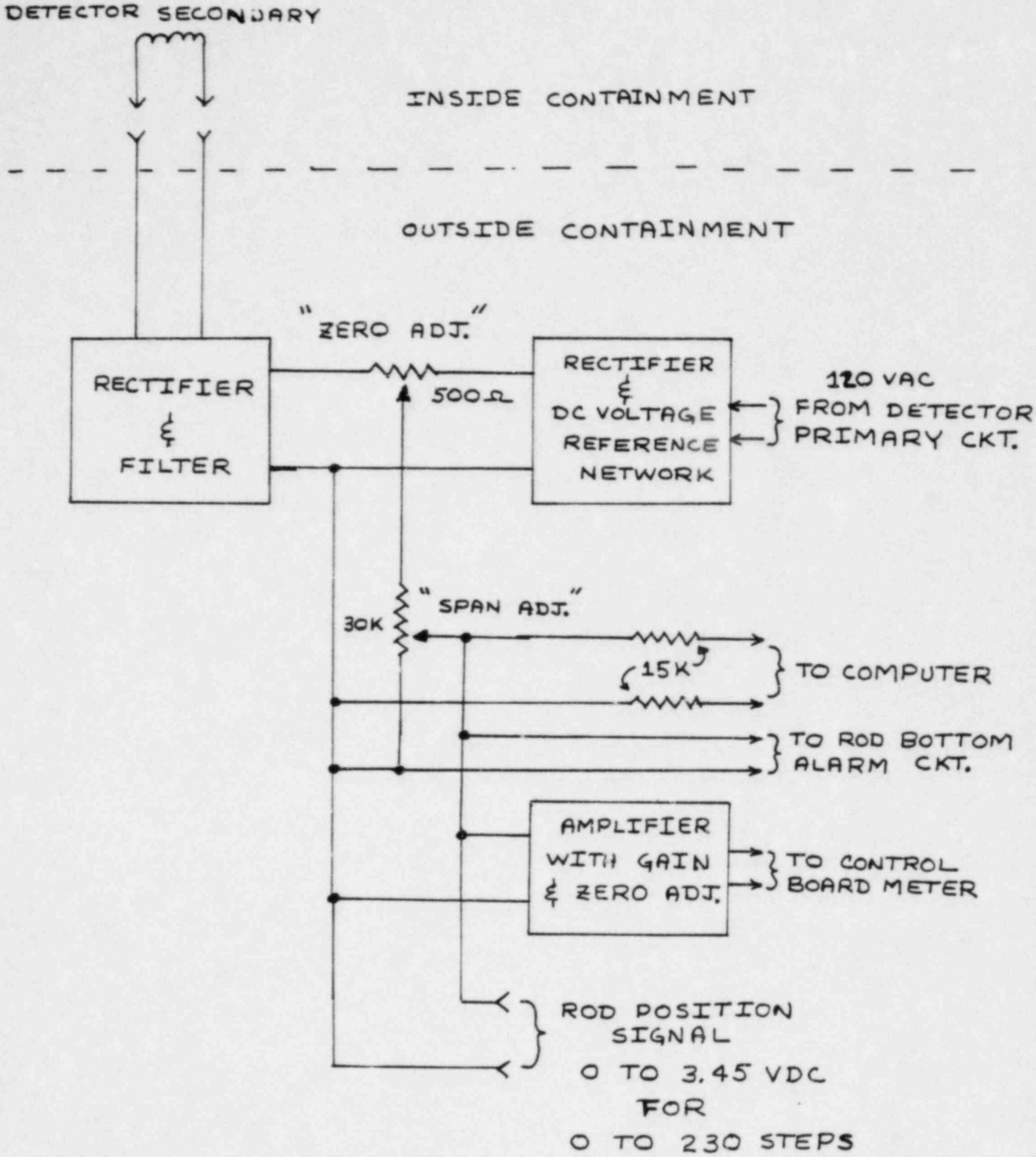


FIG. 3

FIGURE 4
TYPICAL CALIBRATION CURVE
ANALOG ROD POSITION INDICATOR
TEMPERATURE STABILIZED

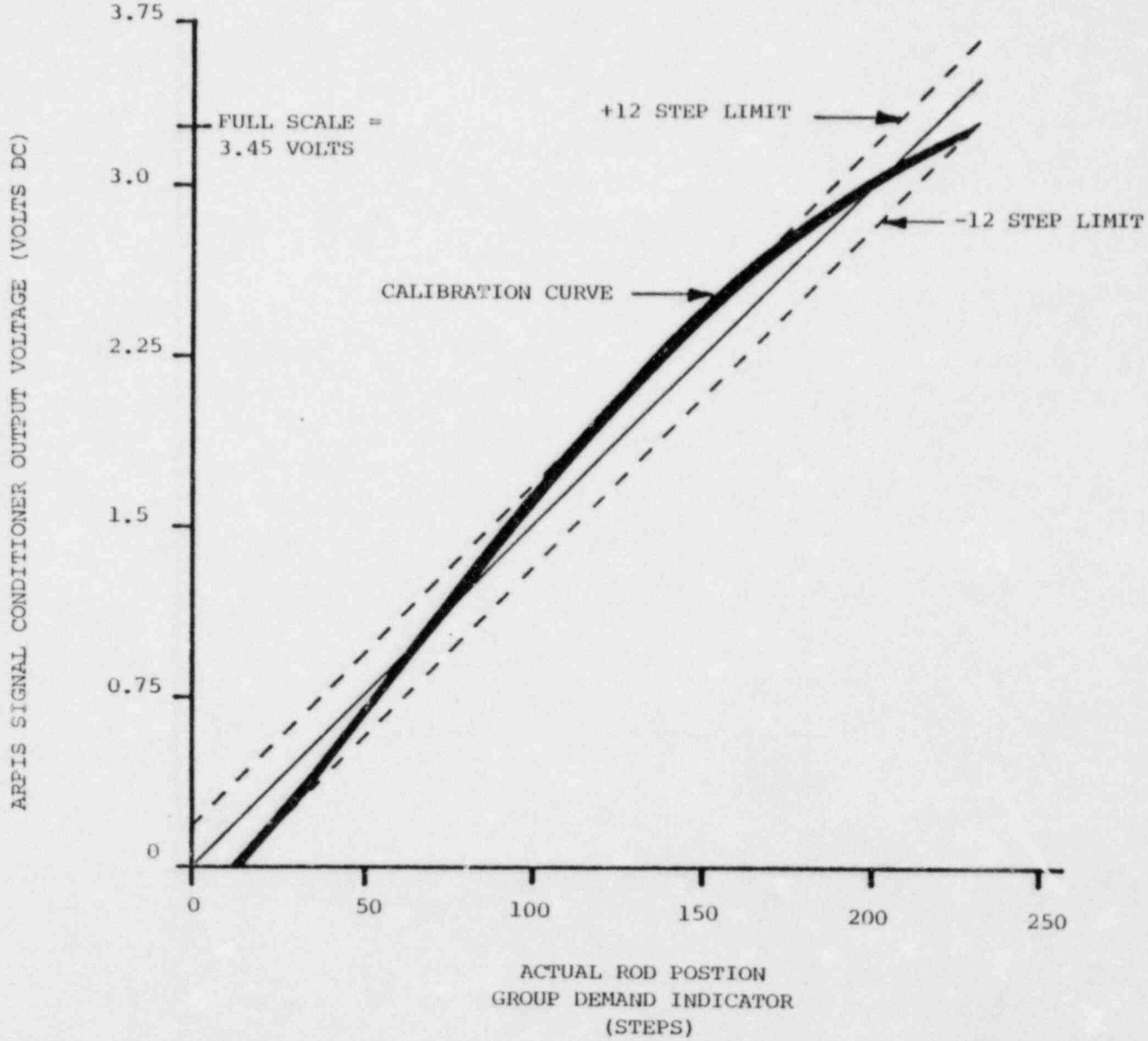


FIGURE 5
TYPICAL CALIBRATION SHIFTS
DUE TO ROD MOTION EFFECTS
(SEVERE CASE)

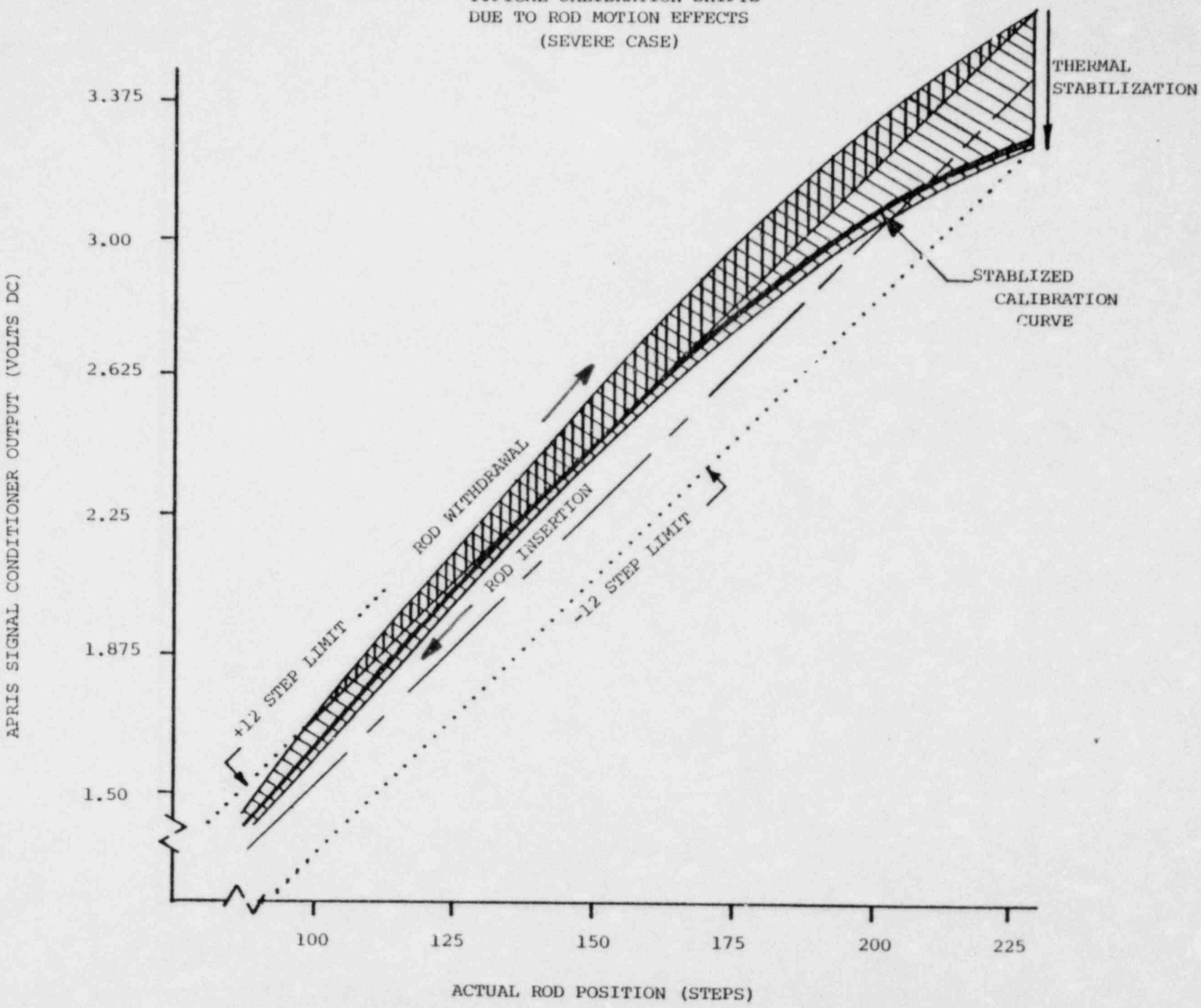


FIGURE 6

TYPICAL
POWER LEVEL EFFECTS
ON RPI CALIBRATION

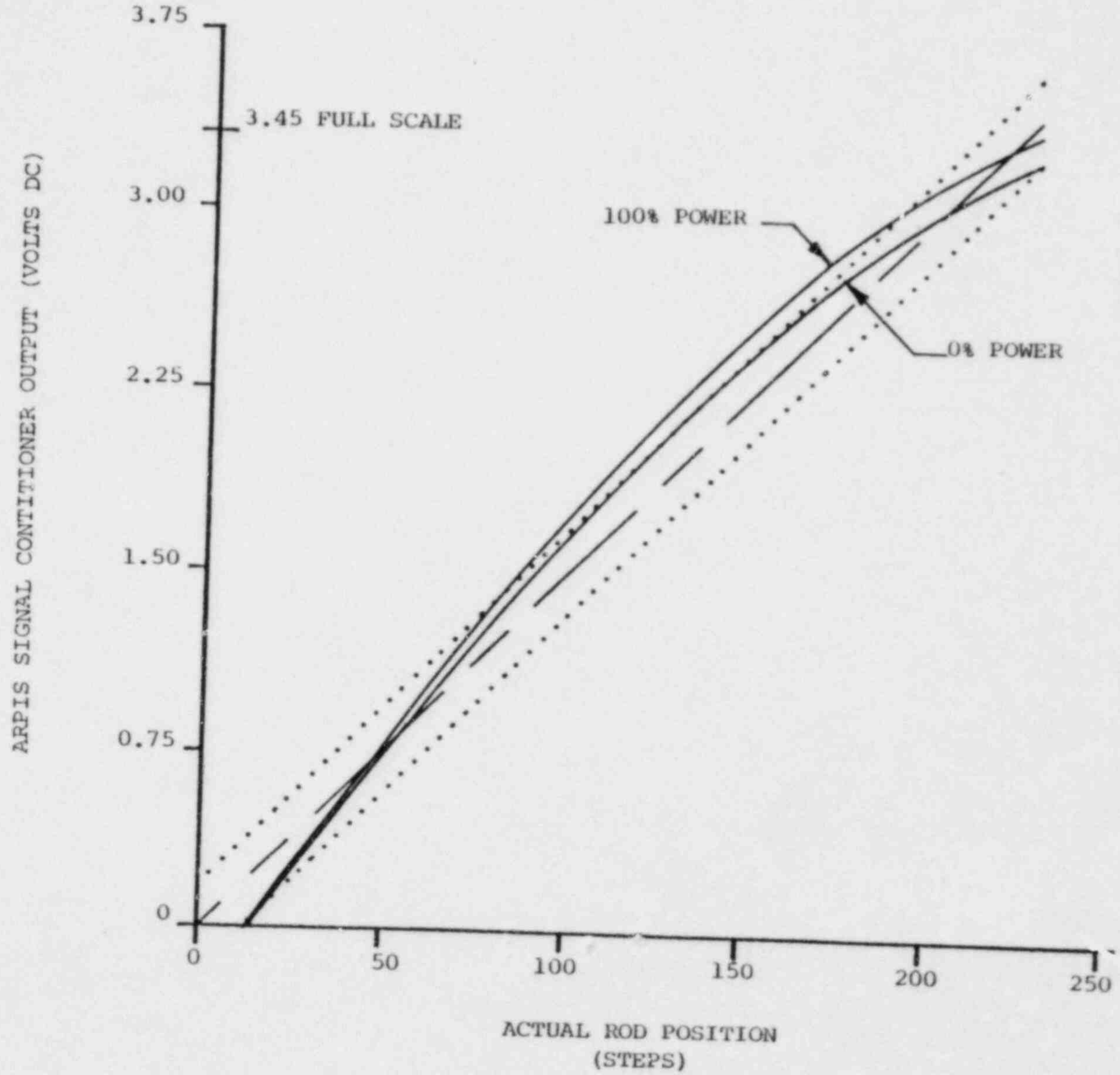
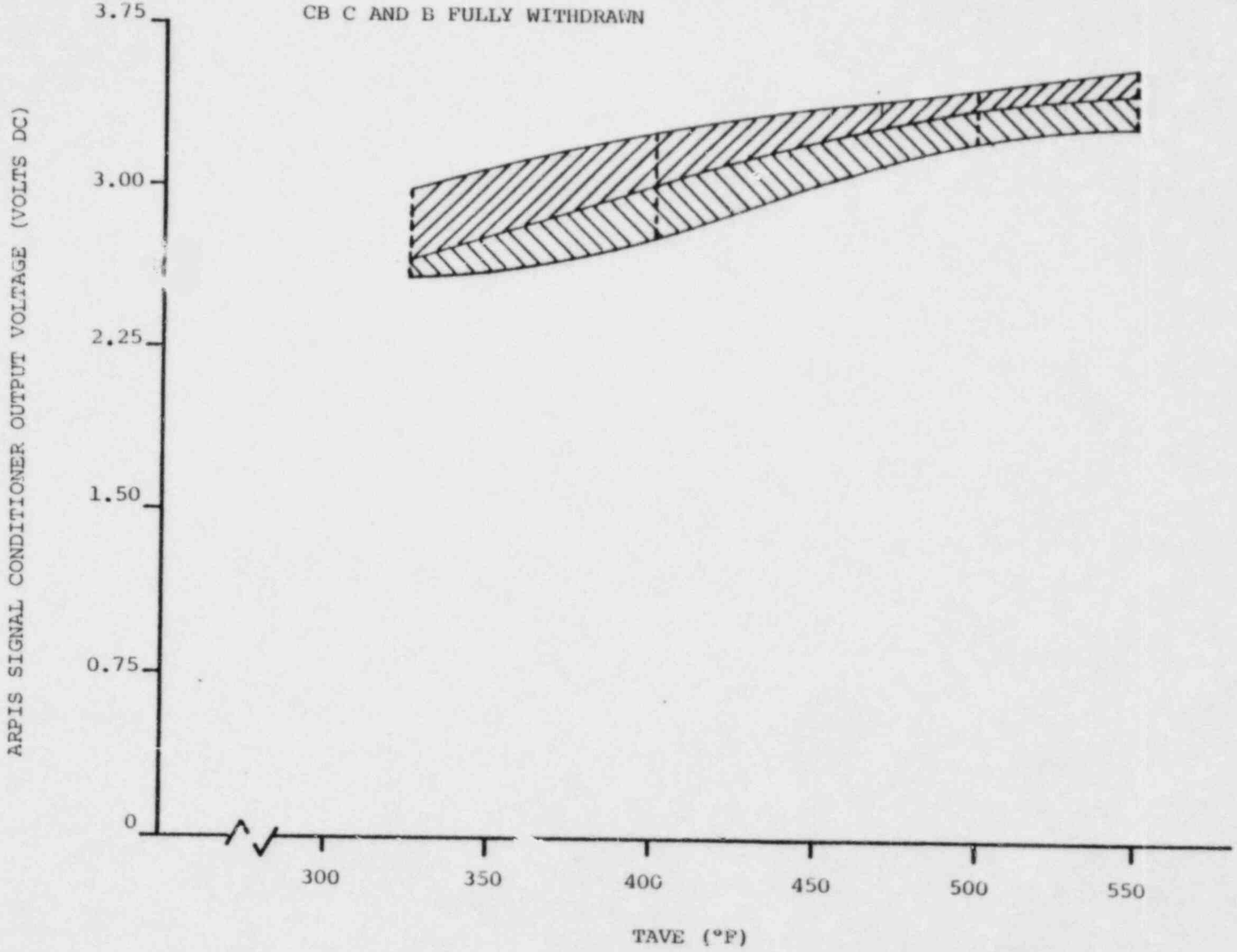
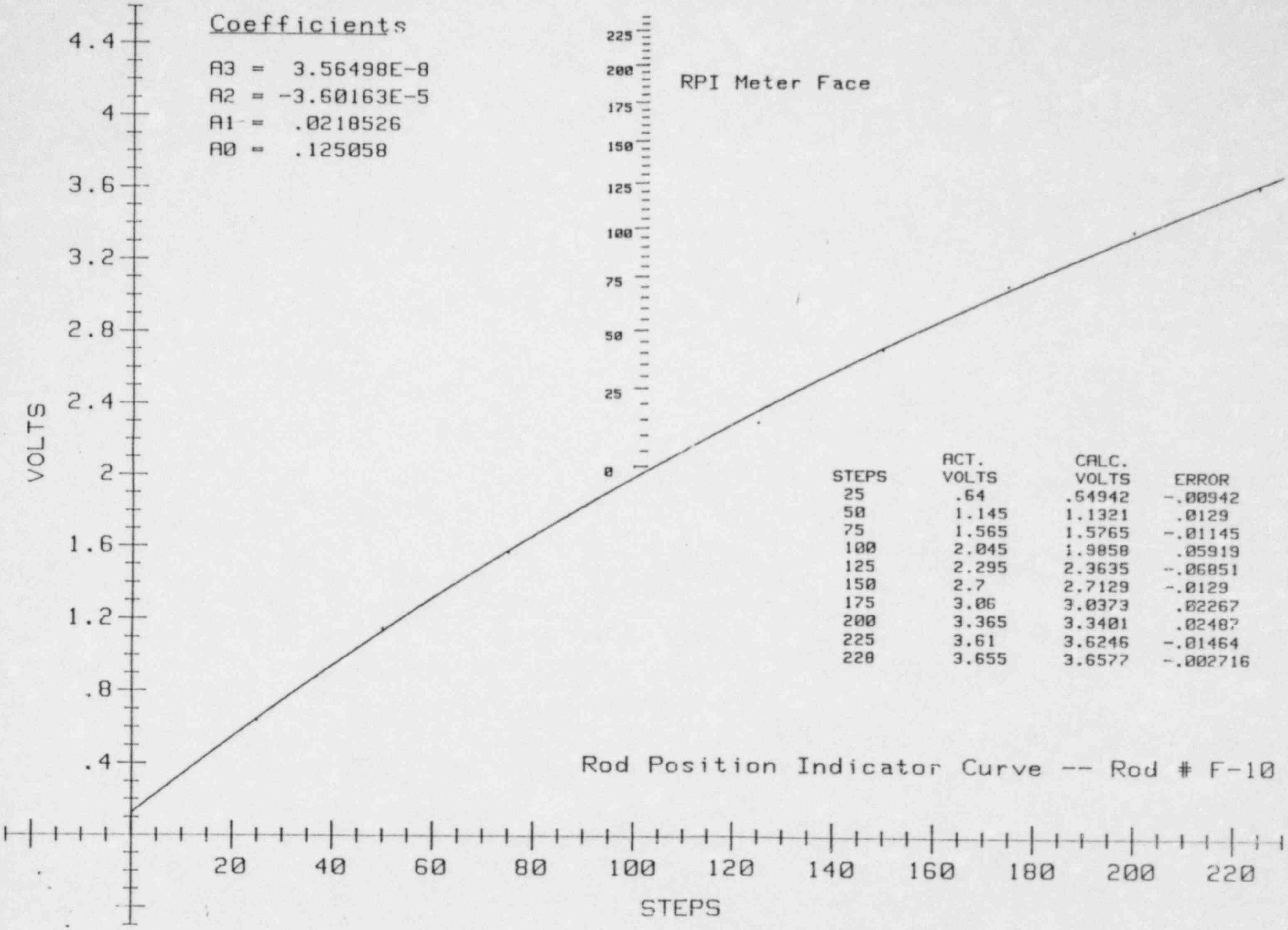


FIGURE 7
RCS TEMPERATURE EFFECTS
ON RPI CALIBRATION





STEPS	ACT. VOLTS	CALC. VOLTS	ERROR
25	.64	.54942	-.00942
50	1.145	1.1321	.0129
75	1.565	1.5765	-.01145
100	2.045	1.9858	.05919
125	2.295	2.3635	-.06851
150	2.7	2.7129	-.0129
175	3.06	3.0373	.02267
200	3.365	3.3401	.02487
225	3.61	3.6246	-.01464
228	3.655	3.6577	-.002716

FIGURE 8