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MIDDLE SOUTH UTILITIES SYSTEM

January 13, 1983

L.V. MAURIN
Vice President Nuclear Operations

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Mr. Thomas M. Novak
Assistant Director for Licensing
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

50-382

SUBJECT: Waterford SES 3
Boron Dilution Alarm System Setpoint Analysis

Dear Mr. Novak:

The Standard Review Plan (section 15.4.6) specified minimum intervals between the time when a boron dilution alarm sounds and the time of loss of shutdown margin:

1. During refueling - 30 minutes
2. During startup, cold shutdown, hot standby and power operation - 15 minutes.

By this letter LP&L transmits the Boron Dilution Alarm System setpoint analysis for Waterford 3 in satisfaction of the above Standard Review Plan requirements.

Should you have any questions or comments please feel free to contact me or Mike Meisner at (504) 363-8938.

Sincerely,

L. V. Maurin

LVM/MJM/pco

Attachment

cc: W. M. Stevenson, E. L. Blake, S. Black (in care of Jim Wilson)

B001

ABSTRACT

This analysis determines the Boron Dilution Alarm System setpoints for the LP&L Waterford III plant. The Boron Dilution Alarm System provides a control grade alarm to alert the operator of a boron dilution event when the reactor is in the shutdown subcritical modes.

The methodology employed to determine the Boron Dilution Alarm System setpoints was to ascertain an acceptable operating limit which mee s the related requirements specified in Section 2.0. The calculated setpoint values are summarized in Table 2. The assumptions used in calculating these setpoints are listed in Section 5.0. These setpoints are only applicable to the LP&L Waterford III first fuel cycle and the respective hardware defined in Reference 5.

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1.0 INTRODUCTION

This analysis is performed to determine the setpoints for the Boron Dilution Alarm System for the LP&L Waterford III plant. The Boron Dilution Alarm System will utilize these setpoints to alarm the operator of the occurrence of an inadvertant Boron Dilution. This alarm will alert the operator, thus preventing a possible inadvertent criticality due to Boron dilution while in Modes 3, 4, 5 and 6 (Reference 5).

The NRC has required an alarm be given to alert the operator at least 15 minutes for (Modes 3, 4, 5) before criticality and 30 minutes for (Mode 6) from the Boron Dilution (Reference 1). The Boron Dilution Alarm System was designed to meet this NRC criteria. The Boron Dilution Alarm System (BDAS) monitors the Nuclear Instrumentation Startup channel and will provide a control grade alarm if the startup channel indication exceeds a setpoint (Reference 5). The setpoint to which the startup channel indication is compared, is manually adjusted as the neutron flux decays. Furthermore, time intervals to reset the setpoint are determined and an allowable voltage for periodic testing of the bistable is calculated.

2.0 CONSTRAINTS AND REQUIREMENTS

The following constraints and requirements are provided for incorporation into the alarm setpoint calculation process as necessary.

Hardware Constraints

1. There are uncertainties in the BDAS equipment (defined in Table 1) which are needed for conservatively calculating the final equipment setpoint.

2. There is only one alarm setpoint provided to alert the operator of a Boron Dilution Event while in Modes 3, 4, 5 and 6.

3. The operator will input the final equipment alarm setpoint manually into the Manual Display Station based on the current flux level indication.

   Also, the setpoint must be reinputted every 5.0 hours based on the current flux reading.

NRC Requirements

1. The NRC has required an alarm be given to alert the operator of a Boron Dilution Event.

2. The NRC has required the alarm be generated 15 minutes before criticality while in Modes 3, 4, and 5; and 30 mins. before criticality while in Mode 6. (From Reference 1, these different Reactor Operating modes are specified below, as defined by the C-E Standard Technical Specifications where Keff = K effective, TP = thermal power, TAVG = average coolant temperature).

Mode	Name	Requirements
3	Hot Standby	Keff < .99, TP = 0, TAVG $\geq$ 300°F
4	Hot Shutdown	Keff < .99, TP = 0, 300°F > TAVG > 200°F
5	Cold Shutdown	Keff < .99, TP = 0, TAVG $\leq$ 200°F
6	Refueling	Keff $\leq$ .95, TP = 0, TAVG $\leq$ 140°F

Operational Engineering Constraints

1. There should be a reasonable length of time between resetting the Final Equipment Alarm Setpoint.

2. There should not be any spurious alarms which would degrade or invalidate the alarm's function.

3. There needs to be a range or deadband around the periodic reset time of the Final Equipment alarm setpoint in which the operator has to reset the setpoint.

3.0 SETPOINT CALCULATION

The setpoint calculation for the Boron Dilution Alarm System needs to incorporate several aspects to ensure proper operation of the alarm. The equipment uncertainties will be statistically summed and factored into the equipment alarm setpoint so that the alarm provided is always given within the required time (e.g. 30 minutes before criticality). Secondly, the methodology for determining the alarm setpoints needs to conservatively accommodate the several reactor operating modes for which the alarm setpoint (and alarm) is provided. Thirdly, the final equipment alarm setpoint must conservatively account for the neutron flux decay experience during the initial days of a shutdown. Further, the constraints and requirements defined in Section 2.0 must be factored into the setpoint calculation process as necessary.

A block diagram of the BDAS is shown in Figure 1. The raw neutron flux is observed at the startup channel detector. Signal processing equipment is used to provide the observed neutron flux, with a range of 1 counts/sec (0.0 volts) to 1.0×10^5 counts/sec (10.0 volts). This flux indication (log scale) is inputted both to the setpoint bistable and the manual display station. The manual display station has one meter which displays the current flux indication and another meter displays the final equipment alarm setpoint in counts per second (CPS). The final equipment alarm setpoint, inputted by the operator through the manual display station, is sent to the setpoint bistable. If the current flux indication is greater than the final equipment alarm setpoint, then the setpoint bistable will generate an alarm to an annunciator in the control room.

Inputting of the setpoint is described in Section 4.0, a graph (Figure 5.0) is provided to make this procedure easier.

3.1 DETERMINATION OF EQUIPMENT UNCERTAINTIES

STARTUP CHANNEL NUCLEAR INSTRUMENTATION UNCERTAINTY

The startup channel nuclear instrumentation is composed of the startup channel detector and the associated signal processing (Refer to Figure 1). The startup channel output is 0 to 10 volts corresponding to 1. to 1. x 10^5 counts/sec (Reference 5). As listed in TABLE 1, the uncertainties associated with the startup channel are:

A) Channel Accuracy = ±1.5% (of full scale)
B) Long Term Drift* = ±0.5% (of full scale)
C) Buffer Accuracy = ±1.0% (of full scale)
D) Buffer Long Term Drift* = ±0.2% (of full scale)

*These drift uncertainties are the possible error due to drift after 1000 hours. For conservatism these drift uncertainties are assumed to always be present.

SETPOINT BISTABLE UNCERTAINTY

The Setpoint Bistable is the equipment which will compare the current setpoint to the inputted startup channel indication. If the Setpoint Bistable detects the inputted startup channel indication exceeding the current setpoint, then an annunciation alarm is activated. The following uncertainties arise from this Setpoint Bistable:

E) Bistable Accuracy = ±0.35% (of full scale)
F) Repeatability = ±0.10% (of full scale)
G) Temperature Effect = ±0.05% (of full scale)

Note: It is assumed the drift of this equipment is negligible (refer to Section 4.0).

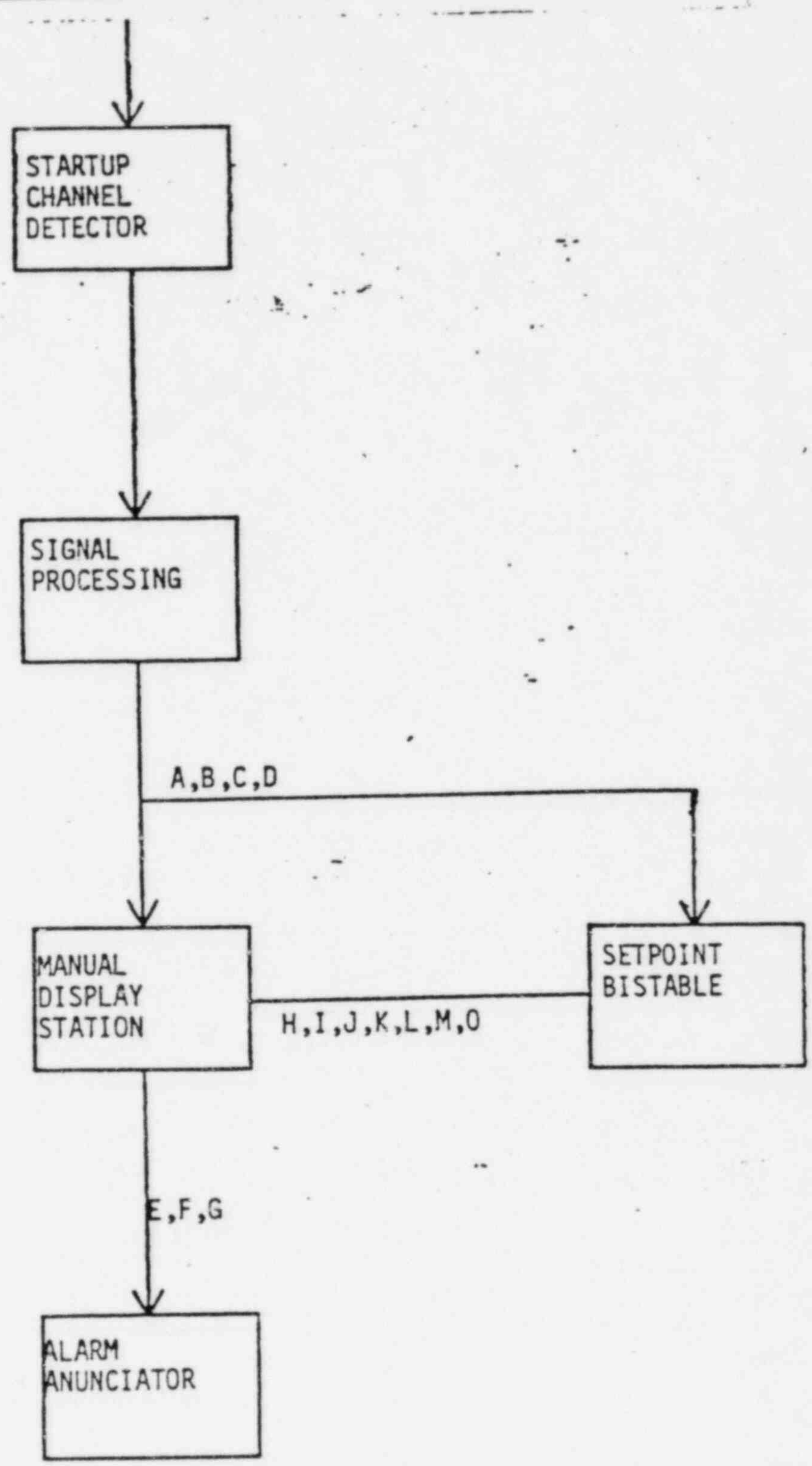
MANUAL DISPLAY STATION UNCERTAINTY

The Manual Display Station is the equipment which displays the current setpoint and the inputted startup channel indication. The operator also inputs the current setpoint through this station. The following uncertainties arise from this Manual Display Station:

H) Setpoint Accuracy = ±0.1% (of full scale)
I) Repeatability = ±2.0% (of full scale)
J) Temperature Effect (of setpoint value) = ±0.05% (of full scale)
K) Input Accuracy = ±0.10% (of full scale)
L) Temperature Effect (of flux indication) = ±0.05% (of full scale)
M) Operator's Ability to Read Flux Indication = ±2.0% (of full scale)
N) Read Graph = ±2.0% (of full scale)
O) Operator/s Ability to Set Current Setpoint = ±2.0% (of full scale)

Figure 1

SIMPLIFIED DIAGRAM OF THE BORON DILUTION ALARM SYSTEM



Note: The letters shown are where the uncertainties listed in Table 1 occur.

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TABLE 1

UNCERTAINTIES IN BORON DILUTION ALARM SYSTEM

Component	Uncertainty	Value	Units	Reference
Startup Channel (including signal processing)	A) Channel Accuracy	±1.5%	(of full scale)	6
	B) Long Term Drift	±0.5%	(of full scale)	6
	C) Buffer Accuracy	±1.0%	(of full scale)	6
	D) Buffer Long Term Drift	±0.2%	(of full scale)	6
Setpoint Bistable	E) Bistable Accuracy	±0.35%	(of full scale)	7
	F) Repeatability	±0.10%	(of full scale)	7
	G) Temperature Effect	±0.05%	(of full scale)	7
Manual Display Station	H) Setpoint Accuracy	±0.1%	(of full scale)	7
	I) Repeatability	±2.0%	(of full scale)	7
	J) Temperature Effect (of setpoint value)	±0.05%	(of full scale)	7
	K) Input Accuracy	±0.10%	(of full scale)	7
	L) Temperature Effect (of flux indication)	±0.05%	(of full scale)	7
	M) Operator's Ability to Read Flux Indication	±2.0%	(of full scale)	assumption 9
	N) Read Graph	±2.0%	(of full scale)	assumption 6
	O) Operator's Ability to Set Setpoint	±2.0%	(of full scale)	assumption 5
Raw Flux Level Variation	P) Variation in Flux Level Generation	±2.3%	(of full scale)	Reference 8

There is also a variation in the current flux level being generated in the reactor core. From actual data in Reference 8 of the ANO-II plant, there is an apparent $\pm2.3\%$ (of full scale) variation in the flux level. This variation will be factored into the equipment setpoint. This variation is assumed in Section 5.0.

CALCULATION OF THE TOTAL CHANNEL EQUIPMENT UNCERTAINTY

The uncertainties previously detailed will be combined to determine a total channel equipment uncertainty. This total channel uncertainty will be used to determine the equipment setpoints.

The total channel uncertainty will be statistically calculated using the "Root-Sum-Square" methodology. Therefore, the total channel uncertainty can be calculated as:

$$= ((\pm1.5)^2 + (\pm0.5)^2 + (\pm1.0)^2 + (+0.2)^2 + (+0.35)^2 + (\pm0.10)^2 + (\pm0.05)^2 + (\pm0.10)^2 + (\pm2.0)^2 + (\pm0.05)^2 + (\pm2.0)^2 + (\pm0.10)^2 + (\pm0.05)^2 + (\pm2.0)^2 + (+2.0)^2 + (\pm2.3)^2)^{1/2}$$

$$= \pm4.99\% \text{ (of full scale)}$$

Rounding the uncertainty in the conservative direction, the total channel equipment uncertainty is: $\pm5.0\%$ (of full scale)

CALCULATION OF AN ALLOWABLE VALUE

An allowable value for the Boron Dilution Alarm System needs to be calculated to facilitate testing of the Setpoint Bistable equipment. To calculate the allowable value, the uncertainties of the Setpoint Bistable need to be employed. As listed in Table 1, the uncertainties with the Setpoint Bistable are:

E. Bistable Accuracy - $\pm0.35\%$ (of full scale)
F. Repeatability - $\mp0.10\%$ (of full scale)
G. Temperature Effect - $\pm0.05\%$ (of full scale)

The allowable value is calculated by statistically combining the equipment uncertainties attributed to the Setpoint Bistable. Thus, the allowable value can be calculated as:

$$= ((\pm0.35)^2 + (+0.10)^2 + (\pm0.05)^2)^{1/2}$$

$$= \pm0.37\% \text{ (of full scale)}$$

Rounding the result in the conservative direction, the allowable value for the BDAS is:

+0.35% (of full scale)

(or)

+0.035 volts

Note: The allowable value provided is actually the delta increment above the current equipment alarm setpoint. The Bistable must indicate an alarm before the allowable value plus current equipment alarm setpoint is exceeded by inputted test equipment. The allowable value is only defined in the "PLUS" direction because this is the direction of the alarms indication (i.e. if the uncertainty due to the Setpoint Bistable in this "PLUS" direction is more than expected, then the setpoint alarm will be non-conservative).

3.2 EQUIPMENT SETPOINT METHODOLOGY

The setpoints calculated for the Boron Dilution Alarm System will be governed by the constraints and requirements specified in Section 2.0. Analysis setpoints were obtained from the Physics group (Ref. 9). The analysis setpoint provided for each mode is listed in the following table. These alarm setpoints are the point when an alarm must be given to meet the NRC requirements. The NRC requires an alarm be given 15 mins. before criticality (30 mins. for mode 6) for a boron dilution event. The BDAS is designed to provide an alarm while in modes 3-6.

TABLE OF ANALYSIS SETPOINTS

Mode	Analysis Setpoint
3-Hot Standby	12.2 (ratio)
4-Hot Shutdown	12.2 (ratio)
5-Cold Shutdown	4.6 (ratio)
5'-Cold Shutdown (reduced volume, 1 pump operational)	6.0 (ratio)
6-Refueling	6.4 (ratio)

Note: Reference 9 which transmitted these analysis setpoints, actually specified a range where the analysis setpoint should be depending on the initial conditions of boron dilution. For conservatism, the limiting (smaller) value is used in the above table.

The limiting analysis setpoint of modes 3, 4, 5, 5 (with reduced volume and 1 pump operational) & 6 is 4.6. This analysis setpoint is actually the ratio of the analysis alarm setpoint to the current flux indication. (The reason the provided analysis setpoint is a ratio is because the actual current indication experienced during the shutdown cannot be exactly determined). An example of this ratio follows:

Example: If current flux indication is = 1.0×10^2 counts/sec

analysis setpoint (ratio) is = 4.6 (ratio)

current analysis alarm setpoint = 4.6×10^2 counts/sec

Thus the current analysis alarm setpoint is 4.6 times the current flux indication.

Equipment Uncertainties need to be factored into the current analysis alarm setpoint to derive the current equipment alarm setpoint. The uncertainties will be applied such that the alarm is provided within the required time (e.g. 15 mins.). As calculated in Section 3.1, the total channel equipment uncertainty is $\pm 5.0\%$ (of full scale).

The current flux indication and current alarm setpoint will both be displayed on a meter which indicates from 0.0 to 10.0 volts which represents 1 to 1 X 10^5 counts/sec. (respectively). The correlation between X counts/sec and Y volts is:

$$\log_{10} (\text{ X counts/sec}) * 2.0 = \text{Y volts}$$

First, we will continue to use our example and convert the current analysis alarm setpoint calculated (4.6 x 10^2 $\frac{\text{counts}}{\text{sec}}$), to volts.

$$\log_{10} (4.6 \text{ X } 10^2 \text{ counts/sec}) * 2.0 = \text{Y volts}$$

current analysis alarm setpoint (in volts) = +5.325 volts

The calculated total channel equipment uncertainty can easily be converted to volts units because it is represented in "% of full scale". The full scale indication of the meter is 10.0 volts.

Thus:

$$\text{Y volts} = \frac{5.0\% \text{ full scale}}{100\%} * 10.0 \text{ volts (full scale)}$$

0.5 volts = total channel equipment uncertainty (in volts)

The current equipment alarm setpoint (for our example) can be calculated as follows:

Current analysis alarm setpoint	=	+ 5.325 volts
total channel equipment uncertainty	=	- .50 volts
current equipment alarm setpoint	=	+ 4.825 volts

Thus the current equipment alarm setpoint (for our example) is +0.825 volts. This current equipment alarm setpoint can also be represented as a delta increment over the current flux indication. In our example, the current Flux Indication was 1 X 10^2 counts/sec., which converts to 4.0 volts. The delta increment would then be:

current equipment alarm setpoint	=	4.825 volts
current flux indication	=	4.0 volts
delta increment of equipment setpoint over flux indication	=	0.825 volts

Let us quickly do another example to observe an interesting phenomena.

current flux	=	1 X 10^4 CPS or	(8.0 volts)
analysis setpoint (ratio)	=	4.6	(ratio)
current analysis alarm setpoint	=	4.6 X 10^4	CPS or (9.325 volts)

Continuing:

current analysis alarm setpoint	=	9.325	volts
total equipment uncertainty	=	0.5 volts	
current equipment alarm setpoint	=	8.825	volts

Delta increment is:

current equipment alarm setpoint	=	8.825	volts
current flux indication		8.0	volts
delta increment		0.825	volts

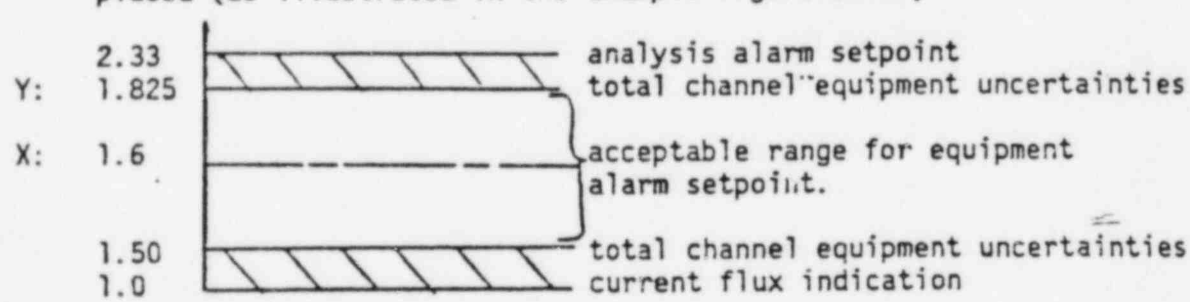
As shown by these two examples, the delta increment of the current equipment alarm setpoint over the current flux indication is 0.825 volts, for all times. The operator will input the current equipment alarm setpoint as a delta increment over the present indication of the flux. The final equipment alarm setpoint will be calculated in the next section based on timing constraints and the above methodology.

3.3 EQUIPMENT SETPOINT AND RESET TIME CALCULATION

The above methodology for calculation of the equipment alarm setpoint was generated based on a current flux indication. When the operator sets the equipment alarm setpoint, he will place it at a delta increment above the current flux indication. A problem arises in that the flux in the reactor will decay with respect to time. After some period of time, the inputted setpoint will become invalid because the flux would have decayed so far that if a boron dilution event occurred, the alarm would NOT be given within 15 mins (or 30 mins for mode 6) before criticality. This is basically because the event is now starting at a much lower flux level than the setpoint was set (See Figure 2). Therefore, the operator needs to periodically reset the equipment alarm setpoint to account for this flux decay during shutdown.

Figure 3 shows a typical relative flux decay curve for a shutdown. The equipment alarm setpoint needs to be placed and periodically reset to remain valid. Figure 4 illustrates the range of acceptable setpoint values with respect to time. Notice that not only is the total channel equipment uncertainty subtracted from the current analysis alarm setpoint; but the total channel equipment uncertainty also needs to be added on to the current flux indication to prevent spurious alarms. Thus, figure 4 shows, in general, the placement of the equipment alarm setpoint and the periodic resetting time scale.

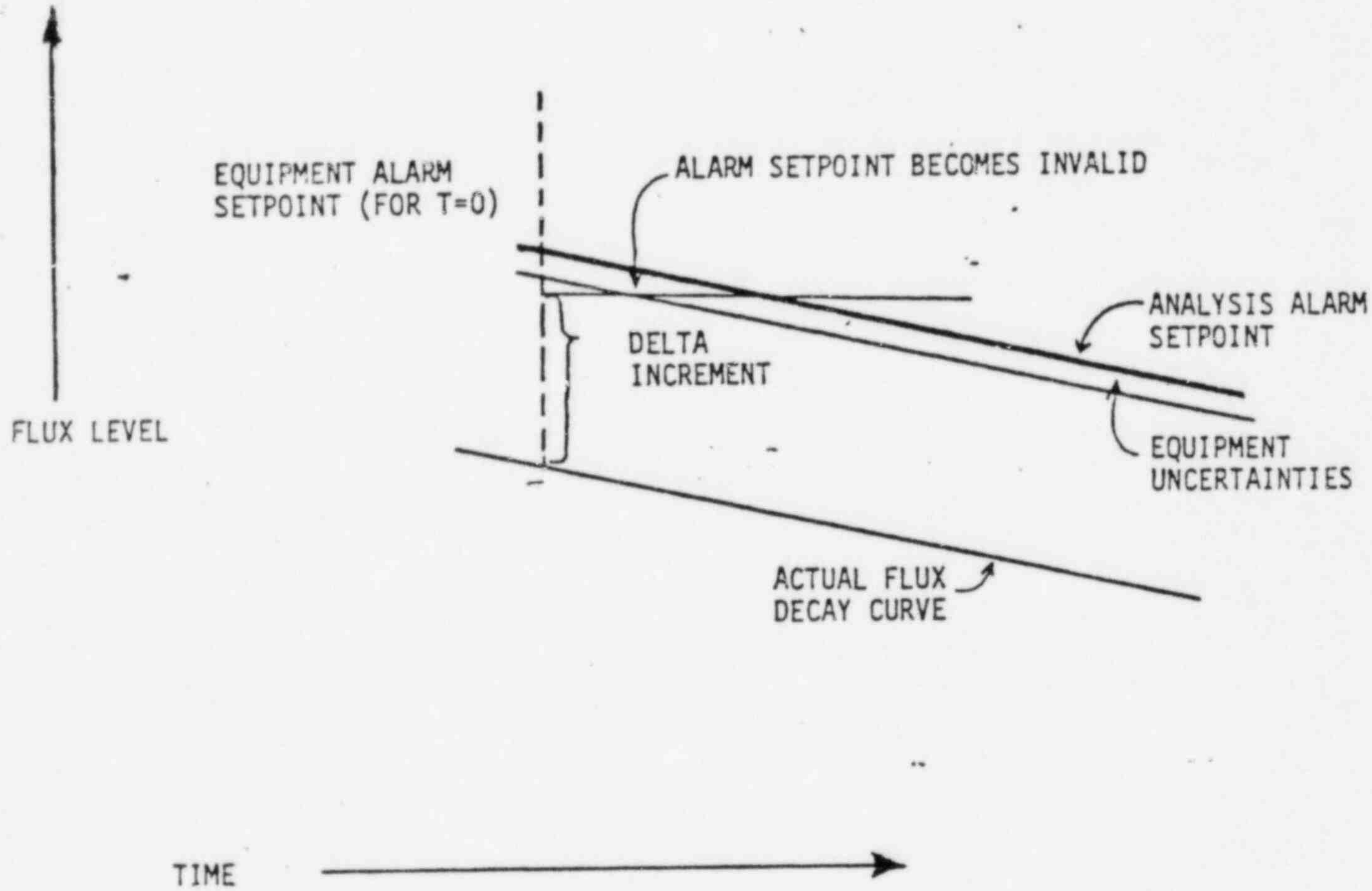
The analysis alarm setpoint, as calculated in Section 3.2, is 1.33 volts above the current flux indication. The current equipment alarm setpoint (from Section 3.2) was calculated as 0.825 volts above the current flux indication. The total channel equipment uncertainty was determined to be ±0.5 volts. A range can be determined where the current equipment alarm setpoint should be placed (as illustrated in the example figure below).



The equipment setpoint should be placed just above the current flux level plus total channel equipment uncertainties (Point "X"). This is because as the flux decays, the setpoint will remain valid longer. When the flux decays to a point where the equipment setpoint reaches the analysis alarm setpoint minus equipment uncertainties (Point "Y"), then the equipment setpoint must be reset.

Figure 2

PROBLEM OF STATIC EQUIPMENT ALARM SETPOINT



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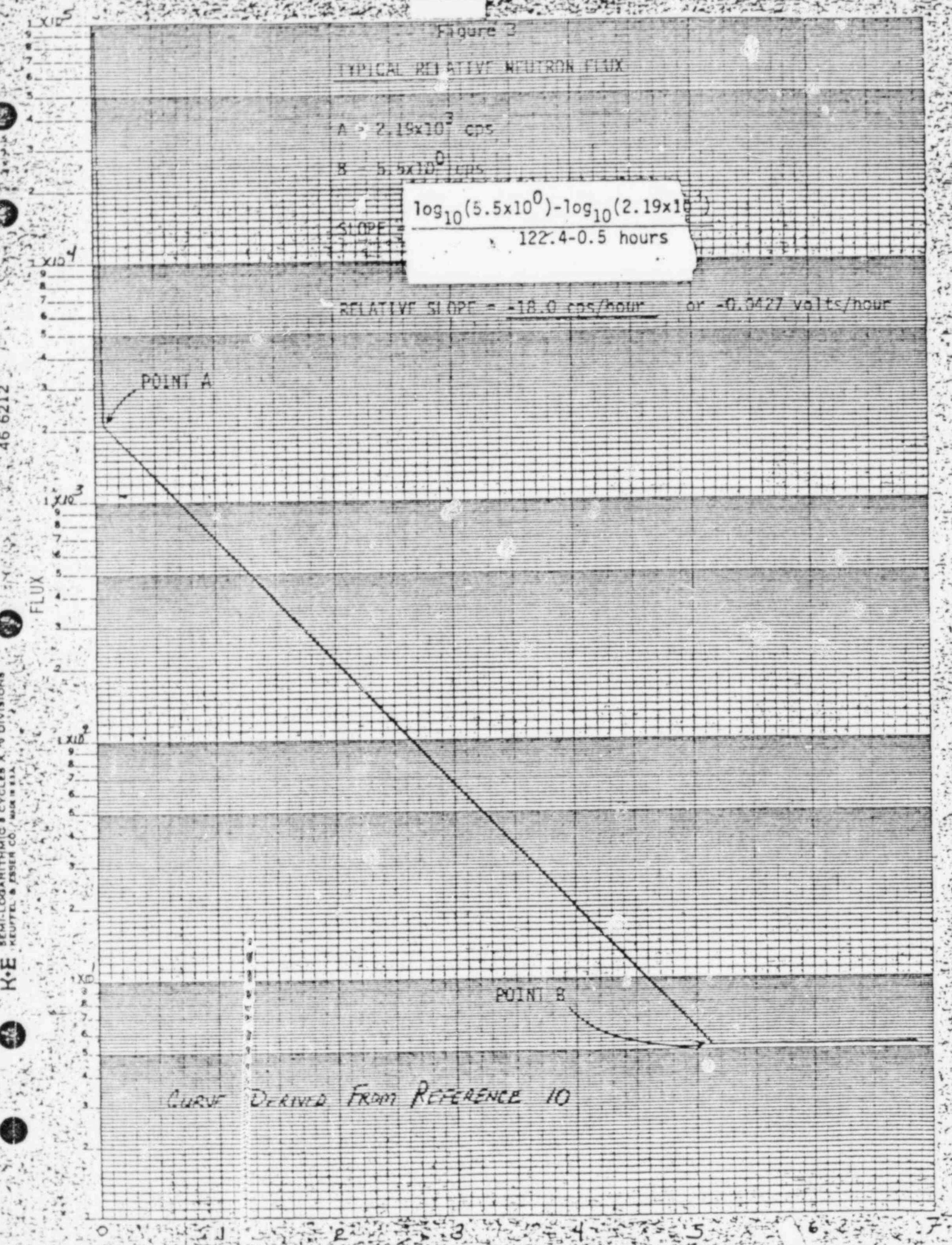
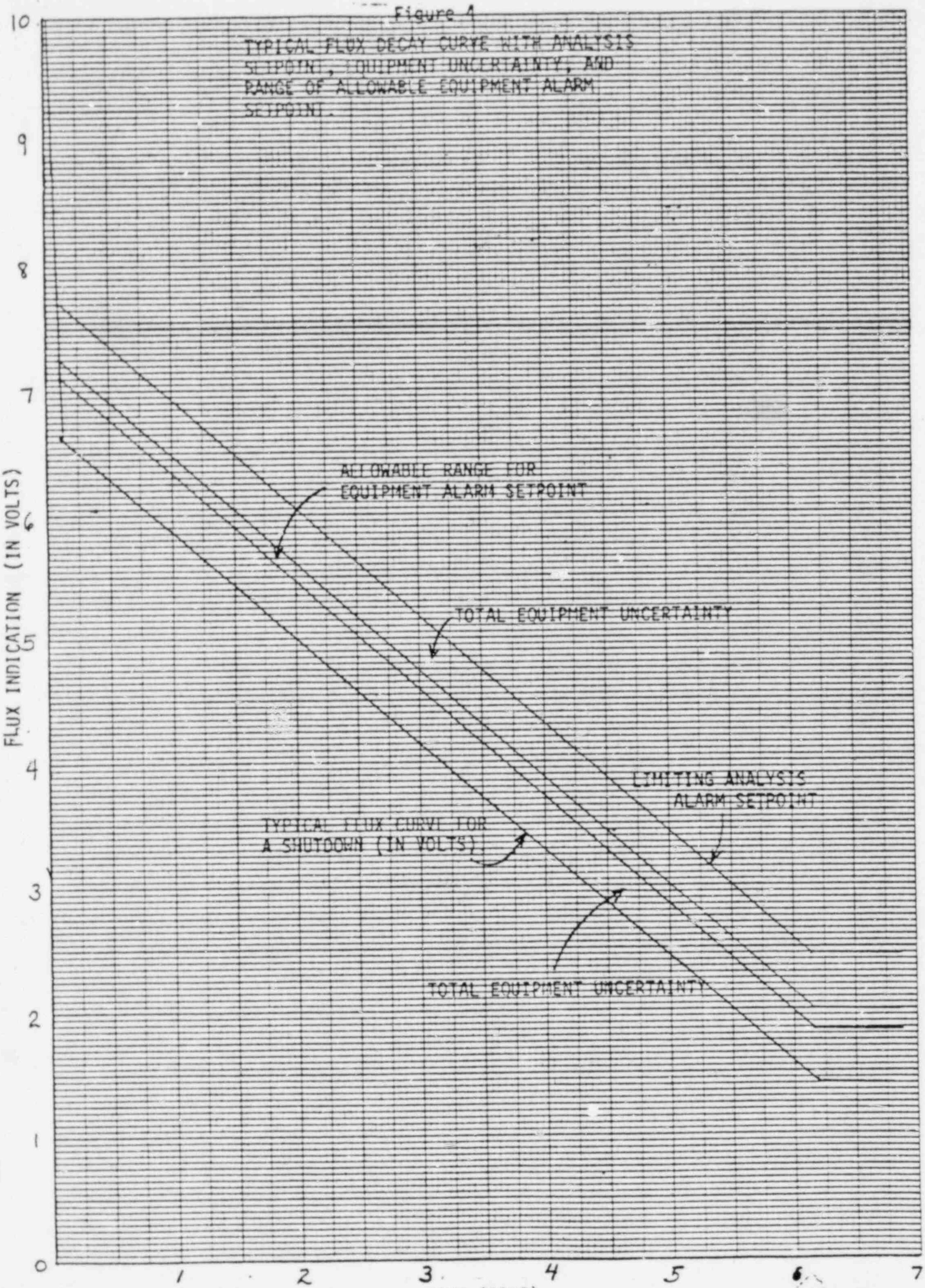


Figure 3
TYPICAL RELATIVE NEUTRON FLUX
A = 2.19x10^3 cps
B = 5.5x10^0 cps
SLOPE = $\frac{\log_{10}(5.5\times10^{0})-\log_{10}(2.19\times10^{3})}{122.4-0.5\text{ hours}}$
RELATIVE SLOPE = -18.0 cps/hour or -0.0427 volts/hour
POINT A
POINT B
CURVE DERIVED FROM REFERENCE 10
FLUX
DAYS
0 1 2 3 4 5 6 7
1 X10^5
1 X10^4
1 X10^3
1 X10^2
1 X10^1
K•E SEMI-LOGARITHMIC 5 CYCLES X 70 DIVISIONS KEUFFEL & ESSER CO. MADE IN U.S.A.
46 6212

Figure 4



K·E 10 X 10 TO ½ INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1320

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The slope of the decay curve (from Figure 3) is -18 CPS per hour or -0.0427 volts/hour. (This is the steepest slope obtained from the range of shutdown slopes provided in Reference 10, which is conservative).

Thus:

Top limit of equipment alarm setpoint is = 0.825 volts (relative)

Bottom limit of equipment alarm setpoint is = 0.60 volts (relative)*

Delta limit = 0.225 volts

$$\text{Time available before resetting} = \frac{\text{delta limit}}{\text{slope of decay}} = \frac{0.225 \text{ volts}}{-0.0427 \text{ volts/hour}}$$

Time Between resetting ≈ 5.28 hours

In the procedures, the operator will be informed to reset the equipment alarm setpoint within a ± 1/4 hour range. Thus, the reset time will be conservatively set to:

5.0 hours

The equipment alarm setpoint will be set, in order to support the above reset time calculation to,

0 .60 volts

above the current flux indication.

*Note: This number was chosen since it is in the allowable range on Figure 4 and it permits a reasonable period of time between alarm reset.

TABLE 2

SETPOINT CALCULATION RESULTS

Final equipment alarm setpoint (delta increment above highest current flux level)	=	+0.60 volts
Periodic reset time (Refer to note below)	=	5.0 hours
Allowable setpoint value (for periodic testing of setpoint bistable)	=	+0.035 volts

NOTE: There is a ± 1/4 hour dead band around this periodic reset time within which the operator must reset the equipment alarm setpoint. Further, the equipment alarm setpoint only needs to be initially set after entering Mode 3 and then reset for up to (6) days.

4.0 INPUTTING OF SETPOINTS

The manual BDAS has two meters on the front panel. One meter shows the current flux in counts per second (CPS). The other meter is for inputting the setpoint also in CPS.

The input for the setpoint in CPS can be found by using Graph 5.

The following steps should be followed:

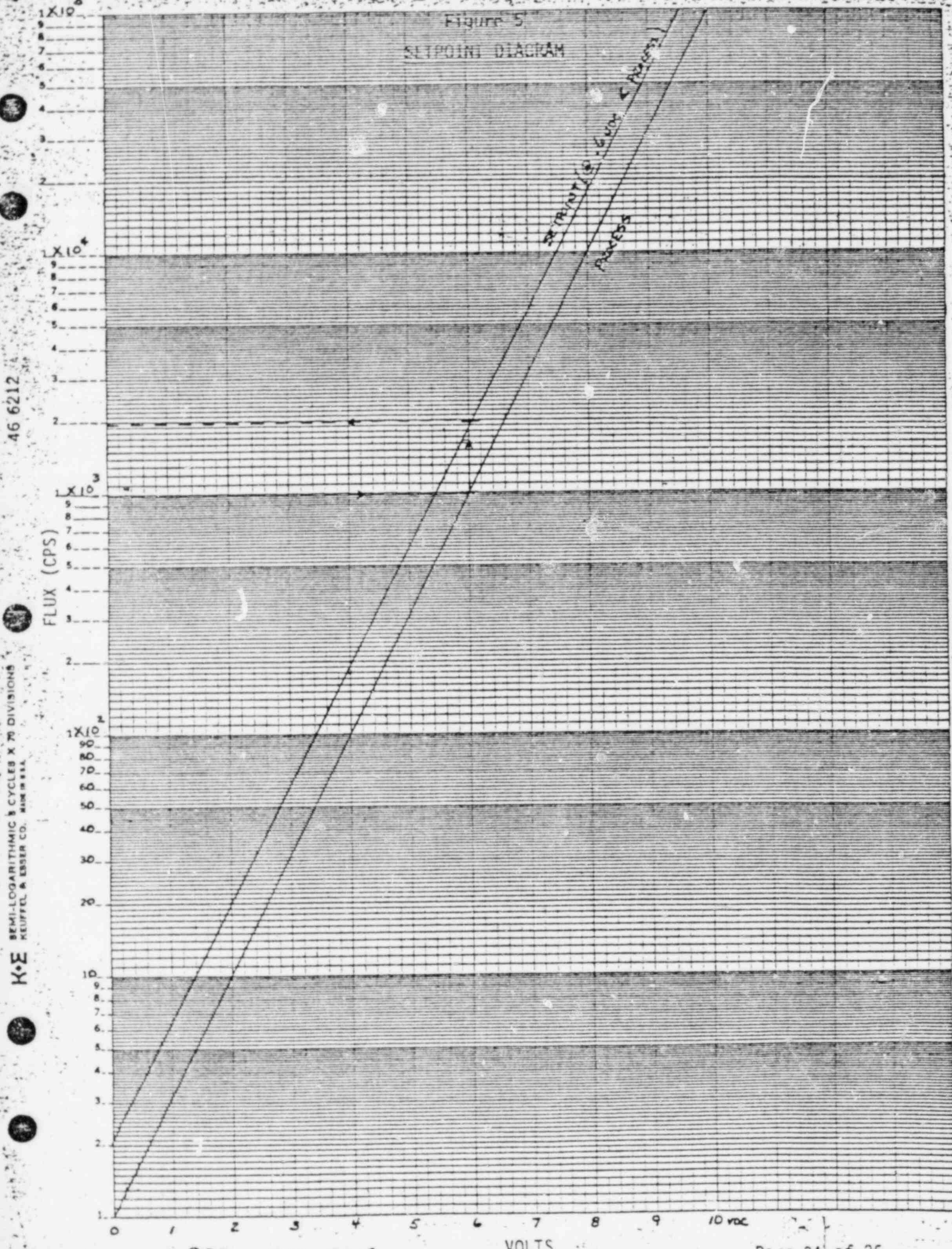
1. Look up the current flux in CPS off of the appropriate meter.
2. Read it on Graph 5 by going across to the process line.
3. Go up to the setpoint line and go across to read the flux setpoint on the left-hand side.

These steps are illustrated by the dotted line on Graph 5.

This value is the flux setpoint to be inputted every 5.0 hours ± 1/4 hour.

Figure 5

SETPOINT DIAGRAM



5.0 ASSUMPTIONS

1. The Boron Dilution measurement channel power supply variation is assumed to be negligible (from Reference 7).

2. The Boron Dilution measurement channel is assumed to be in a temperature controlled environment with a temperature variation of ±5°F (from Reference 7).

3. Test equipment for calibration of the Boron Dilution measurement channel is assumed to be four times more accurate than the measurement instrumentation. (Reference 7).

4. The variation in the observed startup channel indication is assumed to be less than ±2.3% of full scale.

*5. The operator's ability to adjust the setpoint is assumed to have an accuracy of ±2.0% of full scale.

*6. The operators ability to read the graph for a setpoint flux is assumed to be ±2.0% of full scale.

7. The uncertainty due to drift is considered negligible, if the equipment is recalibrated within the time interval specified by the manufacturer.

8. It is assumed that the thermal power is zero, uniform mixing occurs, and each charging pump produces 44 gallons per min. flow rate, for the Boron Dilution Analysis (from References 2 & 3).

*9. The operators ability to read the flux off the meter is assumed to have an accuracy of ±2.0% of full scale.

*Note: These represent conservative estimates.

6.0 REFERENCES

1. NRC Standard Review Plan, "Chemical and Volume Control System Malfunction That Results in a Decrease in Boron Concentration in the Reactor Coolant (PWR)", Section 15.4.6, dated April, 1975.

2. A. A. Mody, "PSS Input to the Waterford Startup Channel Alarm Setpoints for Boron Dilution Protection", Memo Number C-PSS-81-008, to G. P. Cavanaugh, dated July 27, 1981.

3. A. A. Mody, "PSS Input to the Waterford Startup Channel Alarm Analysis: RCS Mass Replacement", Memo Number C-PSS-81-013, to G. P. Cavanaugh, dated September 10, 1981.

4. A. A. Mody, "QA Verification of PSAE (Formerly PSS) Data Transmittal to Nuclear Engineering on Waterford Startup Channel Alarm Analysis", Memo Number C-PSAE-82-004, to G. P. Cavanaugh, dated March 15, 1982.

5. "Functional Design Specifications for Boron Dilution Alarm System for LP&L Waterford 3", Functional Design Specification.

6. P. Dowgewiez, "Waterford Unit 3 Startup Channel NI Uncertainties", IOC to M. G. Tsiouris, dated July 8, 1982.

7. "NSSS Manual Boron Dilution Alarm System Uncertainties", Analysis Number 9270-ICE-4607.

8. Recording of Startup Flux Channel from ANO-II plant, dated September 3, 1980

9. L. B. Tarko, "Source Range Monitor Response Ratio for Waterford III, Cycle I During Boron Dilution Events", Memo Number C-PH-133, to M. G. Tsiouris, dated September 8, 1982.

10. D. W. Stephen, "Source Range Monitor Response for SCE 2/3 During Boron Dilution Events," Memo Number S-PH-257, to J. G. Castagno, dated December 8, 1980.