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February 15, 1984

Docket No. 50-423
B11034

Director of Nuclear Reactor Regulation
Mr. B. J. Youngblood, Chief
Division of Licensing
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Reference: (1) E. P. Rabe (Westinghouse) letter to D. G. Eisenhut (NRC), dated, August 15, 1983.

Dear Mr. Youngblood:

Millstone Nuclear Power Station, Unit No. 3
Sensor Response Time - Westinghouse Topical Report

In Reference (1) Westinghouse submitted to the NRC a topical report entitled "The Use of Process Noise Measurements to Determine Response Characteristics of Protection Sensors in U. S. Plants". This report was in reply to the NRC staff's request for submittal of test results and conclusions on the use of the process noise measurement technique for protection sensor response time testing. It is our intention to utilize degradation monitoring as a basis of complying with the requirements of Technical Specifications, subject to the acceptability of this method by the NRC. Therefore we are hereby submitting six (6) copies of the Westinghouse Report on sensor response time (Reference 1) on the Millstone 3 docket to initiate your review and approval.

Very truly yours,

NORTHEAST NUCLEAR ENERGY COMPANY ET AL
By Northeast Nuclear Energy Company,
Their Agent

W. G. Counsil

W. G. Counsil
Senior Vice President

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STATE OF CONNECTICUT)
) ss. Berlin
COUNTY OF HARTFORD)

Then personally appeared before me W. G. Counsil, who being duly sworn, did state that he is Senior Vice President of Northeast Nuclear Energy Company, applicant herein, that he is authorized to execute and file the foregoing information in the name and on behalf of the applicants herein and that the statements contained in said information are true and correct to the best of his knowledge and belief.

Lorraine J. D'Amico
Notary Public

My Commission Expires March 31, 1988

THE USE OF PROCESS NOISE MEASUREMENTS TO DETERMINE RESPONSE CHARACTERISTICS OF PROTECTION SENSORS IN U.S. PLANTS

This report contains information requested by the U.S. Nuclear Regulatory Commission in Support of Specific Licensing Applications.

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear Energy Systems
P.O. Box 355
Pittsburgh, Pennsylvania 15230

August 1983

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The Use of Process Noise Measurements to Determine Response Characteristics of Protection Sensors in U.S. Plants

W. CIARAMITARO
J. FORKER
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J. MESMERINGER

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ACKNOWLEDGEMENTS

The authors wish to acknowledge the helpful comments from Dr. K. Graham and Dr. R. Gopal.

To Ray Soles and his excellent group of technicians who supported the data collection and analysis of the PSD signatures.

To Joel Terry and his group for data collection.

1.0 INTRODUCTION

The response time of a safety function is defined as the interval required for that safety function to be initiated subsequent to the time that an appropriate variable exceeds the allowable limit setpoint. Instrumentation response times are generally verified at surveillance intervals and for the allowable limits specified by the Tech Specs by testing the sensor part of the Protection System at reactor shutdown refueling intervals and the remaining portions of the Protection System during on-line operation. The sensor is defined as being that part of the instrumentation extending from the pick-off point in the process to the instrumented electrical signal that is input to the signal conditioning equipment, i.e., process cabinets. Present technology does not provide for complete response time testability because a portion of the instrument impulse line is valved off, i.e., bypassed from the processed when a simulated signal is injected into the sensor at shutdown.

The objective of the methodology presented in this report is to determine in-situ on-line response time characteristics of the complete Reactor Protection System sensor, so that compliance with the allowable limits specified by the Tech Specs can be verified. The methodology has demonstrated successfully the determination of in-situ sensor response time measurements by employing a noise analysis technique which depended on equipment and procedures which were developmental. Westinghouse is confident that the production equipment due to be installed in several operating plants will confirm this developmental technique.

The techniques evaluated herein monitor the sensor output process noise. This process noise is inherent in the NSSS system. The process noise or natural fluctuations measured at the sensor output is an attenuated signal at the pick-off point because the sensor acts as a low pass filter. In general sensor response time reduction can be related to an increase of the filtering attenuation. Specifically, the sensor output is analyzed to generate a power spectral density. The response characteristic is evaluated by a least square fit to the power spectrum to obtain a transfer function. The emperically determined transfer function is used to calculate the response time of the sensor to a step input.

This noise analysis technique is an on-line method for response time verification. It is a state-of-the-art method that is able to detect response time and response time degradation assuming that the sensor had an acceptable response time during the baseline testing program.

2.0 BACKGROUND

The response times of sensors used for reactor protection could conceivably deteriorate over the lifetime of a nuclear power plant because of the demanding environment in which sensors are installed. Therefore, considerable interest exists in developing an efficient method for response time verification that would not require plant shutdown or other inconvenient testing procedures and would not reduce the reliability of safety systems through the addition of active components.

The presence of natural plant perturbations in the process variables of nuclear power reactors (1,2,3,4), small induced perturbations, and large transients indicates the potential for determining protection sensor response characteristics on-line and in situ during routine plant operation without the addition of complicated mechanisms. If the response characteristics of sensors to these plant perturbations could be translated into response times, there would be no need for intentional perturbations of the plant, removal of the sensors for laboratory testing, or valving out of the sensor to inject test signals. The natural plant perturbations under consideration are process noise and small process perturbations due to normal induced plant transients.

The term, process noise, describes the natural, random variations in plant parameters that exist about the average value of a variable such as coolant temperature during steady-state operation. With nominal plant operating conditions and no significant transients, there is a small variation superimposed

upon the steady-state values of the process variables. For example, there is noise in the hot leg reactor coolant temperature because of temperature variations due to the incomplete mixing and streaming of coolant which has come from different parts of the core, and which, as a result has a variable temperature due to the fact that some fuel assemblies operate at higher power levels than others. The process noise does not necessarily have to be "white", random noise that has constant energy per unit bandwidth at every frequency of interest, but could be non-white or deterministic. The point is that small fluctuations in the process variable exist naturally in a nuclear power plant. Explanation for the mechanism which causes all the process noise is not required. By considering a known non-whiteness the sensor response time characteristic can be evaluated. It is only necessary to show that the noise characteristics do not vary significantly for the same plant operating conditions to preclude the use of process noise as a constant response time testing signal for the sensor.

The basic concept used to determine the time response of a sensor from its response to a noise input is straightforward. The sensor acts as a filter to the natural process variations or noise sensed at the input of the sensor. If the sensor has a relatively fast time response, it will pass the higher frequency components of the process noise. If the response time of the sensor lengthens for some reason, it will increasingly attenuate the high frequency components which it initially passed when new.

With enough time response degradation, the high frequencies will disappear completely from the output of the sensor. If periodic (or even continuous) measurements of the frequency spectra of a sensor's output at steady-state operating conditions are analyzed, an indication of any change in the sensor's time response can be derived. Specifically, for a first order lag approximation of the dynamic behavior of a sensor, the time response, or time constant, of the sensor is the reciprocal of 2π times the characteristics cutoff frequency of the sensor. For a second order system with a damping coefficient of one which many sensors approximate, the response time to reach 63.2 of its final value is .34/cutoff frequency of the sensor.

If all frequency components are present, i.e., the noise is white, at least up to the cutoff frequency, the cutoff frequency is obtained directly from the frequency spectrum of the sensor's output. If the noise is not white but contains distinct frequency components, then the relative attenuation of these components can be used to derive information about the sensor's time response degradation.

A sensor which has an unacceptably long response time will produce output noise with an unacceptably low cutoff frequency, or, equivalently, too much attenuation of the frequency components above this same cutoff frequency. Action can be taken concerning that sensor to restore the protection system to the required performance capability. The major advantage of the noise technique is response time characteristic of the sensor can

be determined while the plant is operating. A degraded sensor can be detected without:

- removing it from the plant for testing
- valving it off to inject test signals in place, or
- internally, perturbing the plant to test a sensor's response

Licensing Considerations

The surveillance requirements of the Technical Specifications for Protection Systems ensure that the system functional operability is maintained comparable to the original design standards. Periodic tests at frequent intervals demonstrate this capability for the system, excluding sensors.

Overall protection system response times are demonstrated by test procedures detailed on plant specific situations by the individual utilities involved. Sensors are demonstrated to be adequate for these plant specific designs by vendor testing, in-situ tests in operating plants with appropriately similar design, or by suitable type testing. The response time verification requirement is that the protection channel total response time be verified no greater than the value assumed in the safety analysis report. The subcomponents of each protection channel including the sensors may have target values for response times but they are not required to be verified individually. Only the sum of the subcomponent response times is required to be verified. The response time to be satisfied must be consistent with the safety analysis and the Technical Specifications. These response times include the interval of time which will elapse between the time

the parameter as sensed exceeds the safety setpoint and the time the Protection System slave relay dry contacts are operated in the case of the ESF and the rods begin to fall in the case of the Reactor Trip System.

A periodic verification test program for sensors for determining any deterioration of installed sensor's response time has been sought. Although this issue is industry generic, Westinghouse believes that the methodology for an acceptable test procedure for determining deterioration of installed sensor's response time is embodied in the techniques described in this report.

Certain major efforts in the past with respect to this issue have included the Electric Power Research Institute (EPRI) programs.[3][6][7] Research and development contracts awarded included those to the following agencies to, primarily, seek viable means for in-situ response time measurements for primary sensors:

a) University of Tennessee: for deriving time constants for resistance temperature detectors by the loop current method. This method causes a temperature rise due to a current flow set up in the resistance temperature detector element. Response time characteristics may be derived by monitoring temperature decay to ambient.

b) Nuclear Services Corporation: for developing a hydraulic input signal generator for pressure and differential pressure cells and associated impulse line systems. This method applies a known pressure to the valved off cell and a certified standard; additionally a program calling for removal of resistance temperature detectors for immersion into a high temperature bath.

c) Babcock & Wilcox: for determining response time characteristics of pressure cells and resistance temperature detectors, on-line, by taking advantage

of random fluctuations or temperature noise normally inherent in the system. By analysis of the sensor's ability to respond to fluctuations of sufficiently high frequency, it is possible to guarantee its performance to expected transients during design basis events.

Approach b) has been employed at a Westinghouse operating plant, and was reviewed by other operating plants. Such information as this, as well as data being gathered as part of its environmental qualification test programs and manufacturer's data, has been used to arrive at a suitable method for periodic verification that sensor response times are within those assumed in the safety analyses and that possible deterioration will be detectable. When finalized for plant specific cases, Technical Specifications are requiring periodic verification testing on at least 18 month intervals.

The Technical Specifications have required that sensor response time tests be performed at least on one logic train at a time such that both logic trains are tested at least once per 36 months, and on one channel at a time per function such that all channels are tested at least once every N times 18 months, where N is the total number of redundant channels in a specific function.

The measurement of sensor response time at the specified time intervals provides assurance that the protective and engineered safety features action function associated with each channel is completed within the time limit assumed in the accident analyses.

The sensor is defined as being that part of the instrumentation extending from the pick-off point in the process

to the instrumented electrical signal that is input to the signal conditioning equipment, i.e., process cabinets. Present technology does not provide for complete response time testability because a portion of the instrument impulse line is valved off; i.e., bypassed from the process when a simulated signal is injected into the sensor at shutdown, such as, in the development referred to in Item b) above.

On the occasion of previous NRC ICSB reviews of sensor response time measurement technology, the staff has suggested that either verification data of the response time contribution from the impulse lines should be provided or justification should be provided for not making such data available. Whereas previously this justification has been furnished, the methodology presented herein proposes a feasible methodology for formulating this actual data.

3.0 TEST PROCEDURES

Considerable interest exists in developing in situ methods for response time verification that would not require plant shutdown or reduce the reliability of safety systems through the addition of active components. The noise analysis technique is a passive method which measures the output of the sensor to natural process fluctuations in the plant.

The procedure for this technique is quite simple; it is performed by measuring the voltage output at the first test point in the process loop prior to any filtering.

In order to reduce the amount of time the protection cabinets are open for testing. The process noise signals are collected on one protection set, recurring simultaneously 14 protection channels on a magnetic tape recorder. (Older plants have 14 process protection sensors per cabinet, but 4-loop plants with new steam line break protection like SNUPPS, have 15 per cabinet.)

Data is collected from only one protection set at a time in order not to violate the standard technical specs. If a protection sensor is also used for control, that control function is switched to another channel's sensor for the period of data collection to prevent adverse effects on plant control in case of instrumentation failure. During the recording of protection channel sensors, the channel should be placed in partial trip.

Data Collection

With the reactor at stable operating conditions, each of the four protection racks was transferred to a test condition in sequential order. That is, one rack was taken out of service and the doors were unlocked. A group of fourteen sensor points was monitored. The sensor groups recorded are listed in Table 3-1. The data was recorded for 45 minutes to 67 minutes for each group to allow for proper signal averaging in later analysis. For each data group, the time, tape number, tape position, plant conditions, recording parameters, and signal conditioning parameters were noted on a data log sheet. The steady state DC levels were noted at the beginning and end of each data set. Also, the control board meter values were noted during the data collection.

TABLE 3-1

FOUR LOOP PLANT

DATA COLLECTION LIST

Protection Set	Process Variable	W Tag Number
I	Pressurizer Pressure	PT-455
	Pressurizer Level	LT-459
	Reactor Coolant Flow	FT-414
		FT-424
		FT-434
		FT-444
	THOT	TE-411A
	TCOLD	TE-411B
	Steam Generator Level	LT-529
		LT-539
	Steam Line Pressure	PT-514
		PT-524
		PT-534
		PT-544
	Steam Flow	FT-512
		FT-522
		FT-532
		FT-542

TABLE 3-1 (Continued)

Protection Set	Process Variable	W Tag Number
II	Pressurizer Pressure	PT-456
	Pressurizer Level	LT-460
	Reactor Coolant Flow	FT-415
		FT-425
		FT-435
		FT-445
	THOT	TE-421A
	TCOLD	TE-421B
	Steam Generator Level	LT-519
		LT-549
	Steam Line Pressure	PT-515
		PT-525
		PT-535
		PT-545
III	Pressurizer Pressure	PT-457
	Pressurizer Level	LT-461
	Reactor Coolant Flow	FT-416
		FT-426
		FT-436
		FT-446
	THOT	TE-431A
	TCOLD	TE-431B

TABLE 3-1 (Continued)

Protection Set	Process Variable	W Tag Number
III	Steam Generator Level	LT-518
		LT-528
		LT-538
		LT-548
	Steam Line Pressure	PT-526
		PT-536
IV	Pressurizer Pressure	PT-458
	THOT	TE-441A
	TCOLD	TE-441B
	Steam Generator Level	LT-517
		LT-527
		LT-537
		LT-547
	Steam Line Pressure	PT-516 PT-546

NOTE: All signal acquisition points will be the first test point in the process protection set downstream of the sensor.

Instrumentation

The instrumentation used at the site to obtain the voltage time history signals of process noise consisted of signal conditioning amplifiers and a magnetic tape recorder located near the protection racks.

The technique used monitors the process noise at the first voltage test point in the protection set downstream of the sensor. This is done to prevent noise filtering due to protection rack electronics. The process noise is superimposed on the DC steady state signal that typically is in the range of 1-5 volts for the process variables. This voltage is measured at a test point which is normally a 250 Ω resistor in the 4-20 ma current loop of a transmitter or the bridge curcuit for an RTD.

Figure 3-1 is a block diagram of the test instrumentation. Signal transmission from the protection rack test points to the first stage differential DC amplifier was via a twisted shielded pair cable. The first stage amplifier was used to null out the steady state DC voltage by means of a DC offset control. A second stage amplifier was used to amplify the AC process noise signal. Both amplifiers also provide low pass filtering of the data with a 30 Hz or 100 Hz cutoff. The nominal frequency response of each amplifier was DC to 30 Hz or 100 Hz (-3 dB) with a 12 dB/octave roll off above 30 Hz or 100 Hz. The function of the low pass filter was to suppress unwanted high frequency noise that may be present which would limit the dynamic range of the recorders.

All data was recorded on a one-inch, fourteen channel FM

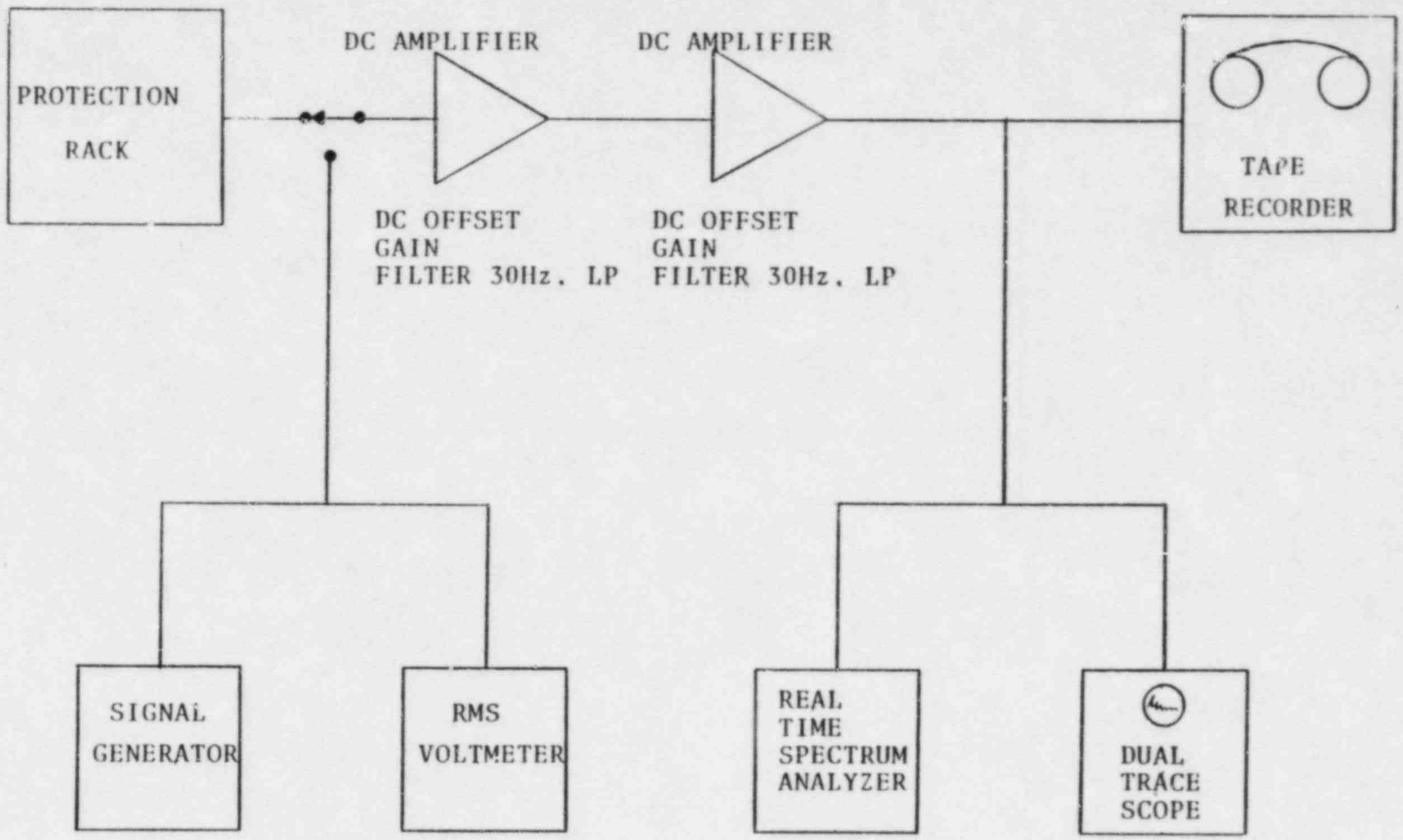

Figure 3-1: Test Instrumentation

standard IRIG magnetic tape recorder. The recorders used were a Sangamo Sabor VI and a Honeywell 101 tape recorder. All recordings were made at 3 3/4 ips intermediate band. The recorder frequency response was DC to 1.25 Khz and the signal to noise ratio was at least 47 dB at this speed.

These recordings provide the flexibility to do data analysis using different techniques and frequency ranges.

To insure calibration of the recording system, two types of test signals are used. The first is a 1.0 volt RMS signal at 100 Hz and is inserted at the test lead to the data acquisition system with the low pass filters in the DC amplifiers out. The second is a white random noise test signal applied at the input to the test leads with the low pass filters set at their normal setting. Both signals are recorded on the tape recorder as a reference for data acquisition response characteristics. All the DC amplifiers were given an operational check prior to the start of the test to check that all gain settings were functioning.

A real time frequency spectrum analyzer was used on-site during the data collection for checking data validity. When testing is done using the sensor response time test cart, described later, the data collection process is much more simplified.

4.0 ANALYSIS TECHNIQUES

The objective of this measurement program is to monitor protection sensor response time degradation using noise analysis techniques. This on-line technique monitors the process noise which is inherent in the NSSS system. The response of the sensor system to process noise input is analyzed to generate a frequency spectrum. Normally, comparison with prior data will indicate if significant degradation has occurred.

Two types of data analysis approaches were used; the first used a FFT spectrum analyzer and a graphical fit technique and the second used the prototype sensor response cart. Both perform the same function of computing the response time; the first is a manual technique and the second is an automatic computerized system.

Graphical Fit Technique

The analysis technique used to evaluate the sensor response time is a straight forward manual procedure using (power spectral density) PSD response curves. The first step in the procedure is to calculate the PSD of the sensor signal obtained at the first test point in the protection racks.

The time history of tape recorded noise signals is connected to the input of a fast fourier transform analyzer which then calculates the PSD spectrum of the sensor signal.

The PSD analyses were done in various frequency ranges depending upon the noise bandwidth of the sensors. Generally, the ranges are 0 - 20 Hz and 0 - 100 Hz using 400 points of spectral resolution. The effective noise bandwidth and weighting

function depended on the spectrum analyzer used. These are .097 Hz and .485 Hz noise bandwidth for 0-20 Hz and 0-100 Hz respectively for a Nicolett 660 spectrum analyzer with a Hanning squared weighting function. A sequence of 64 ensemble averages was used for each data channel for data averaging.

The second step of the procedure is to estimate the response time from the PSD curve. The manual method assumes that the sensor is a second order system with a transfer function (TF) given as: EQUATION 1:

$$TF = \frac{1}{S^2 + 2 \xi W_o S + W_o^2}$$

If the damping ratio (ξ) is assumed equal to 1, which is a good estimate for many of the sensors, then the response time, of an input step to reach 63% of its final value is:

Response Time (63%) = .34/fc where fc is cutoff frequency

Figure 4-1 is a schematic representation of this method to fit a second order curve to RC flow plant data. Figure 4-2 shows the transfer functions and step responses for other damping ratios using the second order model. As noted from the time plot, if the damping ration is less than 1, the response time is conservative. This second order curve fit technique works reasonably well with many of the sensors by manual smoothing and fitting the asymptotes. The steam pressure and turbine pressure contain more spectral peaks but fitting the baseline of the PSD gives a reasonable estimate. By comparing PSD signatures with baseline PSD signatures, information on degradation can be derived by change in peak.

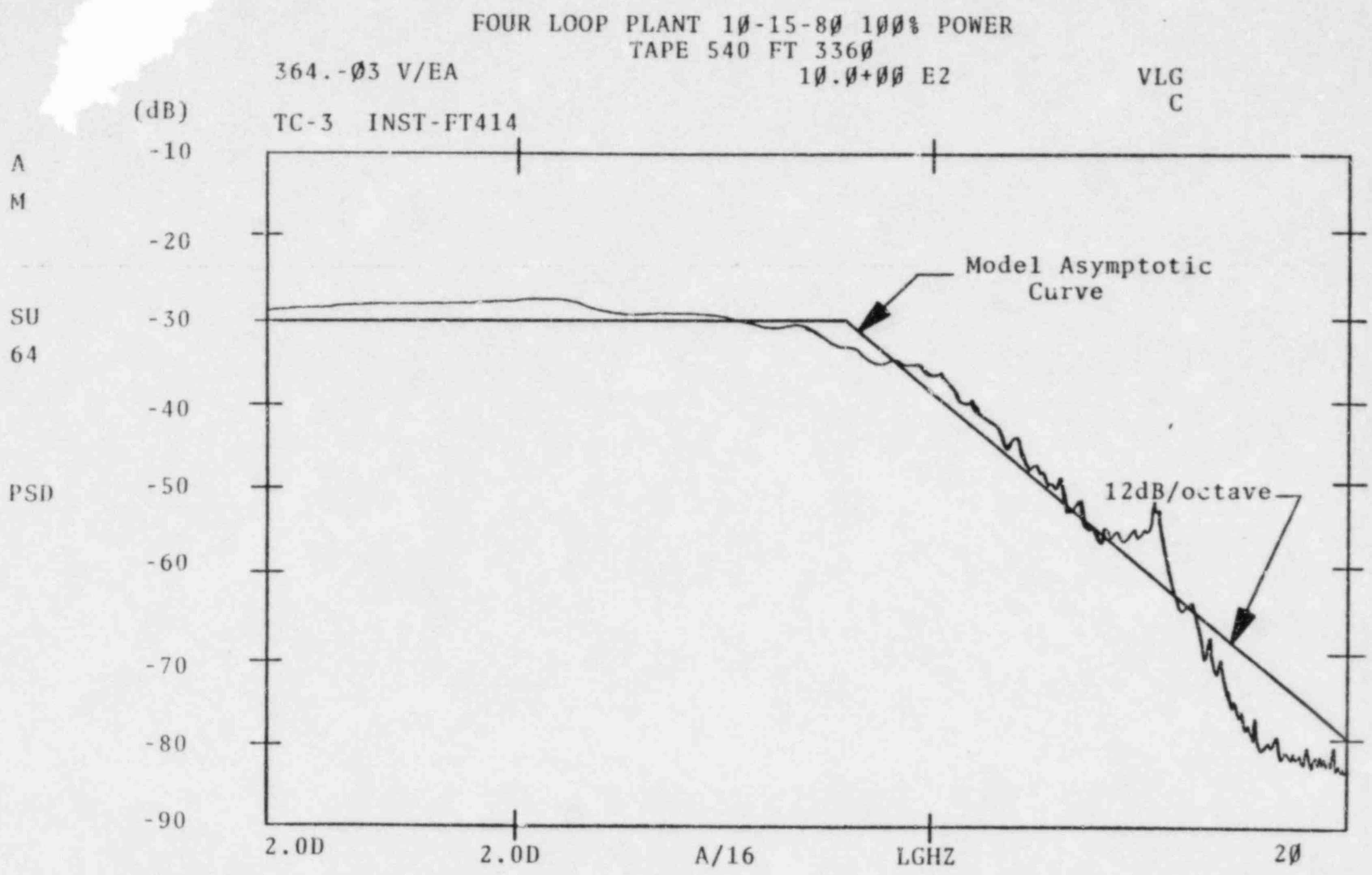

Figure 4-1: Data Fit Technique--Second Order Model

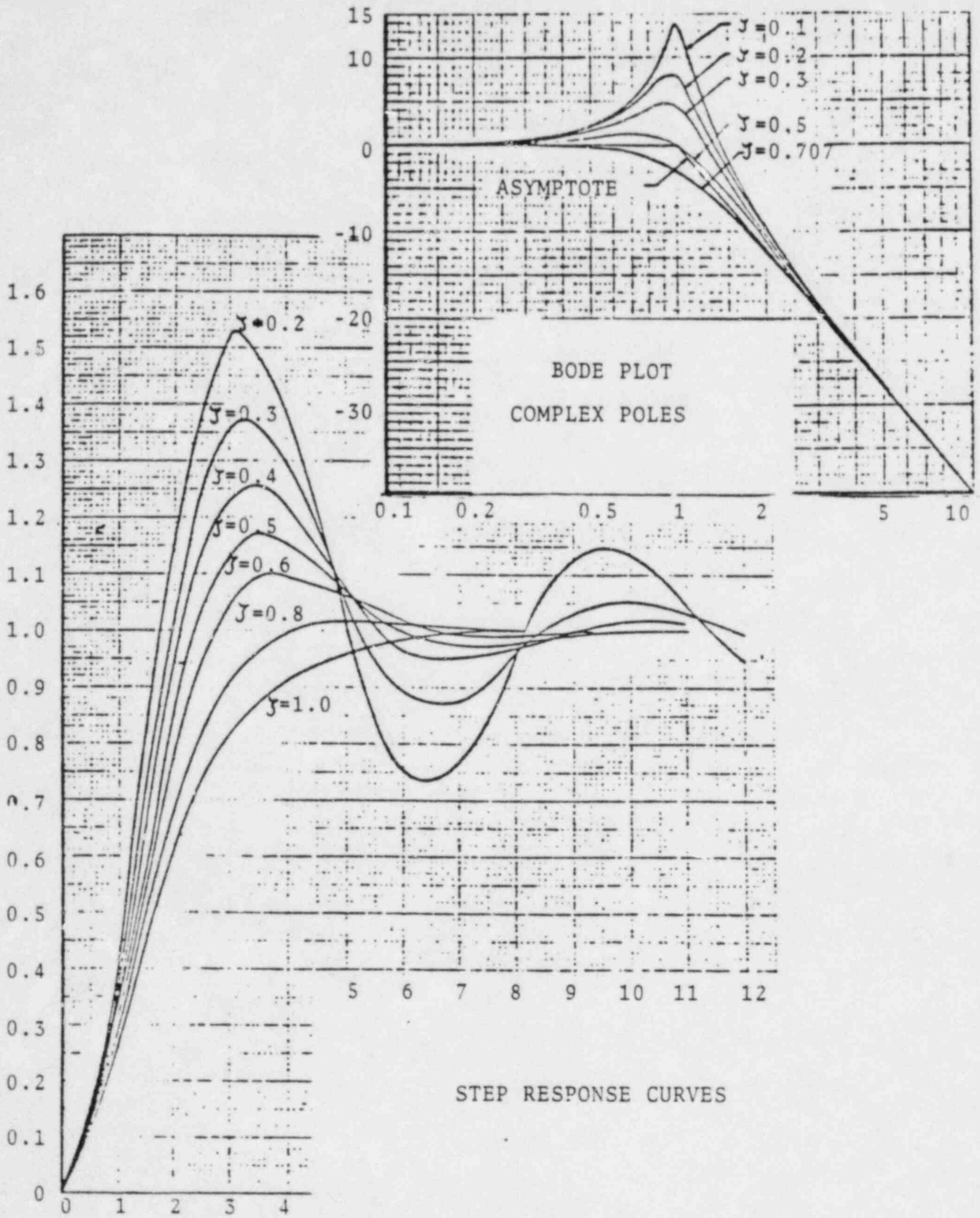

Figure 4-2: Damping Ratio for Second Order Model

This technique is relatively simple and can be used with a majority of the sensors evaluated. A quantitative response time can be found with a simple overlay of the second order asymptotics on the PSD measuring the frequency of the break point, and calculating the response time from the break point frequency which is .34/fc.

Prototype Sensor Response System

Sampling and Filtering

The initial step in determining the response time of a particular sensor is to perform an FFT Calculation on data sampled from the selected sensor. The sampling rate needed is determined by the type of sensor to be tested. The Sensor Response Time Test Cart samples 1024 data points at a fixed high rate (256 samples/sec.). Data for sensors needing lower sampling rates is obtained by decimation and digitally filtering the data as it is collected. The digital filter used is a 20 hz low pass Finite Impulse Response Linear Phase filter with a roll off of 60 db/octave. The filter coefficients were calculated utilizing a computer code run on a PDP-11 minicomputer (1). The coefficients were then used during decimation to filter any frequency content between 20 and 100 hz where the electronic filter cutoff occurs. The decimation and filtering is performed using the following algorithm: EQUATION 2:

$$P_j = \sum_{j=0}^{j=80} W_j X_j$$

Where Pj is a filtered data point, Wj are the digital filter coefficients and Xj are the last 81 data points sampled.

FFT Calculation

The FFT calculation is performed using an 8086 assembly language program as described in reference 3. Briefly, the algorithim uses butterfly processing to perform FFT processing on 2 channels simultaneously. A 1024 point FFT can be performed in approximately 2 seconds.

Functional Description of the Sensor Response Time Test System

The Sensor Response Time Test System is housed in a mobile cart, shown in Figure 4-3, to allow for easy transport to the reactor protection system racks during sensor testing, and easy storage when not in use. The system consists of the Process Noise Amplifier Drawer, the Computer Chassis and Power Supply, the Graphics Printer, the Graphics CRT and Keyboard, and the Dual Double Density Disk Drive.

The Sensor Response Time Test hardware is configured as shown in Figure 4-4. The system is capable of testing up to four sensors simultaneously. Connection to the sensor signal is at the input side of the protection system's isolation amplifier. This signal is normally available at test points on the protection system's master test card. The signal is brought into the Process Noise Amplifier Drawer front panel via test cables provided (shielded, twisted pair). The Process Noise Amplifier Drawer houses four identical Process Noise Amplifier Boards. These boards are designed to condition the process noise signal from the sensor so that it is suitable for Analog to Digital Conversion. The sensor is isolated from the test system by a low

noise, precision isolation amplifier. The sensor noise signal is then put through a highpass and lowpass filter network to eliminate the signals d.c. bias component and to limit the upper frequency to 100 Hz. The final stage is automatic or manual gain selection. The sensor noise signal must be properly scaled for the ± 10V swing at the input of the A/D converter. When in the manual move, gain is selected for each of the four channels at the front panel of the Process Noise Amplifier Drawer. When the automatic mode, the A/D converter, under processor control, samples the input and selects the optimum gain setting. In either case, manual or automatic, the signal gain is displayed on the Process Noise Amplifier front panel (Figure 4-5). The choice of gains are: 1, 5, 10, 20, 50, 100 & 200. The four conditioned process noise signals are applied to the inputs of the A/D converter housed in the computer chassis. The A/D converter, under control of the 16-bit processor, sequentially samples the analog level of each of the four signals, converts it to a digital value, and subjects this value to a Fast Fourier Analysis to determine the composition (frequency and amplitude) of the sensor process noise signal. The results of the analysis are stored in the memory where it is available for output to the graphics display, the graphics printer, and the Dual Floppy Disk Drive Unit.

The graphics output functions are controlled by an 8-bit processor housed in the computer chassis. There are three forms of graphics outputs; (1) Power Spectral Density Plot, (2) Fitted Curve Plot, and (3) Step Response Plot. Figure 4-6a is the Power Spectral Density Plot (PSD). This is the basic plot of the

results of the Fast Fourier Analysis (amplitude versus frequency). Figure 4-6b is the PSD with the overlayed fitted curve. The curve fit parameters shown at the right of the plot are user selectable and are used by the processor to perform the curve fit and calculate the sensor response and settling times. Figure 4-6c is the Step Response Plotted using the fitted curve results.

The raw data may be stored on floppy disk for future use. Additional information on the analysis technique is given below. Data recorded on magnetic tape from plant tests was input to the sensor response time cart to curve fit the PSD plots.

Fitting

The data is fit to a mathematical representation of a multi-pole of the form:

$$H(f) = \frac{A}{(1 + T_1^2 f^2)\ (1 + T_2^2 f^2)\ \ldots\ldots(1 + T_N^2\ 2f^2)}$$

where, f, is the frequency, N, is the order of the equation, and, A & T, are the coefficients to be fit.

The fit is performed using the pattern search technique described in Reference 8. Briefly, pattern search is a direct search routine that minimizes a function S(Ti) by selectively incrementing and decrementing the individual variables, Ti.

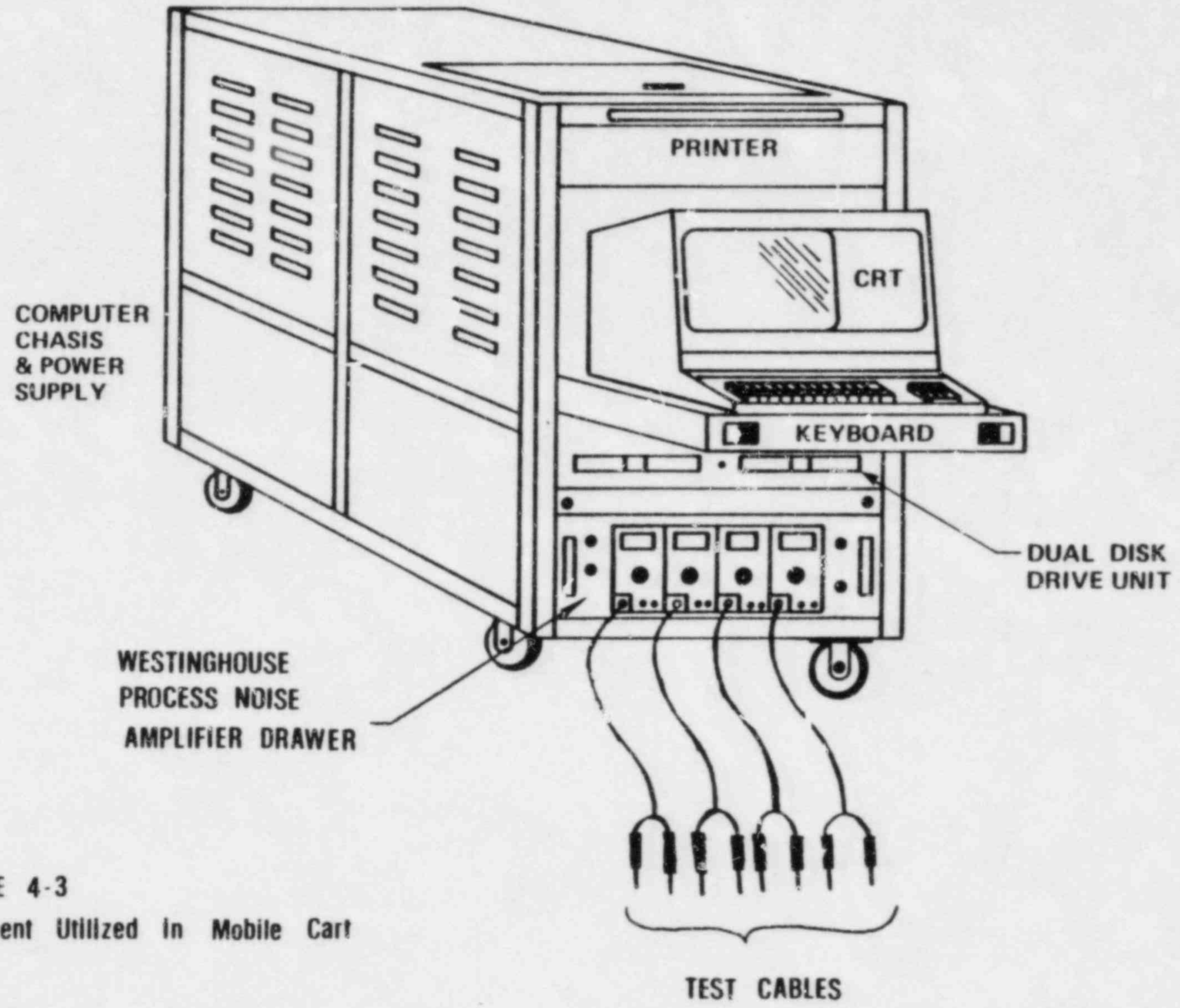

FIGURE 4-3
Equipment Utilized In Mobile Cart

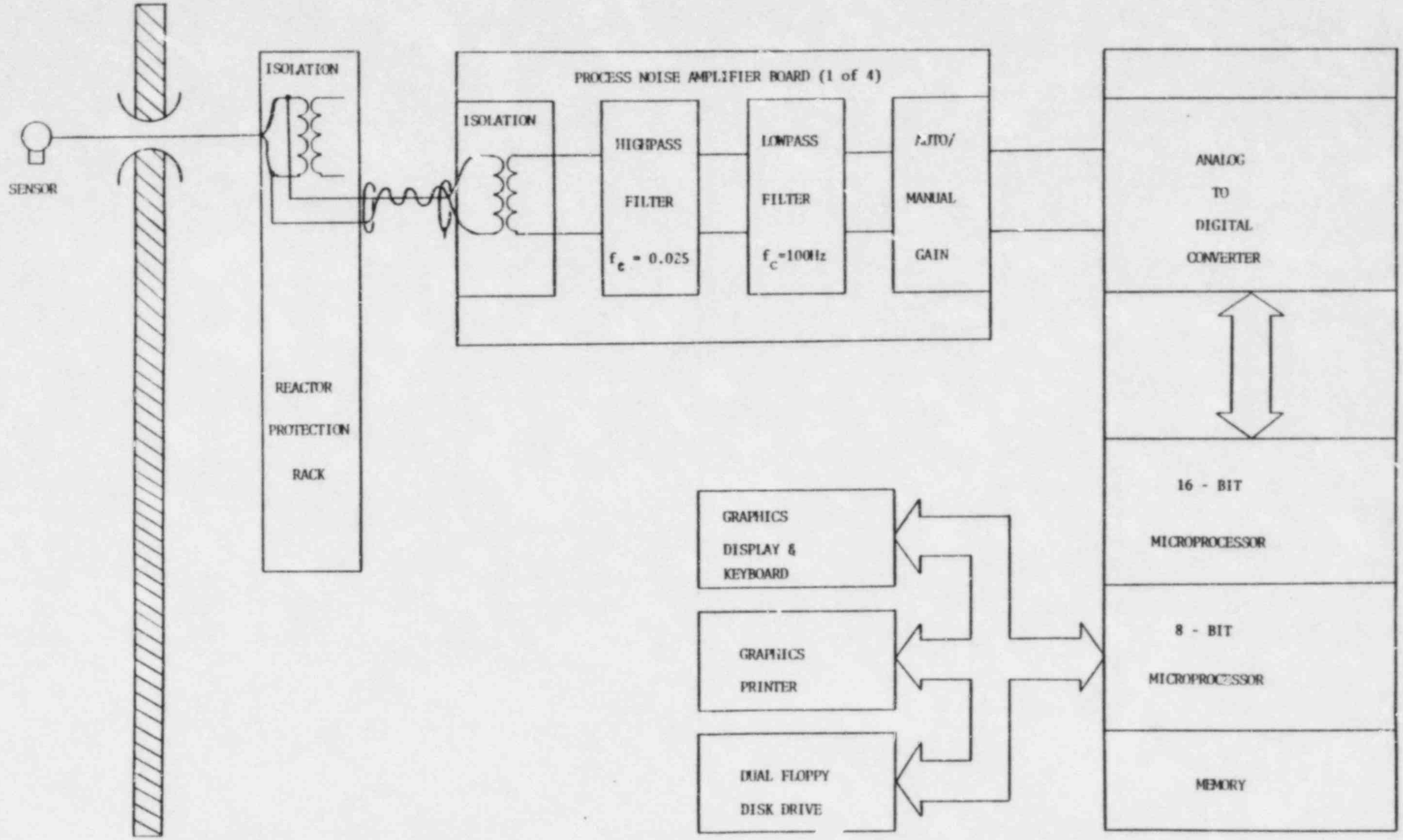

FIGURE 4-4: SENSOR RESPONSE TEST SYSTEM HARDWARE CONFIGURATION

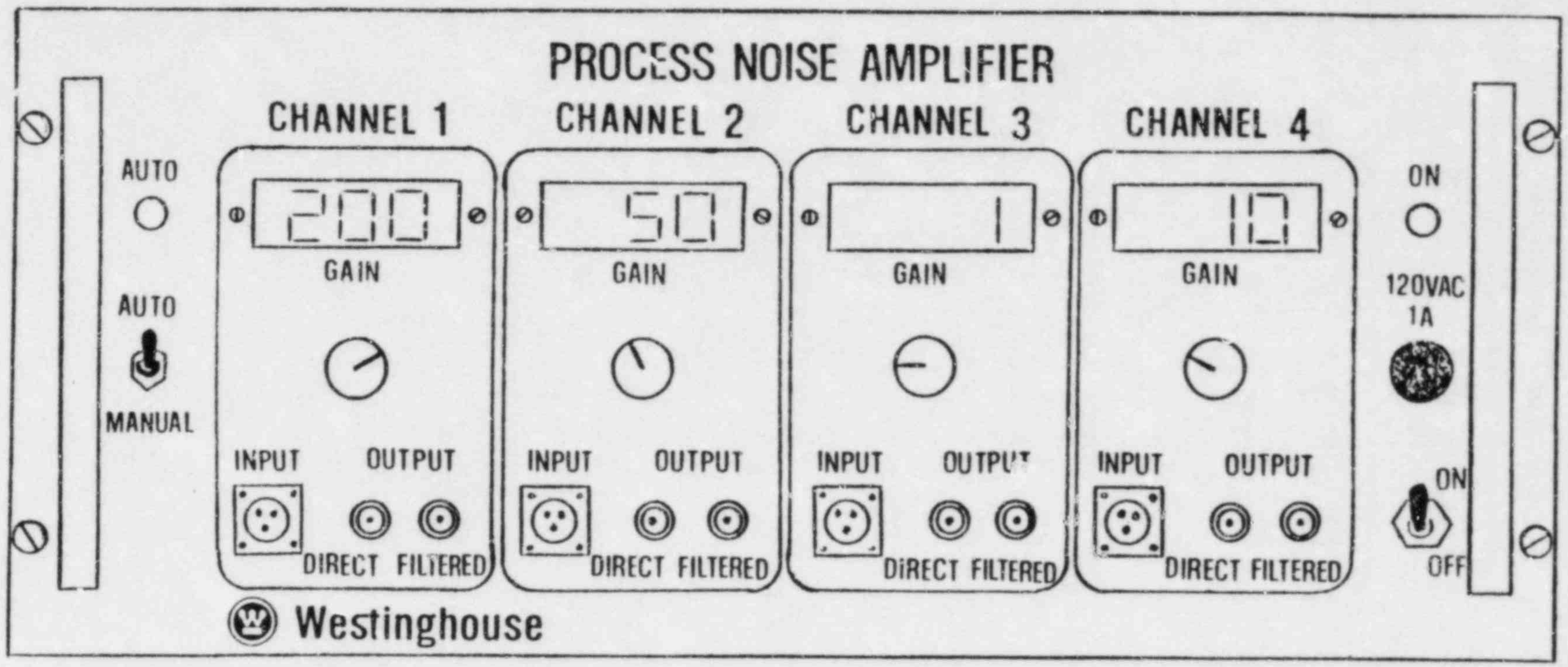

Figure 4-5: Process Noise Amplifier Drawer Front Panel

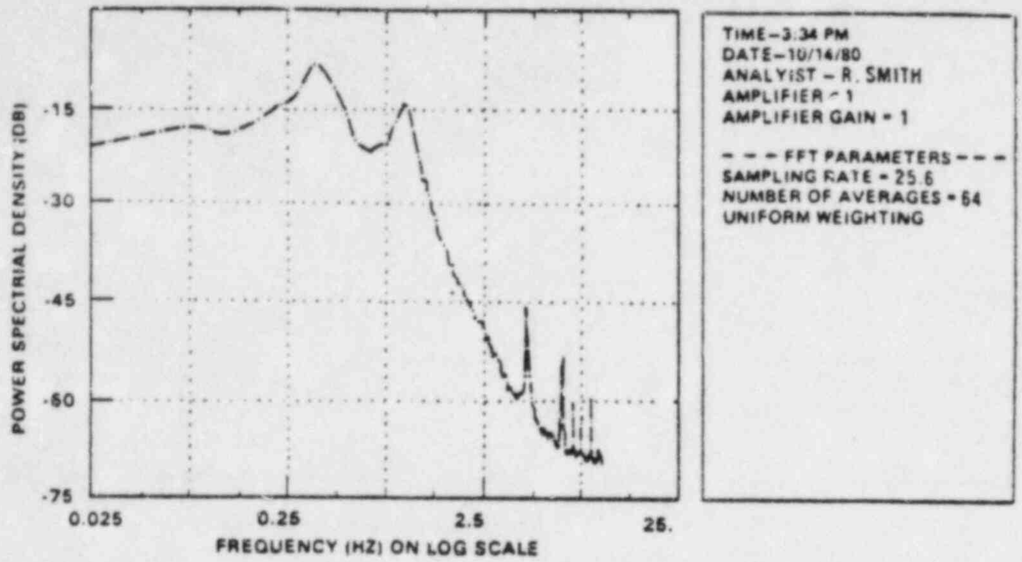

FIGURE 4-6a Power Spectral Density Plot

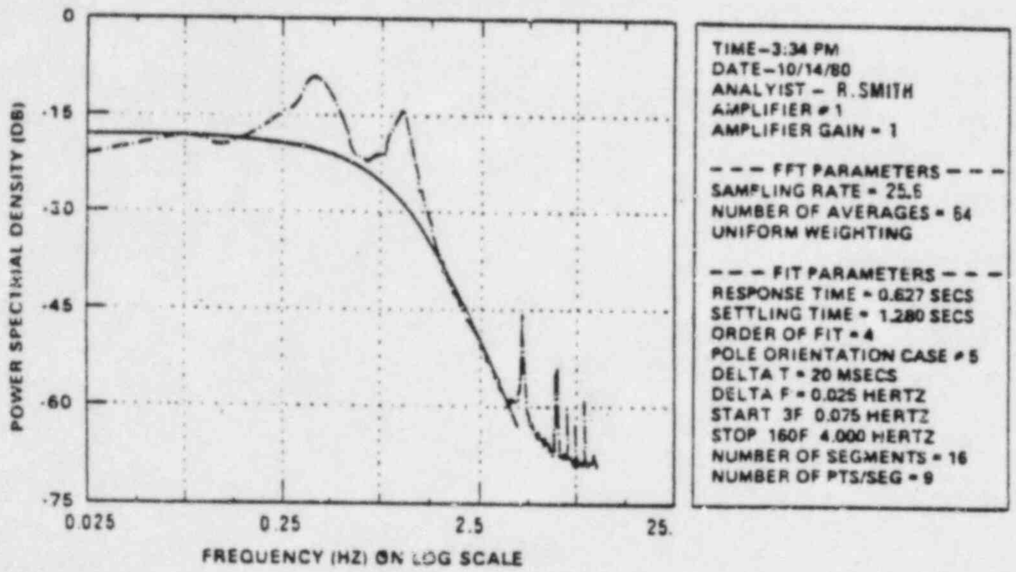

FIGURE 4-6b Power Spectral Density and Fitted Curve Plot

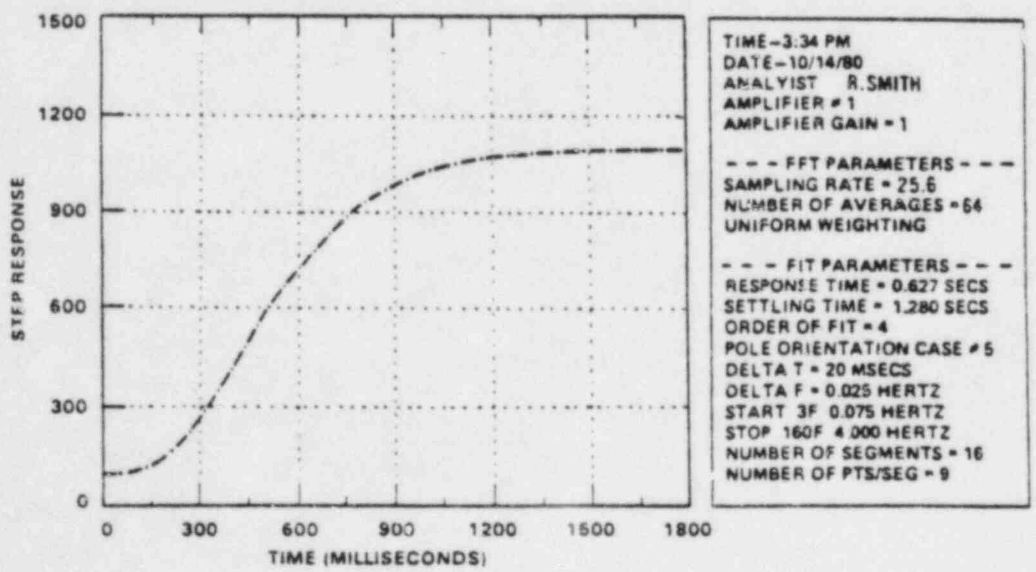

FIGURE 4-6c Step Response Plot

In performing the search algorithim the successive values of the coefficients, Ti, can be interpreted as points in a K dimensional space. The procedure of going from a given point to the following point is called a move. A move is termed a success if the criteria function, (in this case the square root of the sum of the squares) S(s) decreases; otherwise, it is a failure. The pattern search routine makes two kinds of moves. The first type of move is an exploratory move designed to acquire information concerning the behavior of the function S(s). The knowledge gained from the exploratory move is based only on the success or failure of the move and not on any quantitative results. Using the information from the exploratory move, a second type of move called a pattern move is made. In contrast to the exploratory move in which only one coordinate is moved at a time, the pattern move changes all the coordinates in the direction indicated by the exploratory pattern. After each pattern move, a new set of exploratory moves is made and the process repeats.

A flow chart of the pattern search technique is given in Figure 4-7.

In this case, the function to minimize S(T) is the least squares criteria as described in Equation 4.

EQUATION 4

$$S(T) = \sqrt{\sum_{f=f_1}^{fmax} \frac{(H(T) - PSD\ (T))}{N}}$$

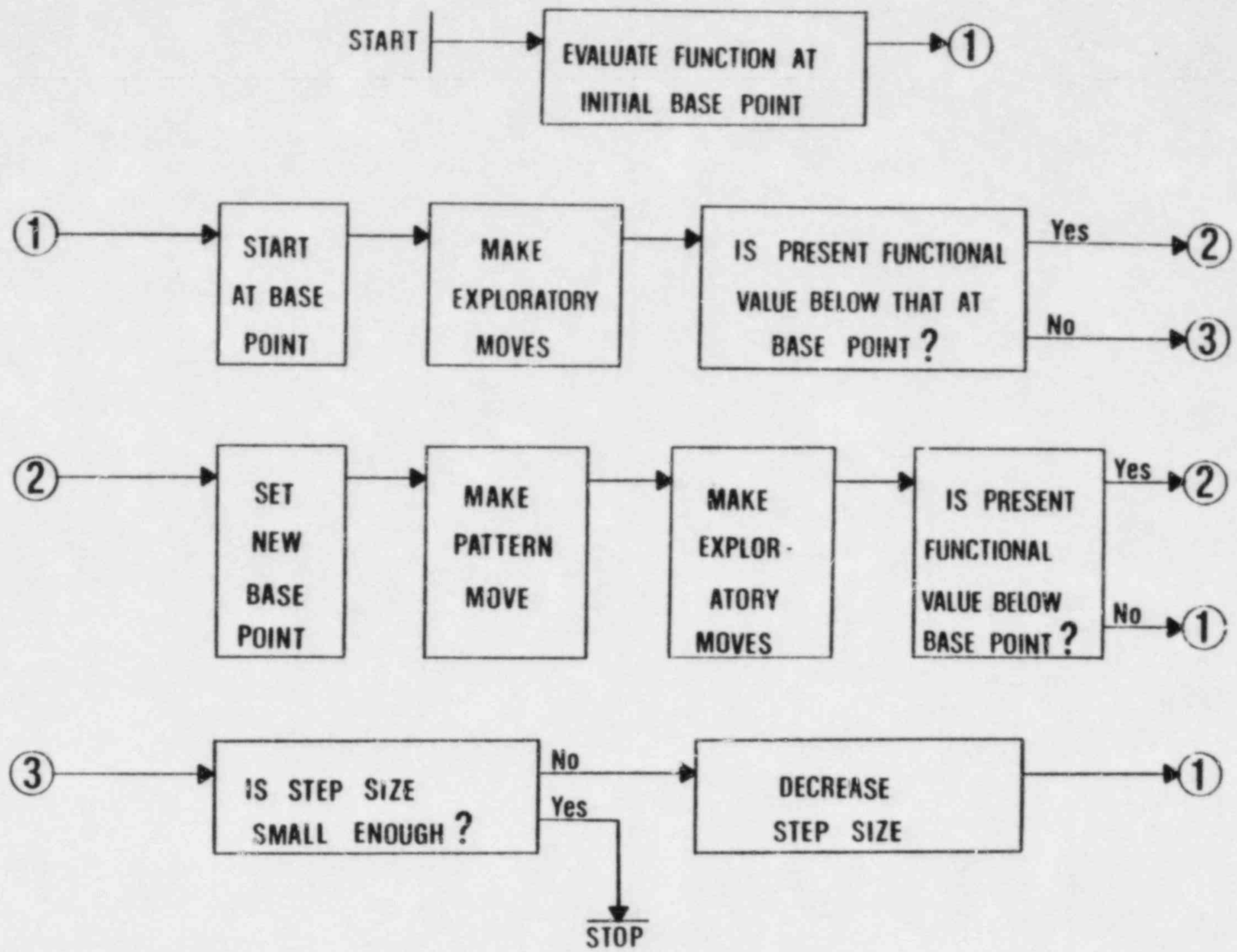

Figure 4-7: Flow Chart For Pattern Fit

The arguments Ti are varied until the minimum S(T) is obtained. The pattern search routine determines the sequence of values for T and an independent routine computes the functional values of S(T). When it has been determined that a set of Ti's has been found which results in a minimizing of the S(T) function, the fit is complete and the set of T's calculated are used in the succeeding calculations.

<u>Step Response</u>

The step response can be defined as the integral $\int_o^T$ dt of the impulse response. The impulse can be defined from the inverse LaPlace transform of Equation 3. Obtaining the transform from tables and performing the integration provides Equation 5:

EQUATION 5:

$$SR(T) = \frac{1-e^{-at}}{(b-a)} + \frac{1-e^{-bt}}{(b-a)}$$

where $a=1/T_1$, $b=1/T_2$, thus this example is a second order system. For higher orders, equation 5 would be expanded similarly.

Once the step response (SR(T)) is obtained, the time response, which is defined as the point at which the step response reaches 63% of its steady state value, can be readily calculated.

From equation 5 it is evident that as the poles of the equation approach a common value the function goes to infinity. It is necessary to check the difference between pole values in order to avoid this situation. When calculations indicate that the poles are too close together for numeric stability, alternate

calculations are performed in order to obtain the step response. For a second order system with common poles, equation 5 is replaced by equation 6.

EQUATION 6:

$$\frac{1 - Tae^{-at}}{a^2}$$

For a fourth order system, the situation is handled in a similar manner. However, this situation is more complicated since there are five separate possible pole orientation cases. For Case 1 which is defined as having four unique valued poles, equation 7 is used.

EQUATION 7:

$$\frac{1 - e^{-at}}{a(b-a)(c-a)(d-a)} + \frac{1 - e^{-bt}}{a(a-b)(c-b)(d-a)} + \frac{1 - e^{-ct}}{c(a-c)(b-c)(d-c)} + \frac{1 - e^{-dt}}{d(a-d)(b-d)(c-d)}$$

However, in the extreme case that all the poles have a value (Case 5), equation 8 is used.

EQUATION 8:

$$\frac{1 - \left(1.0 + aT + \frac{a^2\ T^2}{2} + \frac{a^3\ T^3}{6}\right) e^{-aat}}{a^4} \qquad (8)$$

For each of the other possible pole orientation cases, there is a similar equation.

Root Mean Squared Noise Amplitude

The RMS signal level of the sensor in a given frequency range can be used as a parameter that may give trend information on sensor degradation when used in conjunction with a change in cut off frequency. This 1σ RMS parameter is somewhat sensitive to plant operating conditions and, therefore, may vary between data collections. The 1σ RMS value of the signal is calculated between frequencies from the PSD spectra as follows:

EQUATION 9:

$$\sigma \text{ RMS} = \sqrt{\int_{f_1}^{f_2} \text{PSD } df}$$

which is approximated by post processing in the spectrum analyzer. The frequency ranges chosen are .05-20 Hz for temperature, flow, level and pressurizer pressure sensors and .25 - 100 Hz for other pressure sensors.

5.0 Plant Results

Process noise data has been collected from a number of plants over the last seven years. These include Ginna Unit 1, D.C. Cook Unit 1, Trojan Unit 1, and Beaver Valley Unit 1. This report will mainly discuss a 4-loop plant and a 3-loop plant at which data has been collected over a period of time. Nine sets of data have been collected at a 4-loop plant since 1977 and four sets of data at a 3-loop plant since 1978. The dates are listed in Table 5-1. Table 5-2 is a list of various sensor types used at the 4-loop plant along with range of manufacturer specifications and laboratory tests at Westinghouse Forest Hills.

Not all the test data collected is presented. A sample of each type of sensor is presented for the seven-year period at the 4-loop plant. The power spectral densities of the data available in this report are given in Appendix A.

TABLE 5-1

DATES OF PROCESS NOISE MEASUREMENTS

4-LOOP PLANT

Date	Power
June 1977	100%
December 1977	60%
December 1977	100%
February 1978	95%
February 1979	100%
January 1980	100%
October 1980	100%
April 1981	100%
September 1982	100%

3-LOOP PLANT

Date	Power
March 1978	100%
October 1979	38%
January 1981	98%
August 1982	99%

TABLE 5-2

PROCESS SENSORS 4-LOOP PLANT

Sensor	Make	Manufacturer Specification or Laboratory Test Time Response
Rtd	Rosemount 176	500 ms
Pressurizer Pressure	Barton 393	10-40 ms
Pressurizer Level	Barton 386/351	50-500 ms
Steam Generator Level	Barton 384	20-100 ms
Steam Flow	Barton 384	20-100 ms
Reactor Coolant Flow	Barton 384 (Foxboro E13)	20-100 ms (200-800 ms)
Steam Line Pressure	Barton 345	10-20 ms
After 3/80		
Steam Generator Level	Barton 764	180 ms
Pressurizer Pressure	Barton 763	180 ms

TABLE 5-3

PROCESS SENSOR AND SENSOR RESPONSE TIME

Sensor Tag #	Process Variable	Response Time Noise Analysis (MS)	Response Time Hydraulic Ramp Measurement (MS)
FT414	Reactor Coolant Flow	310	145
FT424	Reactor Coolant Flow	240	180
FT434	Reactor Coolant Flow	220	600
FT444	Reactor Coolant Flow	260	215
PT455	Pressurizer Pressure	840	10
LT459	Pressurizer Level	630	135
LT529	Steam Generator Level	680	20
LT539	Steam Generator Level	680 *	0 **
PT514	Steam Line Pressure	15 *	4
PT524	Steam Line Pressure	12 *	8
PT534	Steam Line Pressure	32 *	20
PT544	Steam Line Pressure	13 *	10
FT512	Steam Flow	670	20
FT522	Steam Flow	520 *	40
FT532	Steam Flow	520 *	70
FT542	Steam Flow	580 *	25

computer fit
* manual fit
** see text

Response Time Comparison

As a starting reference point in monitoring for sensor degradation, the response time using the noise analysis technique was compared with measurements made using the hydraulic ramp test conducted by the plant. The ramp test equipment was constructed using EPRI Report NP-267 as a guide. The results are presented in Table 5-3. The data is for protection set number I. Normally the response time calculated using the noise analysis techniques are longer because it is believed that the process noise is band limited as discussed later. The response time results using the noise analysis technique, therefore, tend to be conservative both with respect to ramp tests and vendor specs. Also, the ramp technique would not account for any effects from the impulse line which is valved off during the test. The plant had mentioned that measuring response time using the hydraulic ramp technique was difficult to perform and interpret which was the reason for the reading of 0 MS response time on the steam generator level sensor. The reading of 500 MS response time on the reactor coolant flow sensor FT 434 also was inconsistent but was the only data available and may be related to hydraulic ramp test method.

Process Noise Tests

The first requirement for the noise monitoring technique for sensor response time verification is that the process noise characteristics should be time invariant, or stationary, for the same plant operating conditions. Any change in sensor noise response should be directly linked to changes in the time

response of the sensor, and not to changes in the process noise itself. The process variables for which time histories of sensor noise response will be recorded are primary cold-leg temperature, primary hot-leg temperature, reactor coolant flow, steam flow, steam pressure, pressurizer pressure, pressurizer level, and steam generator level.

The time history signals that were recorded on magnetic tape were frequency analyzed to determine characteristic PSD spectra.

The two types of time invariance investigations were:

- short term time invariance
- long term time invariance

Short term time invariance refers to a time interval less than an hour over which the noise frequency components do not vary appreciably in frequency or magnitude. Typically, when specta were analyzed one after another, there were no changes in frequency,and only minor change in amplitude of some of the level sensors when the plant was at constant conditions.

The determination of long-term time invariance uses the same criteria but over a longer period of time. Figures 5-1 through 5-9 are overlays of the same nine process sensor monitored in February 1979, the end of life for Cycle II and in October 1980 beginning of life for Cycle IV of the 4-loop plant. Both sets of data were taken at 100% power.

Except for minor variation in amplitude of all but the pressurizer pressure, (Figure 5-8), the data is stationary over the period from the end of Cycle II to the beginning of Cycle IV. The pressurizer pressure signal is very sensitive to low

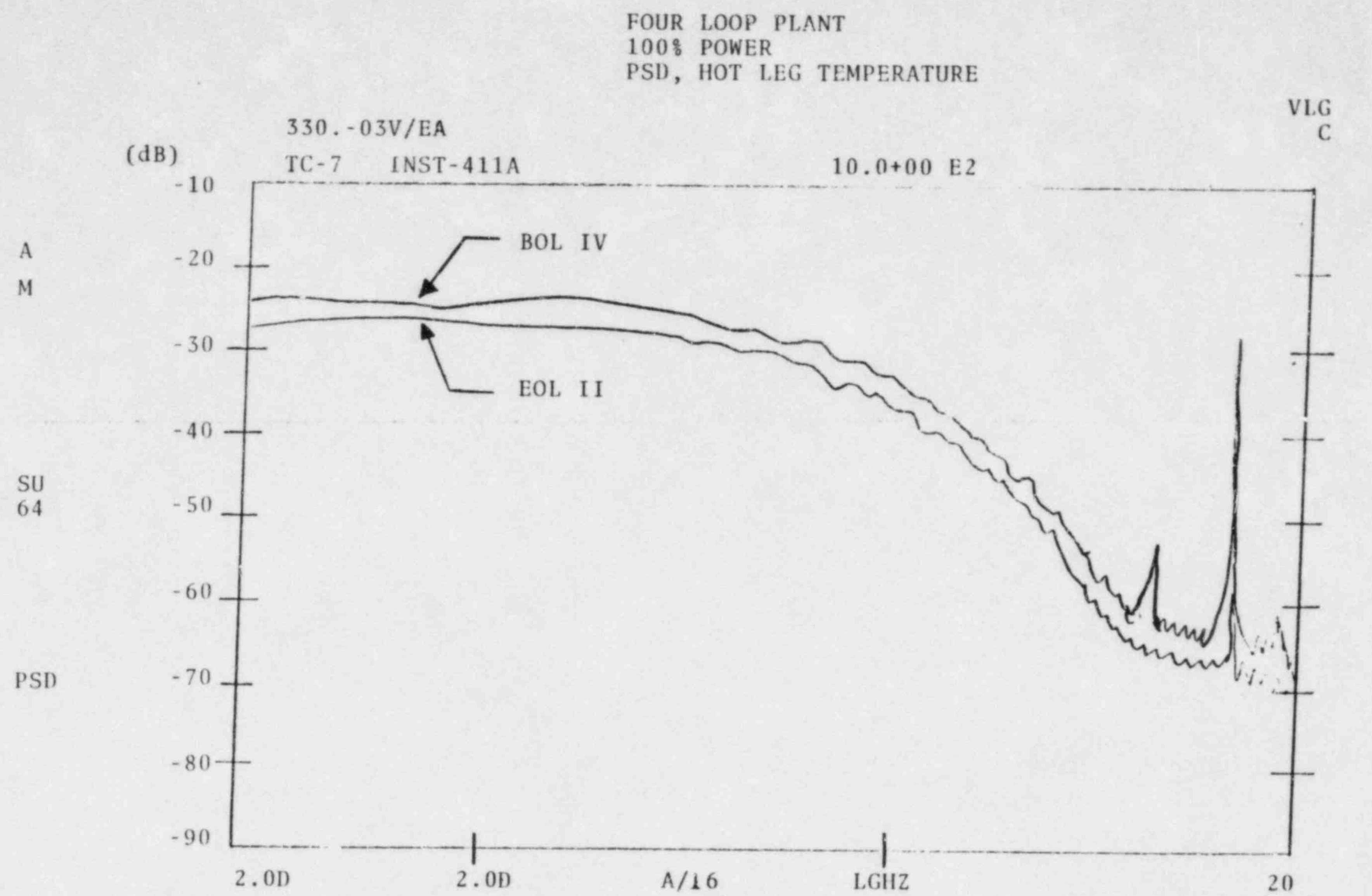

Figure 5-1:
EOL Cycle II
BOL Cycle IV

FOUR LOOP PLANT
100% POWER
PSD, COLD LEG TEMPERATURE

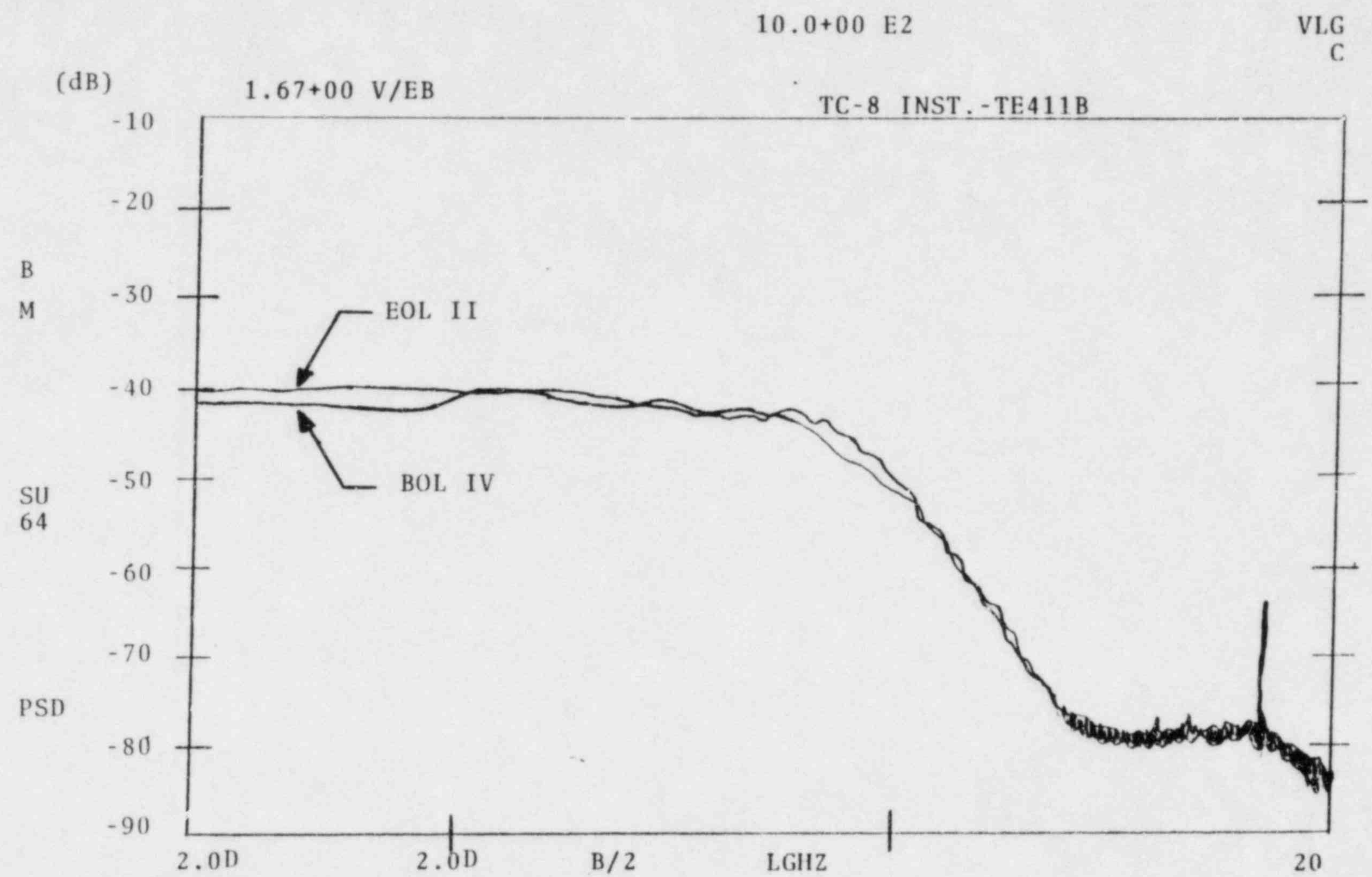

Figure 5-2: EOL Cycle II
BOL Cycle IV

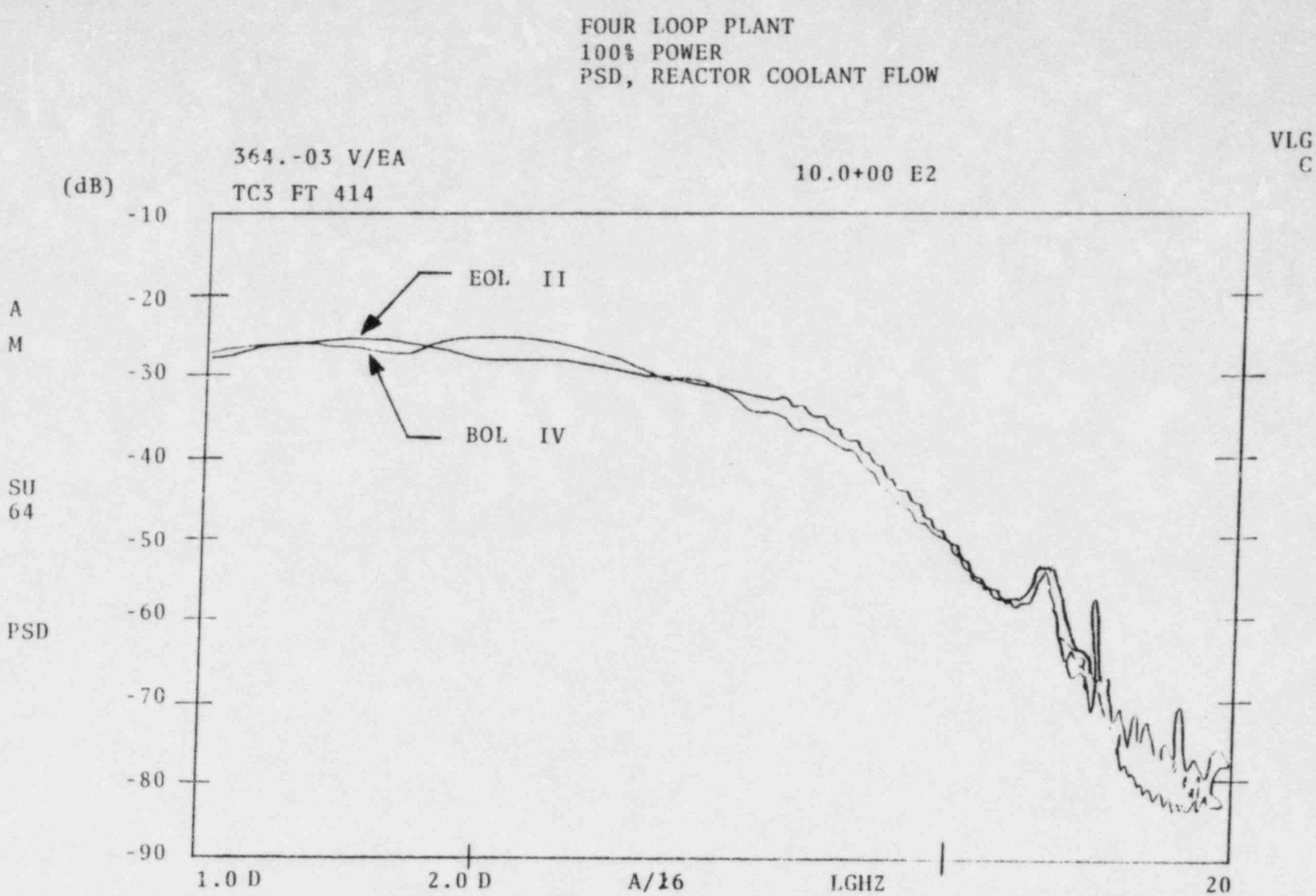

Figure 5-3:
EOL Cycle II
BOL Cycle IV

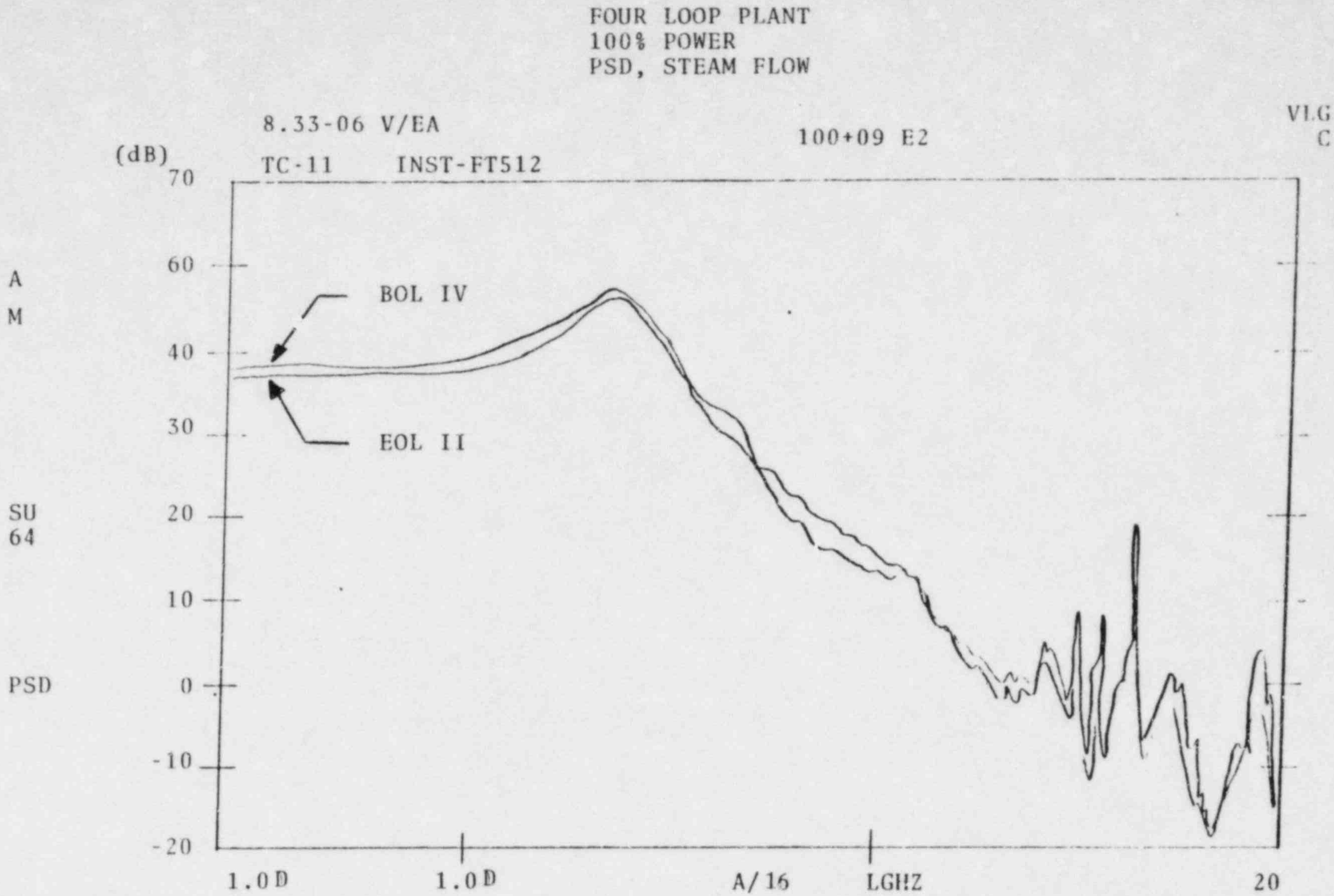

Figure 5-4:
EOL Cycle II
BOL Cycle IV

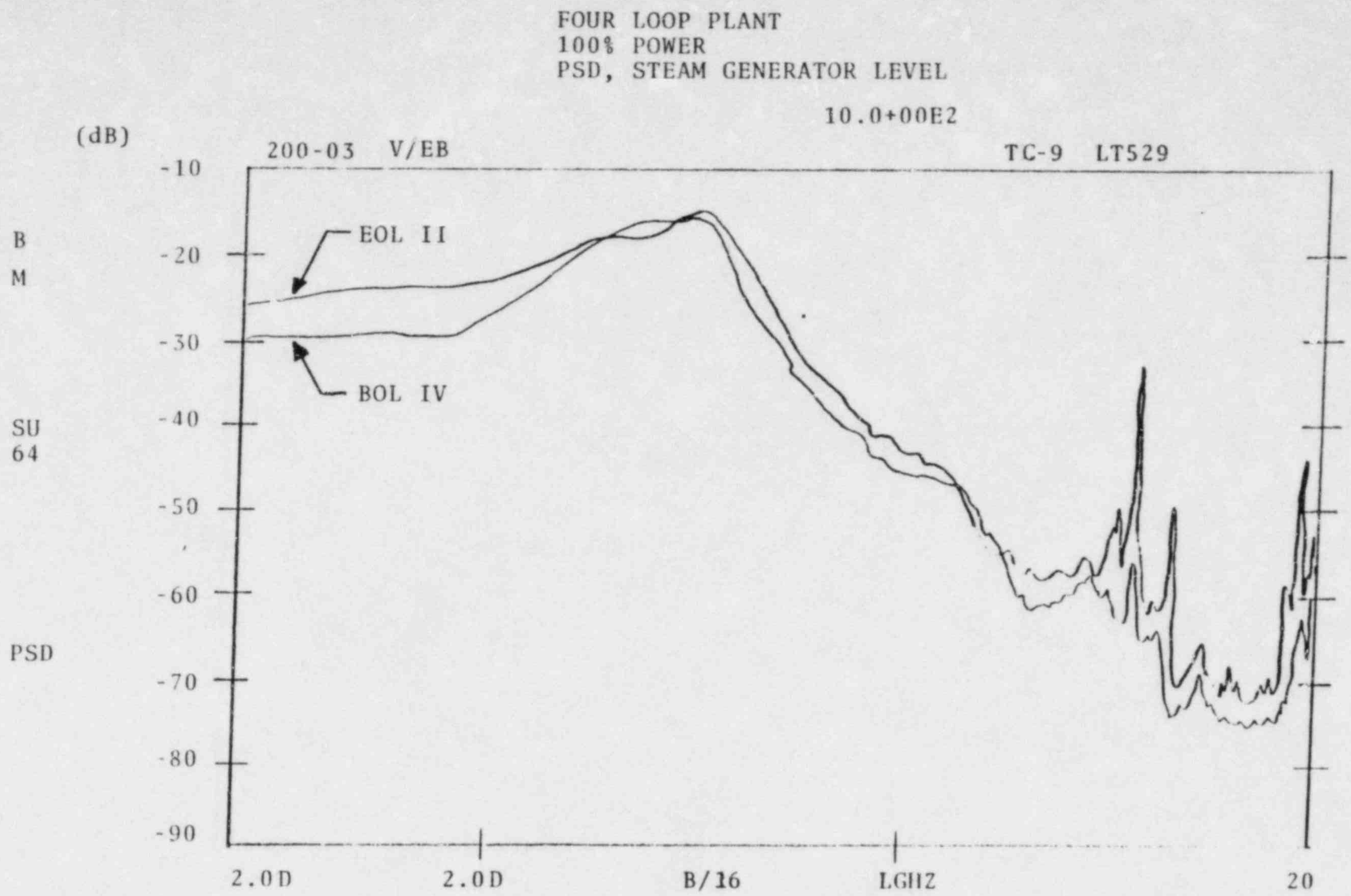

Figure 5-5:
EOL Cycle II
BOL Cycle IV

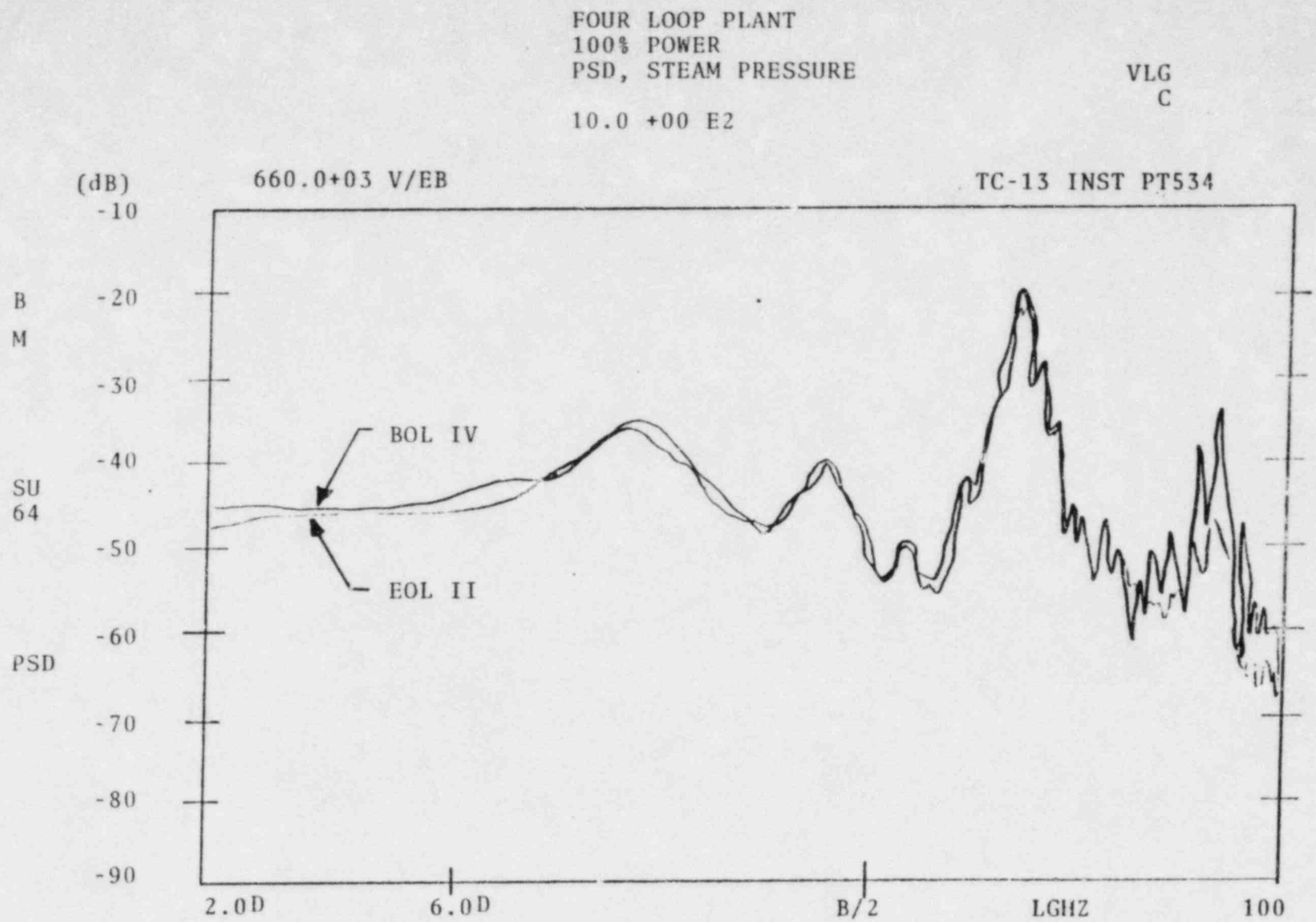

Figure 5-6:
EOL Cycle II
BOL Cycle IV

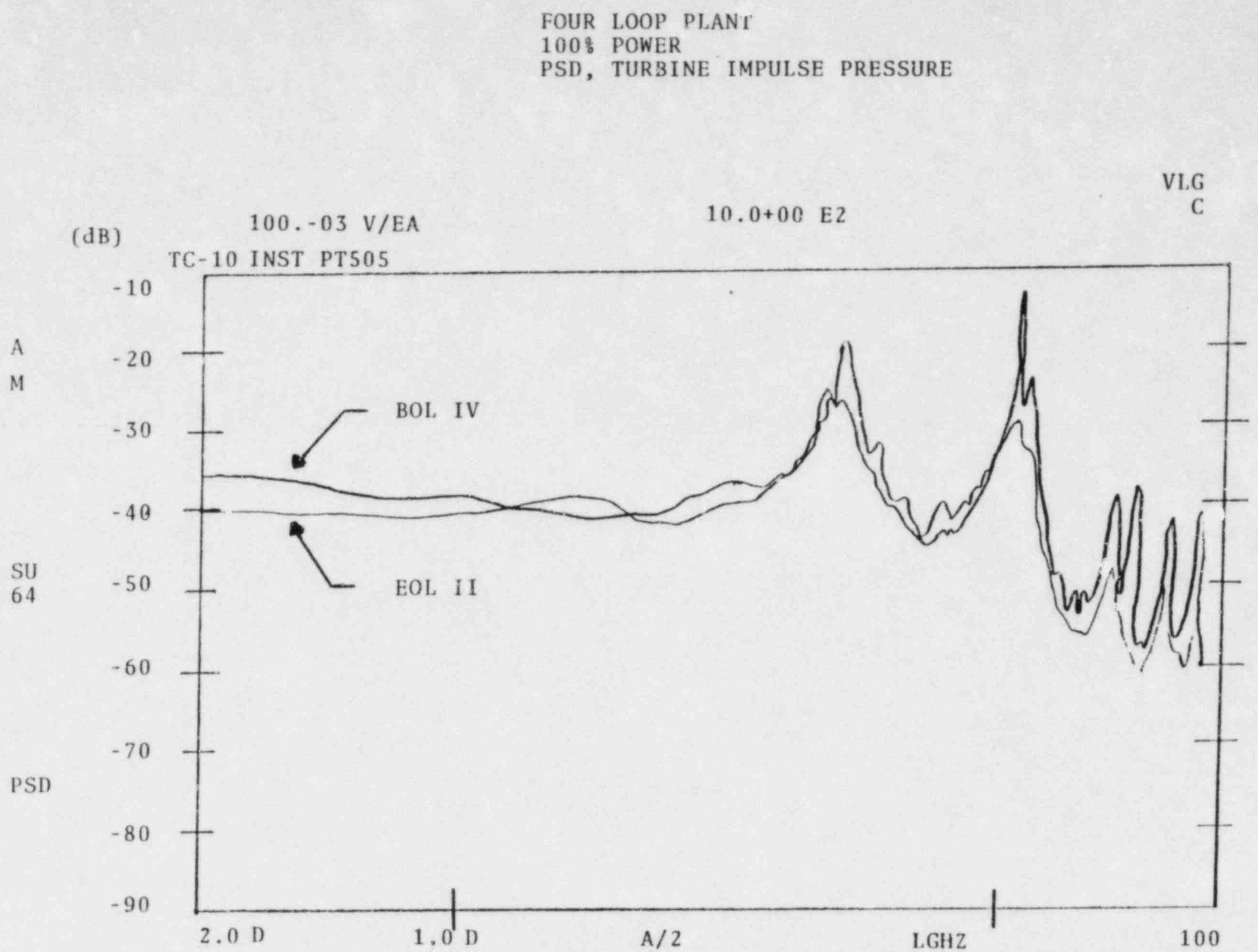

Figure 5-7: EOL Cycle II
BOL Cycle IV

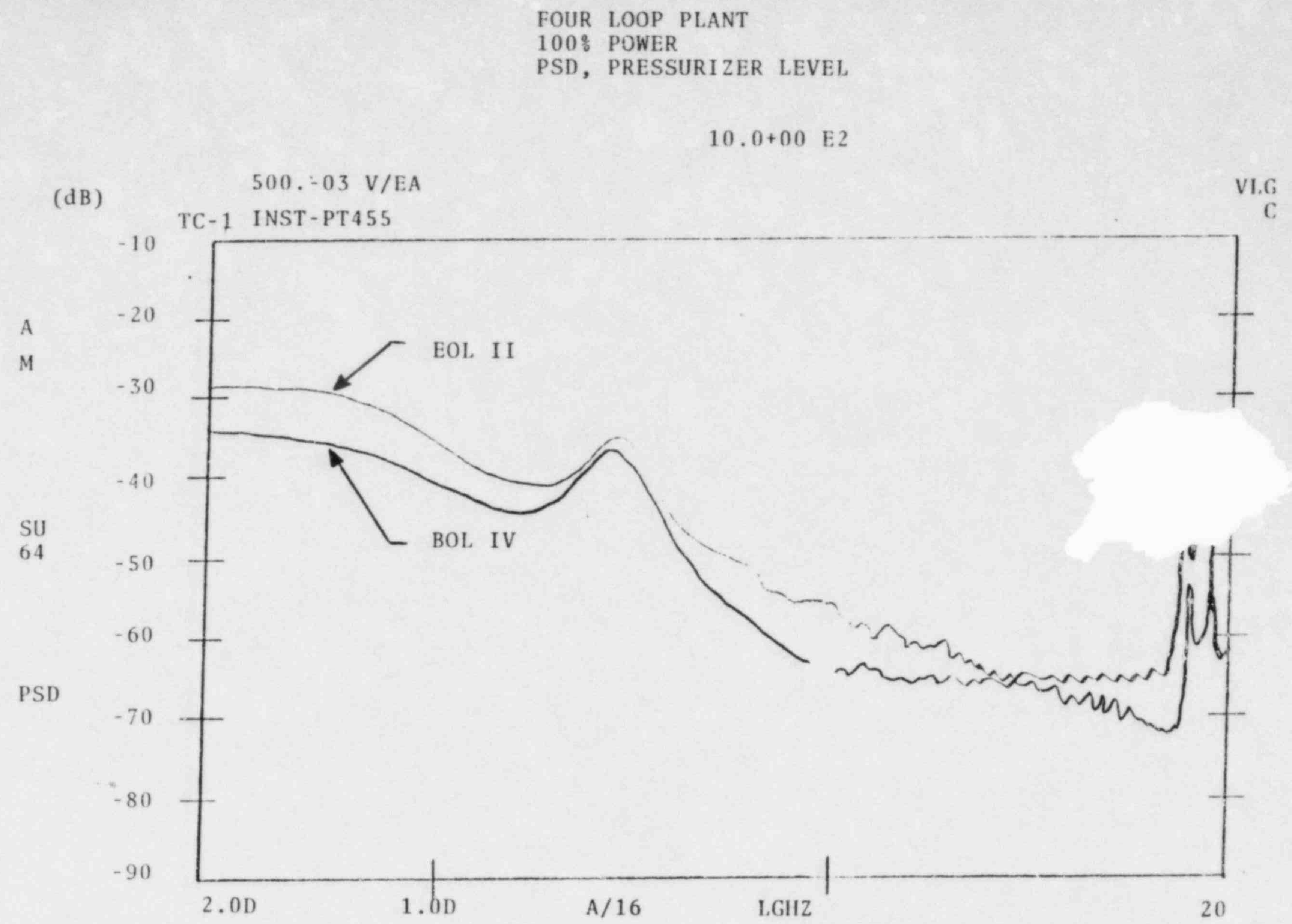

Figure 5-8:
EOL Cycle II
BOL Cycle IV

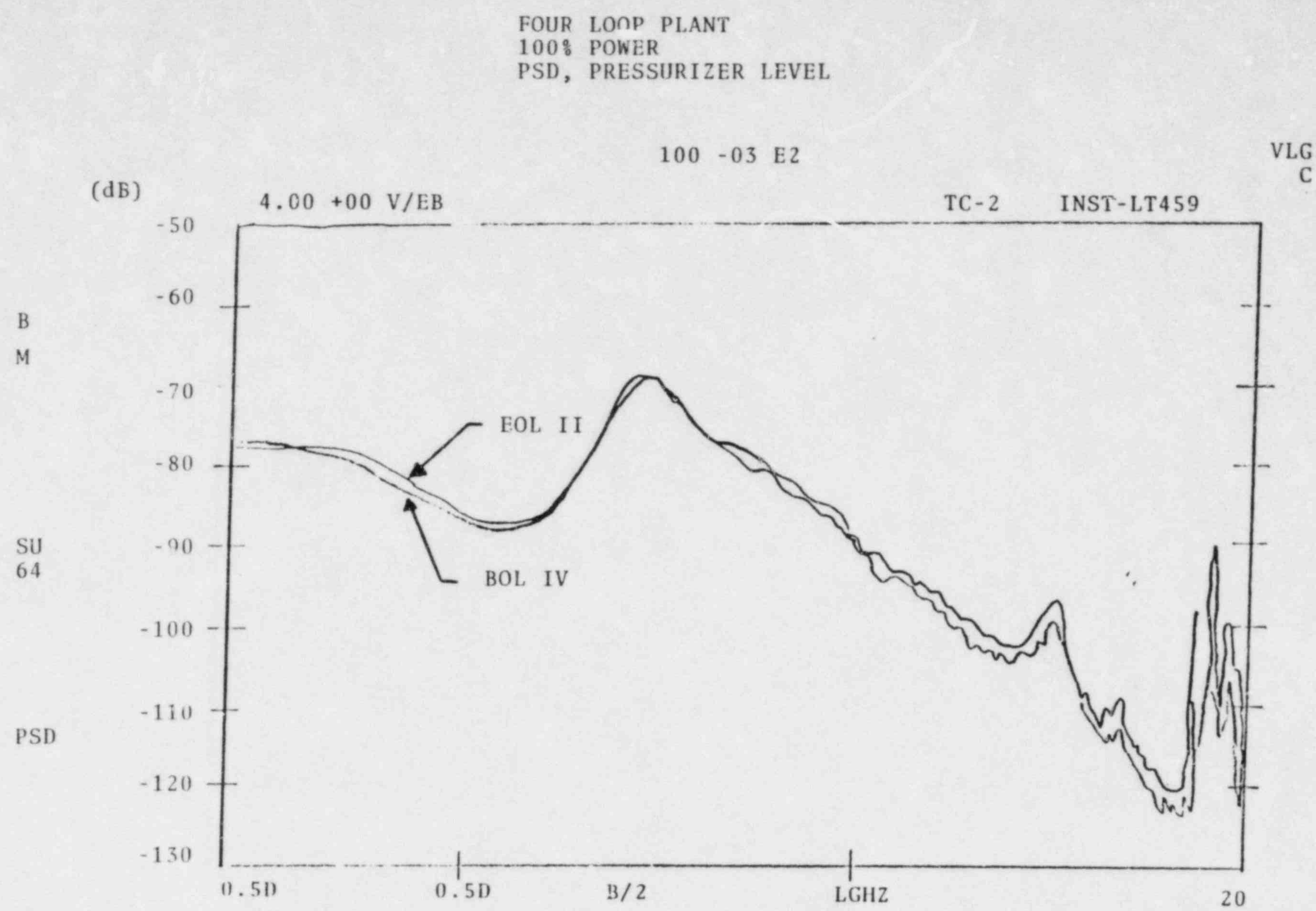

Figure 5-9: EOL Cycle II
BOL Cycle IV

frequency noise which may be dependent on pressurizer level.

Process Noise Frequency Content

The second requirement for the noise monitoring technique for sensor response time verification is that the normal process noise frequency content be sufficient to detect sensor response time degradation. An increase in the response time of any sensor should be indicated by an observed increase in the attenuation of the sensor's frequency response. This requires the presence of process noise frequency components for each variable behond that required by the safety analysis assumptions. The signals from the process sensors at the 4-loop plant were examined for frequency content,and the characteristics are presented in Table 5-4 for each type of variable. Similar characteristics of the PSD spectra were observed at other Westinghouse plants. Additional details are discussed below.

Response Time Characteristics Measured

The noise analysis techniques were applied to the PSD signature of each type of sensor monitored over the six year period observed. The sensor response time was calculated using the manual graphical technique and, in a majority of the cases, the automatic computerized techniques. The RMS amplitude calculated from the PSD' were also evaluated. This data is presented in Tables 5-5 through 5-14. Table 5-14 gives the average value of the response times measured and the standard deviation for the data.

PSD CHARACTERISTICS FOR 4-LOOP PLANT

TABLE 5-4

Variable	Output Noise Characteristics	Cut off Frequency
Temperature Hot Leg	Bandlimited White Noise	Approx. 1 Hz
Temperature Cold Leg	Band Limited Noise that is non white	Approx. .5 - 1 Hz
Reactor Coolant Flow	Band Limited White Noise	Approx. 1 Hz
Steam Generator Level	Flat Spectrum with Numbered Response Near Cutoff Frequency	Approx. .25 - .5 Hz
Steam Pressure	Wide Band (Approx. 100 Hz) with Many Resonances	Approx. 10 - 30 Hz
Steam Flow	Flat Spectra with Narrow Band Resonance Near Cut off Frequency	Approx. .5 Hz
Pressurizer Pressure	Decreasing Spectrum with Resonance at Approx. 6 Hz Same High Frequency Resonances	Approx. .3 - 4 Hz
Pressurizer Level	Decreasing Spectrum with Resonance at Approx. .6 Hz	Approx. .3 - 1 Hz
Turbine Impulse Pressure	Flat Spectrum with Many Resonances	Approx. 20 - 30 Hz

TABLE 5-5

4 LOOP US PLANT TEST RESULTS

SENSOR TE411A T HOT RTD TEMP. RESPONSE TIME (MS) RMS DEG F

DATE	POWER	MANUAL 2ND ORDER	PROTOTYPE 2ND ORDER	PROTOTYPE 4TH ORDER	0-20 HZ
6/77	100%	309	459	293	0.24
12/77	60%	315	342	290	0.090
12/77	100%	298	282	287	0.142
2/78	EOL 95%	274	390	155	0.142
2/79	EOL 100%	303	378	303	0.090
1/80	ECL 100%	--	--	--	--
10/80	BOL 100%	315	346	335	0.5
4/81	EOL 100%	309	382	309	0.13
9/82	BOL 100%	326	597	441	0.16

TABLE 5-6

4 LOOP US PLANT TEST RESULTS

SENSOR TE411B T COLD RTD TEMP. RESPONSE TIME (ms) RMS DEG F

DATE	POWER	MANUAL 2ND ORDER	PROTOTYPE 2ND ORDER	PROTOTYPE 4TH ORDER	0-20 HZ
6/77	100%	351	509	395	0.096
12/77	60%	382	527	386	0.057
12/77	100%	333	395	362	0.10
2/78	95%	377	540	392	0.093
2/79	100%	340	565	733	0.094
1/80	100%	--	--	--	--
10/80	100%	340	534	--	0.094
4/81	100%	340	546	421	0.10
9/82	100%	333	354	--	0.064

TABLE 5-7

4 LOOP US PLANT TEST RESULTS

SENSOR FT 414 RC FLOW RESPONSE TIME (MS) RMS %

DATE	POWER	MANUAL 2ND ORDER	PROTOTYPE 2ND ORDER	PROTOTYPE 4TH ORDER	RMS % 0-20 HZ
6/77	100%	304	535	313	0.43
12/77	60%	304	295	303	0.37
12/77	100%	274	--	--	0.44
2/78	95%	358	551	337	0.40
1/80	100%	--	--	--	--
10/80	100%	288	507	296	0.40
4/81	100%	327	413	392	0.45
9/82	100%	253	375	371	0.47

TABLE 5-8

4 LOOP US PLANT TEST RESULTS

SENSOR FT 512 STEAM FLOW RESPONSE TIME (MS) RMS #/HR

DATE	POWER	MANUAL 2ND ORDER	PROTOTYPE 2ND ORDER	PROTOTYPE 4TH ORDER	RMS #/HR 0-20HZ
6/77	100%	790	826	674	18.1 x 103
12/77	60%	871	867	848	10.6 x 103
12/77	100%	723	713	723	40 x 103
2/78	95%	739	--	--	31.9 x 103
2/79	100%	772	906	712	32.3 x 103
1/80	100%	--	--	--	--
10/80	100%	768	--	768	40 x 103
4/81	100%	790	958	924	36.6 x 103
9/82	100%	790	955	673	25.8 x 103

TABLE 5-9

4 LOOP US PLANT TEST RESULTS

SENSOR	LT 529	SG LEVEL	RESPONSE TIME (MS)		RMS %
		MANUAL	PROTOTYPE		
DATE	POWER	2ND ORDER	2ND ORDER	4TH ORDER	0-20HZ
6/77	100%	680	911	679	1.12
12/77	60%	829	--	--	.56
12/77	100%	567	967	513	1.18
2/78	95%	537	782	730	1.03
2/79	100%	618	857	621	1.04
1/80	100%	--	--	--	--
10/80	100%	523	885	486	1.33
4/81	100%	--	161	--	1.14
9/82	100%	453	471	486	

TABLE 5-10

4 LOOP US PLANT TEST RESULTS

SENSOR	PT534	STM PRES	RESPONSE (MS)		RMS PSI
		MANUAL	PROTOTYPE		
DATE	POWER	2ND ORDER	2ND ORDER	4TH ORDER	0-100HZ
6/77	100%	32	--	--	--
12/77	60%	40	--	--	--
12/77	100%	24	--	--	--
2/78	95%	14	--	--	--
2/79	100%	12	--	--	--
1/80	100%	--	--	--	--
10/80	100%	9	--	--	--
4/81	100%	10	51	38	1.40
9/82	100%	16	53	22	2.39

TABLE 5-11

4 LOOP US PLANT TEST RESULTS

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SENSOR PT505		TUR PRES	RESPONSE TIME (MS)		RMS PSI
		MANUAL	PROTOTYPE		
DATE	POWER	2ND ORDER	2ND ORDER	4TH ORDER	0-100HZ
6/77	100%	N/A	N/A	N/A	N/A
12/77	60%	N/A	N/A	N/A	N/A
12/77	100%	N/A	N/A	N/A	N/A
2/78	95%	N/A	N/A	N/A	N/A
2/79	100%	11	N/A	N/A	1.020
1/80	100%	--	N/A	N/A	--
10/80	100%	13	N/A	N/A	1.130
4/81	100%	14	N/A	N/A	2.160
9/82	100%	14	N/A	N/A	1.000

TABLE 5-12

4 LOOP US PLANT TEST RESULTS

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SENSOR LT 459		PZ LEVEL	RESPONSE TIME (MS)		RMS %
		MANUAL	PROTOTYPE		
DATE	POWER	2ND ORDER	2ND ORDER	4TH ORDER	0-20HZ
6/77	100%	708	616	634	0.033
12/77	60%	829	743	1172	0.032
12/77	100%	723	--	--	0.036
2/78	95%	1000	788	719	0.055
2/79	100%	340	329	349	0.019
1/80	100%	--	--	--	--
10/80	100%	226	329	207	0.040
4/81	100%	326	394	403	0.018
9/82	100%	435	419	372	0.026

TABLE 5-13

4 LOOP US PLANT TEST RESULTS

SENSOR PT 455		PZ PRESS	RESPONSE TIME (MS)		RMS PSI
		MANUAL	PROTOTYPE		
DATE	POWER	2ND ORDER	2ND ORDER	4TH ORDER	0-20HZ
6/77	100%	1030	823	838	0.17
12/77	60%	1307	689	701	0.29
12/77	100%	895	392	723	0.12
2/78	95%	1700	1118	1290	0.20
2/79	100%	1130	823	856	0.18
1/80	100%	--	--	--	--
10/80	100%	1417	--	--	0.13
4/81	100%	1172	407	349	0.11
9/82	100%	1214	--	--	0.19

TABLE 5-14

95% - 100% POWER RESPONSE TIME

	AVERAGE RESPONSE TIME (MS)		STANDARD DEVIATION	
SENSOR	MANUAL 2ND ORDER	AUTOMATIC 4TH ORDER	MANUAL	AUTOMATIC
Temperature Hot Leg	305	328	15	57.8
Temperature Cold Leg	344.8	392	15.4	24.1
Reactor Coolant Flow	309.4	341.8	41.6	39.8
Steam Flow	767.4	748.7	26.9	101.0
Steam Generator Level	563	585	78.9	105.8
Steam Pressure	16.7	30	8.3	11.3
Turbine Pressure	13	--	1.4	--
Pressurizer Pressure	1222.5	926.7	264	249
Pressurizer Level	331.8	332.8	74.0	86.7

Typically the automatic sensor time cart provides more conservative estimates of sensor response time as compared to the geographical method which requires a trained person. The data indicates that the process noise measured by the sensor is bandlimited, that is, it does not contain all the frequencies out to the cutoff frequency of the sensor. Therefore, it is not possible to measure the absolute response time of the sensor with band limited noise, results are conservative. But there is sufficient process noise in the system to monitor sensor

degradation or sensor verification long before the technical specification limits are reached. Using the same model for the sensor, the cutoff frequency corresponding to a response time just on the verge of being unacceptable could be derived. A degraded sensor with this cutoff frequency would be easily detected by its noise PSD spectrum if it changes from the baseline. Once a sensor model is selected, it should be used for sets of measurements to maximize its sensitivity to a possible degrading sensor.

The pressurizer pressure and level are more dependent on plant conditions and are sensitive to low frequency resonance in the pressurizer that may be dependent on pressurizer level. These sensors have a wider degree of variability in response times for a given sensor.

Table 5-15 contains the average and standard deviation of the RMS levels for the same set of sensors.

TABLE 5-15

RMS AMPLITUDE AT 95% - 100% POWER

SENSOR	AVERAGE	STANDARD DEVIATION
Temperature Hot Leg	0.15 Deg. F.	.046 Deg. F.
Temperature Cold Leg	0.092 Deg. F.	.013 Deg. F.
Reactor Coolant Flow	0.43%	.025%
Steam Flow	31×10^3 #/hr.	7.2×10^3 #/hr.
Steam Generator Level	1.1%	.11%
Steam Pressure	1.5 psi	.42 psi
Turbine Pressure	1.3 psi	.56 psi
Pressurizer Pressure	.16 psi	.035 psi
Pressurizer Level	.032%	.013%

These RMS amplitudes are reference values and are sensitive to changes in plant conditions. Gross changes from the reference or baseline values could flag any amplitude changes which could indicate a loss of frequency response.

Plant Noise Characteristics

The operation conditions of a plant in some cases change the process noise environment. It is desirable to collect data as close as possible to the original baseline condition. Table 5-16 provides typical information on the sensitivity of the response time and RMS amplitude of the sample set of process sensors to evaluate the effects of changes in power and the life of the core.

TABLE 5-16

SENSORS	RESPONSE TIME (MS) POWER		RMS UNITS		RESPONSE TIME CYCLE LIFE		RMS UNITS CYCLE LIFE	
	60%	100%	60%	100%	BOL	EOL	BOL	EOL
Temperature Hot Leg	315	298	00.9	.14	.315	309	.15	.13
Temperature Cold Leg	382	333	.060	.10	.34	340	.09	.10
Reactor Coolant Flow	304	274	374	436	288	327	.40	.45
Steam Flow	871	723	10.6x10	32x10	768	790	40x10	36.5x10
Steam Generator Level	829	567	.56	1.18	523	453	1.33	1.14
Steam Pressure	40	24	.37	1.30	9	10	1.40	1.45
Turbine Pressure	--	--	--	--	13	14	2160	100
Pressurizer Pressure	1307	895	.29	.12	1417	1172	.13	.11
Pressurizer Level	825	723	.032	.036	226	326	.040	.018

Normally, the response times of the RTD's and RC flow sensors are not significantly effected by changes in power level or life of the core cycle. The RMS of the RTD is normally proportional to power because the temperature process noise is related to power, but the frequency response spectrum characteristics remain similar. The hot leg RTD's RMS amplitude normally decreases throughout the core cycle as the power shape flattens with burnup but frequency content of the process noise remains the same.

Other processes such as steam pressures, steam generator level, steam flow, pressurizer pressure, pressurizer level which are related to power do effect the bandwidth of the process noise. When performing response time measurements, the plant conditions should be as close to the baseline as possible. The pressurizer signal normally has a high ratio of low frequency to high frequency noise at lower powers which appears to reduce the response time and increase the RMS amplitude.

Process Instrument Location Variations

The channel to channel variation for the same variable has generally similar spectral frequency content with minor variations in amplitudes and location of resonant peaks. These variations are true for both instruments in the same loop and different loops. The small differences are probably related to different impulse line arrangements in the plant.

Changing the steam generator level transmitter from a Barton 384 to a Barton 764 and the pressurizer pressure from a Barton 393 to a Barton 763 did not significantly change the frequency

content of the PSD. This indicates that the process noise is bandlimited for the two sensors as discussed earlier.

If the process noise was not band limited, the PSD signature would be slightly different in the higher frequency range since the sensor intermake are different.

Plant to Plant Variations

Appendix A contains samples of PSD specta from a Westinghouse 3 loop plant operating at 100% power. Table 5-17 is a comparison between the two plants of average response times and RMS amplitude for similar process variables.

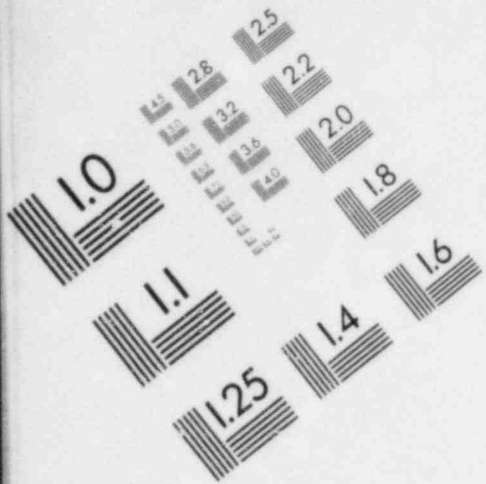
TABLE 5-17

SENSOR	AVG. RESPONSE TIME (MS) 4-LOOP	3-LOOP	RMS AMPLITUDE RESPONSE X10-3 UNITS 4-LOOP	3-LOOP
Reactor Coolant Flow	309	28	.43	2.49
Steam Generator Level	563	970	1.10	1.20
Steam Pressure	16.7	10	1.50	1.40
Pressurizer Pressure	1222	650	.16	.15
Pressurizer Level	331	895	.035	.050

Even though the response times are different, the characteristic PSD spectral shapes are very similar with the exception of the Reactor Coolant Flow. (Example Appendix A, Figure 1 and Figure 75.) The spectrum a has larger noise bandwidth by factor of 10 and has a resonant peak at approximately 9 Hz. The wider bandwidth also accounts for the larger RMS amplitude at the 3-loop plant (Beaver Valley).

Detection of Abnormal Sensor

The usefulness of the noise monitoring technique was demonstrated while monitoring data on a pressurizer pressure sensor PT457. The response time calculated using the noise technique appears to be very large. Investigation of the time history of the signal indicated a negative step in the signal at random intervals. These steps would not be visible at the



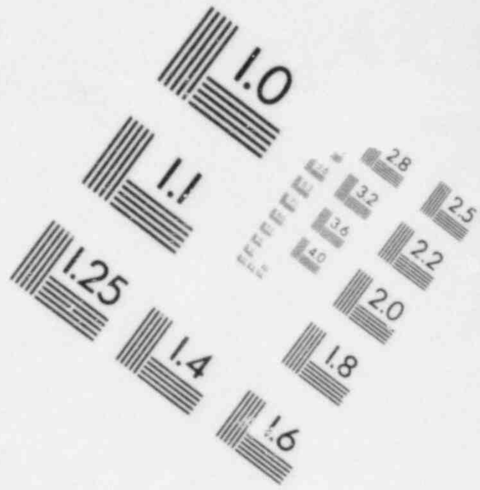
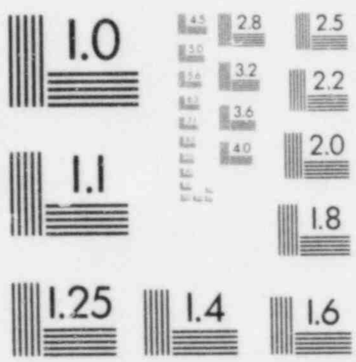
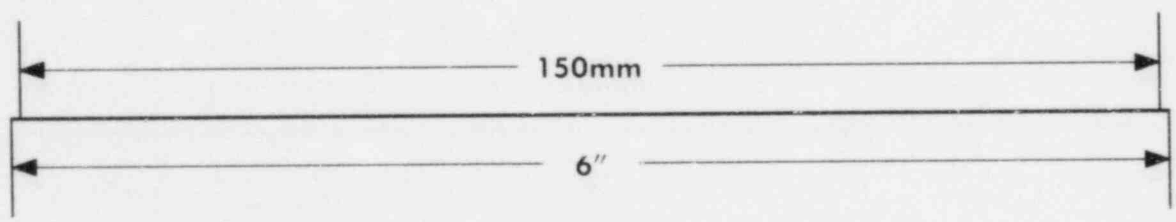
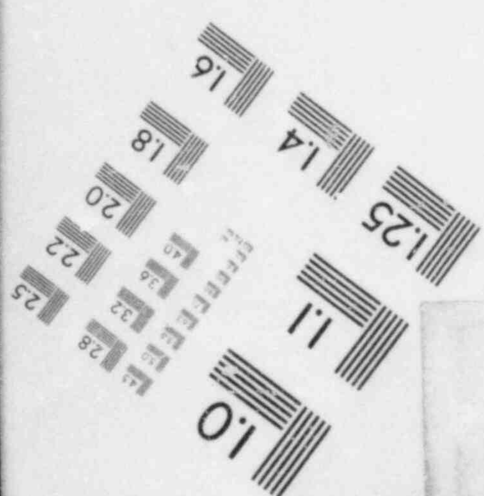


IMAGE EVALUATION TEST TARGET (MT-3)







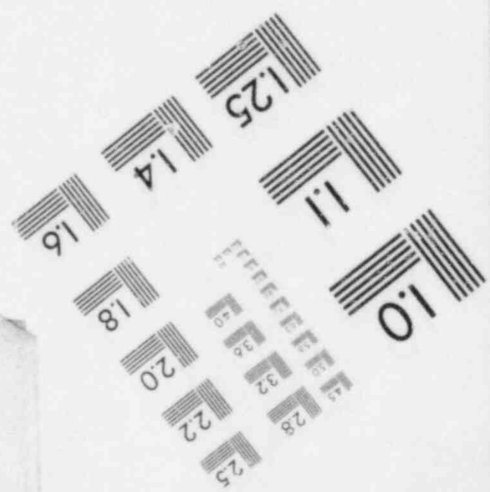


IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

control board since they were only a few psi. These are one sided peaks indicating non-linear effects which resulted in inaccurate PSD estimates. The problem was investigated by the plant I&C staff and was found to be a defective electrical component which was causing the intermittent signal.

<u>Other Test Programs</u>

A joint development program has been in place with Westinghouse, Framatome, Commissariat A L'Enerjie Atomique and Electricite De France from 1978 to 1982 to evaluate effect of degraded sensor response time in various test loops. Appendix D provides a table of test facilities.

6.0 RECOMMENDATIONS

The collection and analysis of process noise signatures generate a large amount of data. Data collected from several plants can provide a useful data base, from which many utilities could benefit, especially in the interpretation of signatures of degraded sensors. A data base of the PSD signature should be established.

- Process noise boundary values for each variable
- PSD's of different sensors measuring the same variable
- Response time and PSD signature variations of degraded sensor
- Type of degradation observed
- Role of change of sensor response time and PSD versus degradation
- Baseline reference sensor response times of all sensors at different plant conditions

The criteria for acceptability of sensor time responses determined by this method will be that the resulting time response will not show any significant degradation of sensor response time established from baseline data obtained during preoperational testing using other direct techniques. Significant degradation of response time means that the new values for the sensor when added to the remainder of the protection channel exceeds the total channel response time assumed in the accident analyses.

7.0 CONCLUSIONS

1. The use of the noise analysis technique for determining protection sensor response time in situ was demonstrated successfully. The procedure is very simple to implement and does not require the disconnection of the instrumentation or the removal of the sensor. Thus, this test can be performed on line and includes the instrument line as well as the sensor in the test.

2. The PSD's of pressure sensors contain a number of peaks which may be line resonances dependent on plant conditions. But the underlying baseline wideband PSD provides information about changes in the response time characteristics by detection of loss of frequency content. In the case for similar operating conditions, changes in relative amplitude of the peaks may be used to derive information about sensor degradation.

3. The process noise is stationary in both short term and long term for all process variables except for the pressurizer pressure which is very sensitive to low frequency noise where low frequency noise changes with plant conditions.

4. Although the process noise in most sensors is bandlimited, there is sufficient process noise in the system to monitor sensor degradation and meet the sensor response time verification requirements.

5. The best results for comparison of sensor response time values calculated using the noise technique are obtained when the

measurements are made at the same operating conditions.

6. The characteristics of the process noise are generally similar from channel to channel of the same process variable. This includes loop to loop and instruments in the same loop. The actual bandwidth of process noise may vary from plant to plant but general spectral shapes of the PSD curves are similar.

7. The sensitivity of the noise technique has been demonstrated by detection of intermittent electrical problems in a pressurizer pressure sensor.

8.0 REFERENCES

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3. A. Poujol, G. Zwingelstein, J. P. Jacquot, J. B. Beaubatie, C. Kramemer, W. Ciaramitaro, R. Gopal, "PWS 5.12 On Surveillance and Test of Sensors Surveillance of Resistance Thermometers Detectors - Final Report", March 11, 1983.

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7. R. L. Currie, C. W. Mayo, D. M. Stevens, "ARMA Sensor Response Time Analysis", EPRI Report NP-1166, December 1978.

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APPENDIX A

Figures

16	4-Loop Plant	9/16/81	100% Power, Pressurizer Level, PSD
17	4-Loop Plant	6/28/77	100% Power, Temperature, Hot Leg, PSD
18	4-Loop Plant	12/16/77	60% Power, Temperature, Hot Leg, PSD
19	4-Loop Plant	12/19/77	95% Power, Temperature, Hot Leg, PSD
20	4-Loop Plant	2/14/78	95% Power, Temperature, Hot Leg, PSD
21	4-Loop Plant	2/20/79	100% Power, Temperature, Hot Leg, PSD
22	4-Loop Plant	10/15/80	100% Power, Temperature, Hot Leg, PSD
23	4-Loop Plant	9/16/81	100% Power, Temperature, Hot Leg, PSD
24	4-Loop Plant	4/7/81	100% Power, Temperature, Hot Leg, PSD
25	4-Loop Plant	6/28/77	100% Power, Temperature, Cold Leg, PSD
26	4-Loop Plant	12/16/77	60% Power, Temperature, Cold Leg, PSD
27	4-Loop Plant	12/19/77	95% Power, Temperature, Cold Leg, PSD
28	4-Loop Plant	2/14/78	95% Power, Temperature, Cold Leg, PSD
29	4-Loop Plant	2/20/79	100% Power, Temperature, Cold Leg, PSD
30	4-Loop Plant	10/15/80	100% Power, Temperature, Cold Leg, PSD
31	4-Loop Plant	4/7/81	100% Power, Temperature, Cold Leg, PSD
32	4-Loop Plant	9/16/81	100% Power, Temperature, Hot Leg, PSD
33	4-Loop Plant	6/28/77	100% Power, Reactor Coolant Flow, PSD

34	4-Loop Plant	12/16/77	60% Power, Reactor Coolant Flow, PSD
35	4-Loop Plant	12/19/77	95% Power, Reactor Coolant Flow, PSD
36	4-Loop Plant	2/14/78	95% Power, Reactor Coolant Flow, PSD
37	4-Loop Plant	2/20/79	100% Power, Reactor Coolant Flow, PSD
38	4-Loop Plant	10/15/80	100% Power, Reactor Coolant Flow, PSD
39	4-Loop Plant	4/7/81	100% Power, Reactor Coolant Flow, PSD
40	4-Loop Plant	9/16/81	100% Power, Reactor Coolant Flow, PSD
41	4-Loop Plant	6/28/77	100% Power, Steam Generator Level, PSD
42	4-Loop Plant	12/16/77	60% Power, Steam Generator Level, PSD
43	4-Loop Plant	12/19/77	95% Power, Steam Generator Level, PSD
44	4-Loop Plant	2/14/78	95% Power, Steam Generator Level, PSD
45	4-Loop Plant	2/20/79	100% Power, Steam Generator Level, PSD
46	4-Loop Plant	10/15/80	100% Power, Steam Generator Level, PSD
47	4-Loop Plant	4/7/81	100% Power, Steam Generator Level, PSD
48	4-Loop Plant	9/16/81	100% Power, Steam Generator Level, PSD
49	4-Loop Plant	6/28/77	100% Power, Steam Line Pressure, PSD
50	4-Loop Plant	12/10/77	60% Power, Steam Line Pressure, PSD
51	4-Loop Plant	12/19/77	95% Power, Steam Line Pressure, PSD

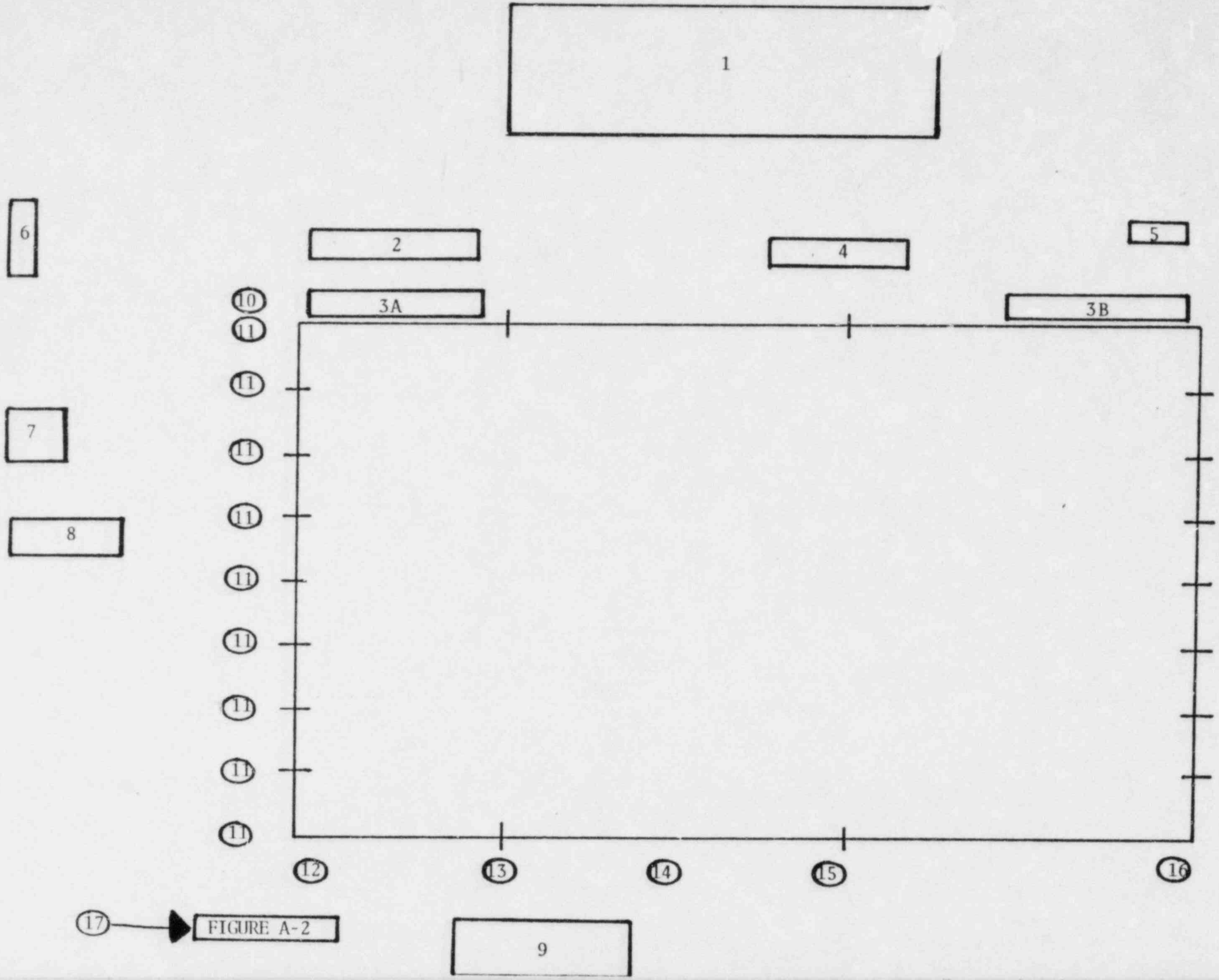
52	4-Loop Plant	12/14/78	95% Power, Steam Line Pressure, PSD
53	4-Loop Plant	2/20/79	100% Power, Steam Line Pressure, PSD
54	4-Loop Plant	10/15/80	100% Power, Steam Line Pressure, PSD
55	4-Loop Plant	4/7/81	100% Power, Steam Line Pressure, PSD
56	4-Loop Plant	9/16/82	100% Power, Steam Flow Pressure, PSD
57	4-Loop Plant	6/28/77	100% Power, Steam Line PSD
58	4-Loop Plant	12/16/77	60% Power, Steam Flow, PSD
59	4-Loop Plant	12/19/77	95% Power, Steam Flow, PSD
60	4-Loop Plant	2/14/78	95% Power, Steam Flow, PSD
61	4-Loop Plant	2/20/79	100% Power, Steam Flow, PSD
62	4-Loop Plant	10/15/80	100% Power, Steam Flow, PSD
63	4-Loop Plant	4/7/81	100% Power, Steam Flow, RSD
64	4-Loop Plant	9/16/81	100% Power, Steam Flow, RSD
65	4-Loop Plant	2/20/79	100% Power, Steam Line Pressure, PSD
66	4-Loop Plant	10/15/80	100% Power, Steam Line Pressure, PSD
67	4-Loop Plant	4/7/81	100% Power, Steam Line Pressure, PSD
68	4-Loop Plant	9/16/82	100% Power, Steam Line Pressure, PSD
69	3-Loop Plant	3/17/78	100% Power, Reactor Coolant Flow III, PSD

70	3-Loop Plant	3/17/78	100% Power, Reactor Coolant Flow II, PSD
71	3-Loop Plant	3/17/78	100% Power, Reactor Coolant Flow II, PSD
72	3-Loop Plant	3/17/78	100% Power, Pressurizer Level, PSD
73	3-Loop Plant	3/17/78	100% Power, Pressurizer Level, PSD
74	3-Loop Plant	3/17/78	100% Power, Pressurizer Pressure, PSD
75	3-Loop Plant	3/17/78	100% Power, Pressurizer Pressure, PSD
76	3-Loop Plant	3/17/78	100% Power, Pressurizer Level, PSD
77	3-Loop Plant	3/17/78	100% Power, Pressurizer Pressure, PSD
78	3-Loop Plant	3/17/78	100% Power, Pressurizer Pressure, PSD
79	3-Loop Plant	3/17/78	100% Power, Pressurizer Level, PSD

LEGEND FOR FIGURE FORMAT

1. General Information
2. Engineering units for Channel "A" or "B"
3. I.D. for Channel "A" or "B"
4. Indicates units of the full scale. The physical readout indicated by the "E2" label is engineering units squared.
5. "VLG" indicates that the vertical axis is logarithmic. "C" indicates continuous data type.
6. Indicates channel of plot "A" or "B"
7. Averaging code "SU" for summation
   "64" for averages
8. Function Label
   "PSD" = Power Spectral Density
   "COH" = Coherence
9. General Information (Optional)
10. Indicates Units of vertical amplitude
11. dB marking in steps of 10 dB
12. Annotation for Channel A and maximum amplitude voltage "D" is for DC coupling.
13. Annotation for Channel B and maximum amplitude voltage "D" is for DC coupling
14. Trigger source Channel "A" or "B". The suffix, "/4", indicates the trigger level is 1/4 of the selected maximum amplitude.
15. "LGHZ" indicates that horizontal axis is logarithmic
16. Indicates horizontal range
17. Indicates Figure I.D. for this report

FIGURE A-1


1
2
3A
3B
4
5
6
7
8
9
10
11
12
13
14
15
16
17
FIGURE A-2

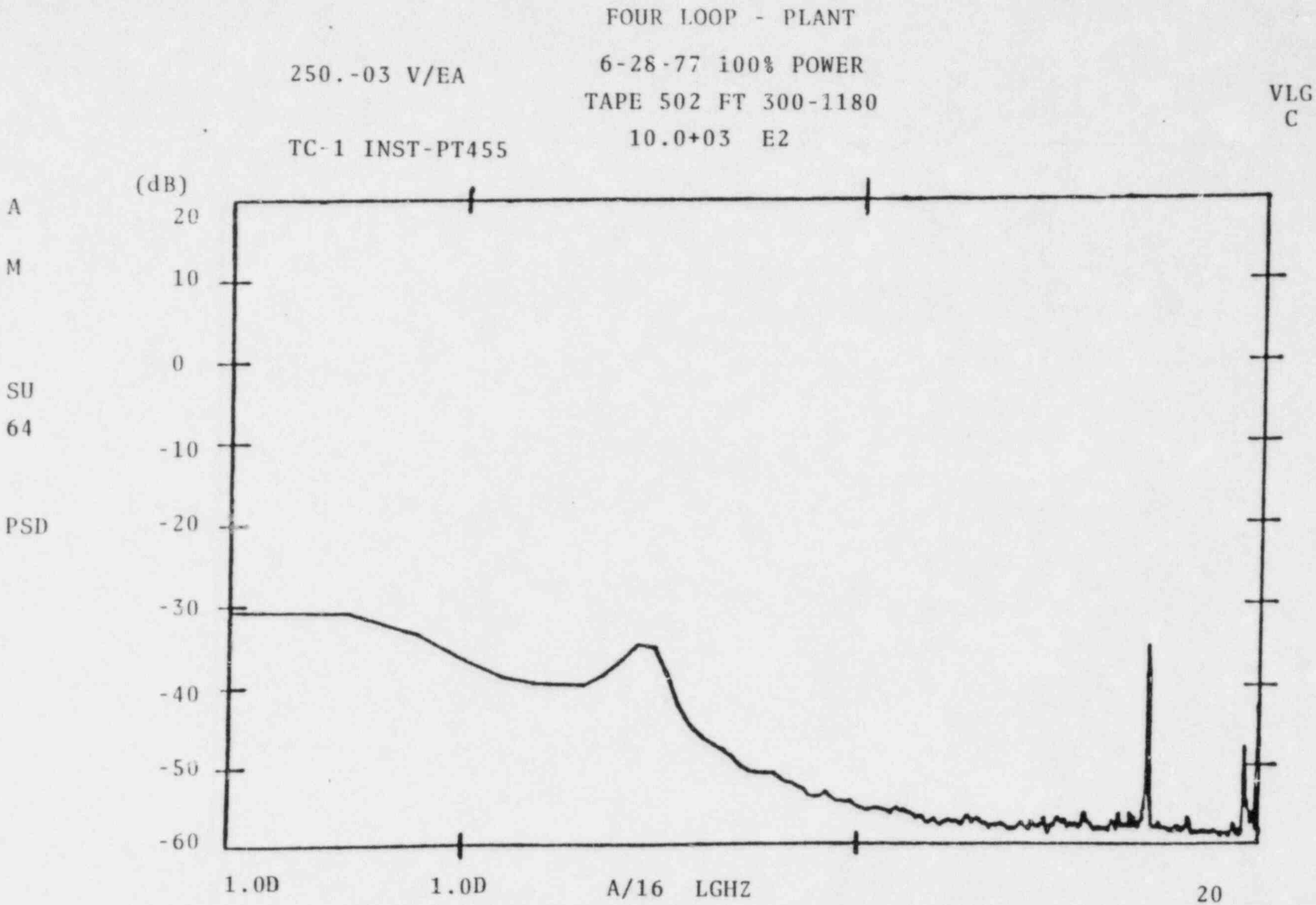


Figure 1:
6/28/77
100% Power
Pressurizer, Pressure, PSD

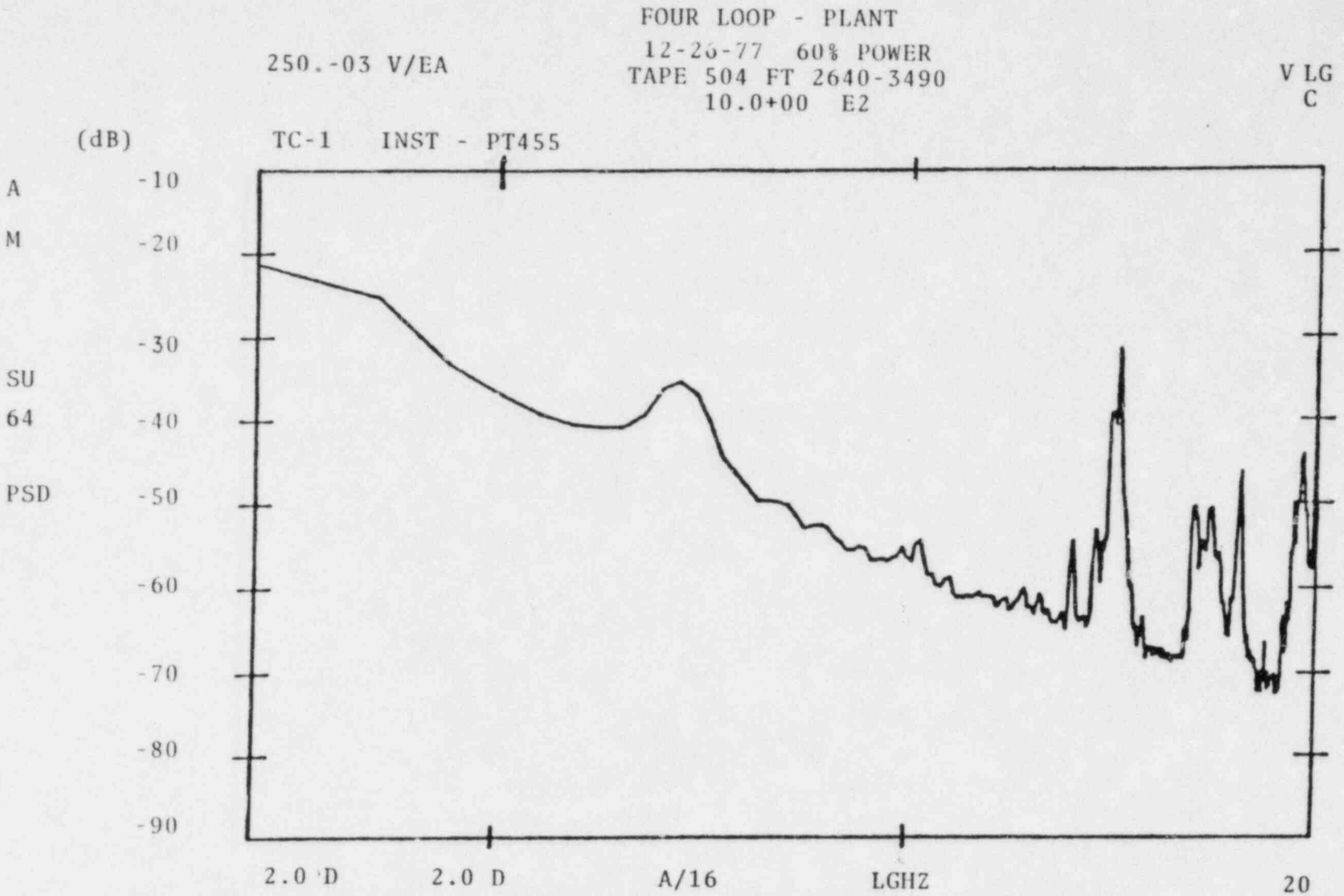


Figure 2:
12/16/77
60% Power
Pressurizer Pressure, PSD

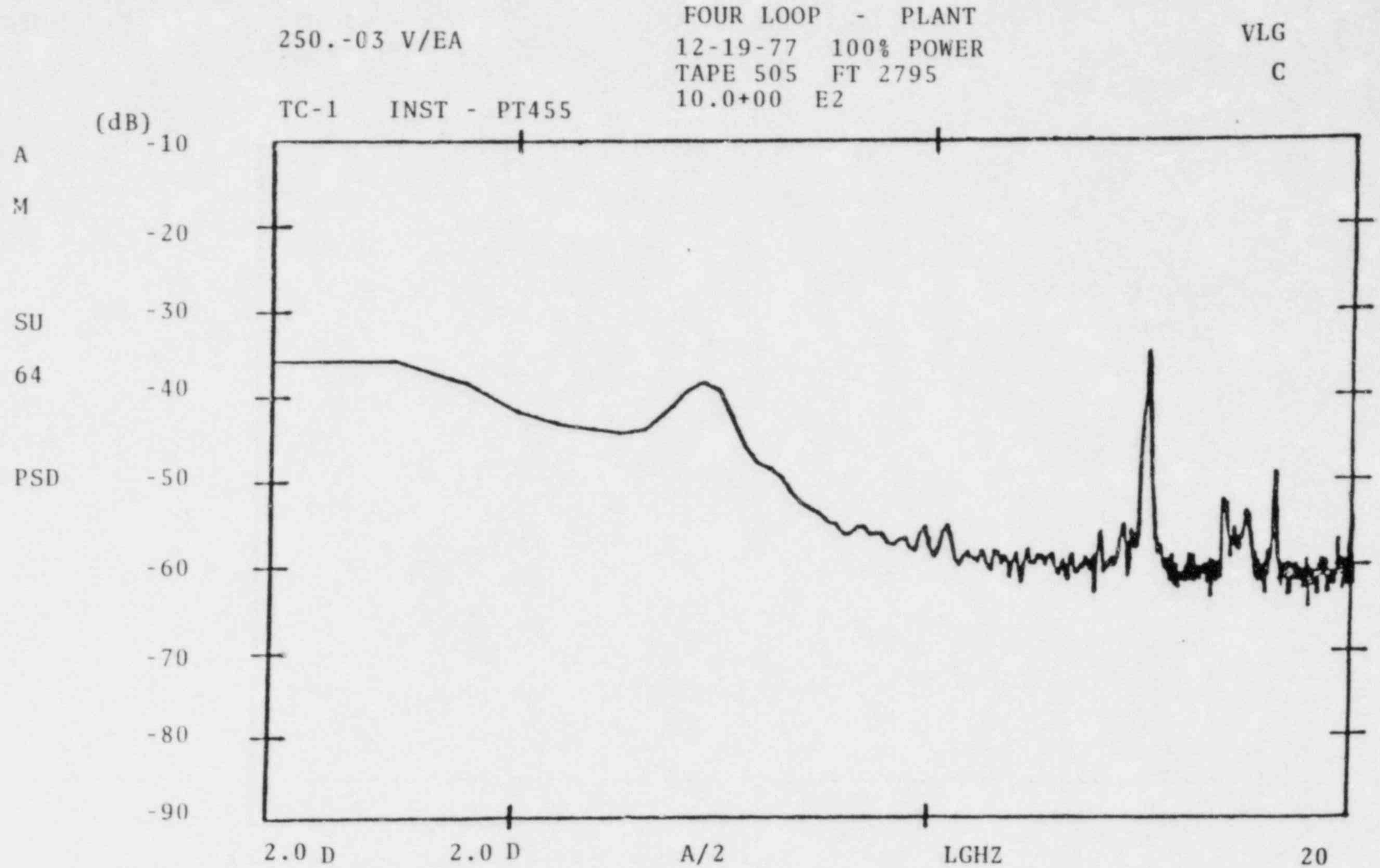


Figure 3:
12/19/77
100% Power
Pressurizer Pressure, PSD

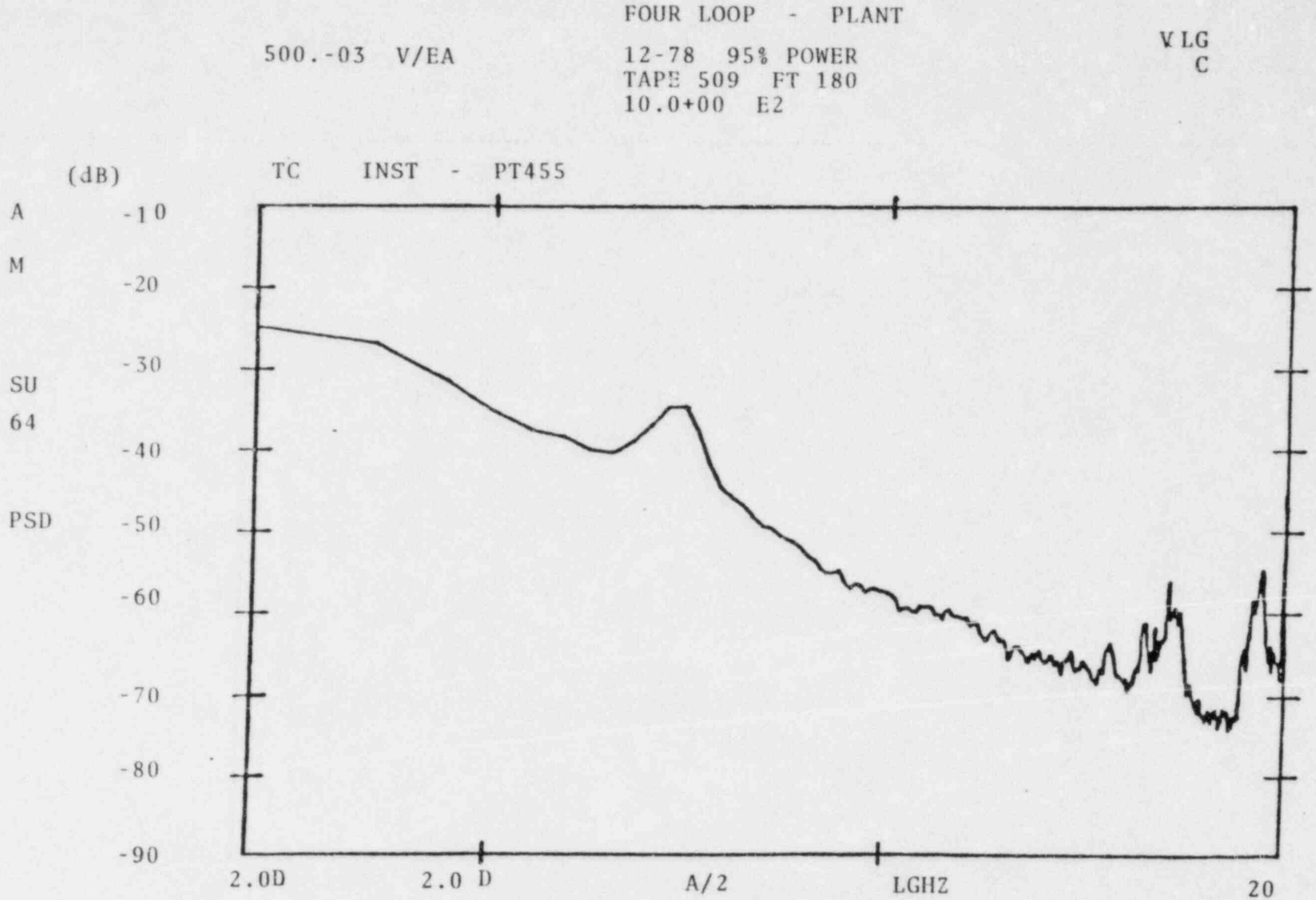


Figure 4:

12/78
95% Power
Pressurizer Pressure PSD

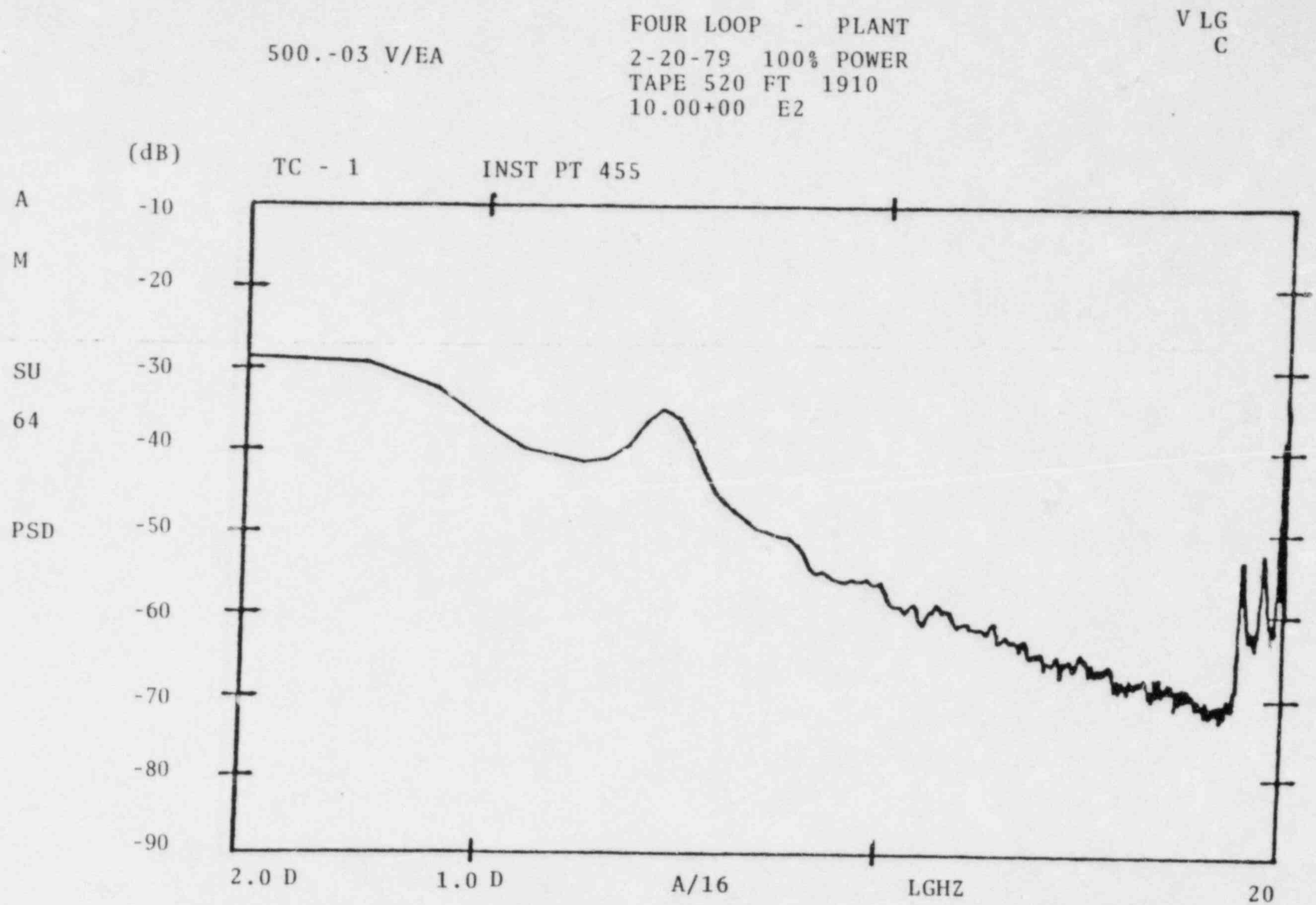


Figure 5:
2/20/79
100% Power
Pressurizer Pressure, PSD

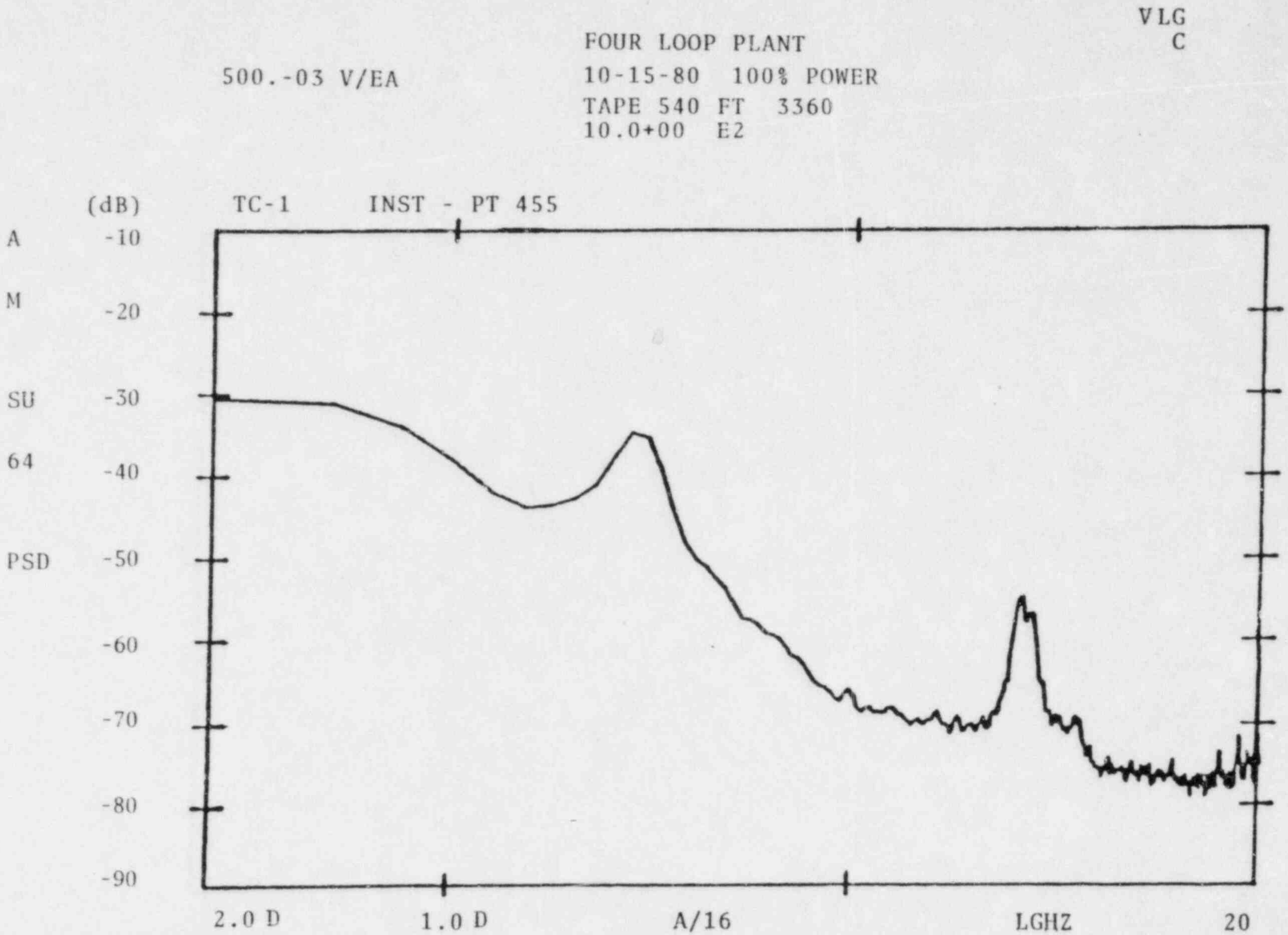


Figure 6:

12/78
95% Power
Pressurizer Pressure, PSD

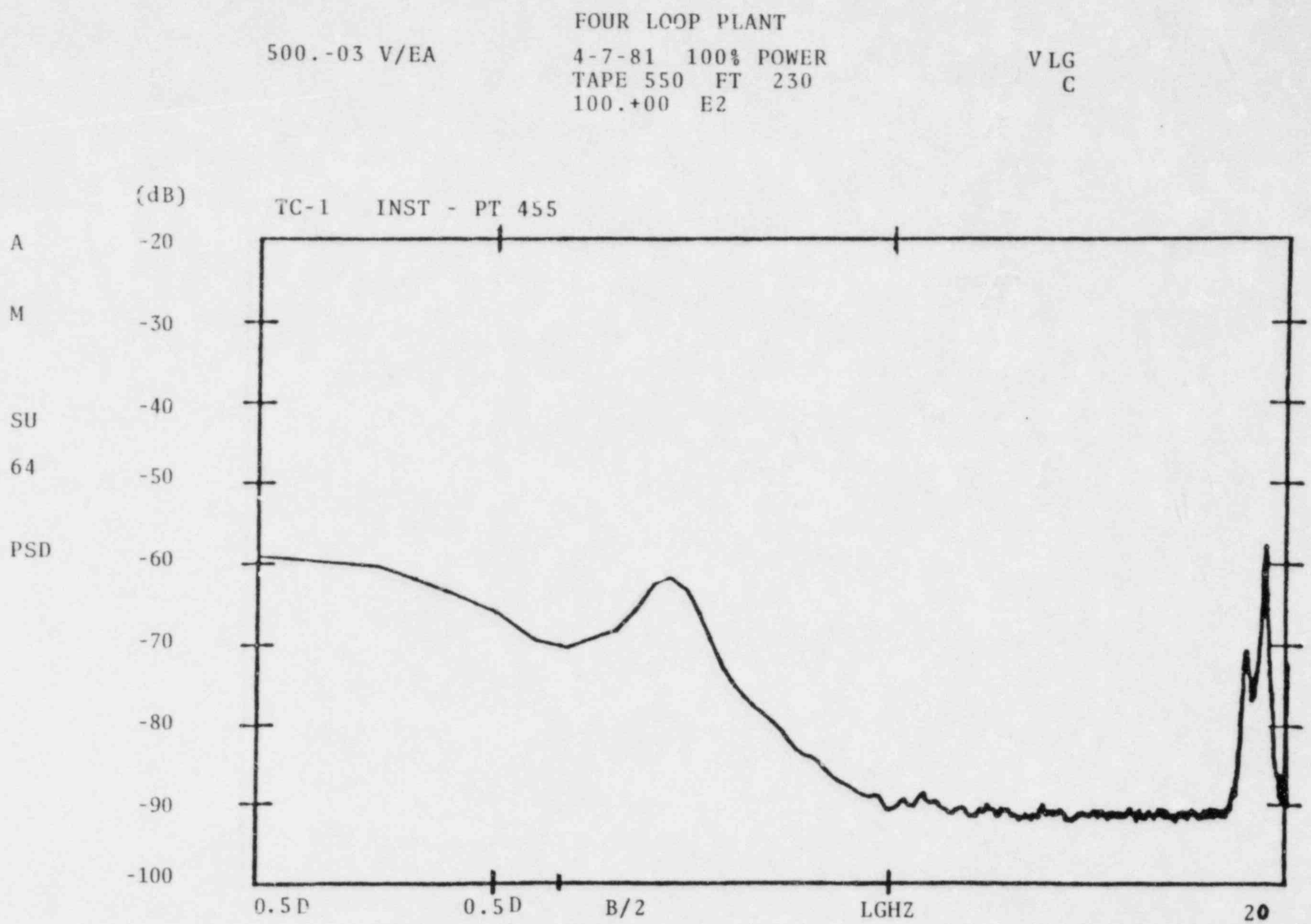


Figure 7: 4/7/81
100% Power
Pressurizer Pressure. PSD

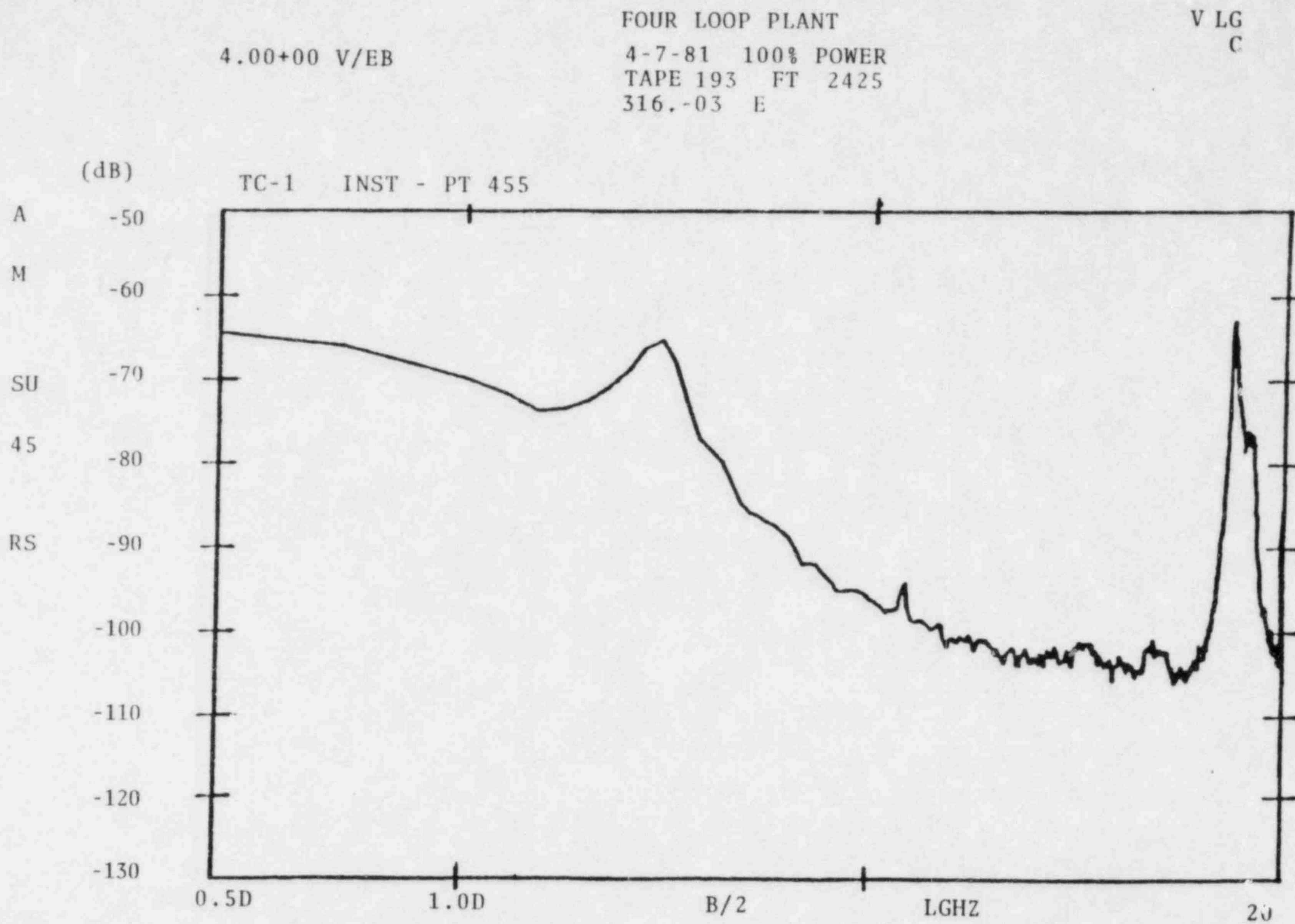


Figure 8:

4/7/81
100% Power
Pressurizer Pressure RS

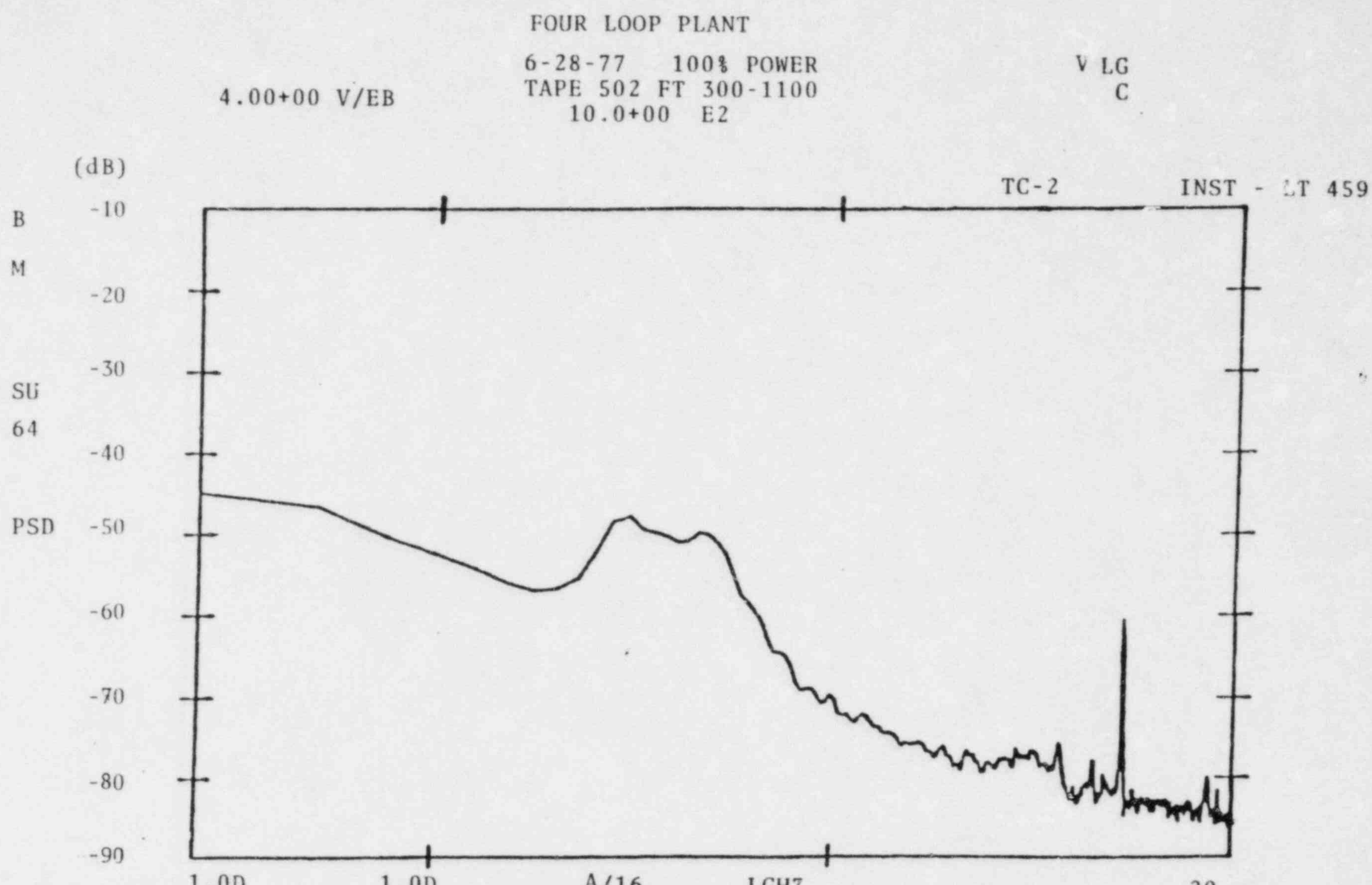


Figure 9:
6/28/77
100% Power,
Pressurizer Level, PSD

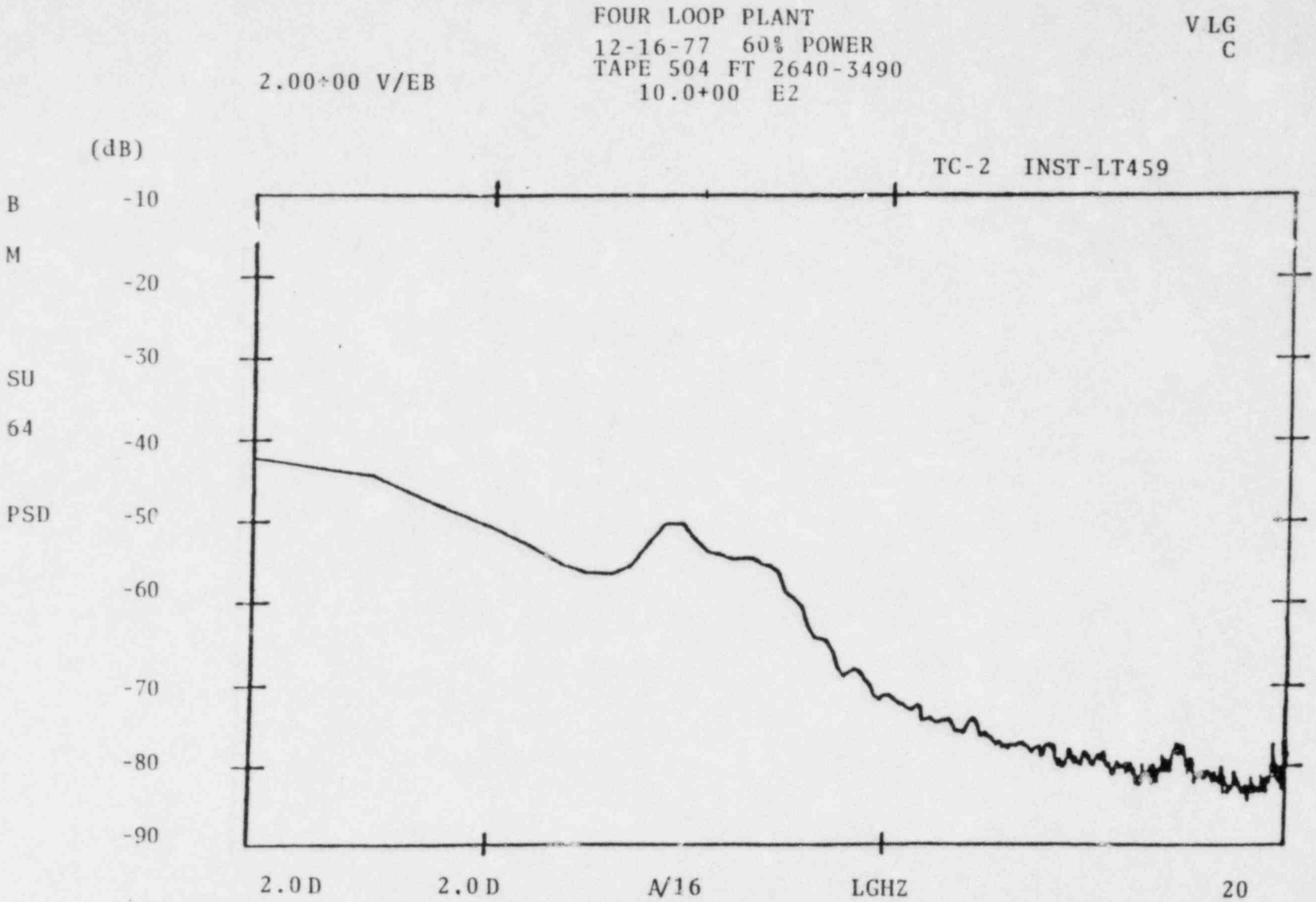


Figure 10:
12/16/77
60% Power
Pressurizer Level, PSD

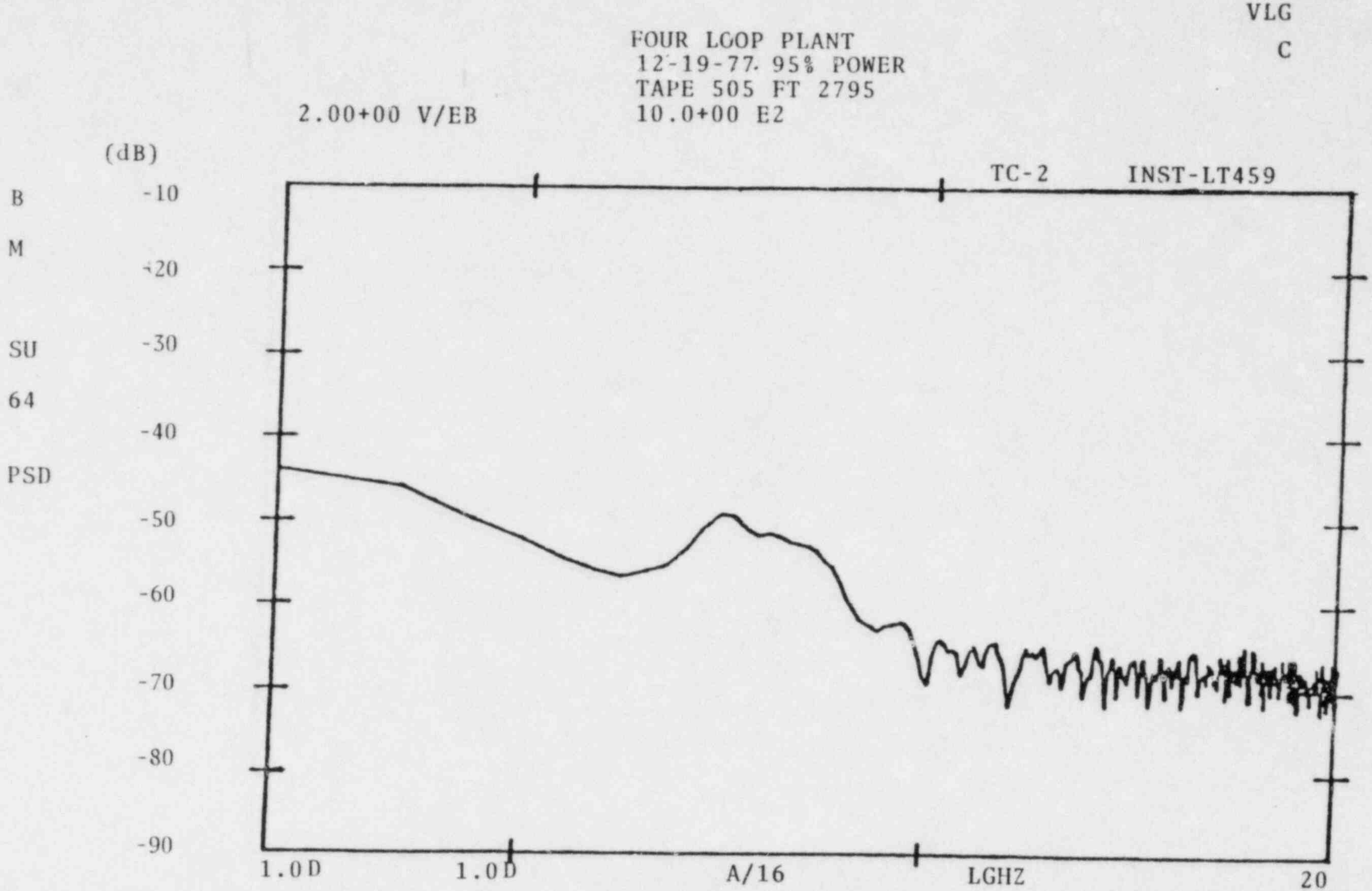


Figure 11:

12/19/77
95% Power
Pressurizer Level, PSD

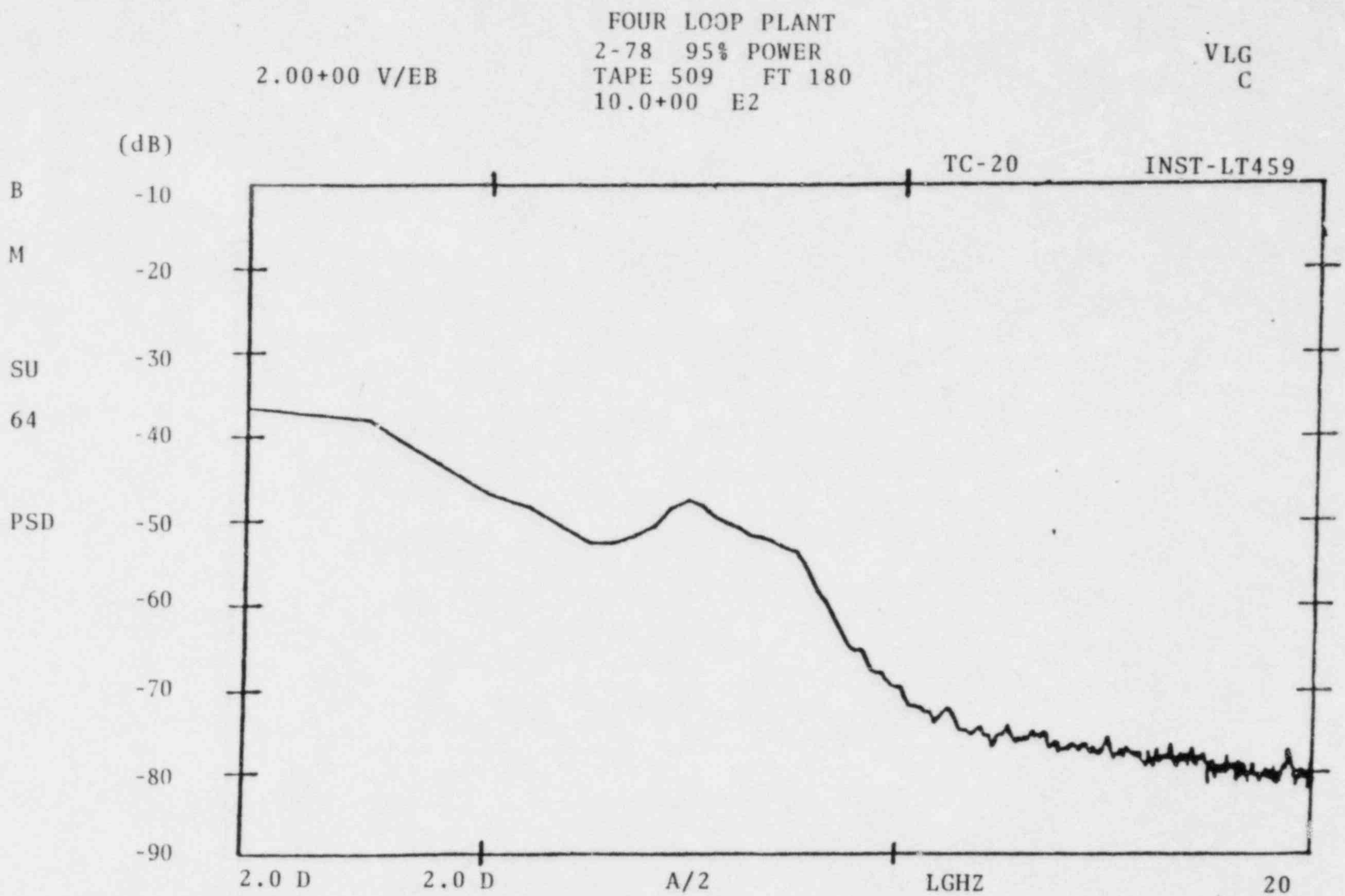


Figure 12:

12/78
95% Power
Pressurizer Level, PSD

VLG
C

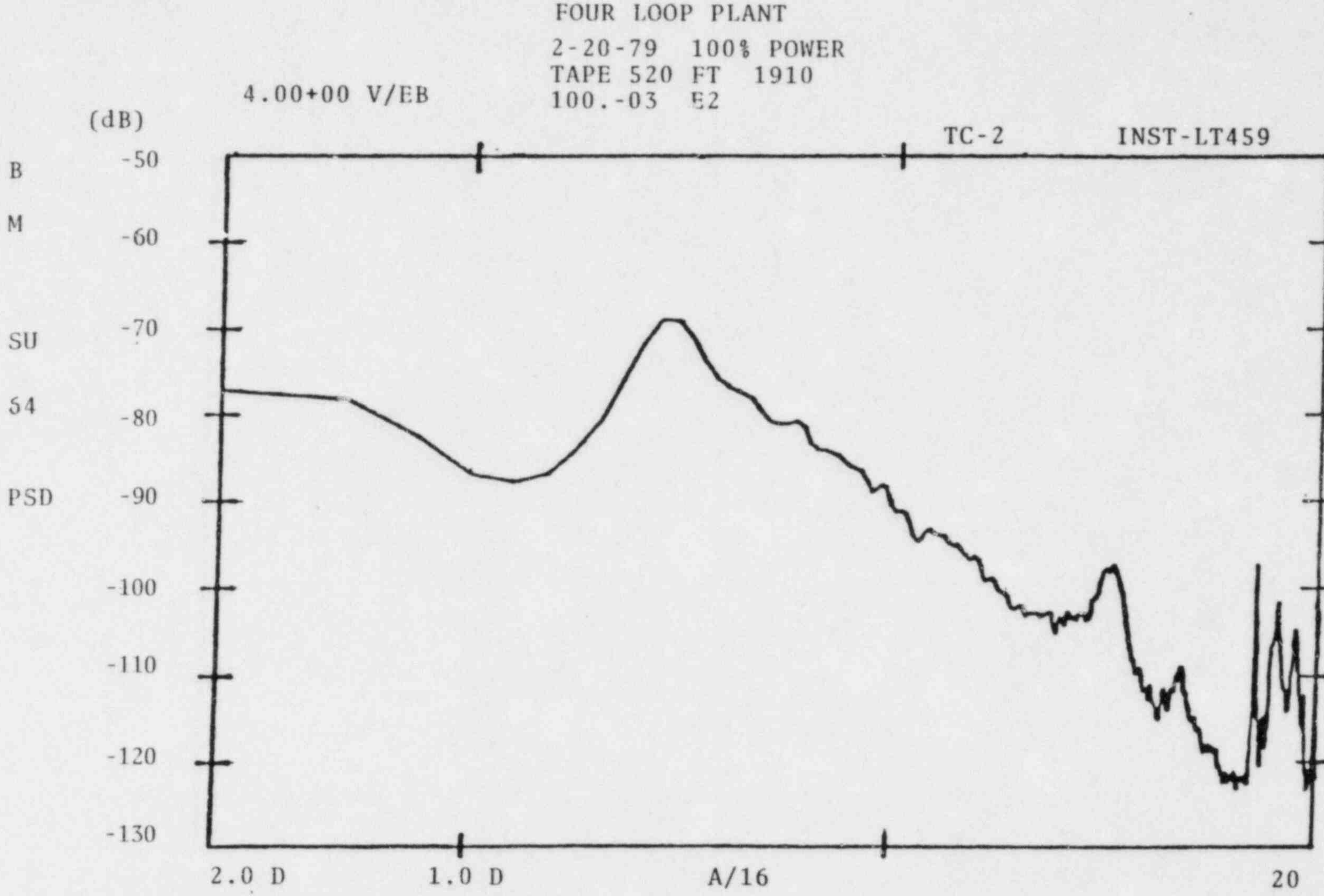


Figure 13:
2/20/79
100% Power.
Pressurizer Level PSD

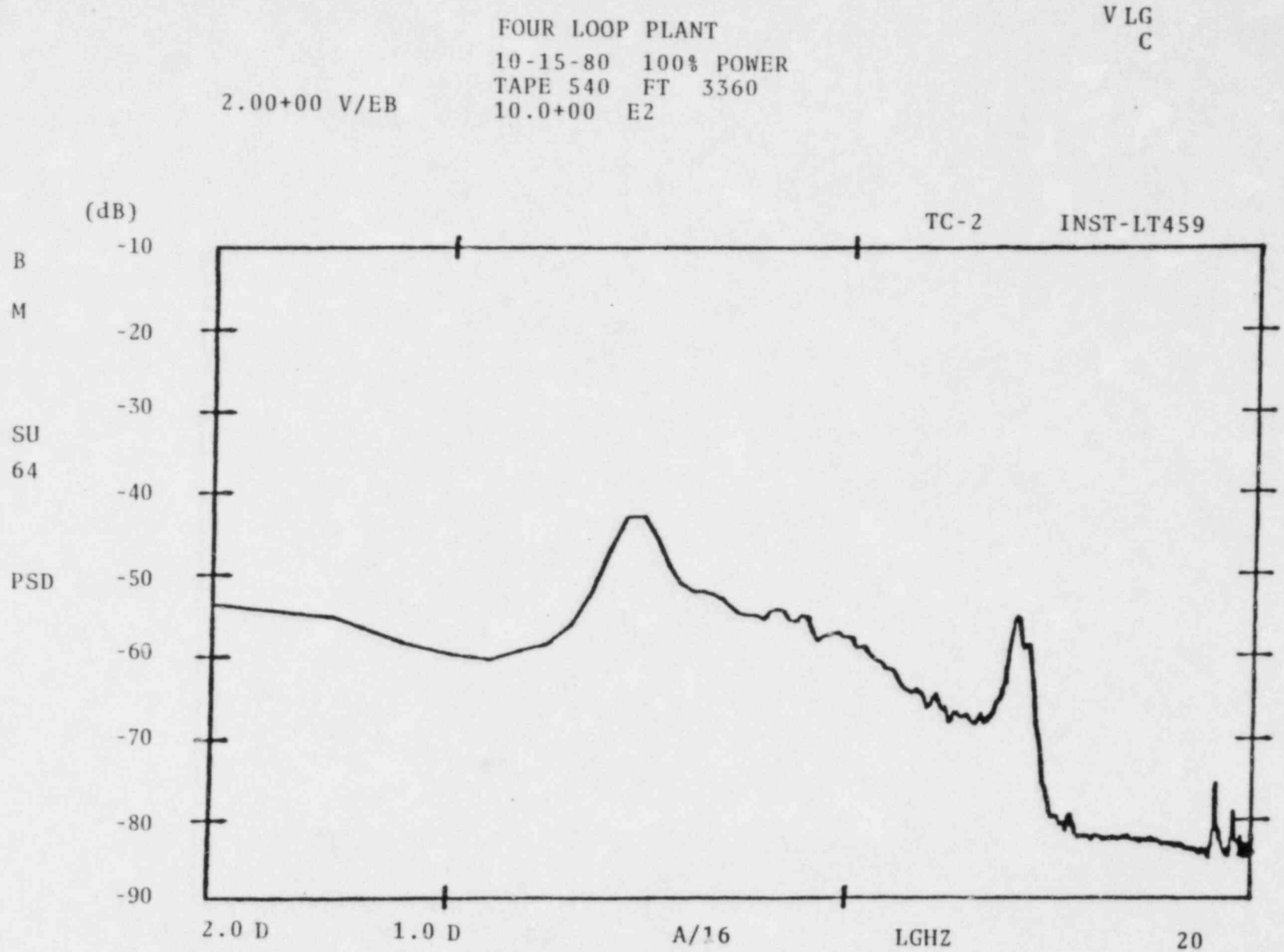


Figure 14:

10/15/80
100% Power
Pressurizer Level. PSD

FOUR LOOP PLANT

VLG
C

4-7-81 100% POWER
TAPE 550 FT 230

800.-03 V/EB

10.0 00 E2

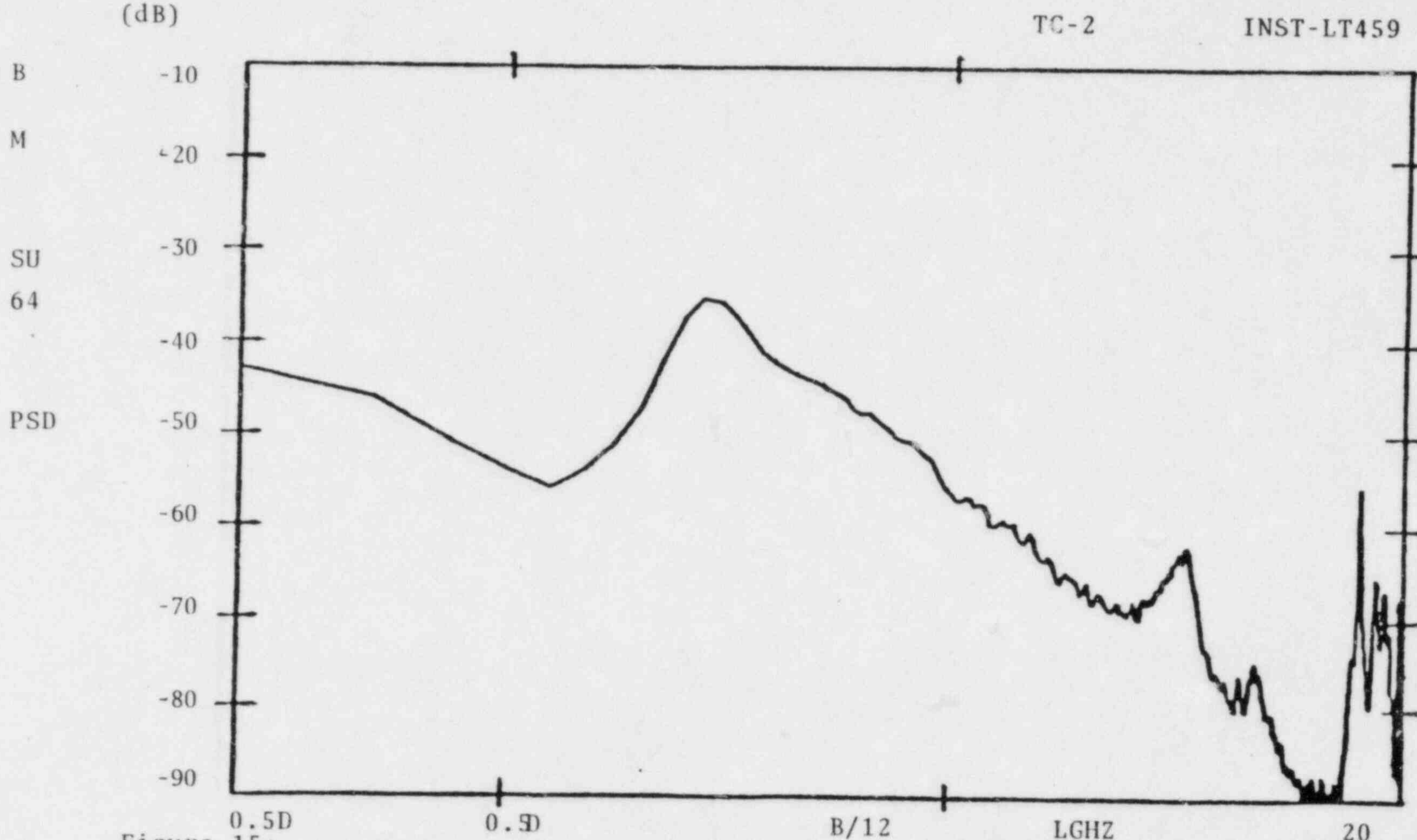


Figure 15: 4/7/81 100% Power, Pressurizer Level, PSD

VLG
C

FOUR LOOP PLANT

4.00+00 V/EB

9-16-81 100% POWER
TAPE 193 FT 2425
31.6-03 E2

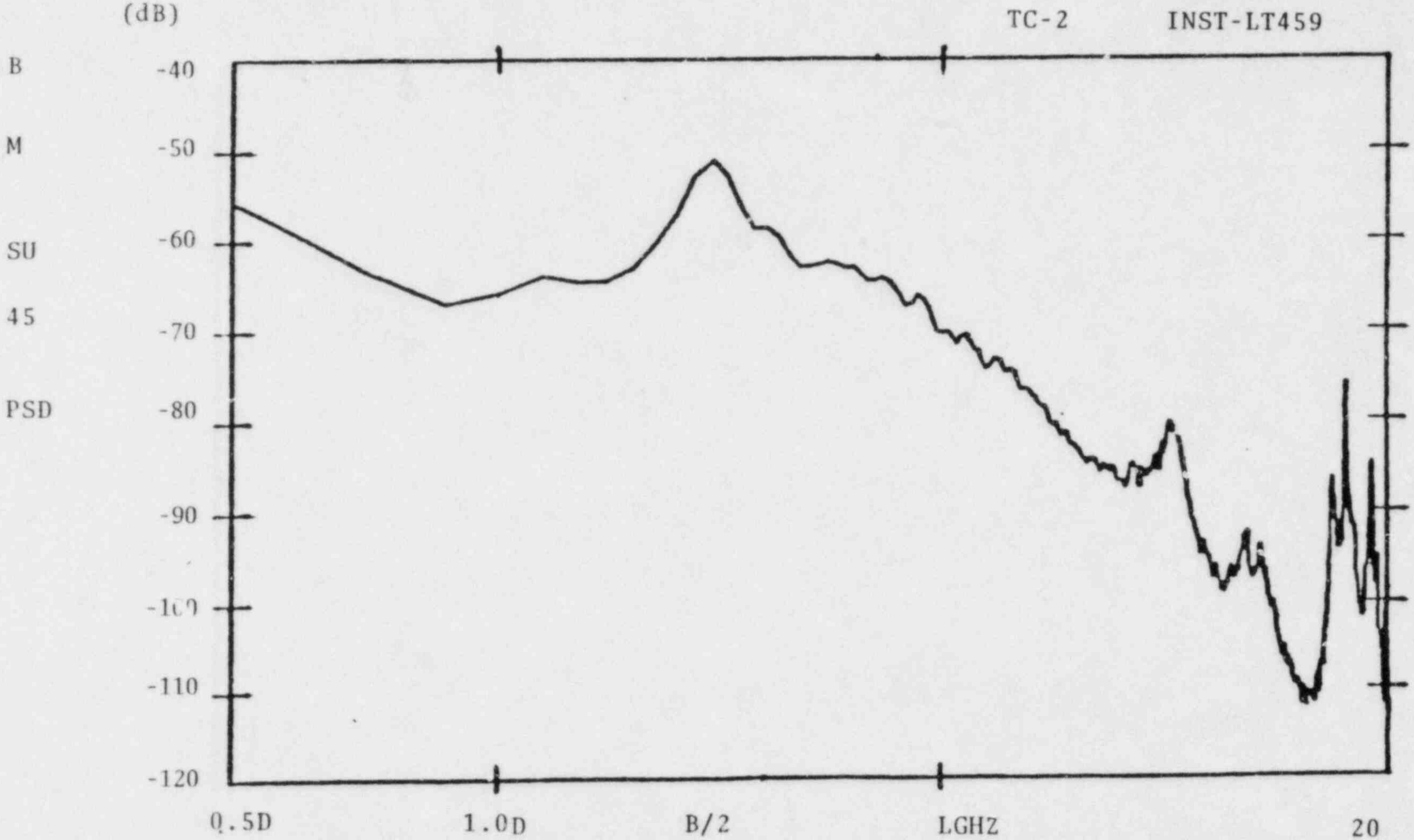


Figure 16:

9/16/83

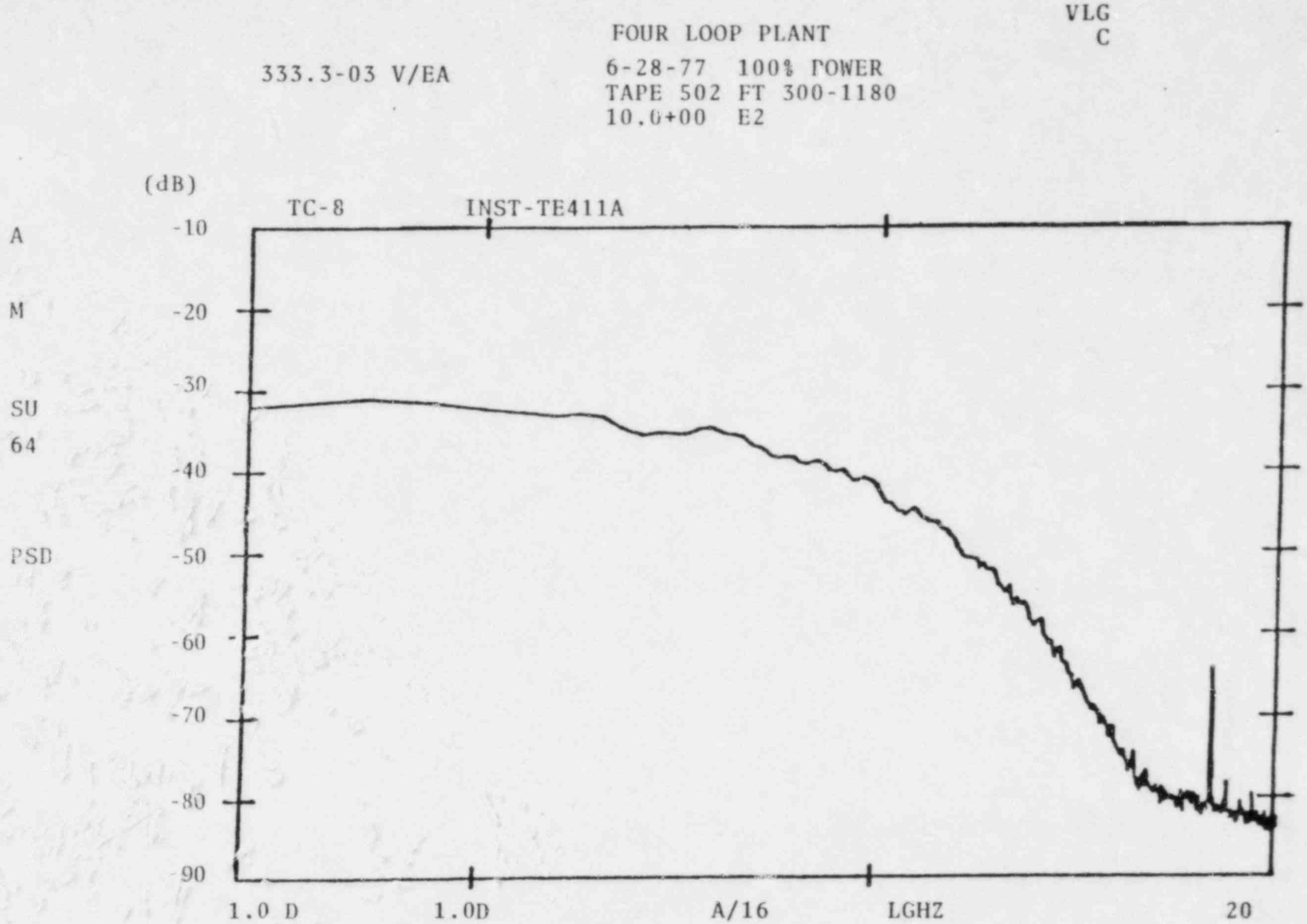


Figure 17:
6/28/77
100% Power
Temperature, Hot Leg, PSD

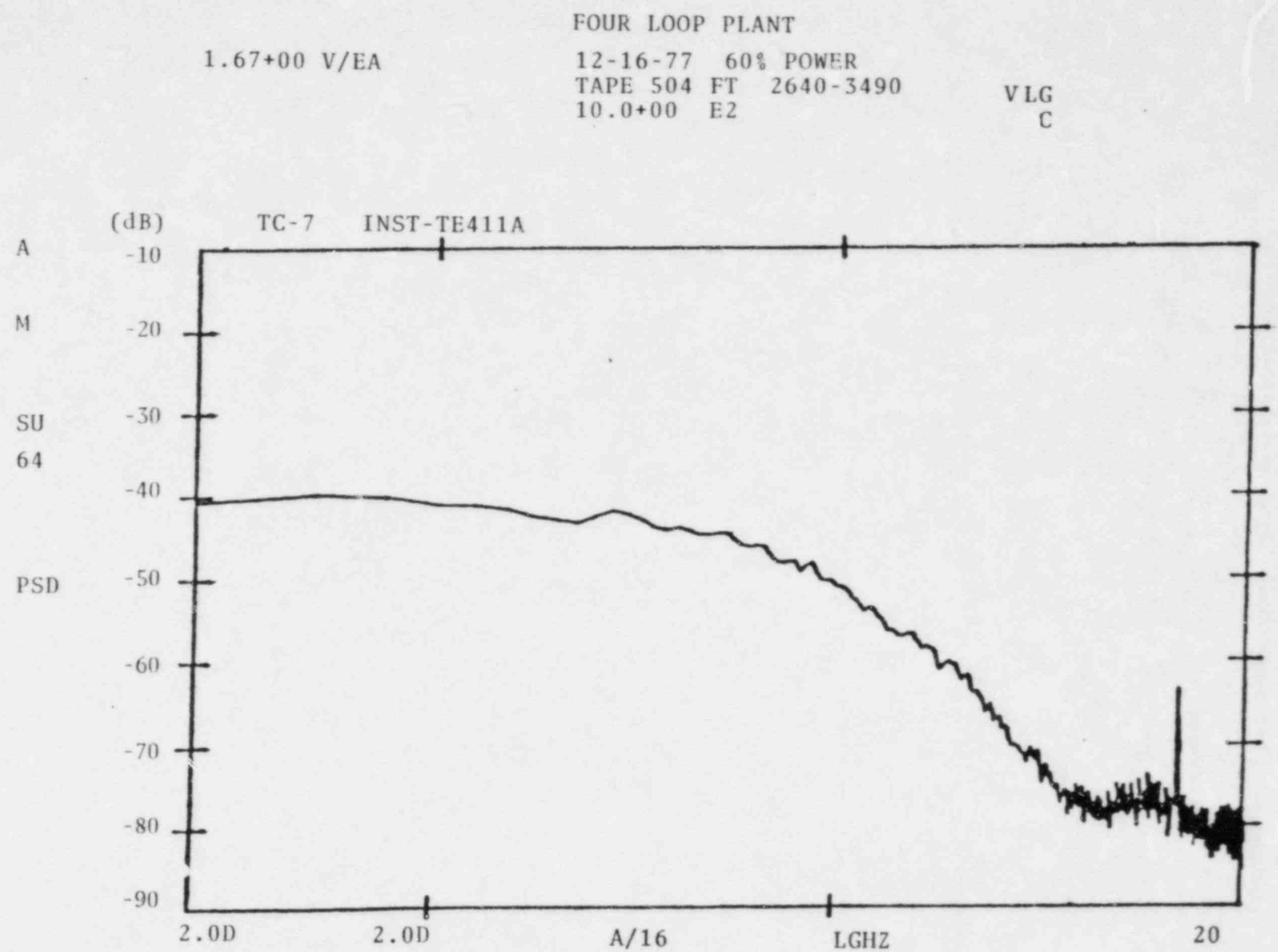


Figure 18:

12/16/77
60% Power
Temperature, Hot Leg, PSD

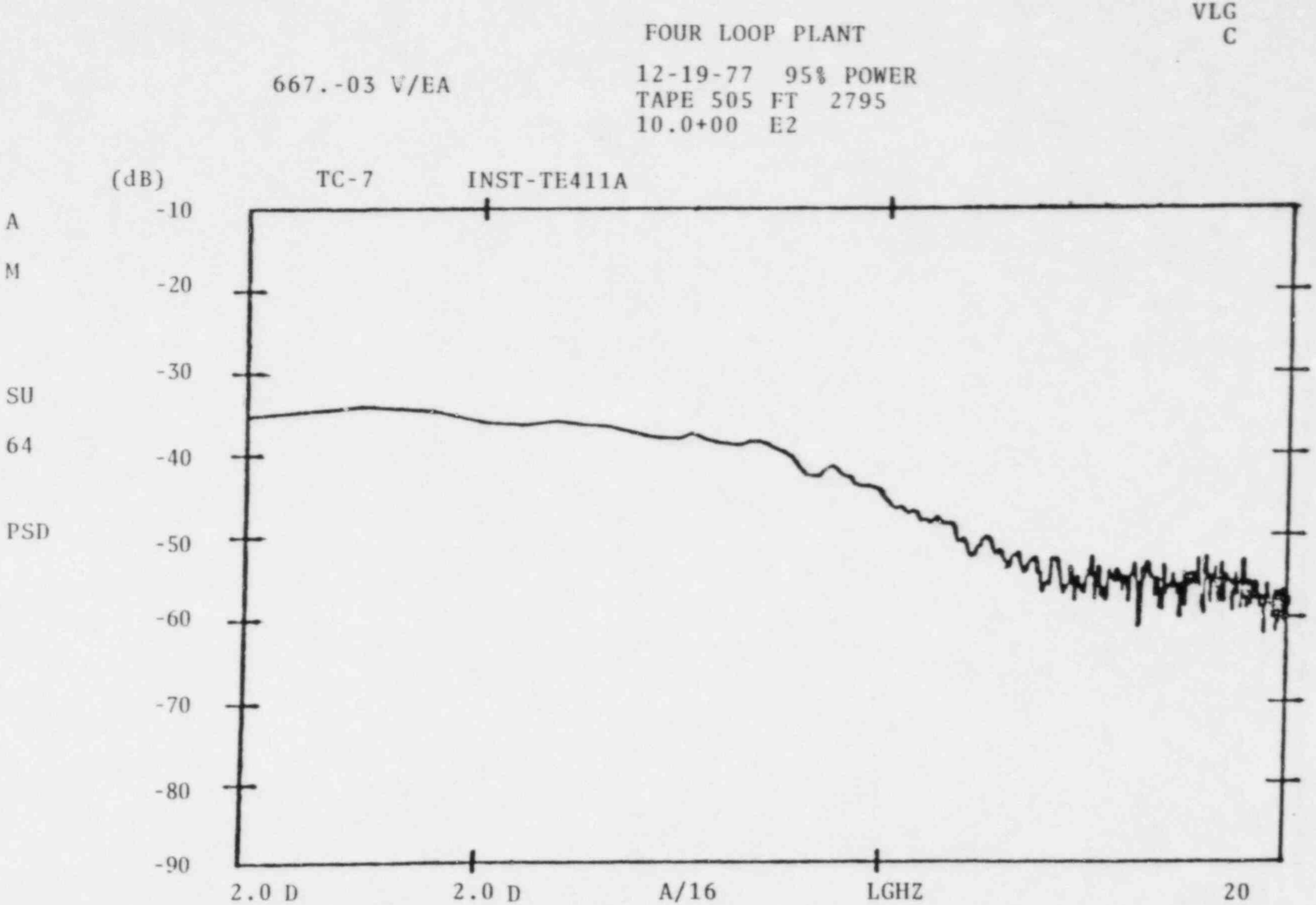


Figure 19:
12/19/77
95% Power
Temperature, Hot Leg, PSD

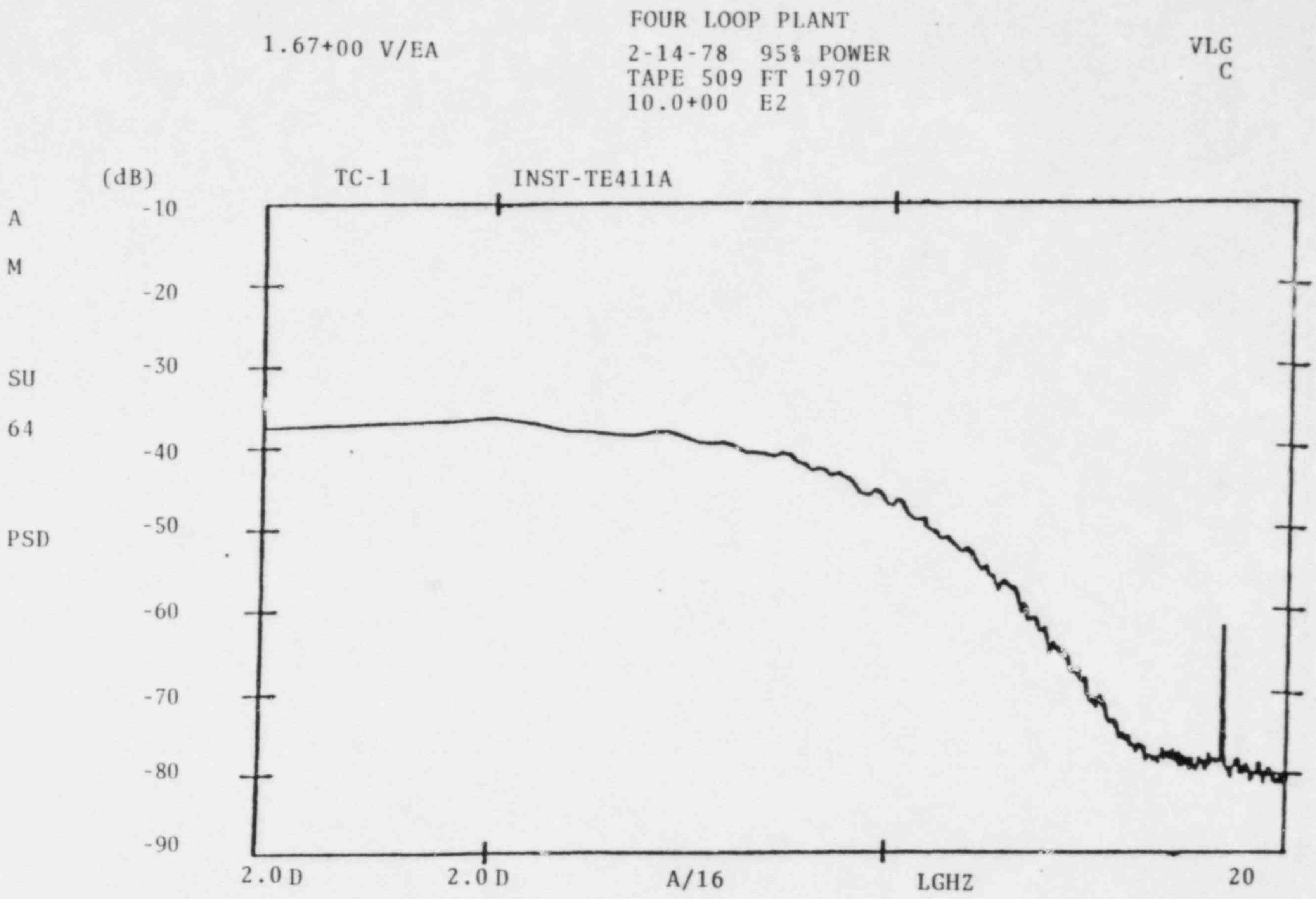


Figure 20: 2/14/83
95% Power
Temperature, Hot Leg, PSD .

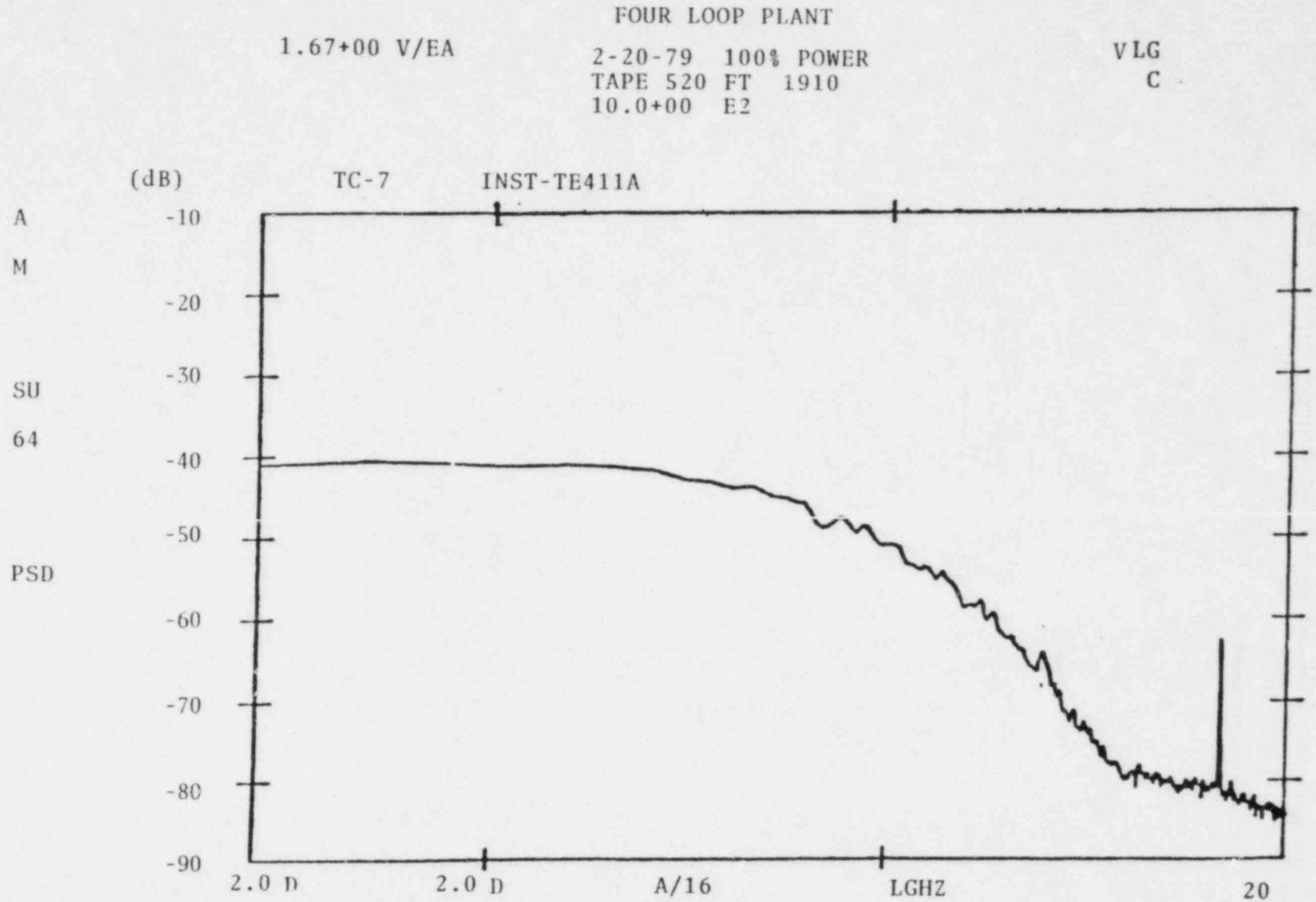


Figure 21:
2/20/79
100% Power
Temperature, Hot Leg, PSD

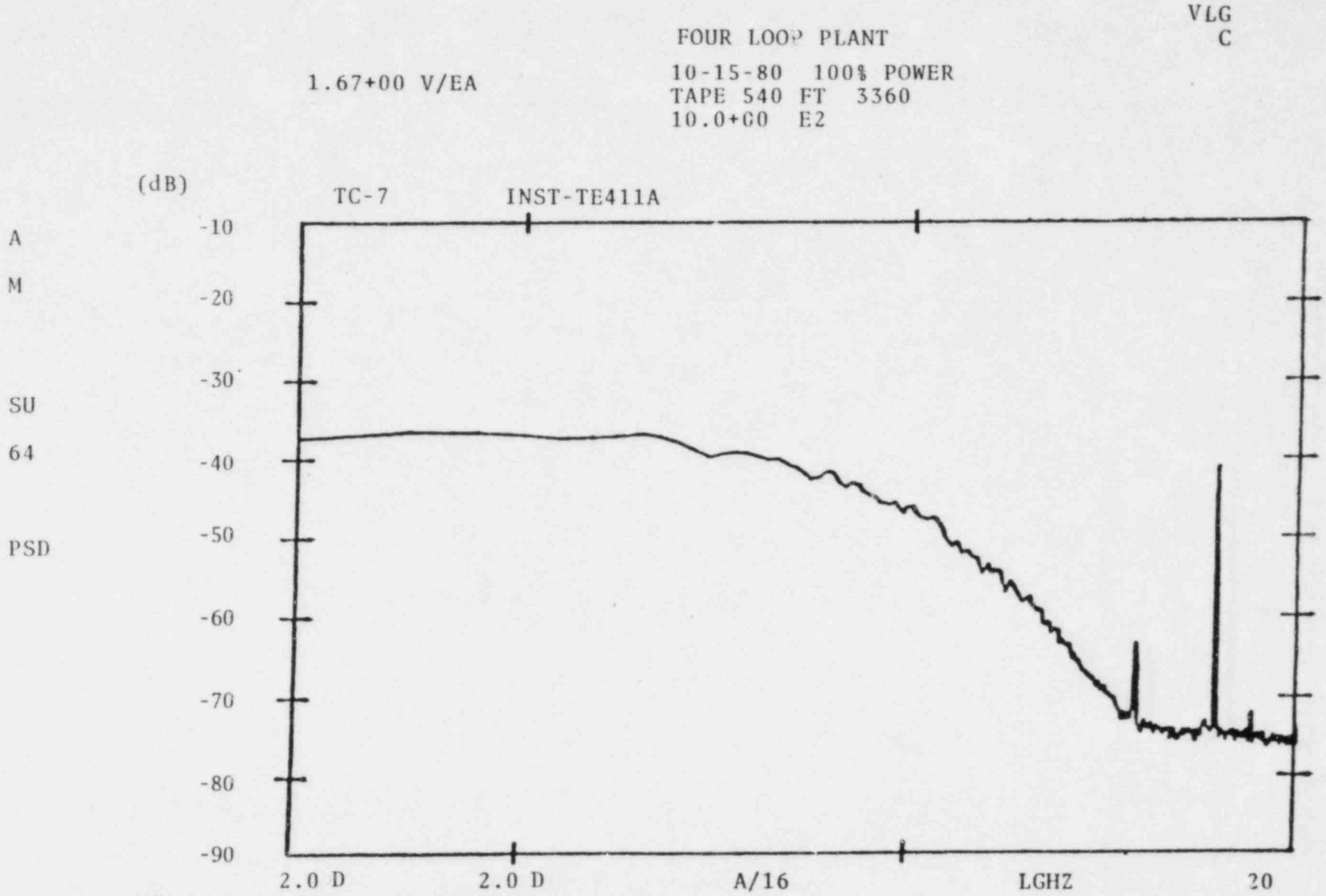


FIGURE 22: 10/15/80
100% Power
Temperature Hot Leg, PSD

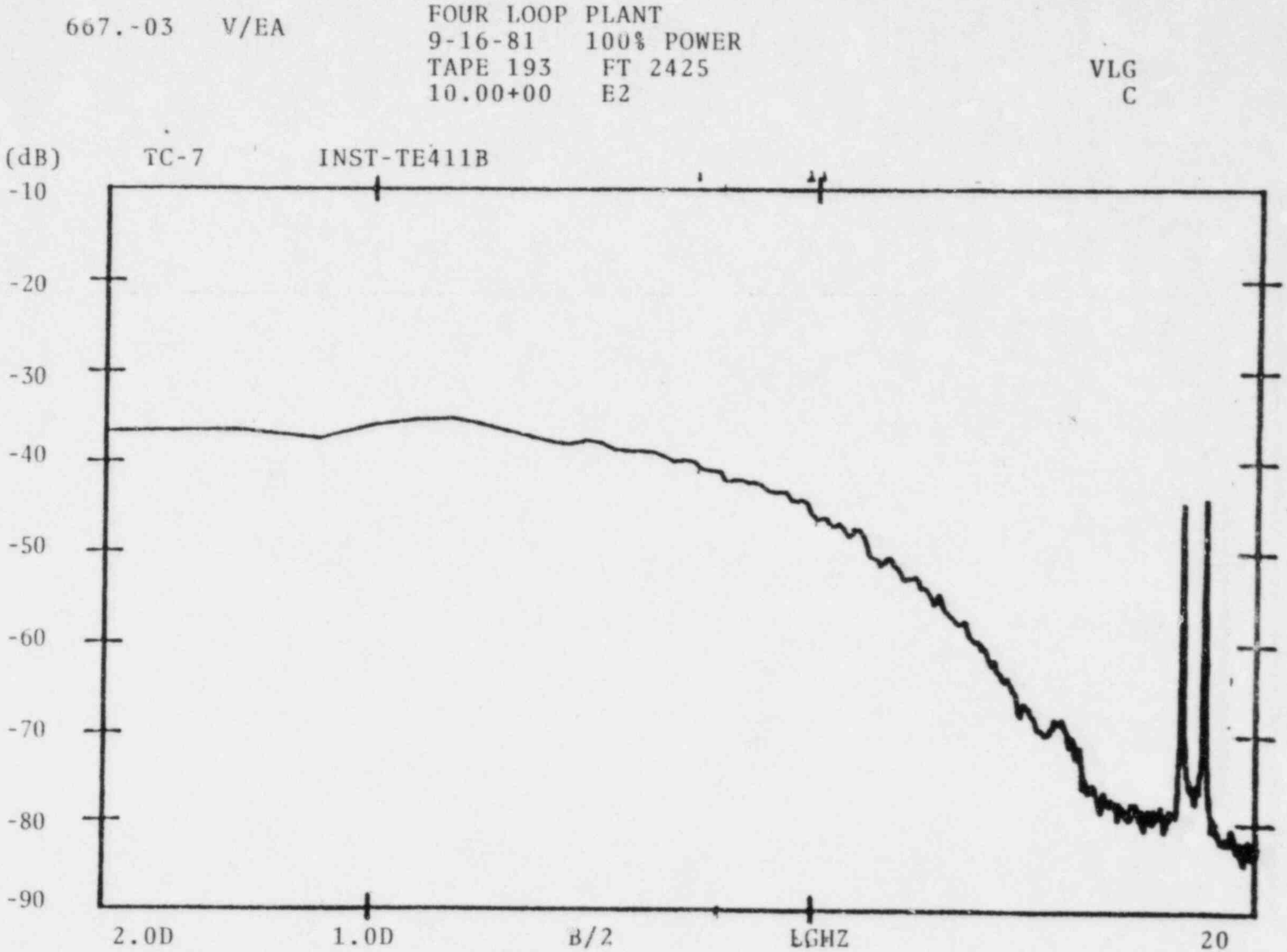


Figure 23: 9/16/83
100% Power
Temperature, Hot Leg, PSD

FOUR LOOP PLANT

1.67+00 V/EA

4-7-81 100% POWER
TAPE 550 FT 230
10.0+00 E2

VLG
C

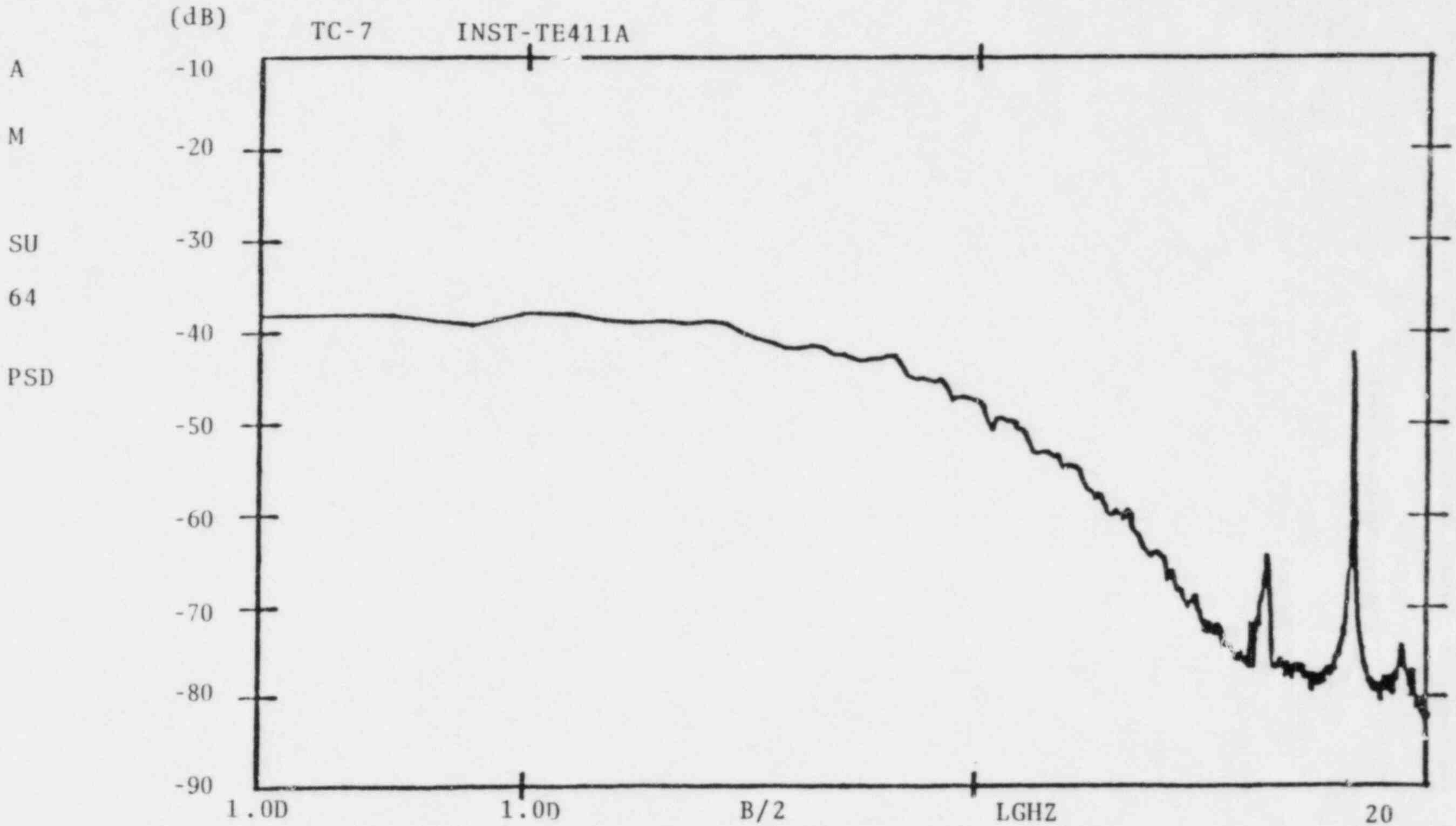


Figure 24: 4/7/81 100% Power Temperature, Hot Leg, PSD

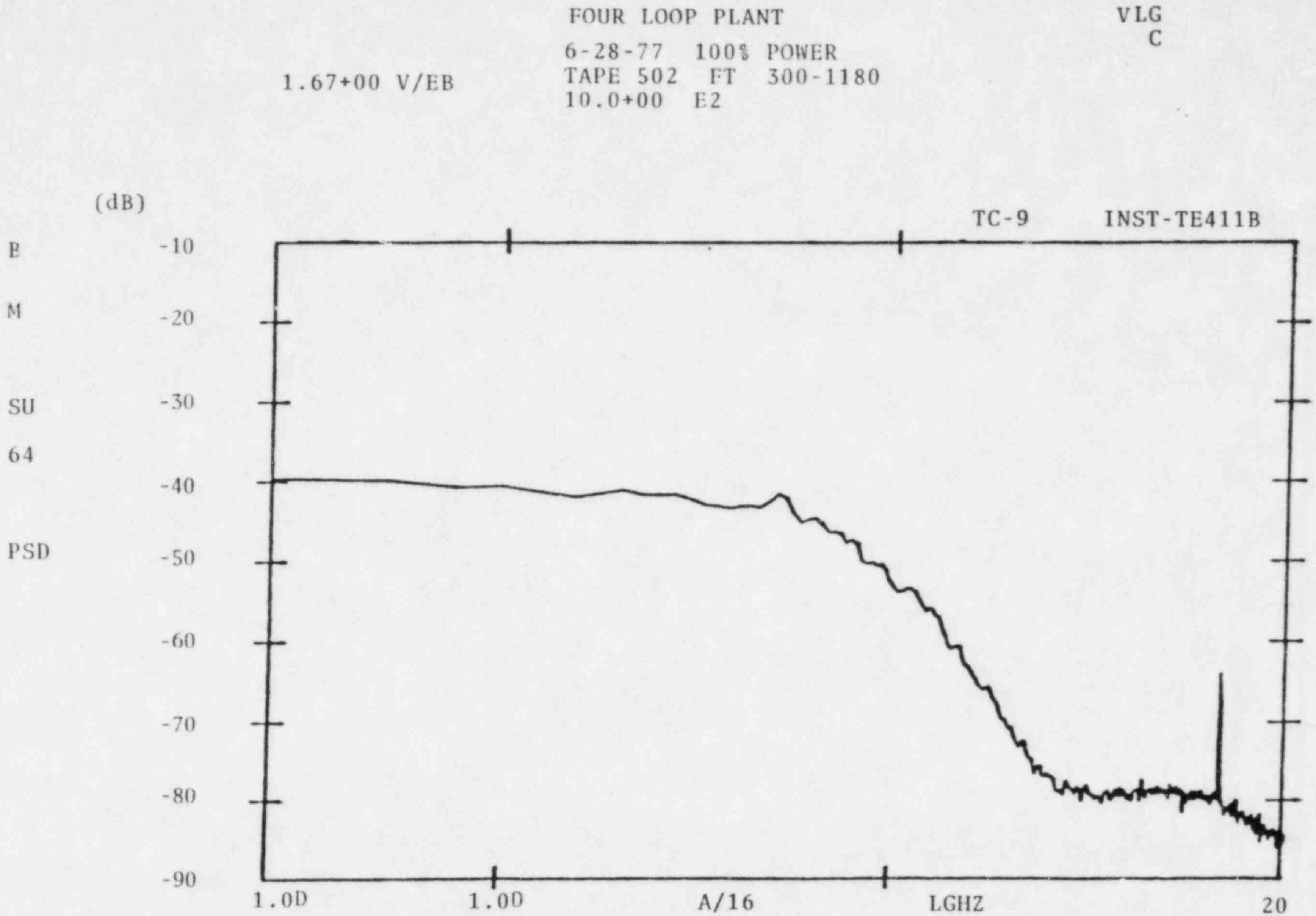


Figure 25:
6/28/77
100% Power
Temperature, Hot Leg, PSD

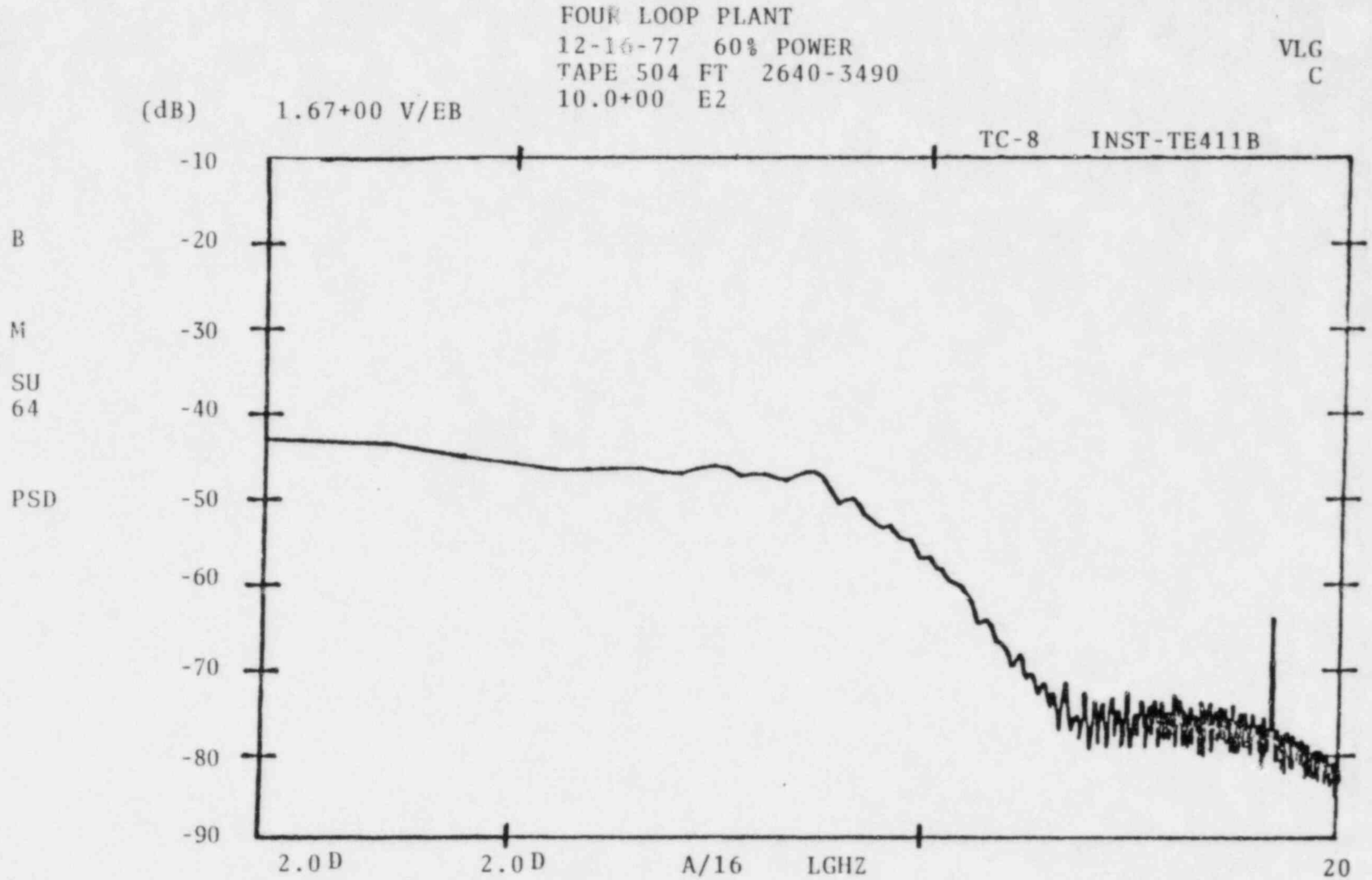


Figure 26:

12/16/77
60% Power, Temperature, Cold Leg, PSD

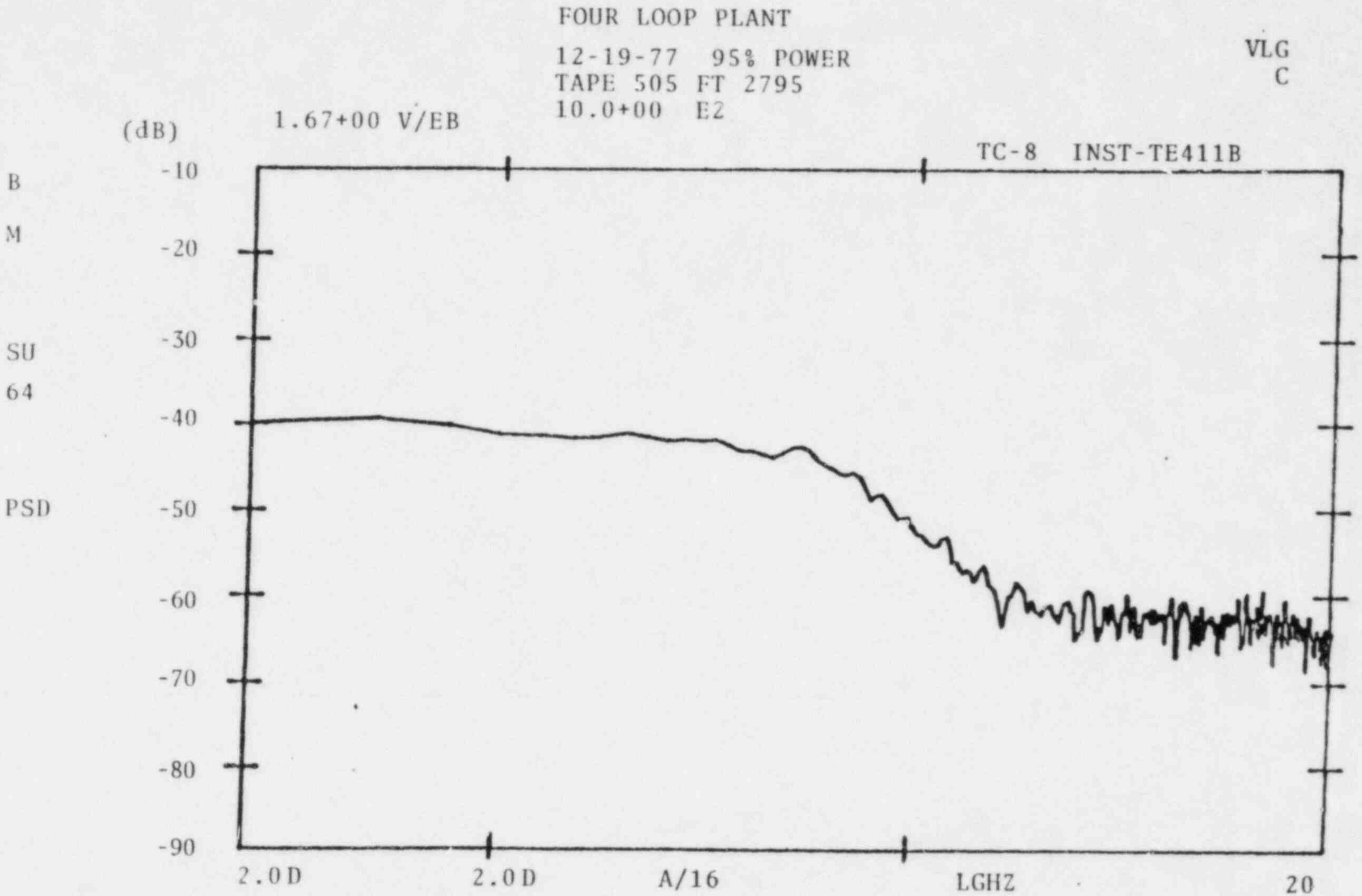


Figure 27:

12/19/77
95% Power, Temperature, Cold Leg, PSD

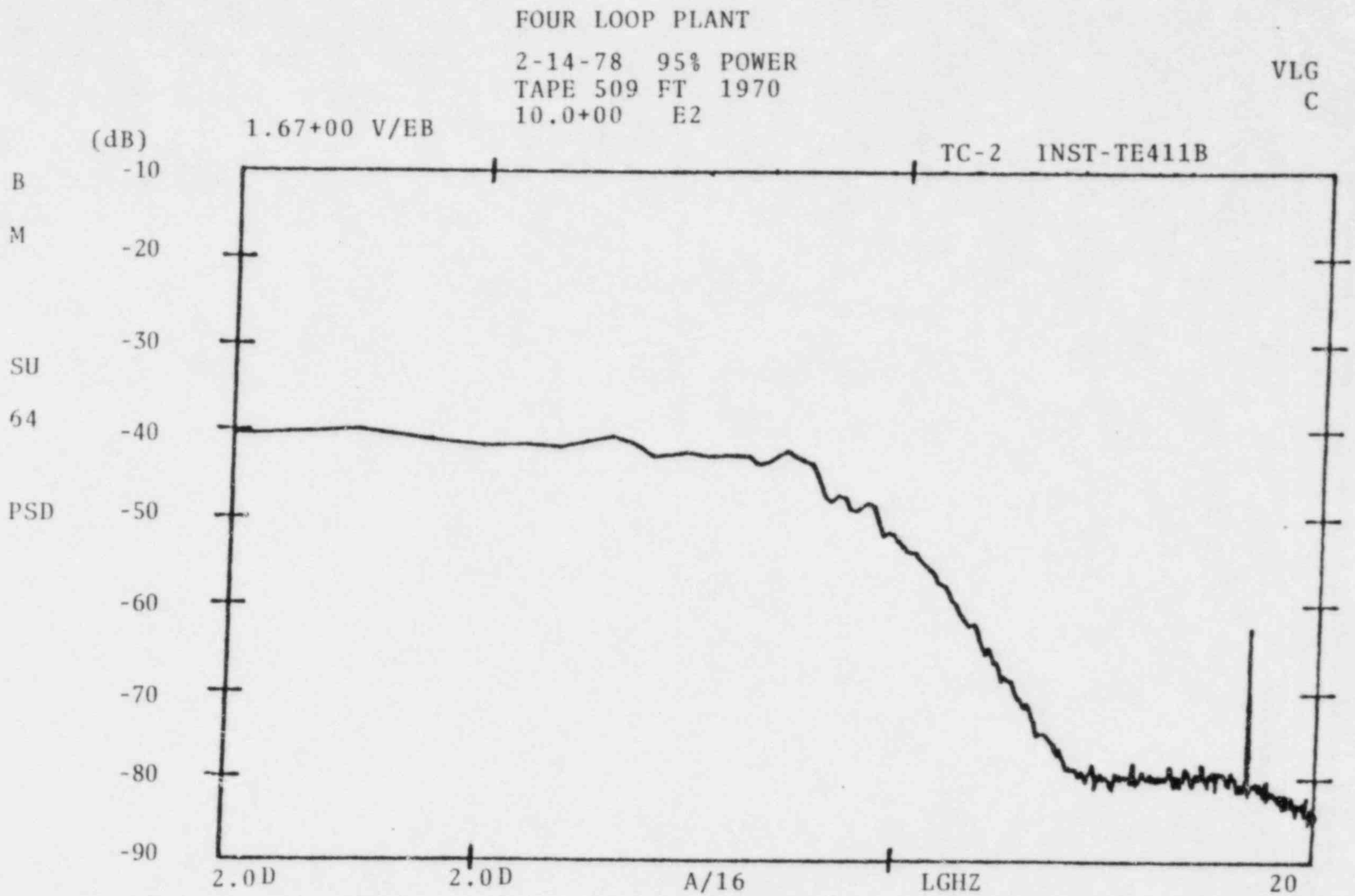


Figure 28 :
2/14/78
95% Power, Temperature, Cold Leg, PSD

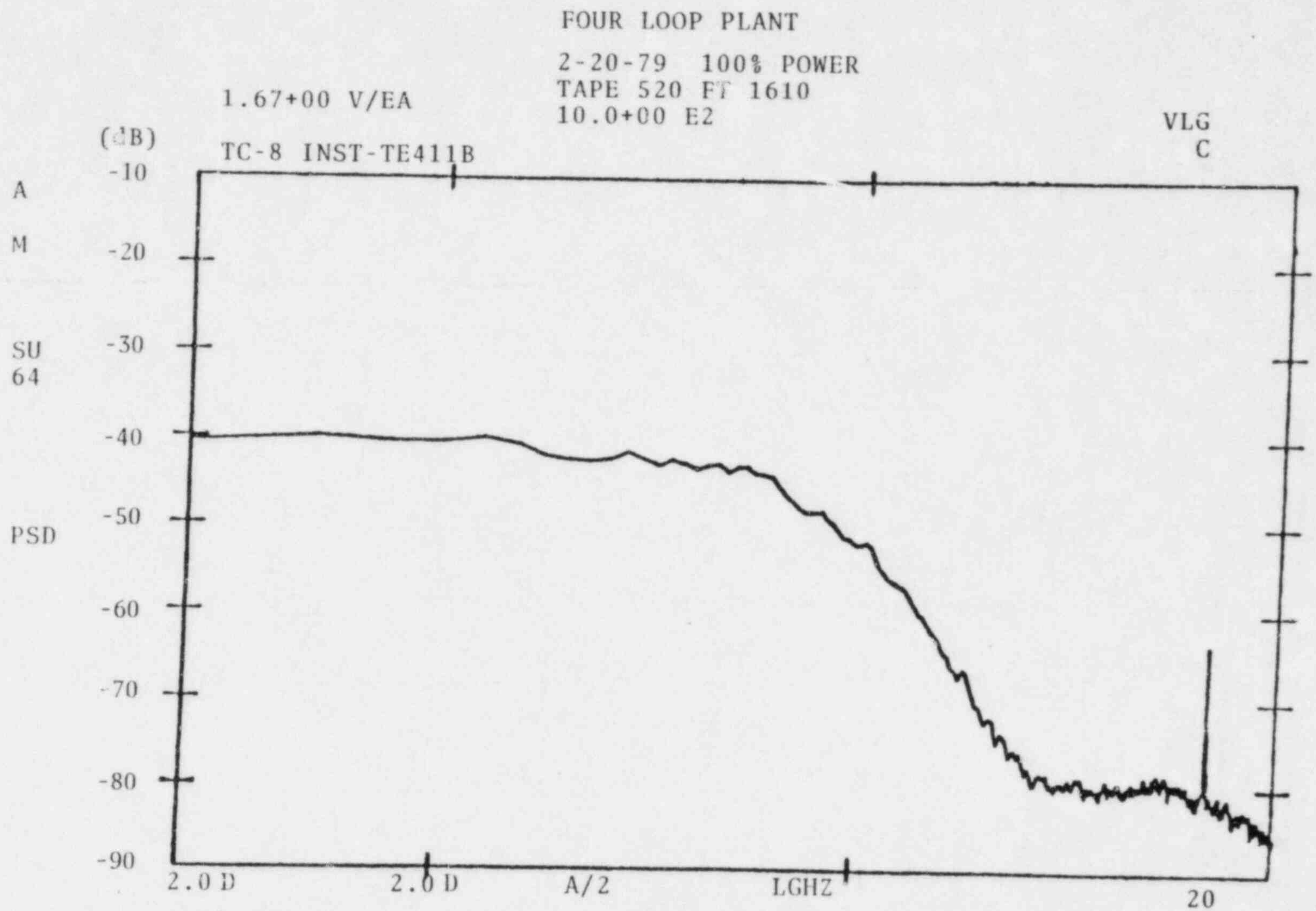


Figure 29:

2/20/79
100% Power, Temperature, Cold Leg, PSD

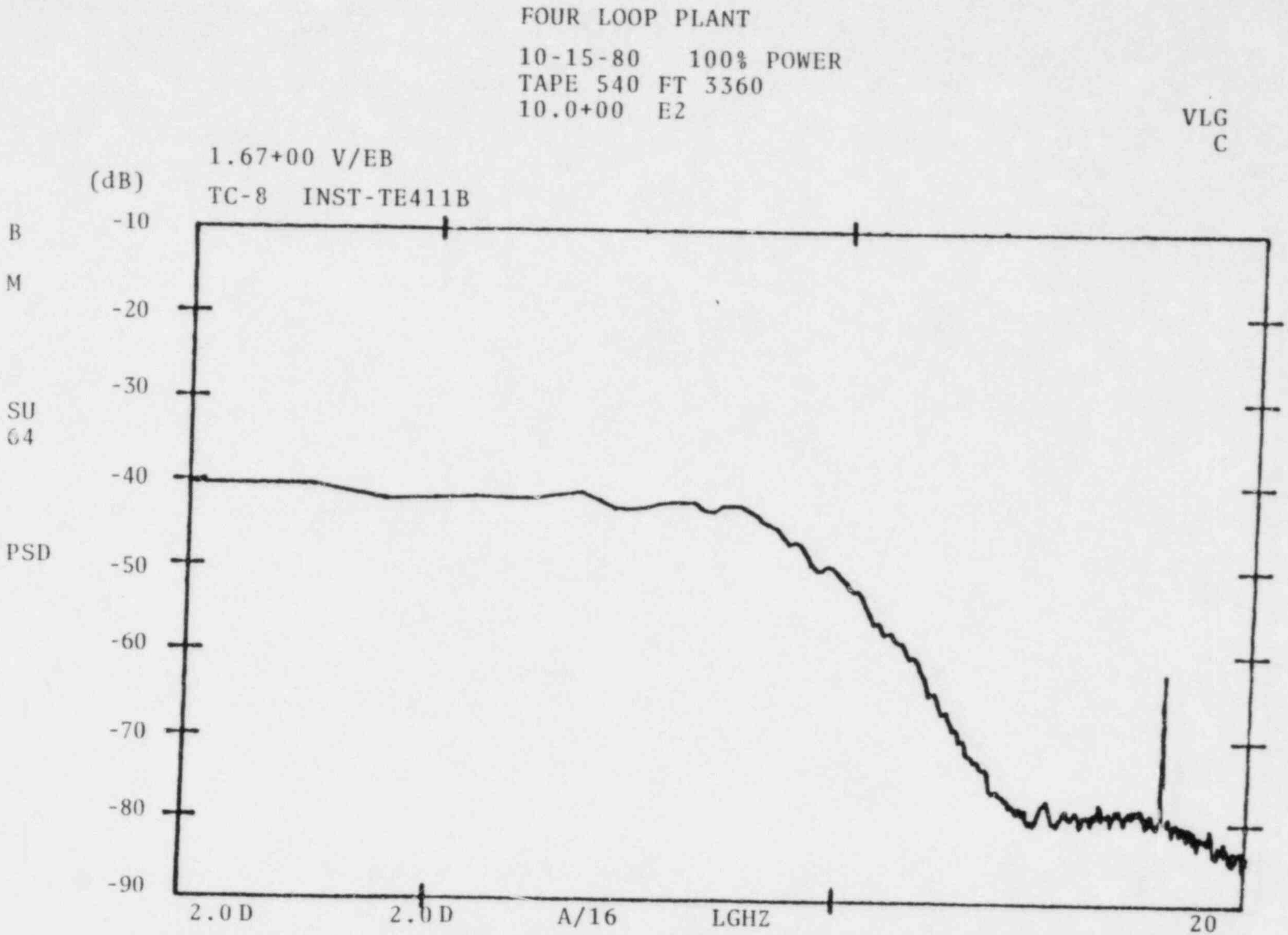


Figure 30:

10/15/80
100% Power, Temperature, Cold Leg, PSD

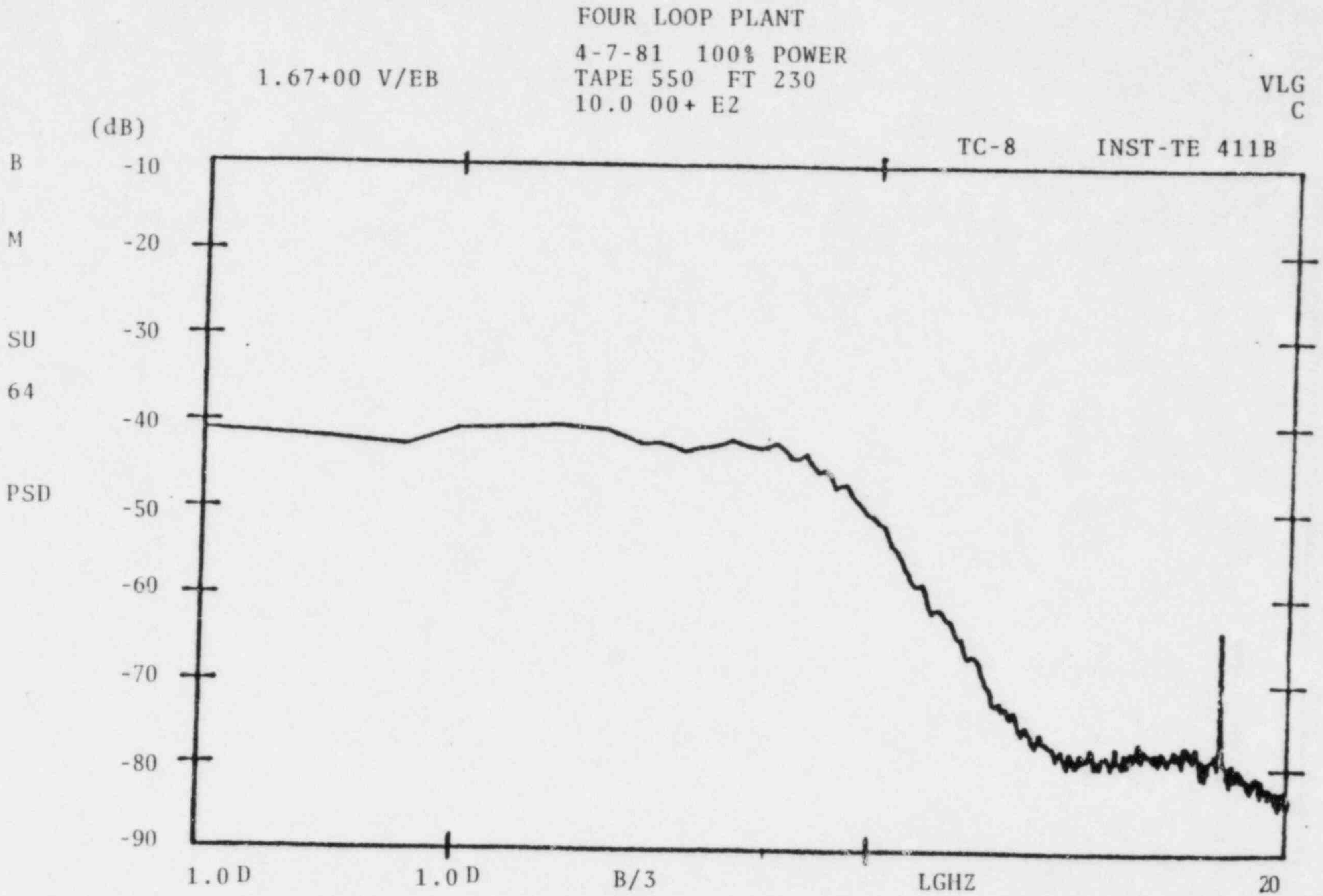


Figure 31:

4/7/81
100% Power, Temperature, Cold Leg, PSD

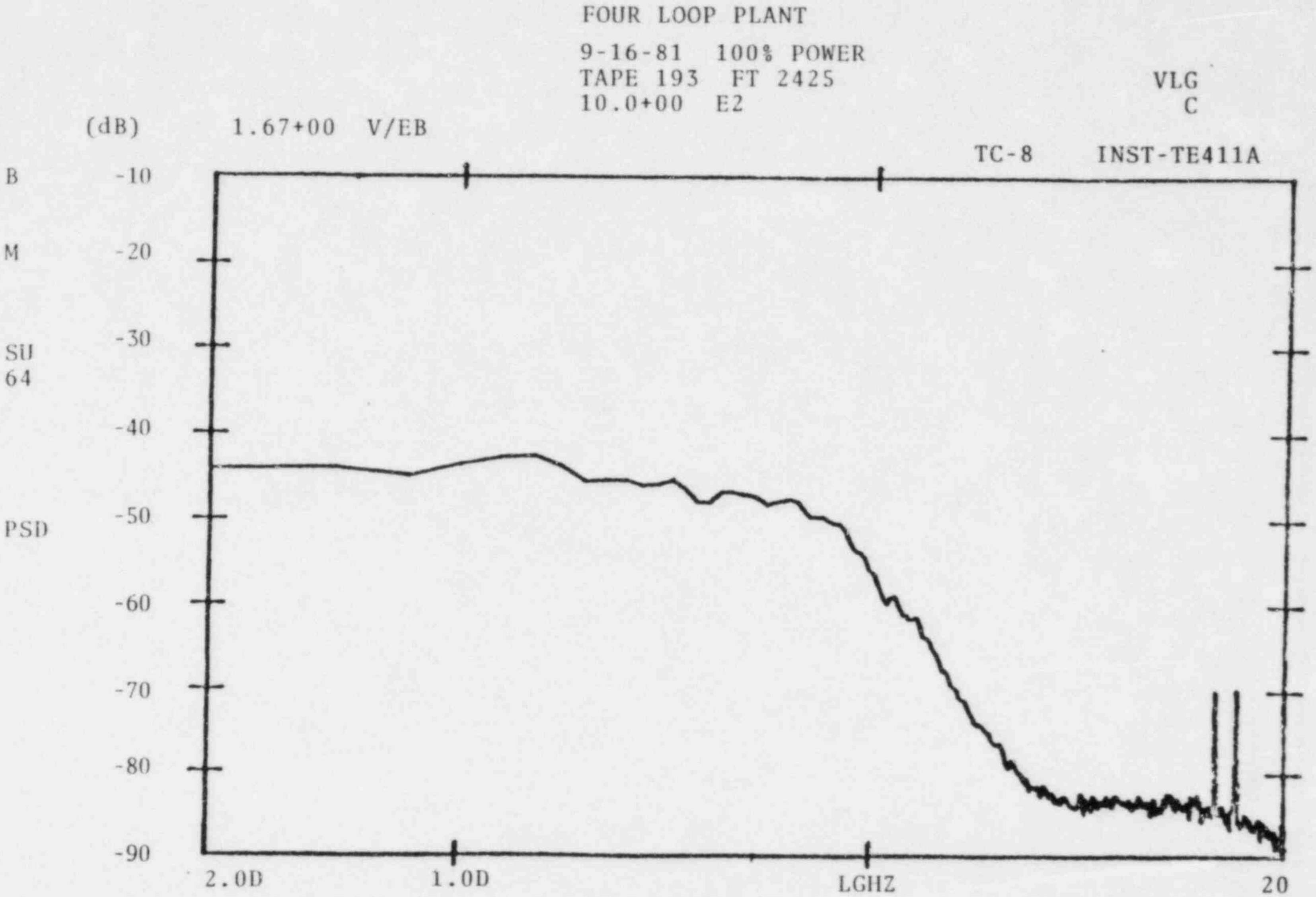


Figure 32:
9/16/81
100% Power, Temperature, Hot Leg, PSD

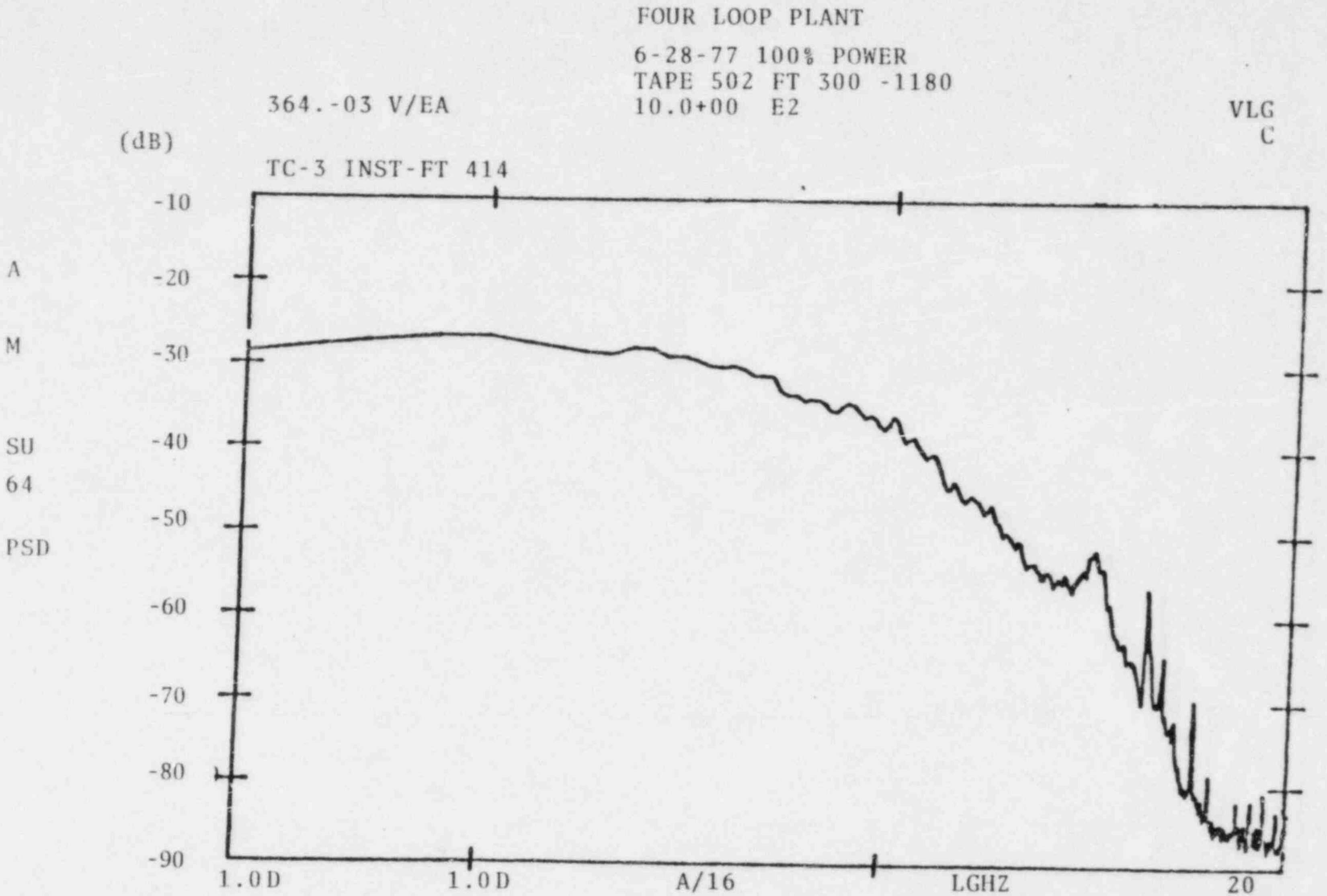


Figure 33:
6/28/77
100% Power Plant, Reactor Coolant Flow, PSD

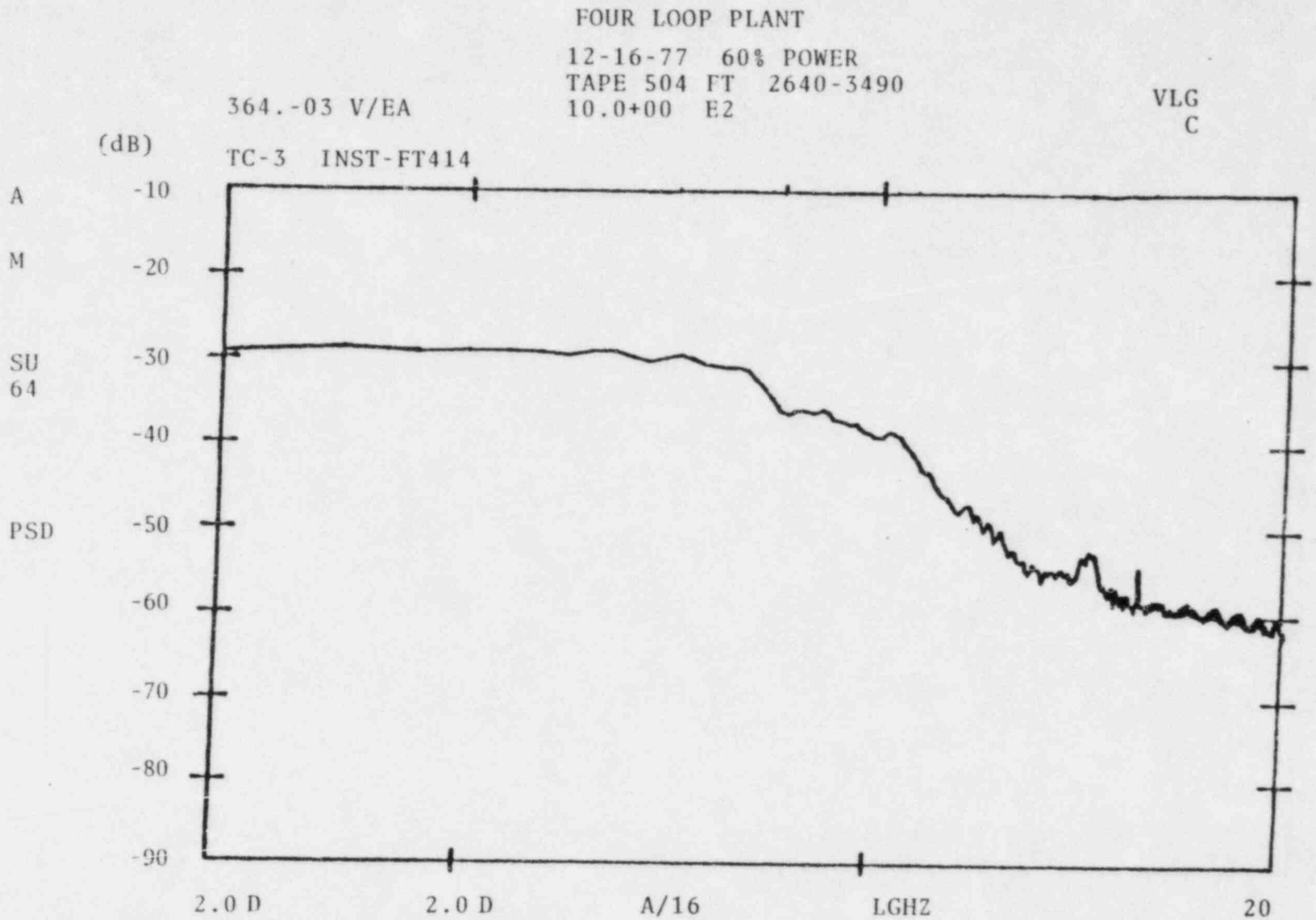


Figure 34: 12/16/77
60% Power, Reactor Coolant Flow, PSD

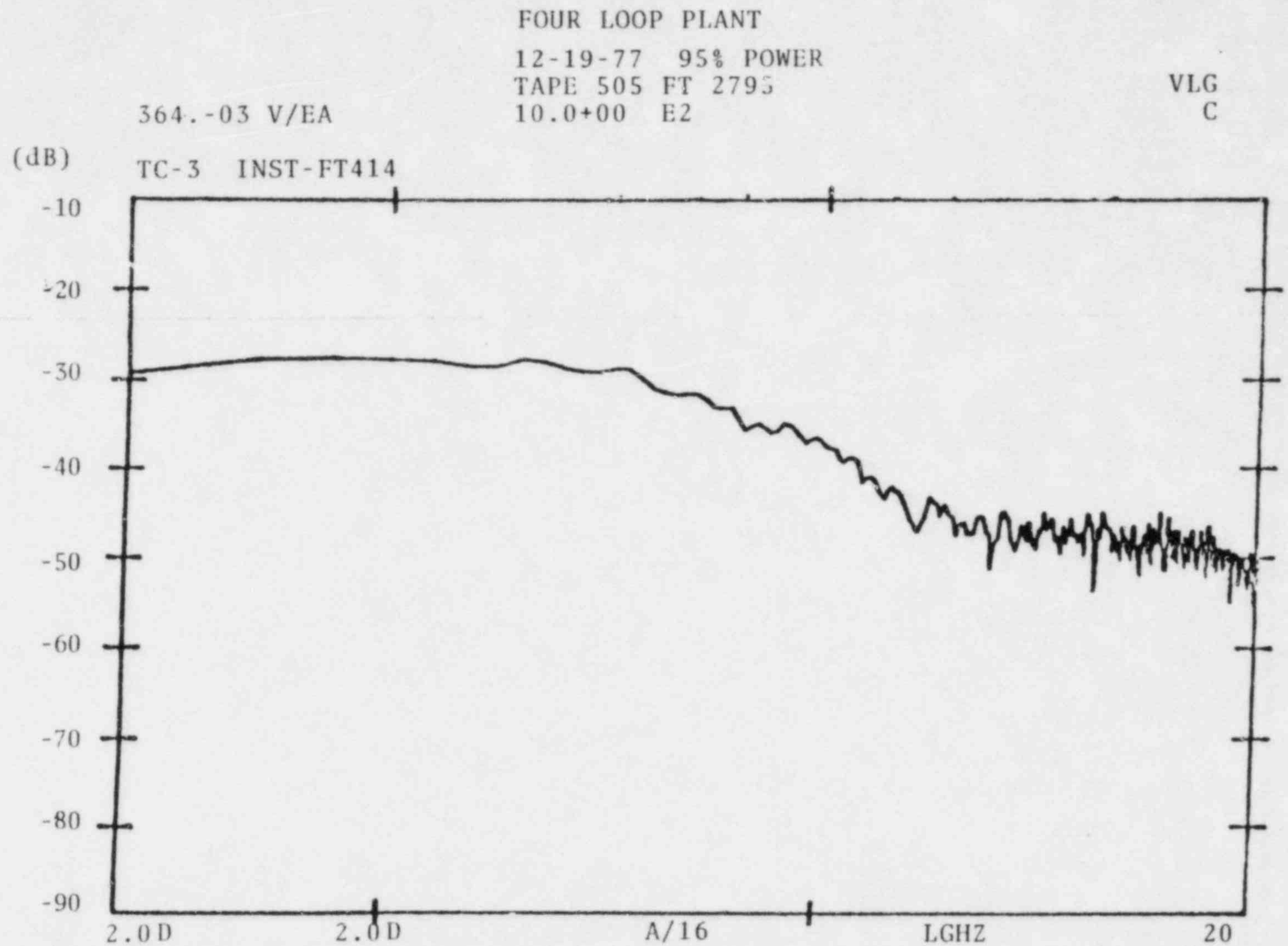


Figure 35:
12/19/77
95% Power, Reactor Coolant Flow, PSD

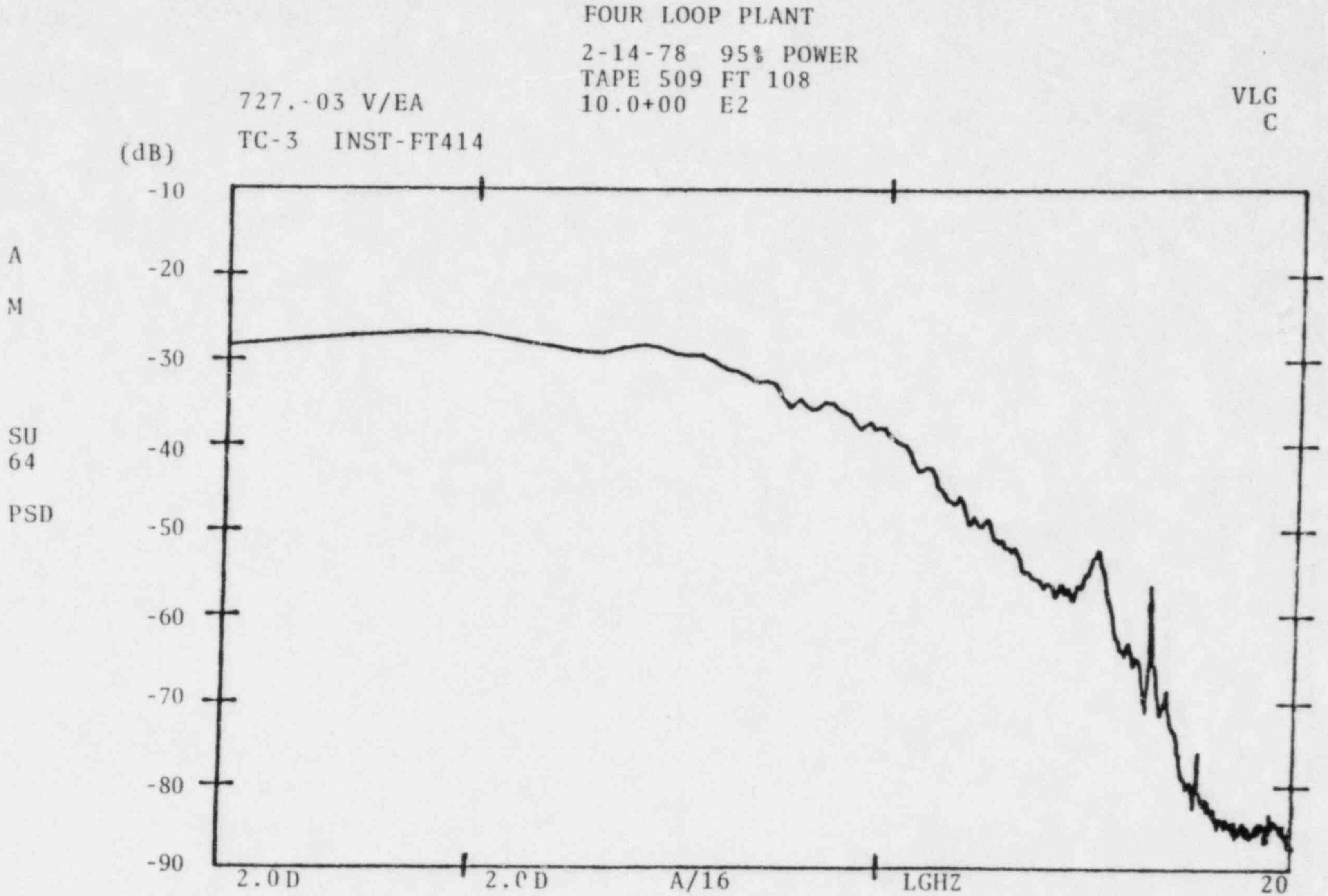


Figure 36:

2/14/78
95% Power, Reactor Coolant Flow, PSD

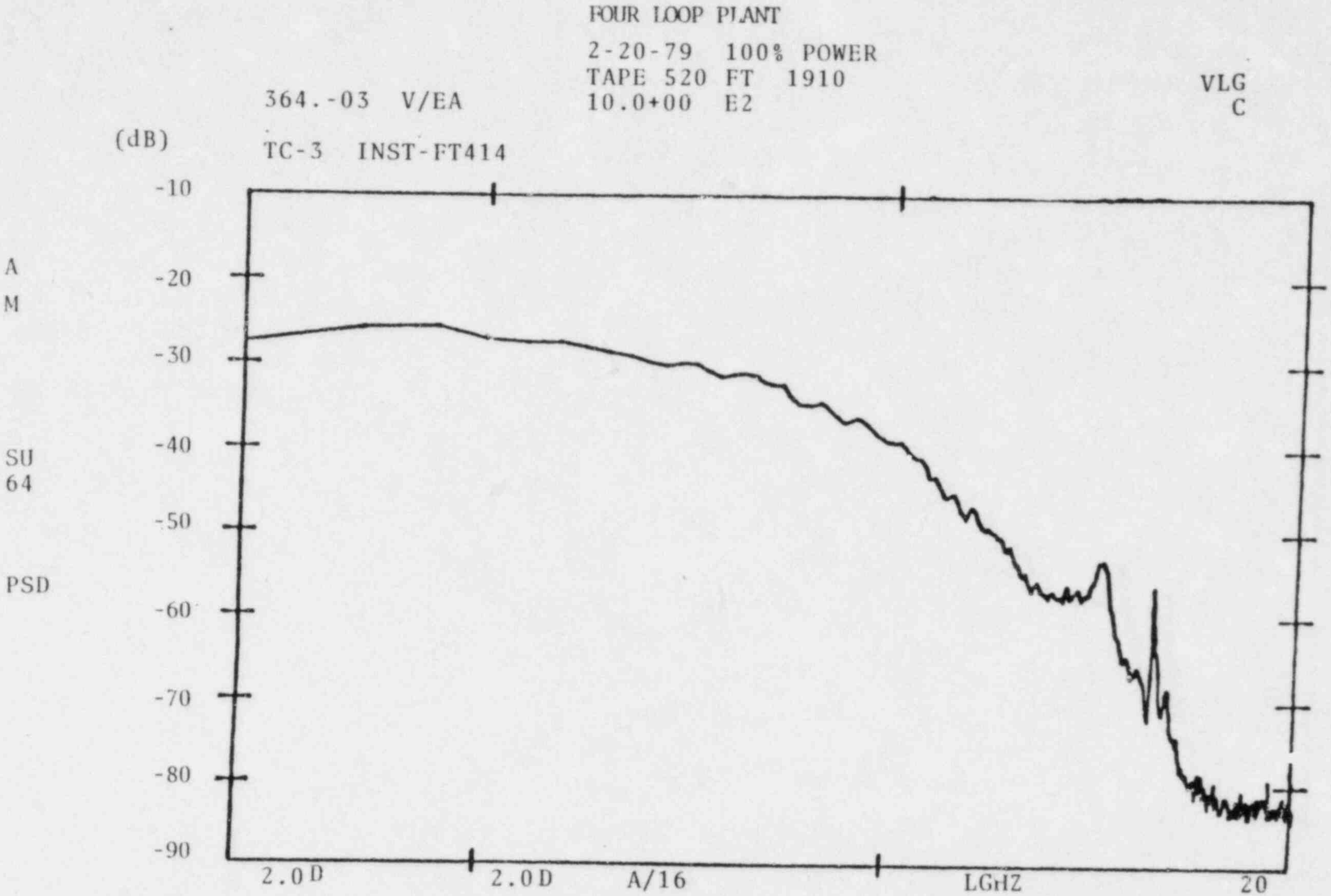


FIGURE 37: 2/20/79
100% Power, Reactor Coolant Flow, PSD

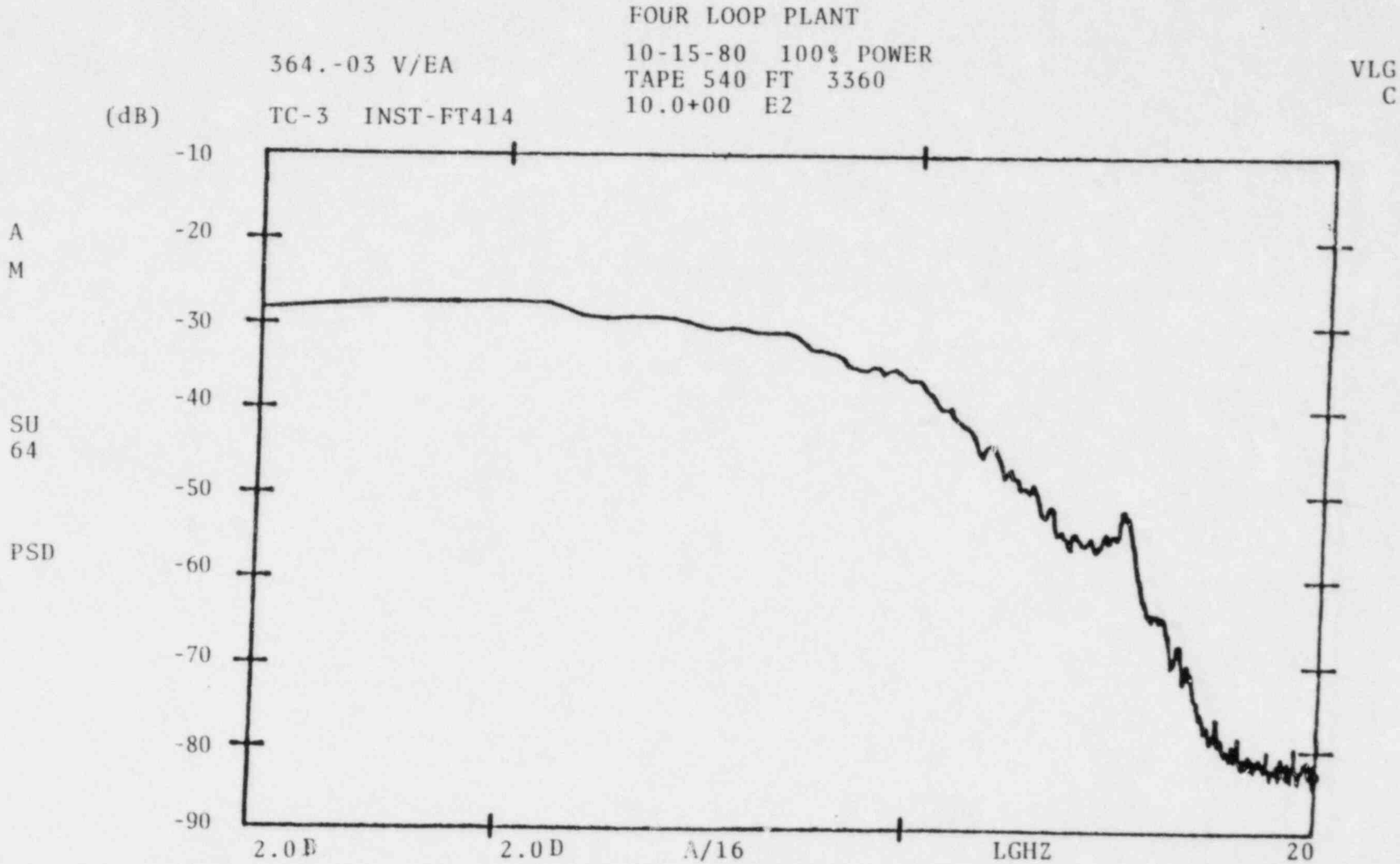


Figure 38:

10/15/80
100% Power, Reactor Coolant Flow, PSD

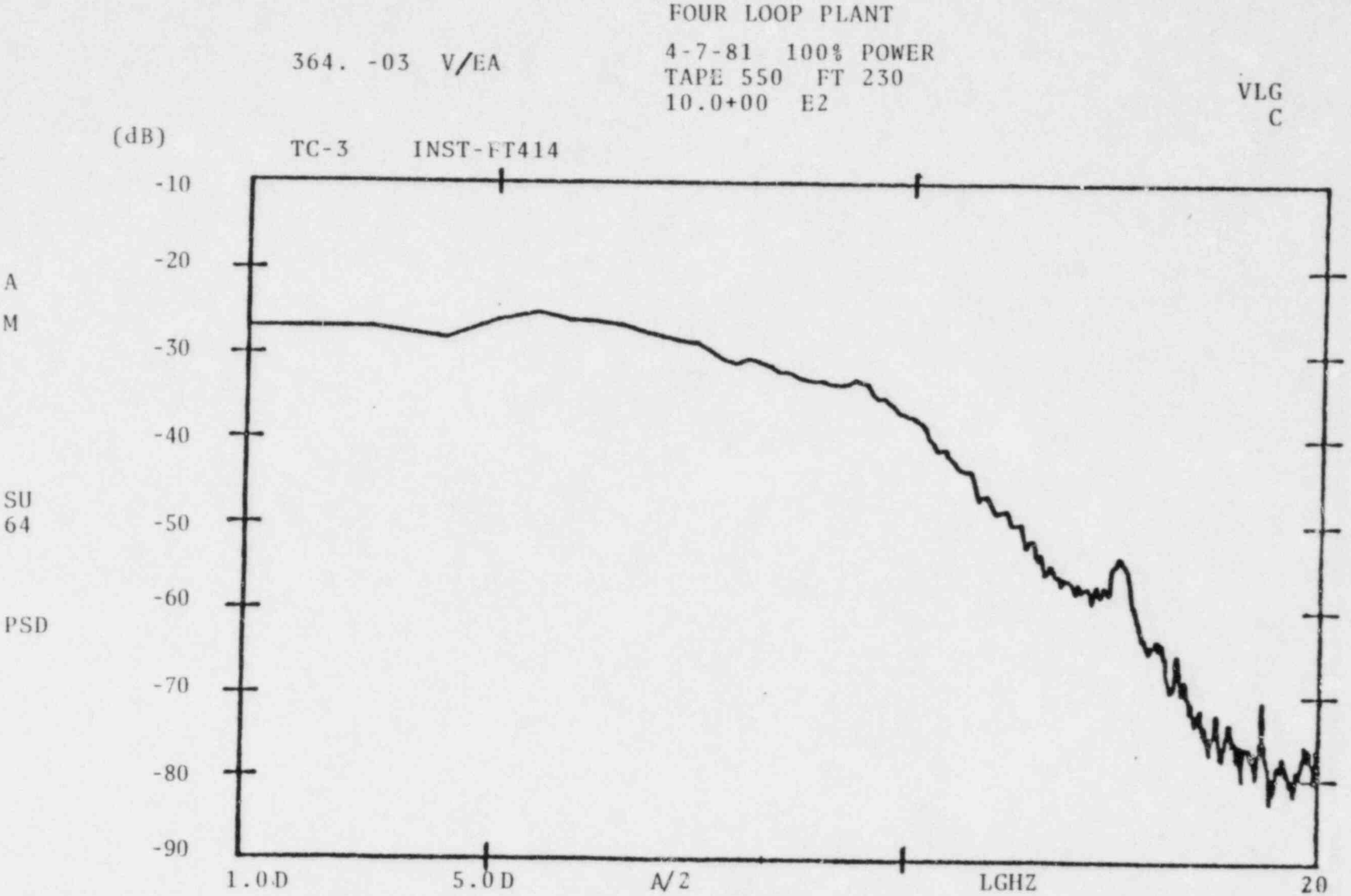


Figure 39:
4/7/81
100% Power, Reactor Coolant Flow, PSD

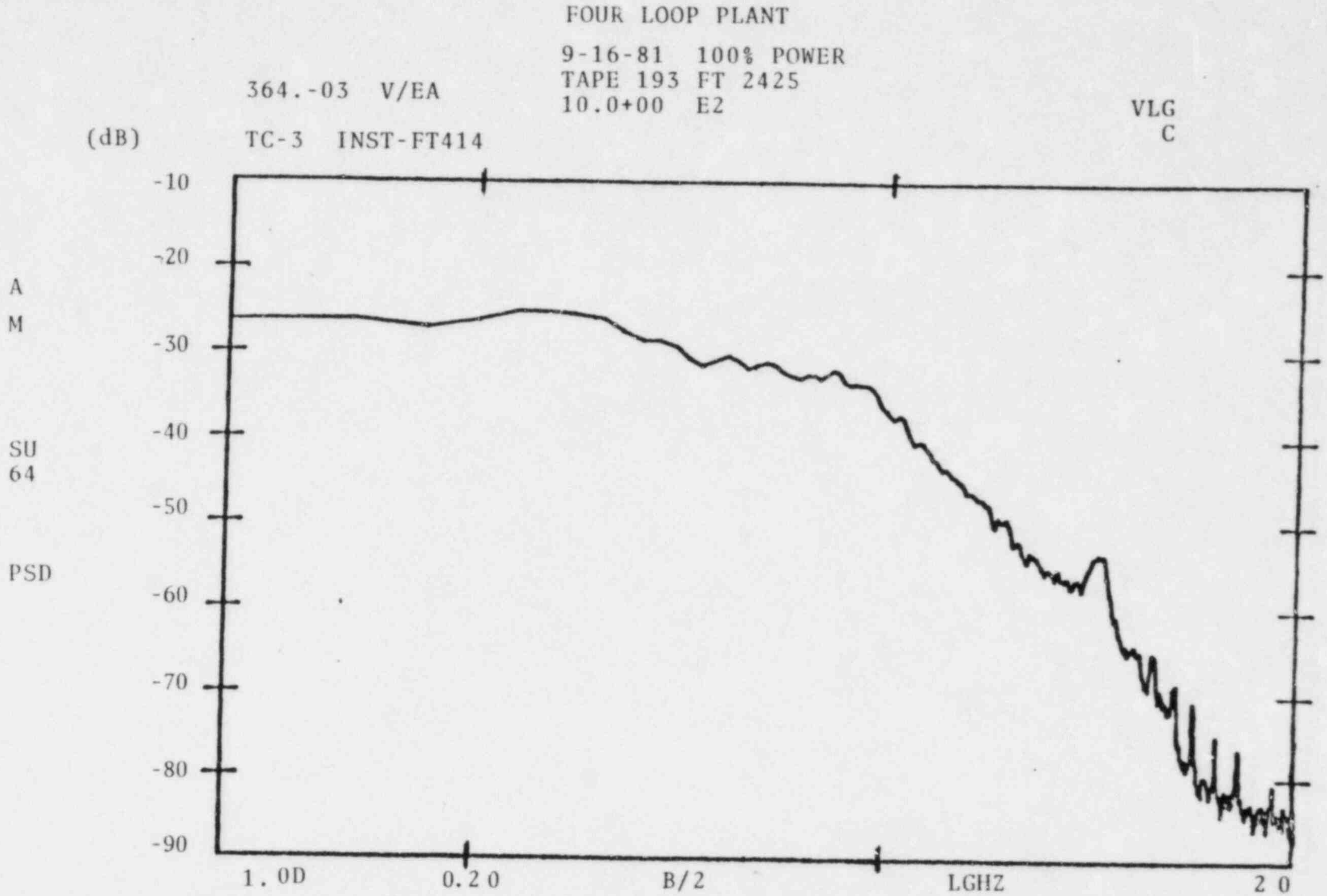


Figure 40:

9/16/81
100% Power, Reactor Coolant Flow, PSD

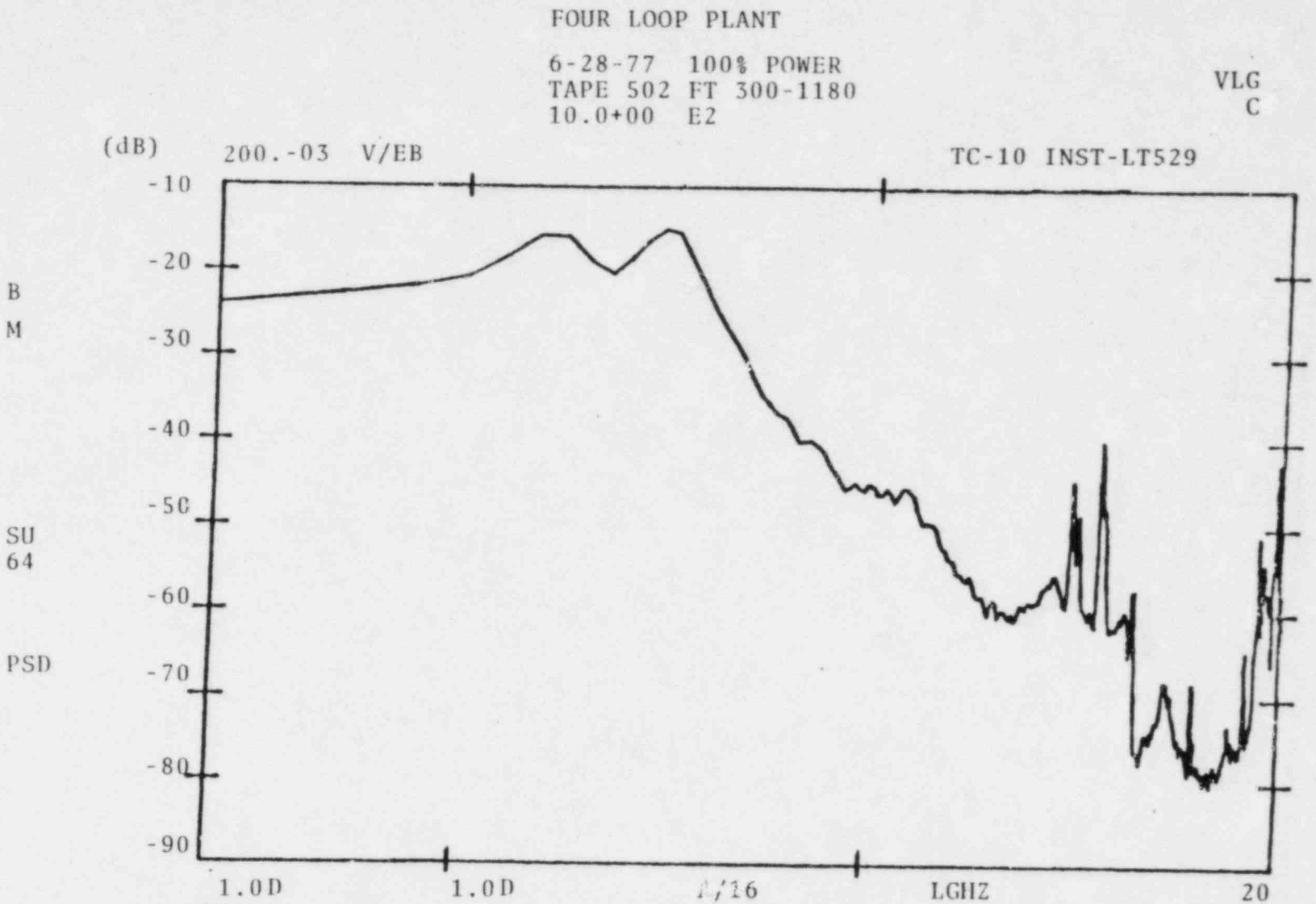


Figure 41:

6/28/77
100% Power, Steam Generator Level, PSD

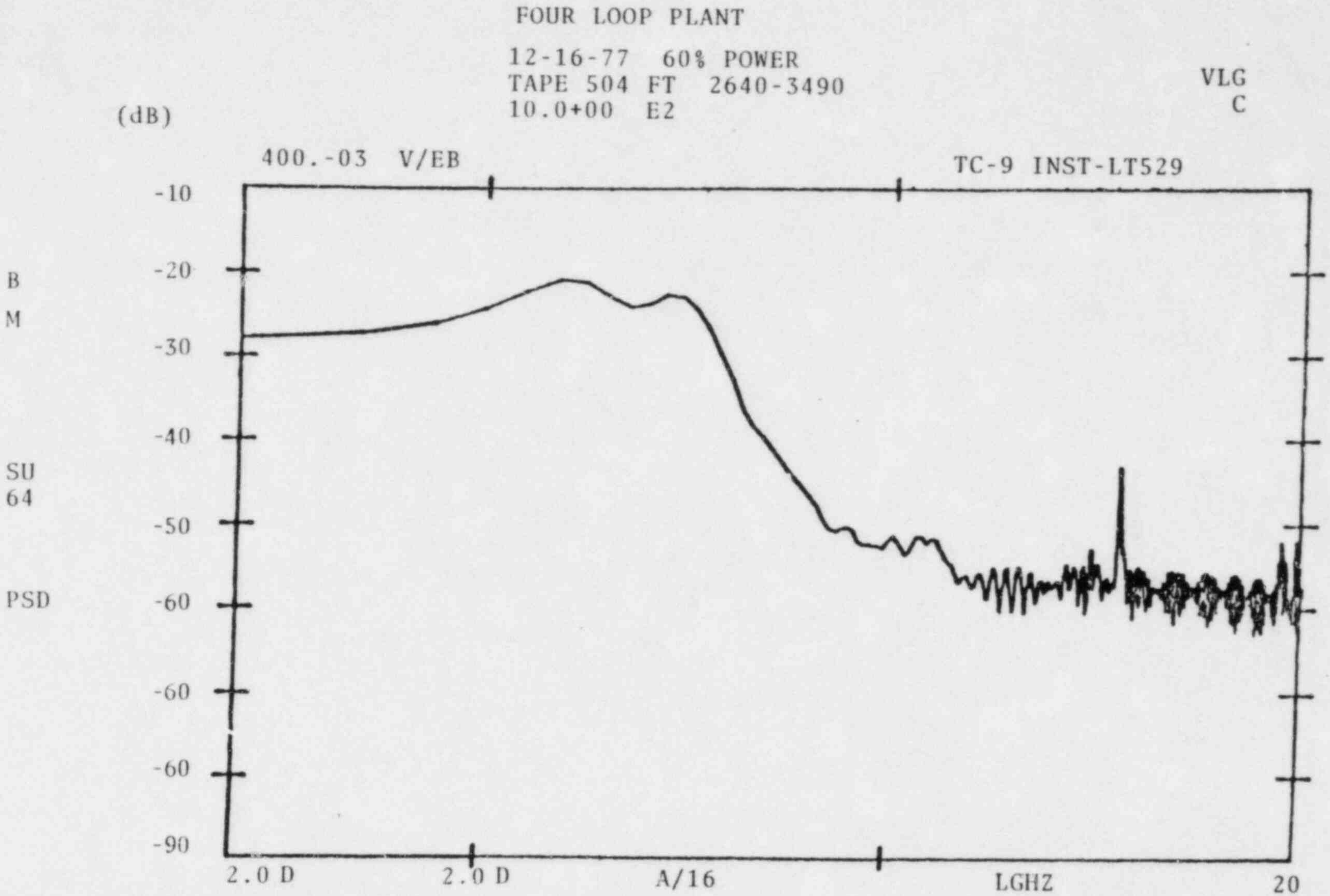


Figure 42:
12/16/77
60% Power, Steam Generator Level, PSD

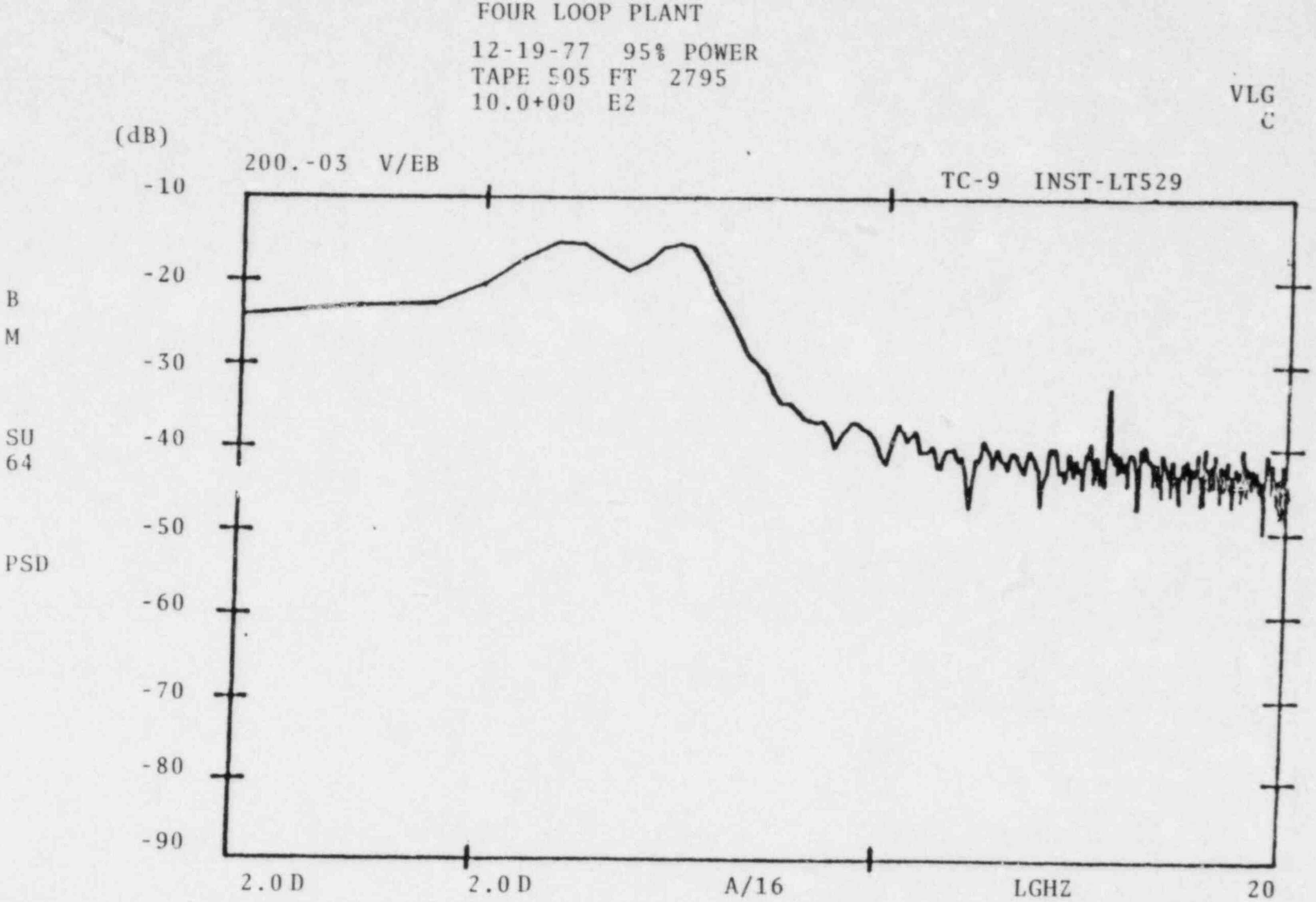


Figure 43:

12/19/77
95% Power, Steam Generator Level, PSD

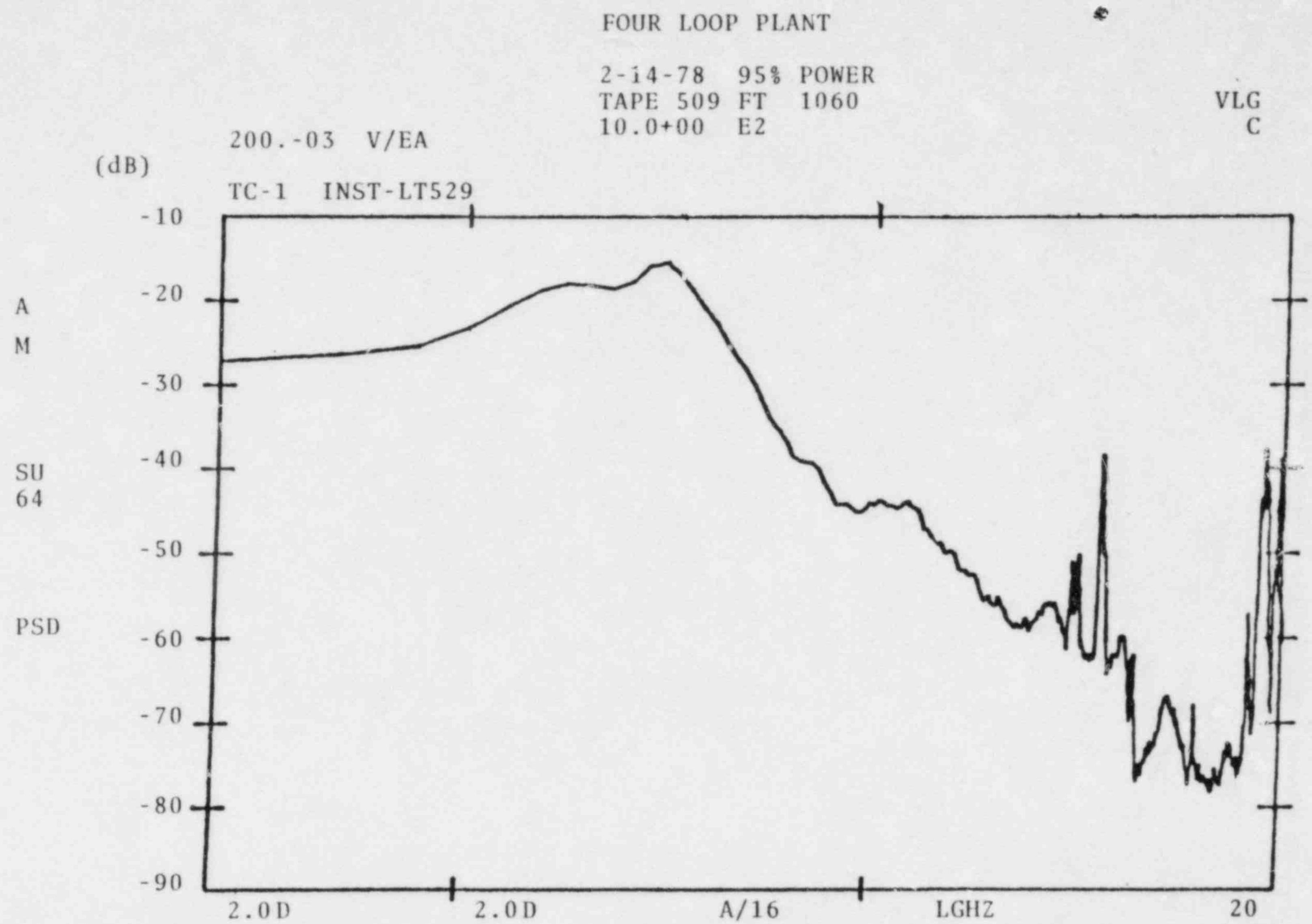


Figure 44:
2/14/78
95% Power, Steam Generator Level, PSD

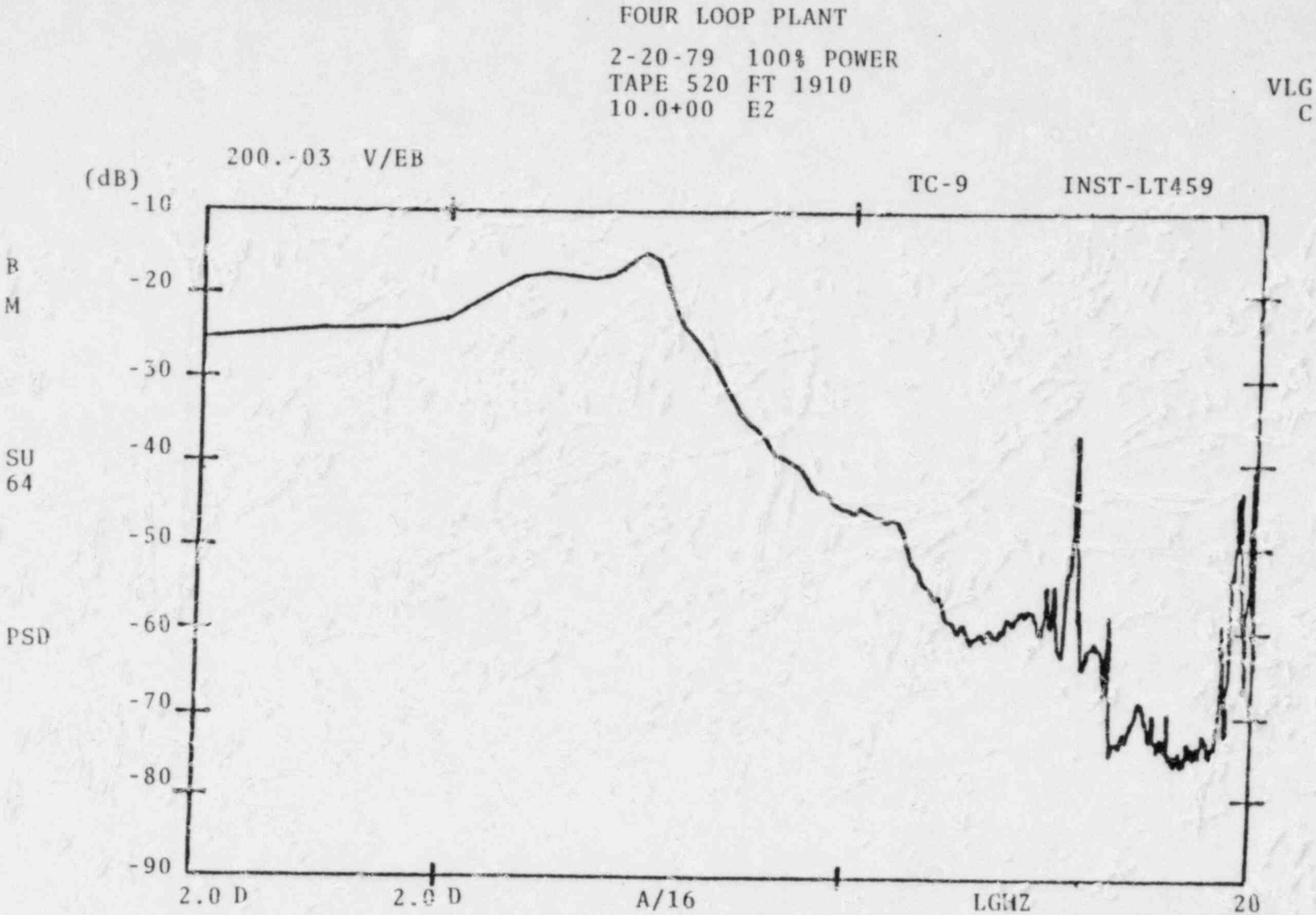


Figure 45:

2/20/79
100% Power, Steam Generator Level, PSD

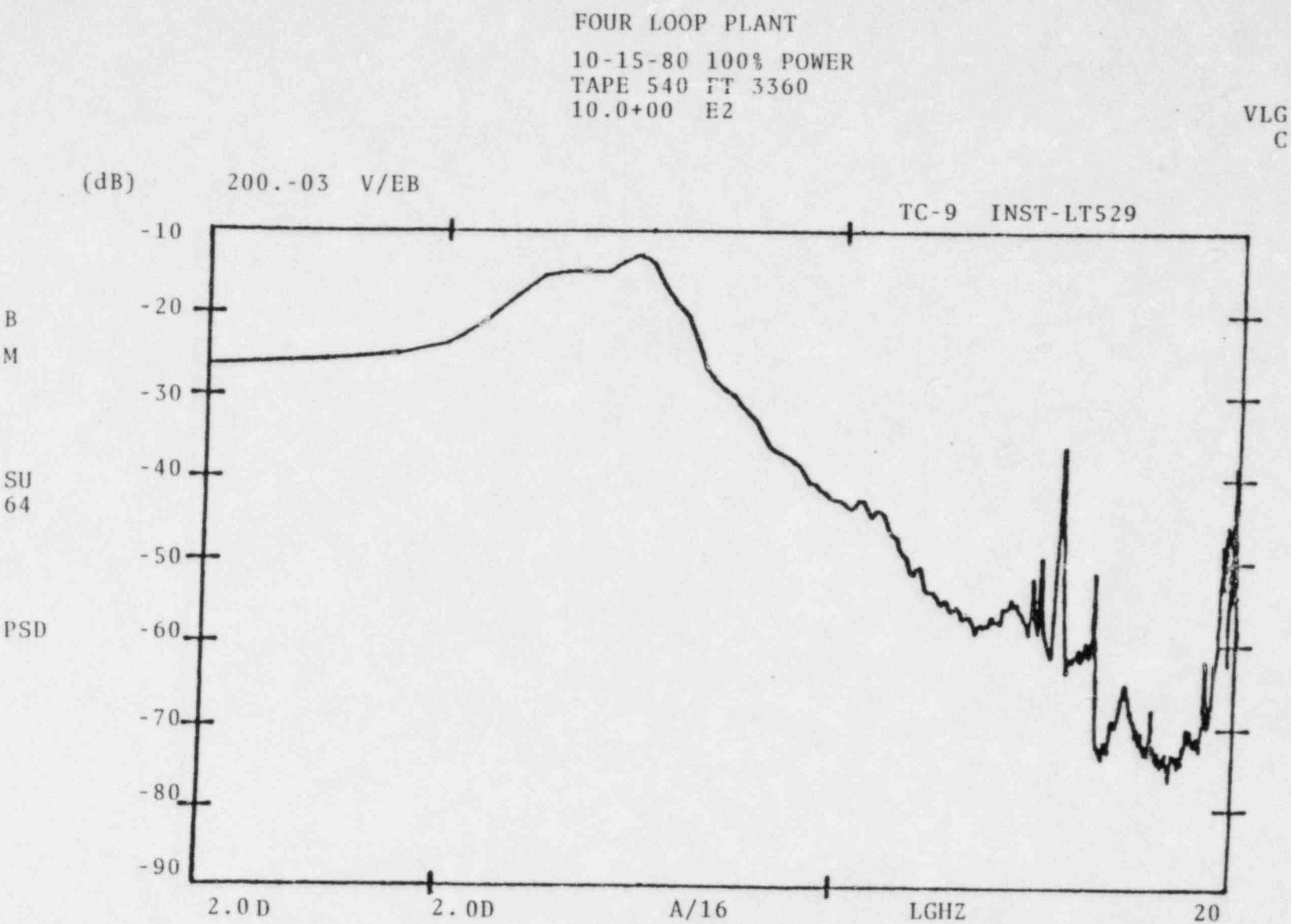


Figure 46:
10/15/80
100% Power, Steam Generator Level, PSD

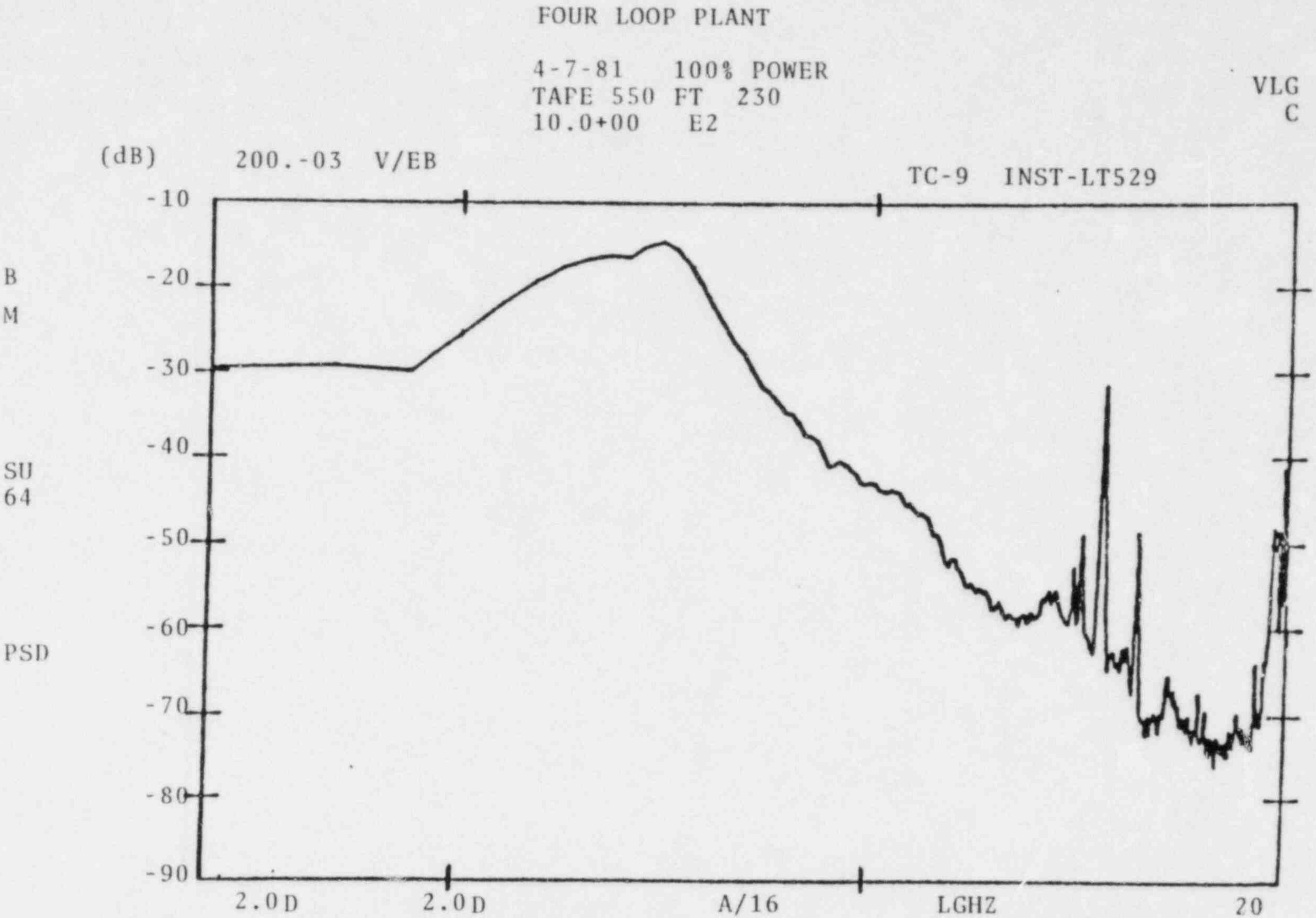


Figure 47:

2/20/79
100% Power, Steam Generator Level, PSD

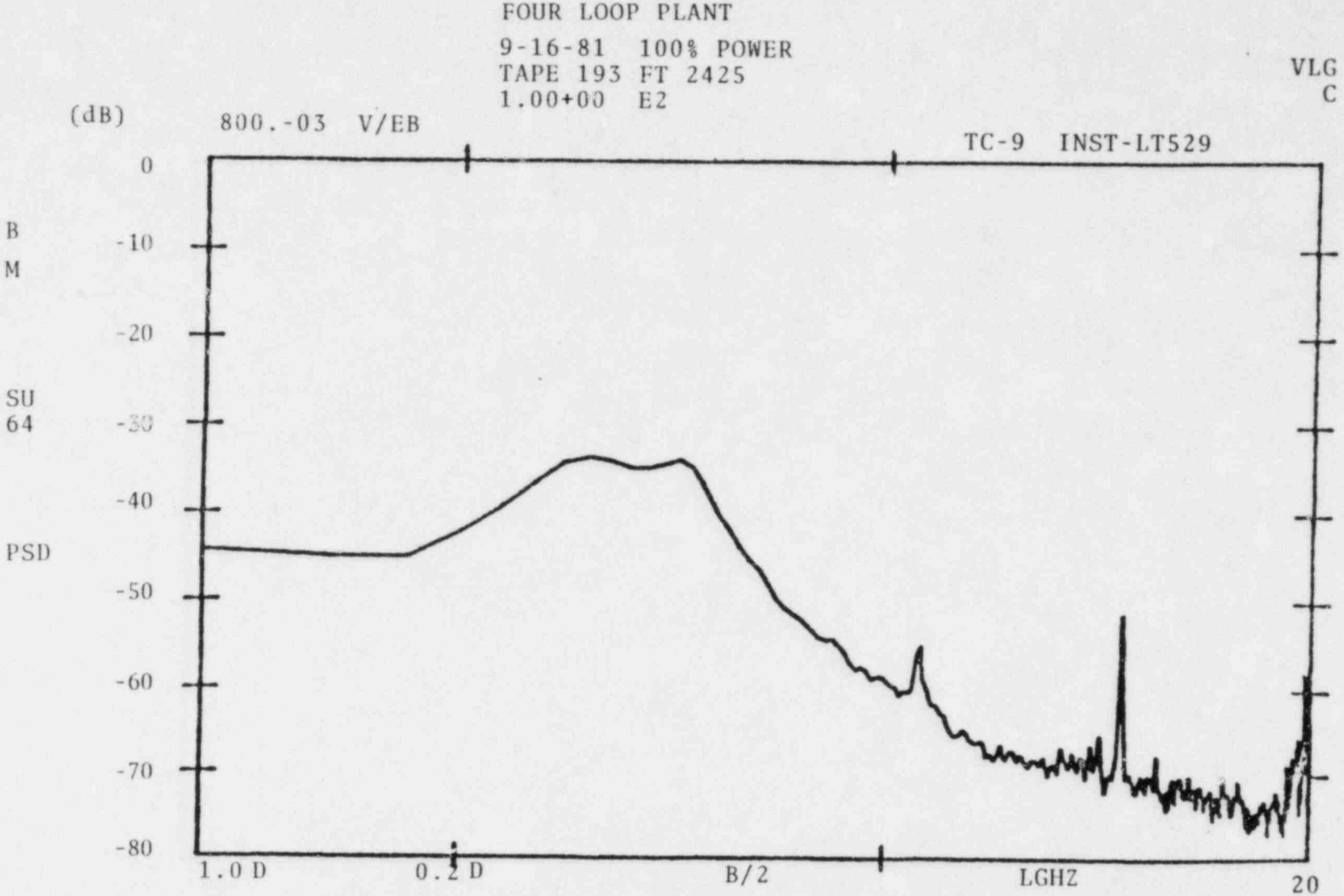


Figure 48:
9/16/81
100% Power, Steam Generator Level, PSD

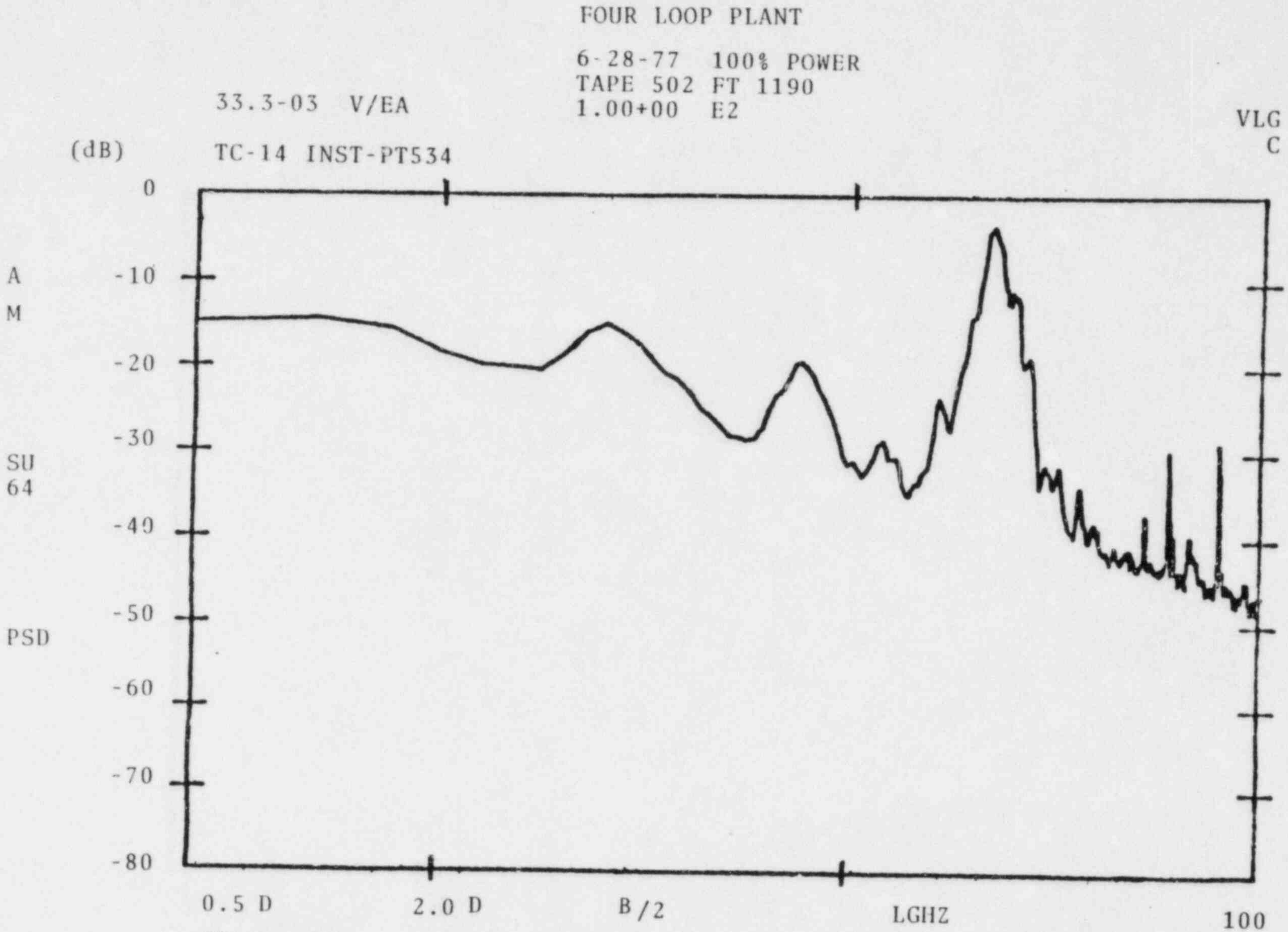


Figure 49:

6/28/77
100% Power, Steam Line Pressure, PSD

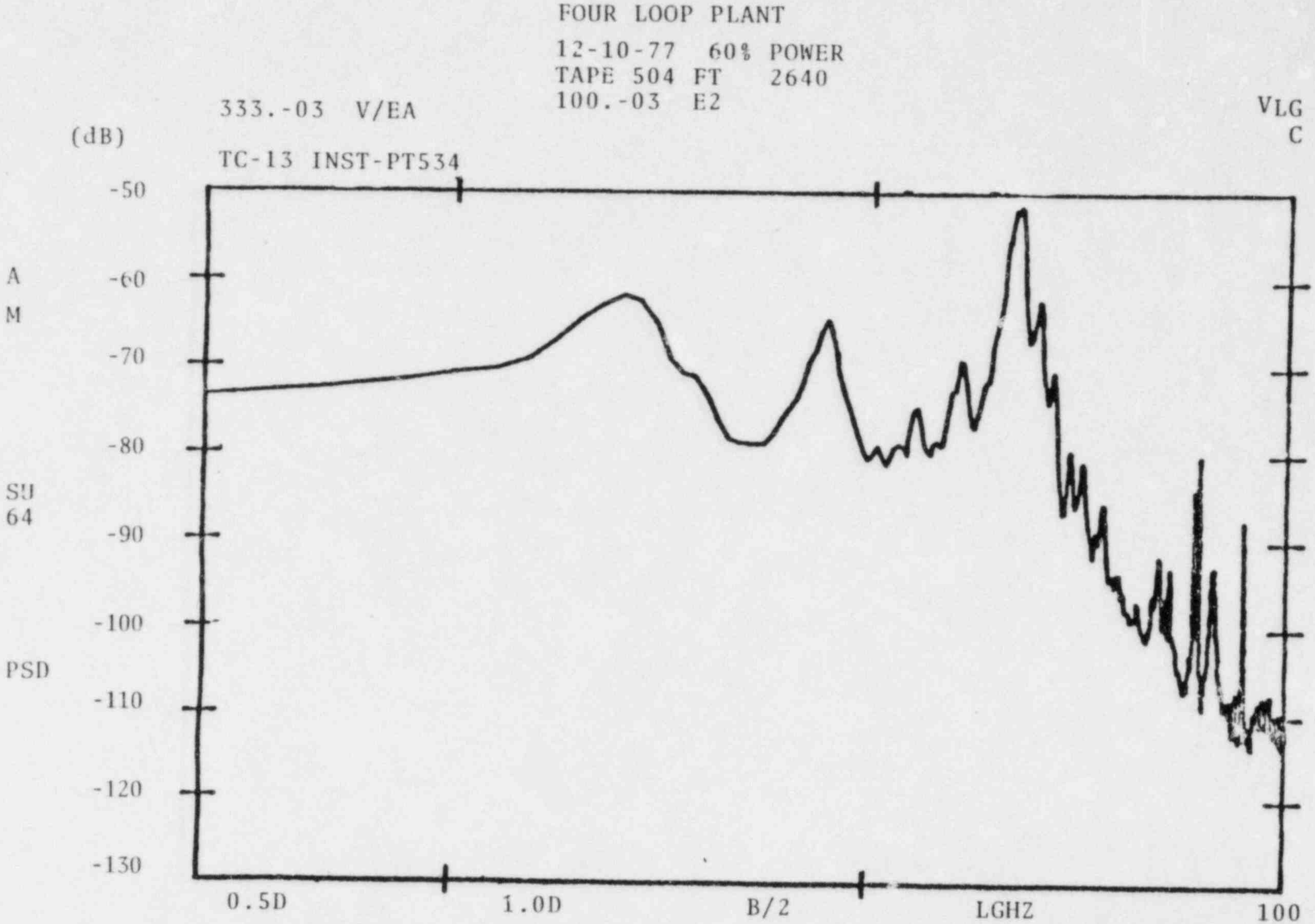


Figure 50:

12/10/77
60% Power, Steam Line Pressure, PSD

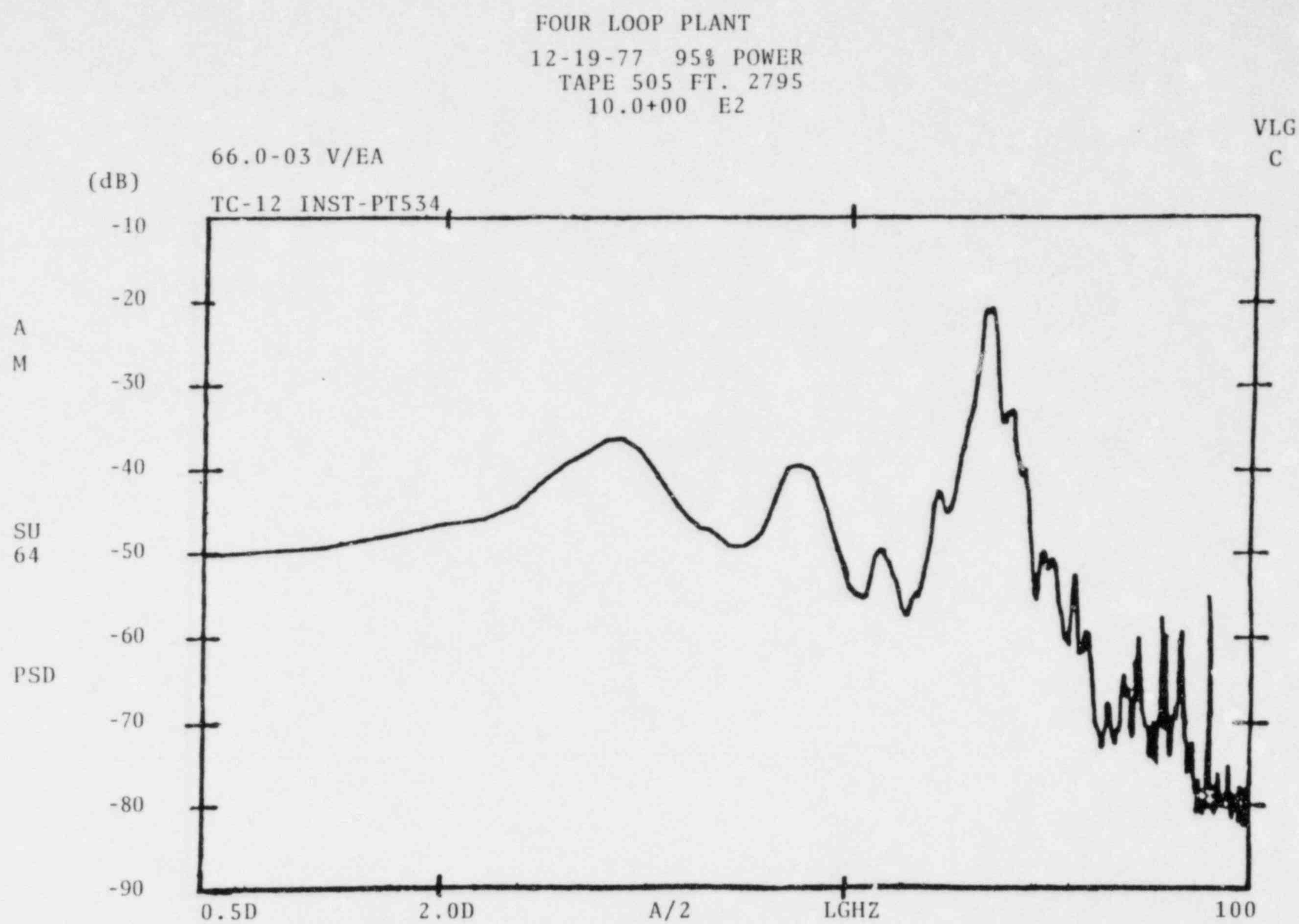


Figure 51:

12/19/77
95% Power, Steam Line Pressure, PSD

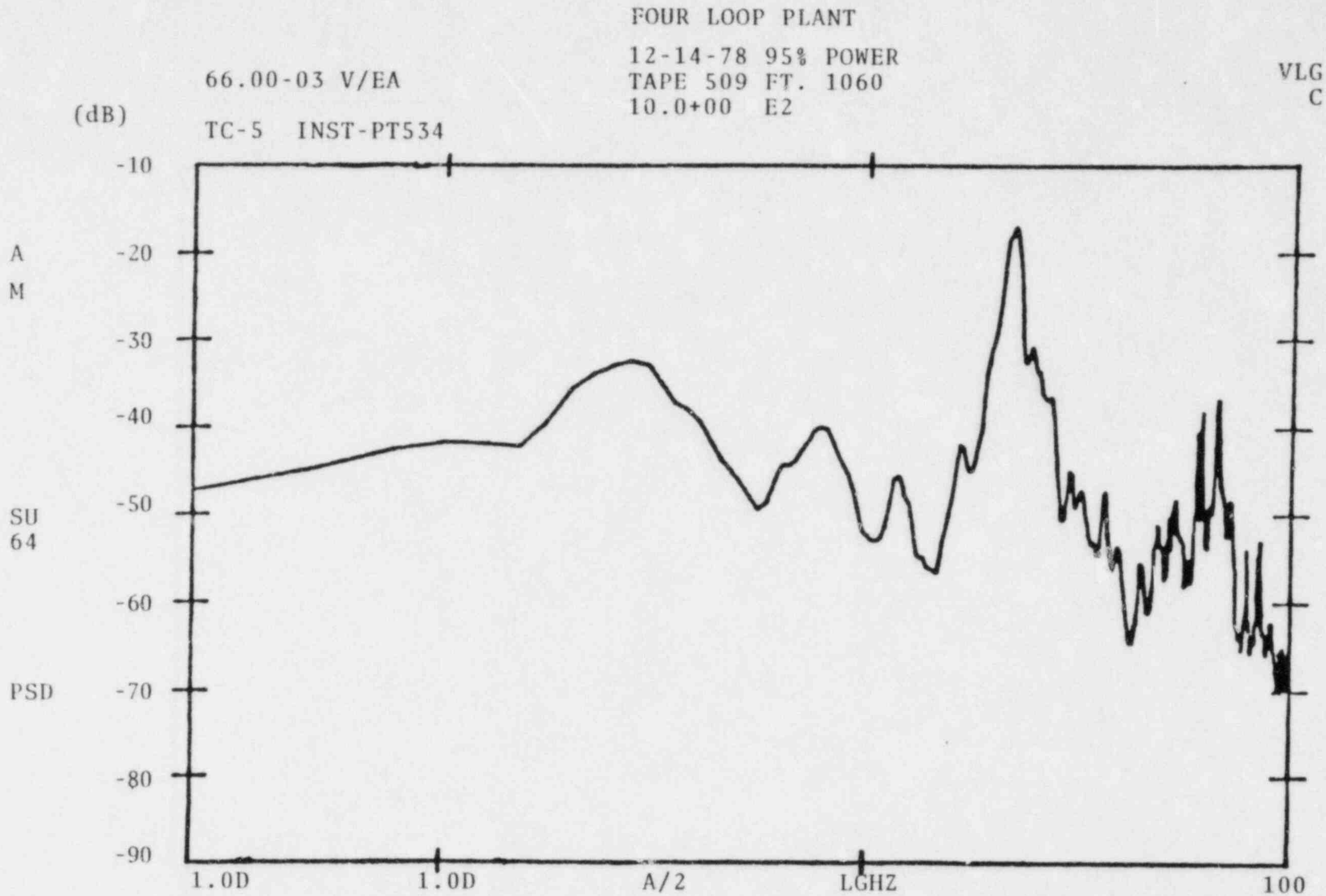


Figure 52:
12/14/78
95% Power, Steam Line Pressure, PSD

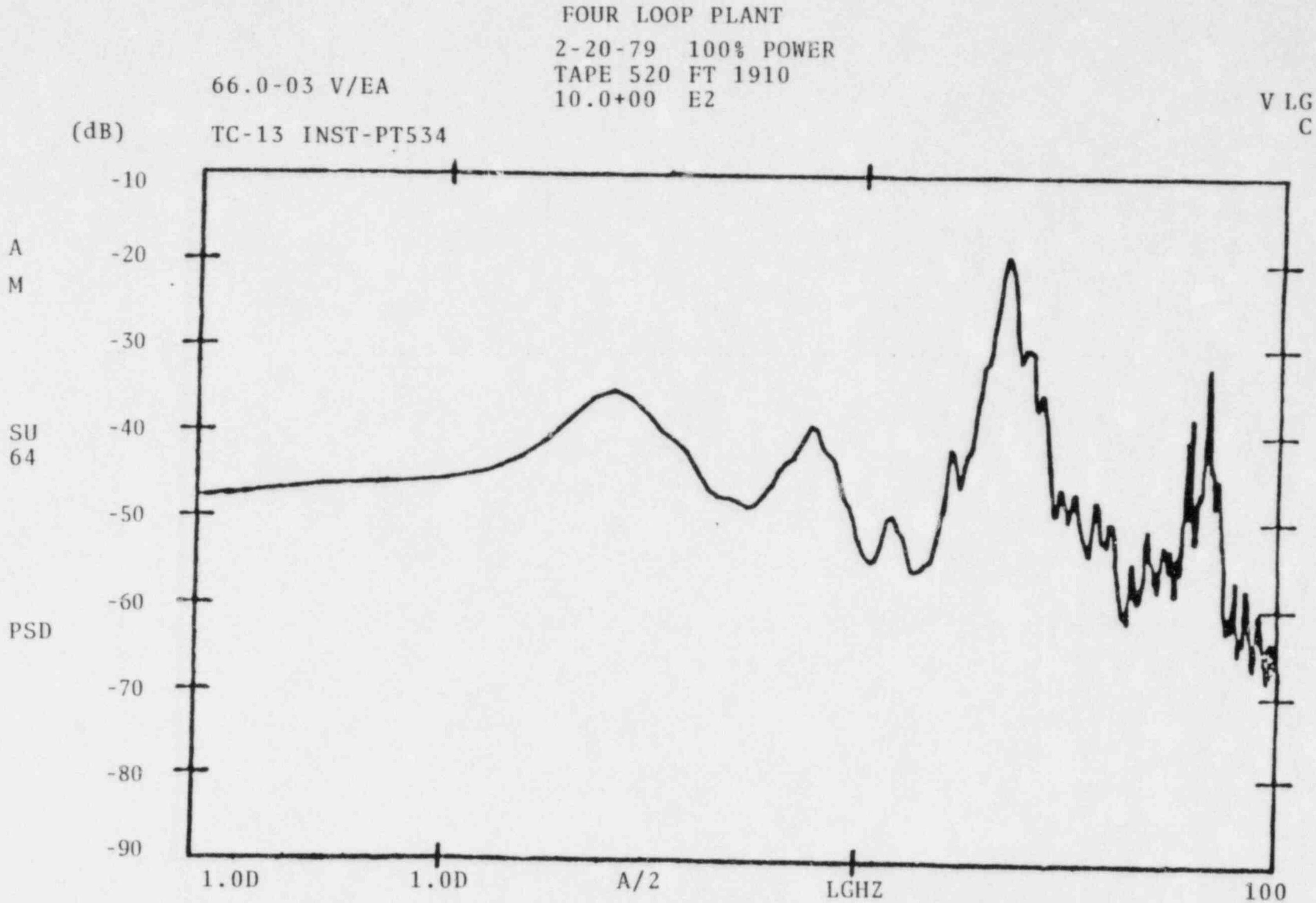


Figure 53:

2/20/79
100% Power, Steam Line Pressure, PSD

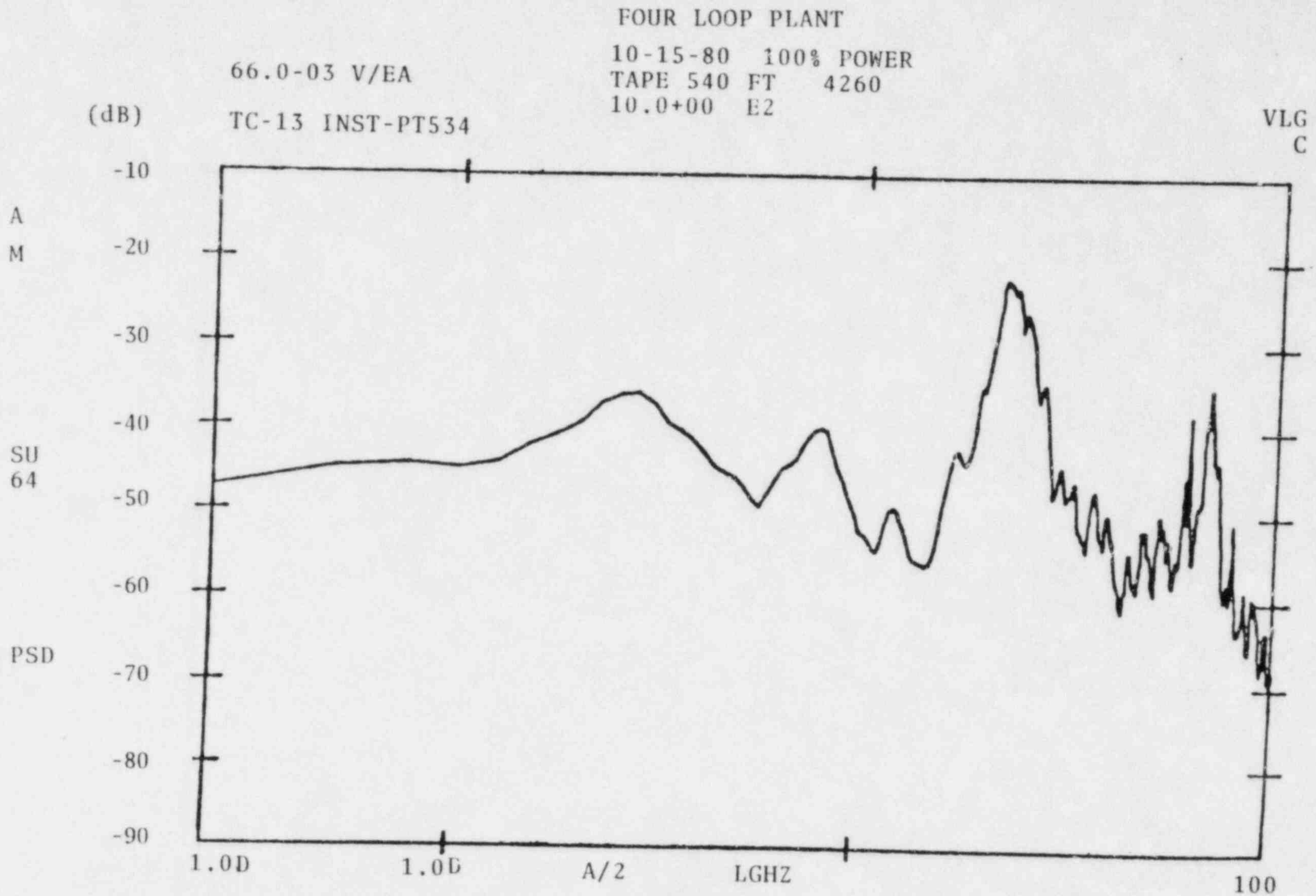


Figure 54:

10/15/80
100% Power, Steam Line Pressure, PSD

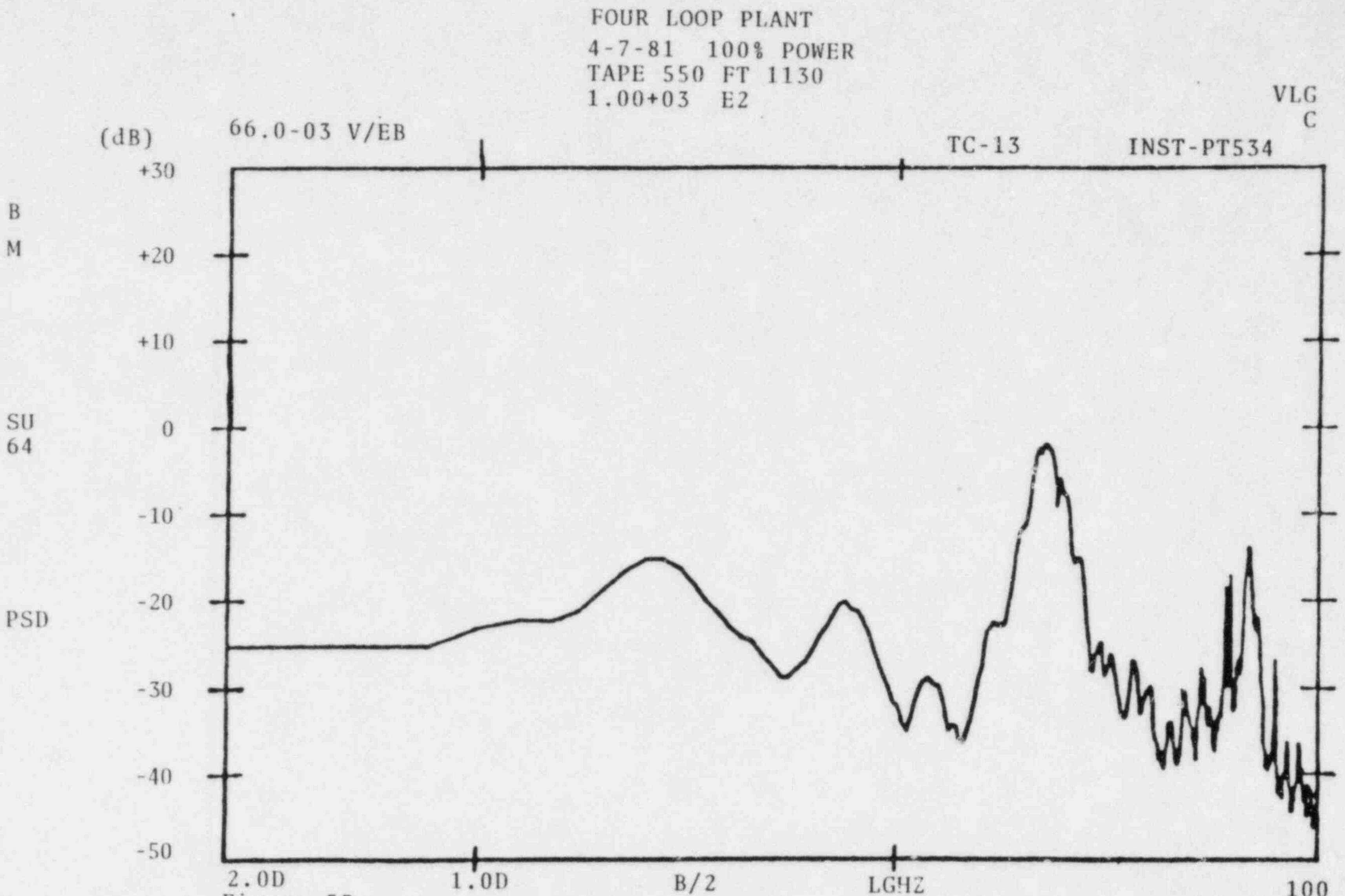


Figure 55:

4/7/81
100% Power, Steam Line Pressure, PSD

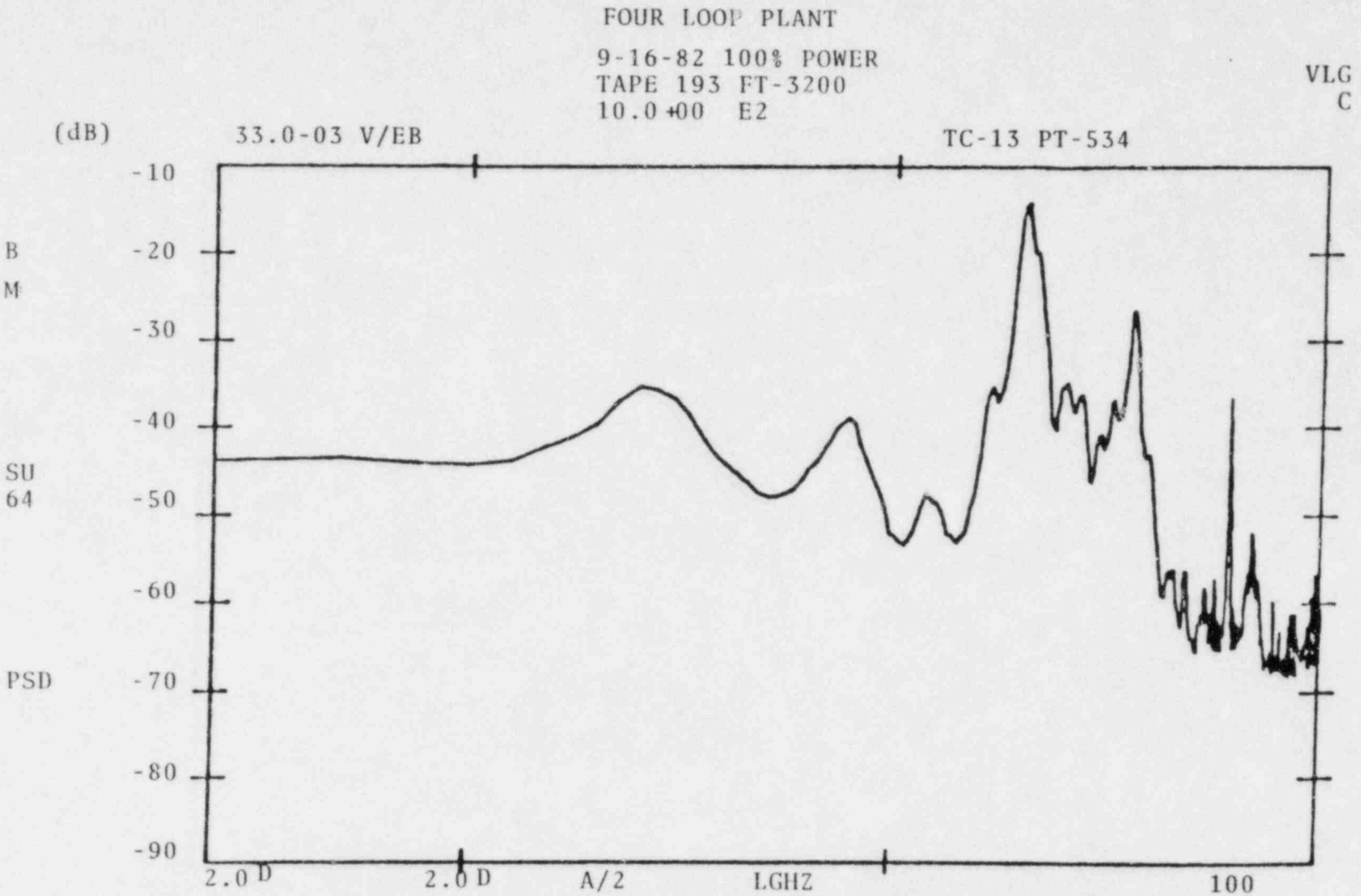


Figure 56:
12/19/77
100% Power,Steam Line Pressure, PSD

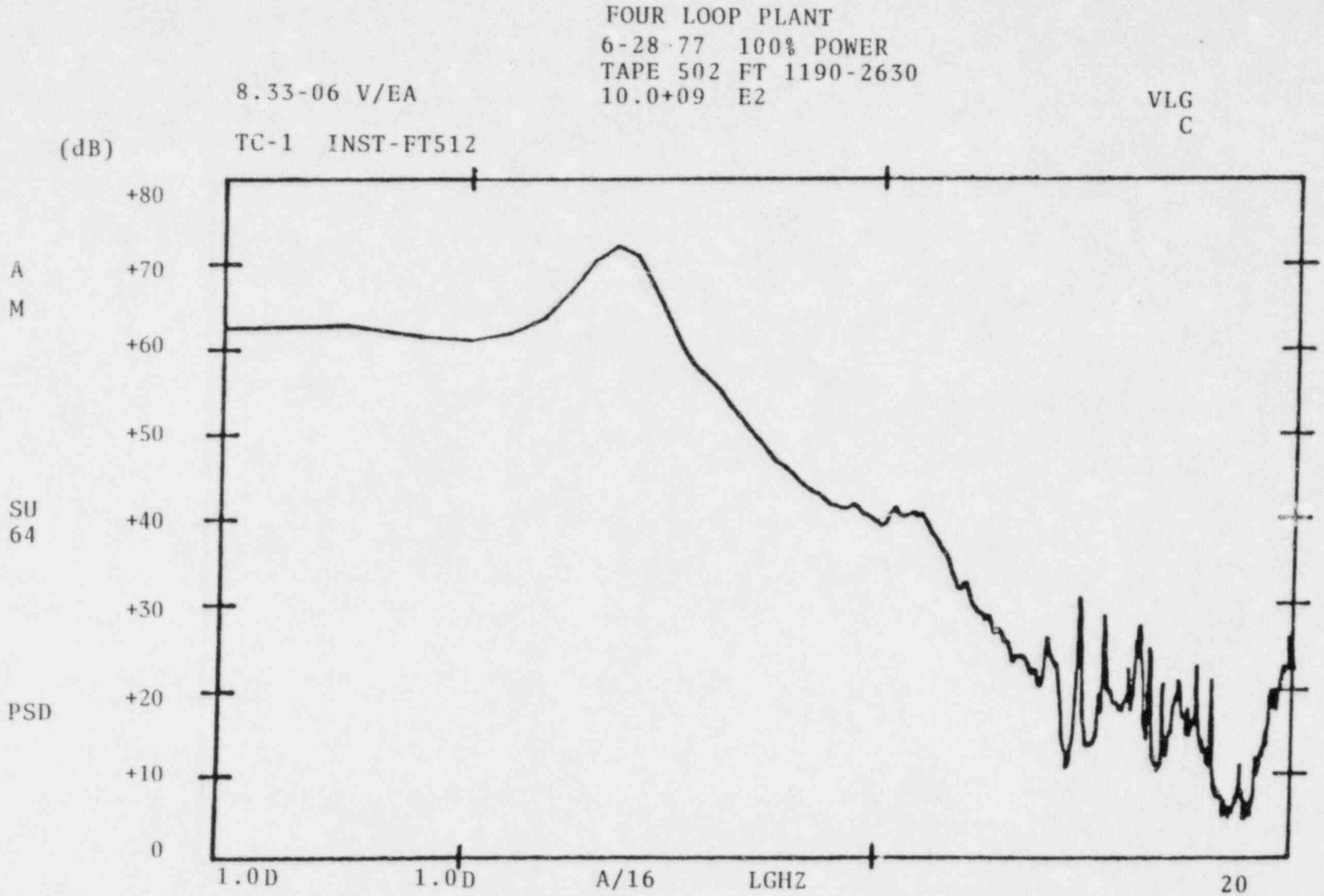


Figure 57:

6/28/77
100% Power, Steam Flow, PSD

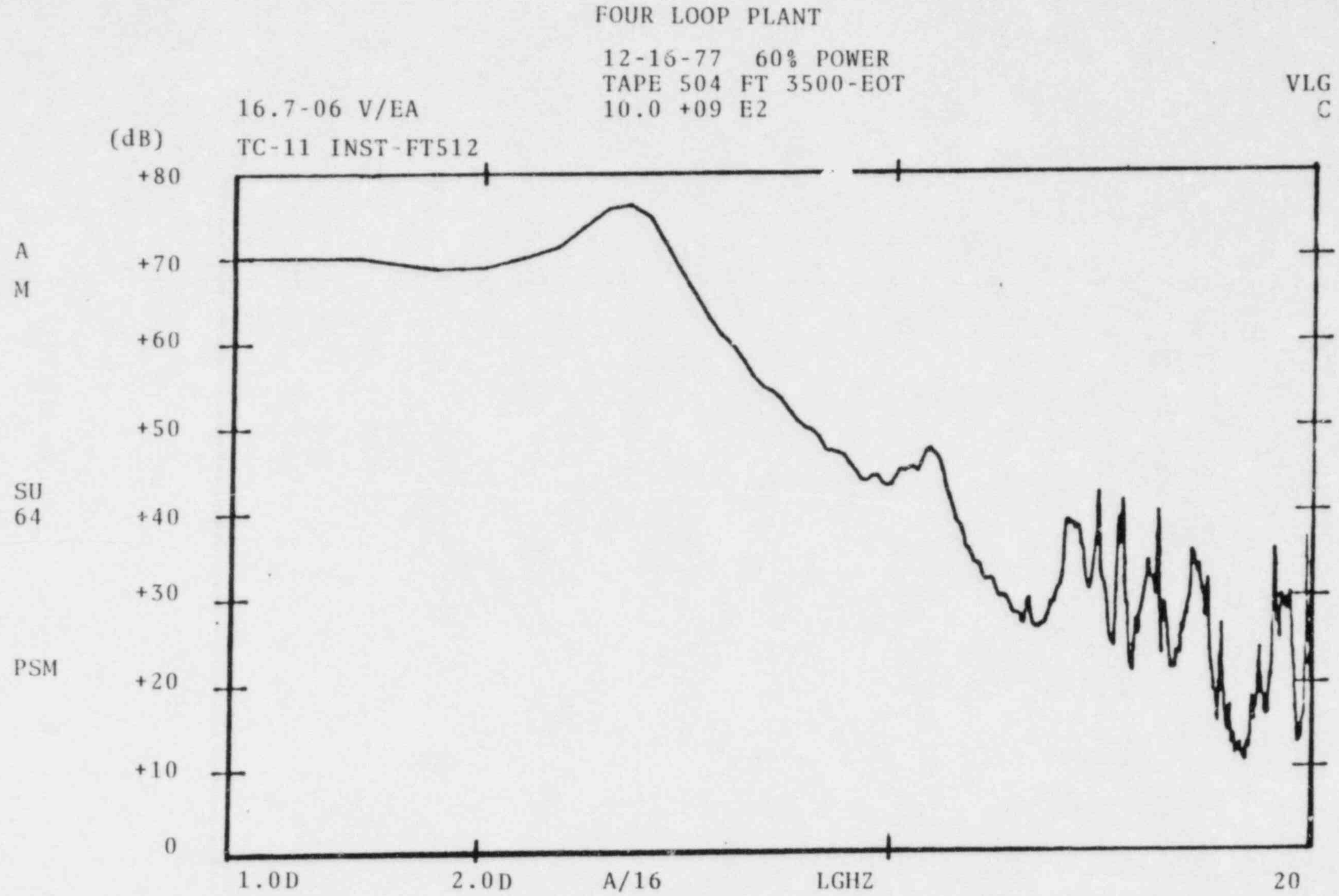


Figure 58:
12/16/77
60% Power, Steam Flow, PSD

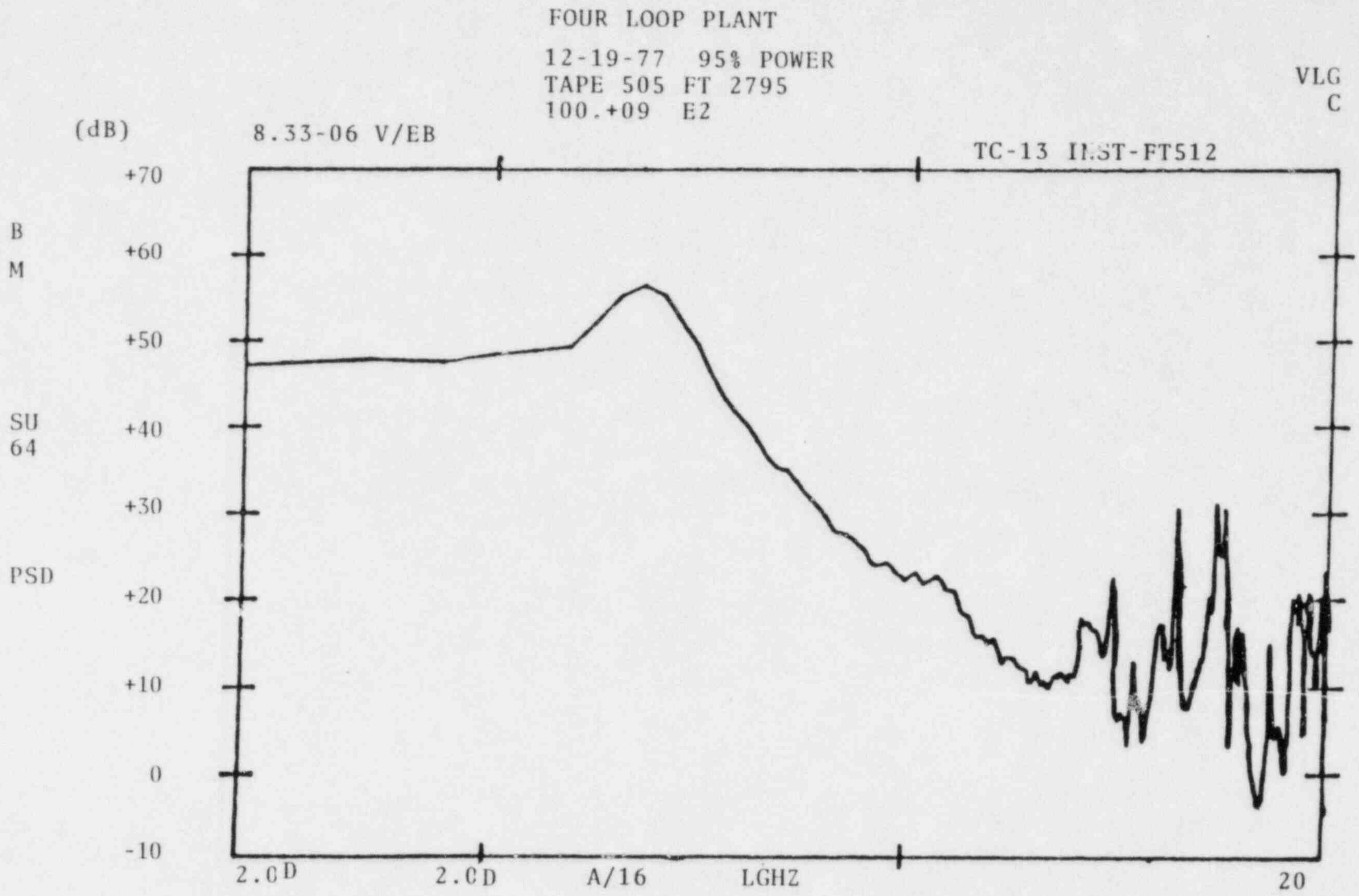


Figure 59:

12/19/77
95% Power, Steam Flow, PSD

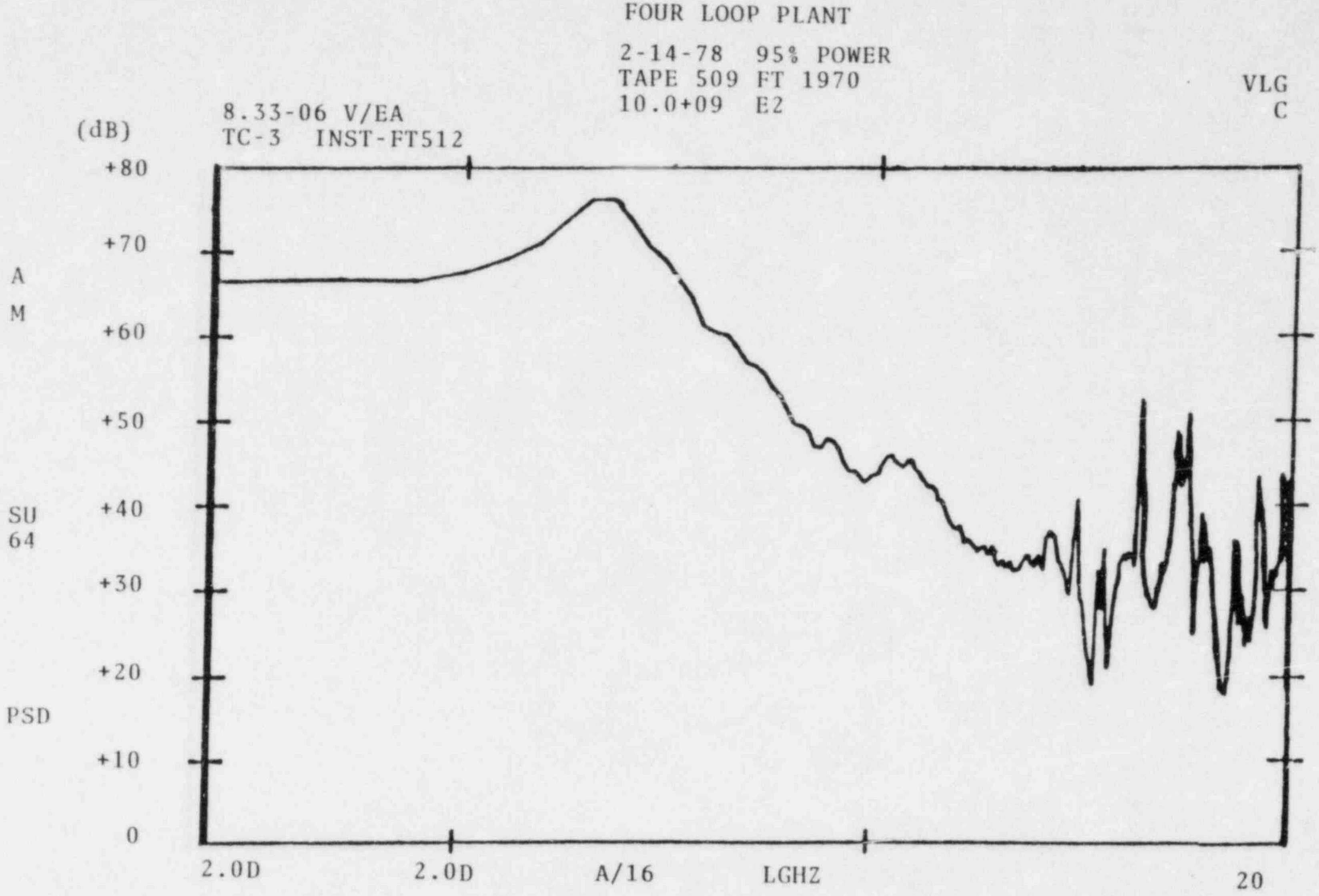


Figure 60:
2/14/78
95% Power, Steam Flow, PSD

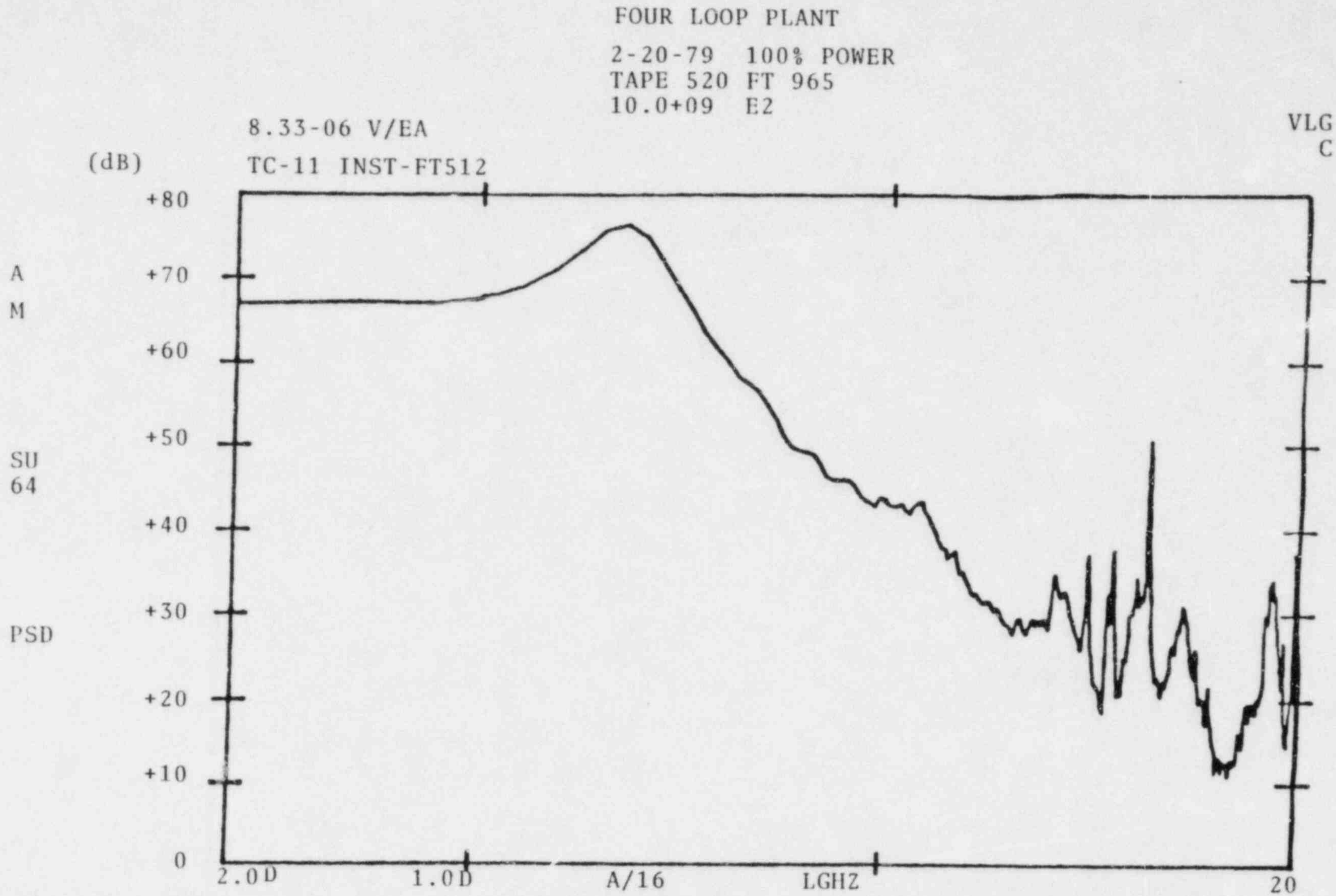


Figure 61:

2/20/79
100% Power, Steam Flow, PSD

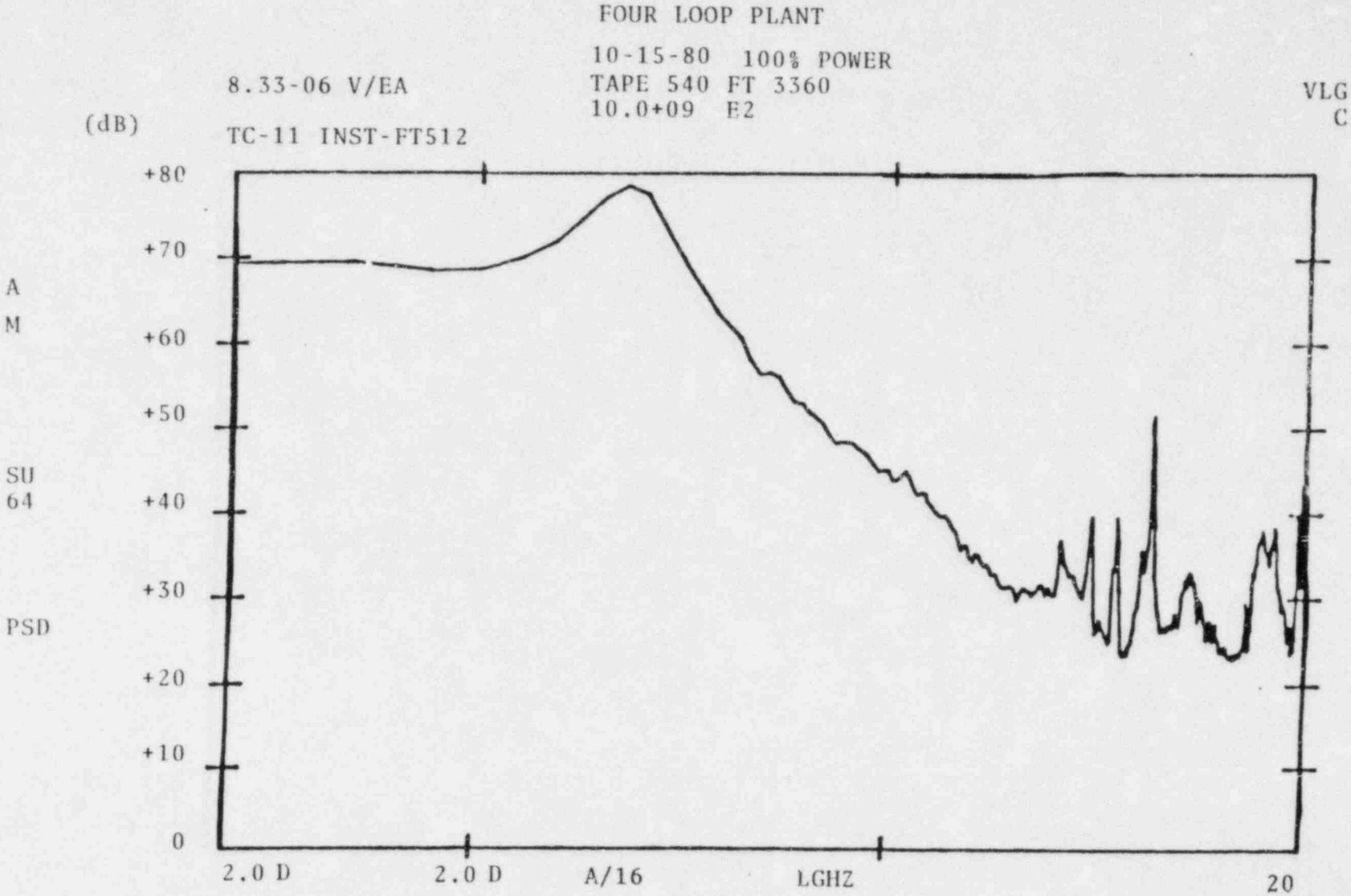


Figure 62:
10/15/80
100% Power, Steam Flow, PSD

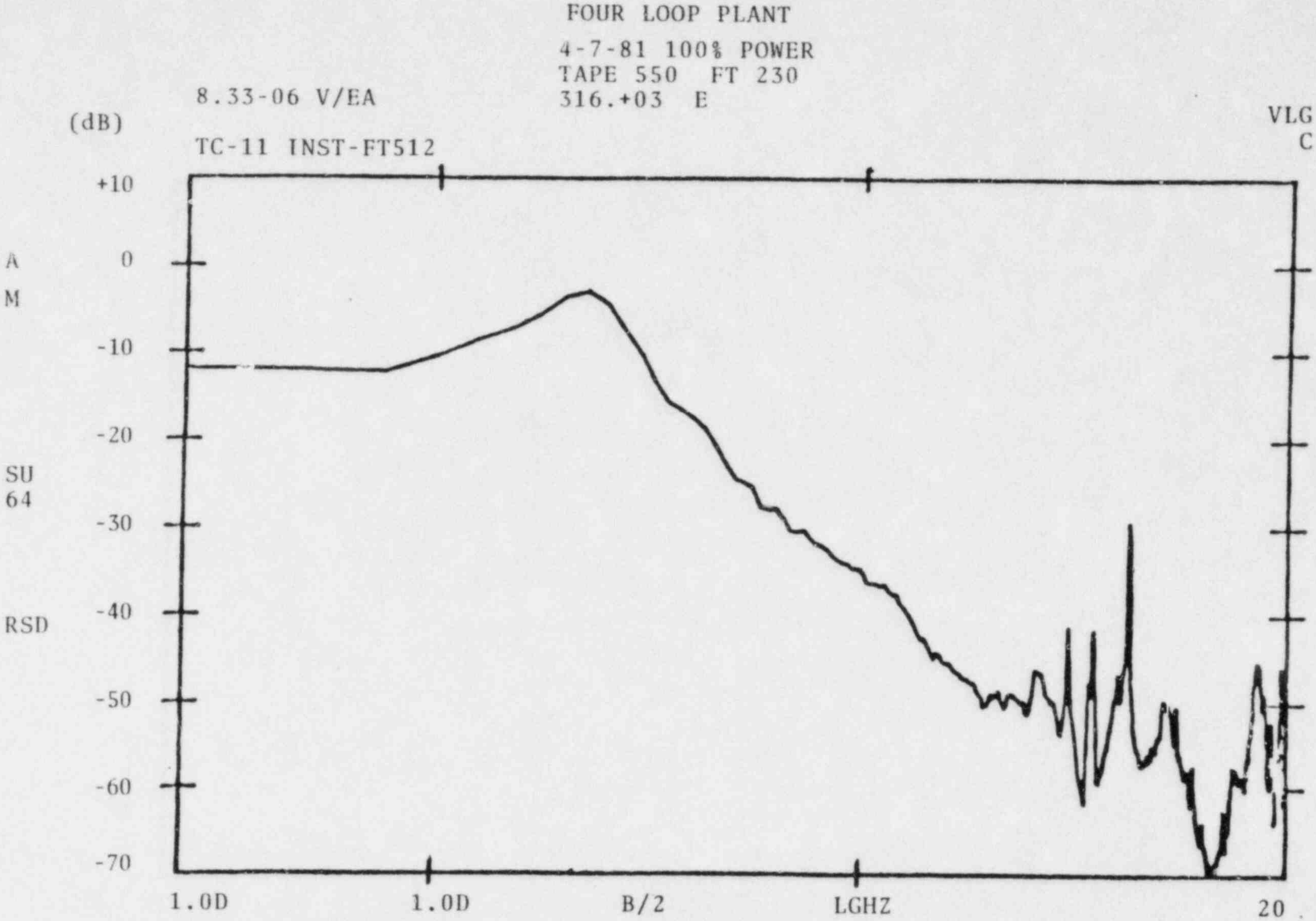


Figure 63:
4/7/81
100% Power, Steam Flow, RSD

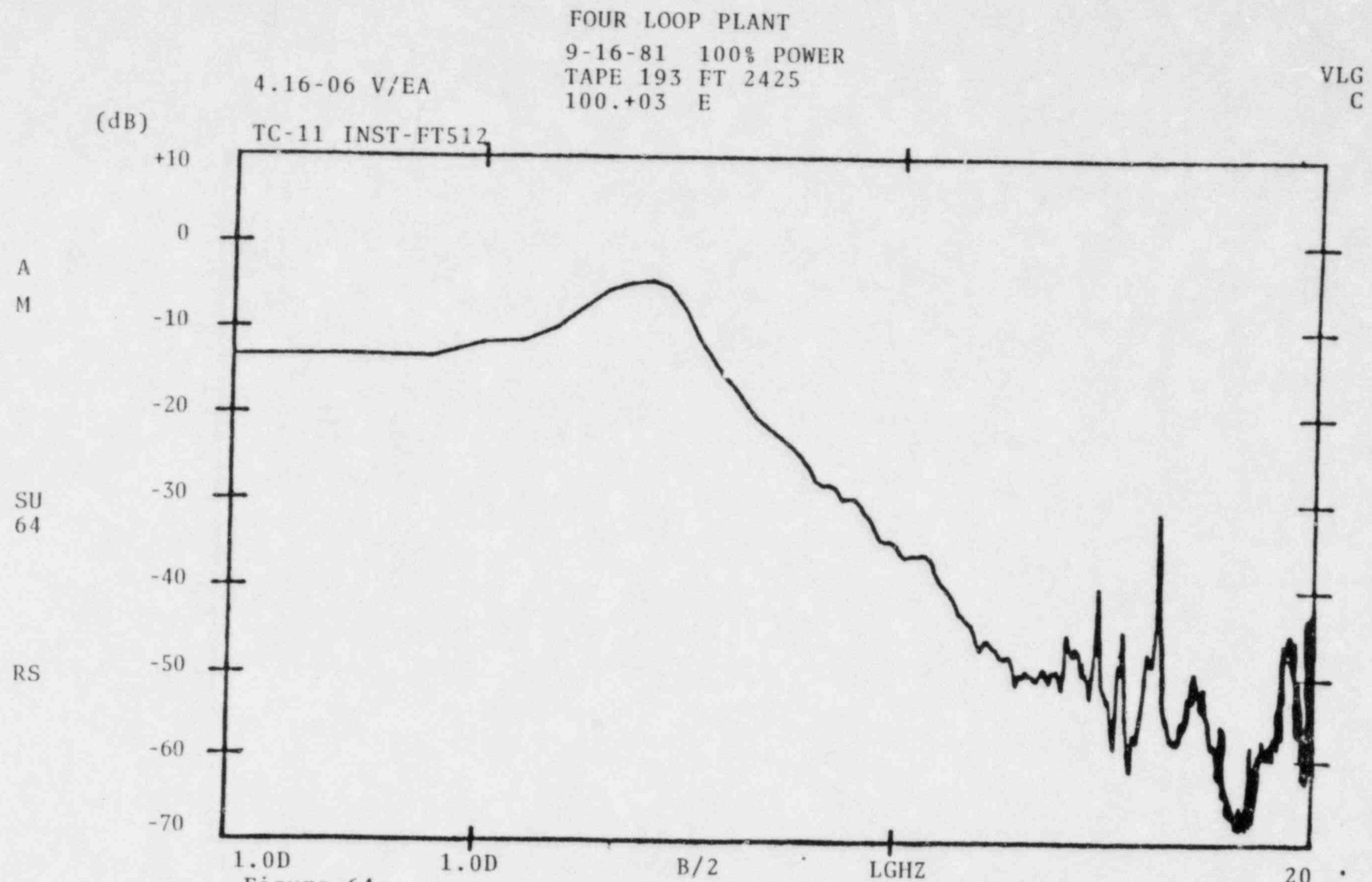


Figure 64:
9/16/81
100% Power, Steam Flow, RS

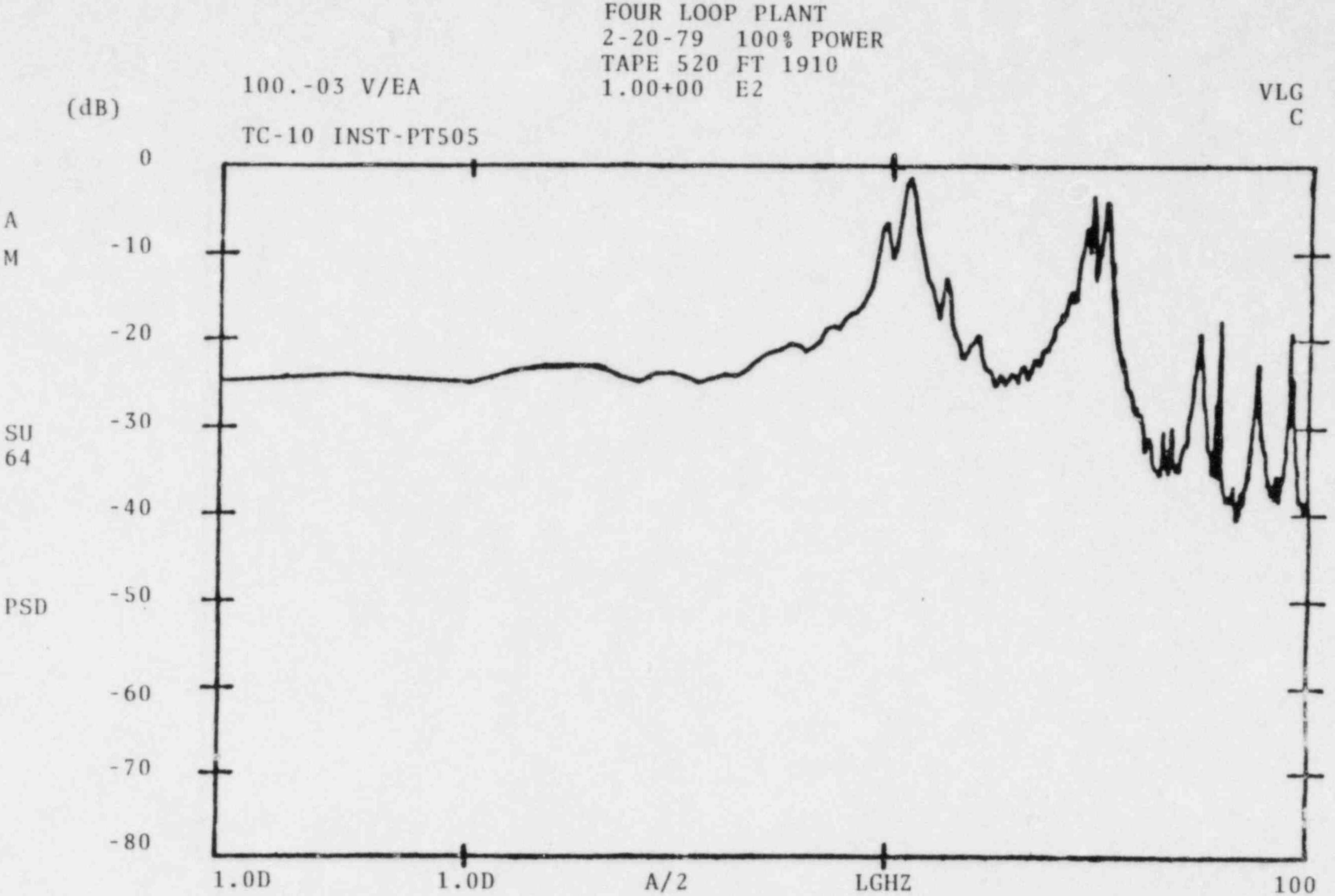


Figure 65: 2/20/79
100% Power, Steam Line Pressure, PSD

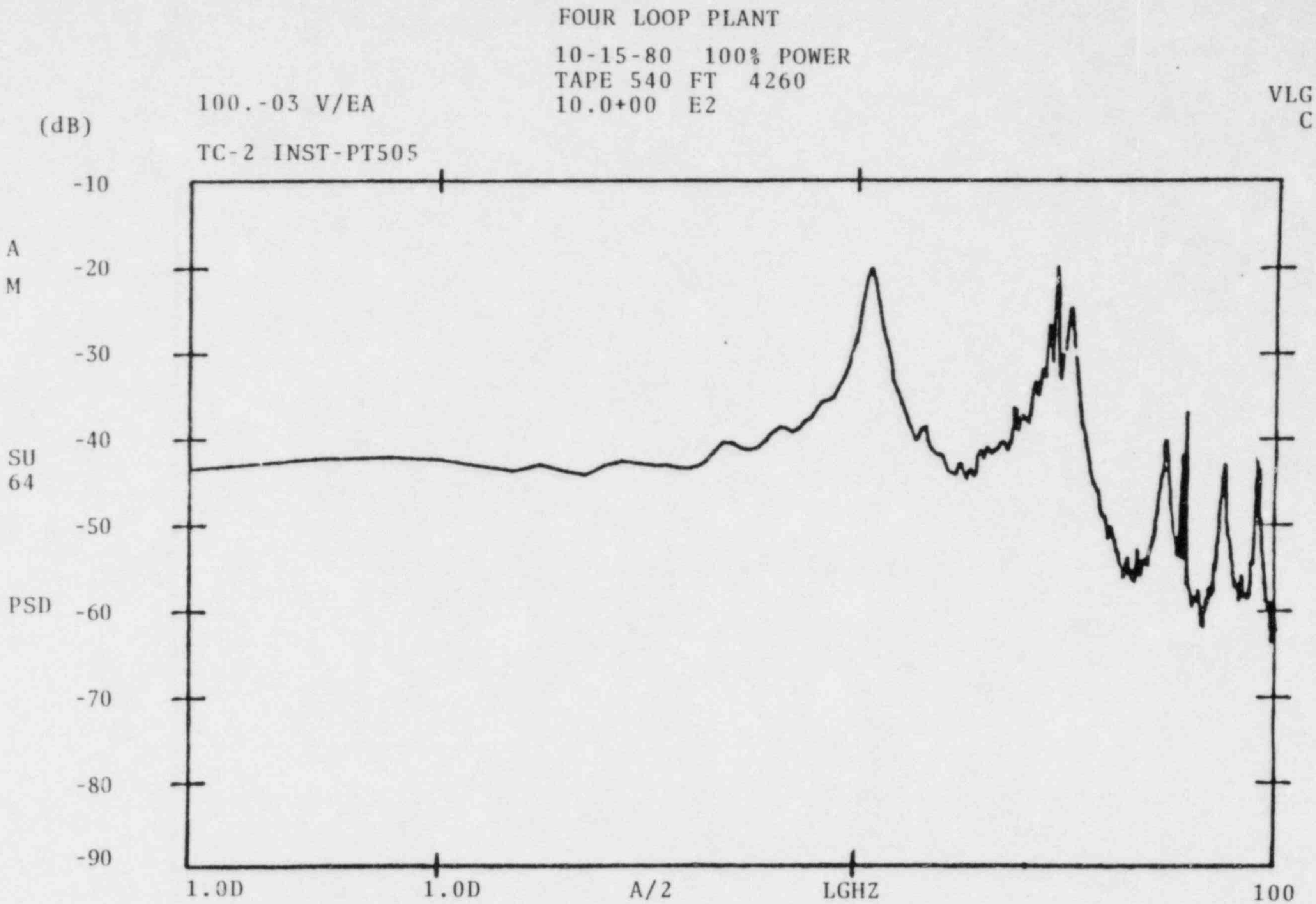


Figure 66: 10/15/80
100% Power, Steam Line Pressure, PSD

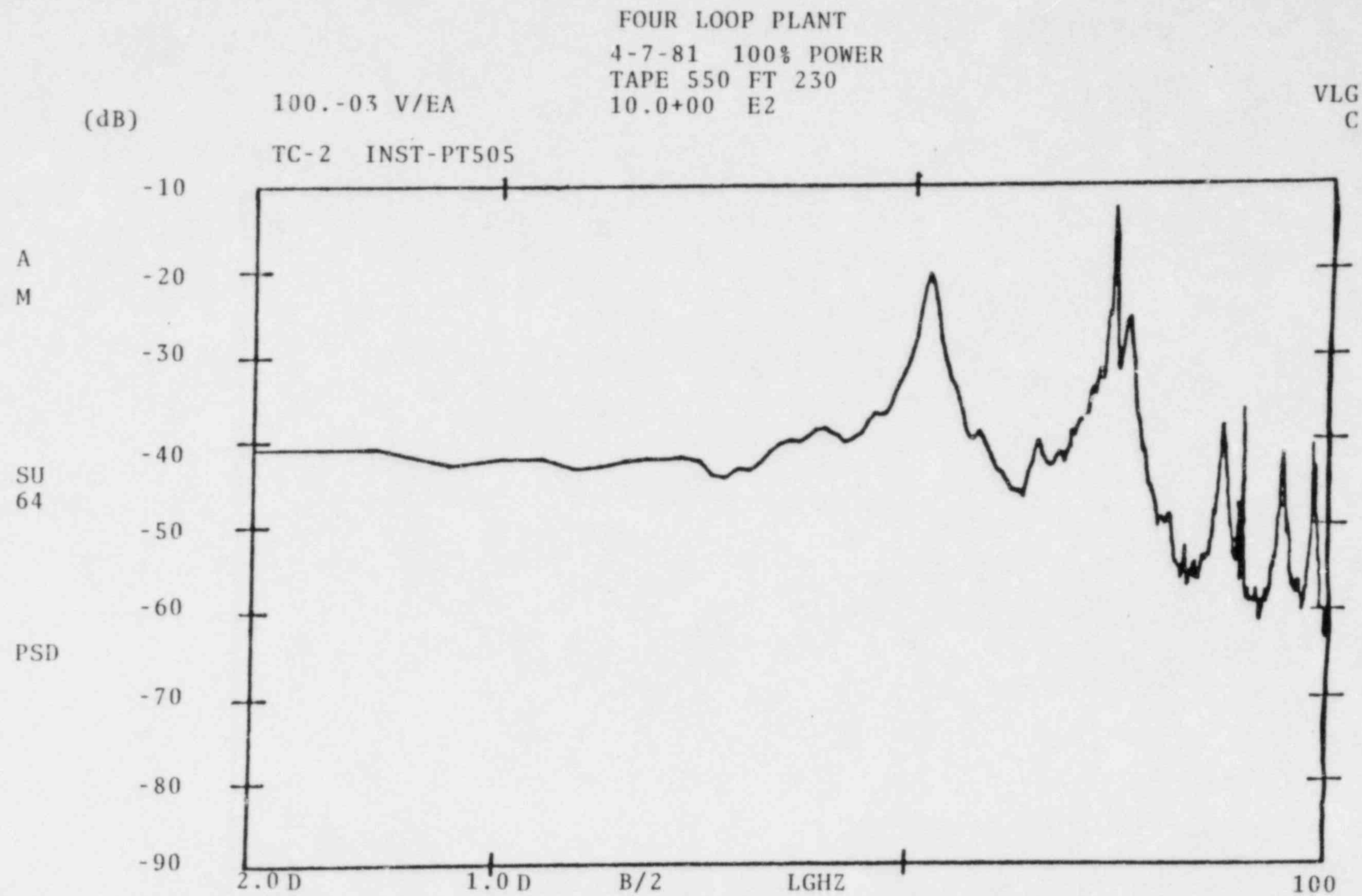


Figure 67:
4/7/81
100% Power, Steam Line Pressure, PSD

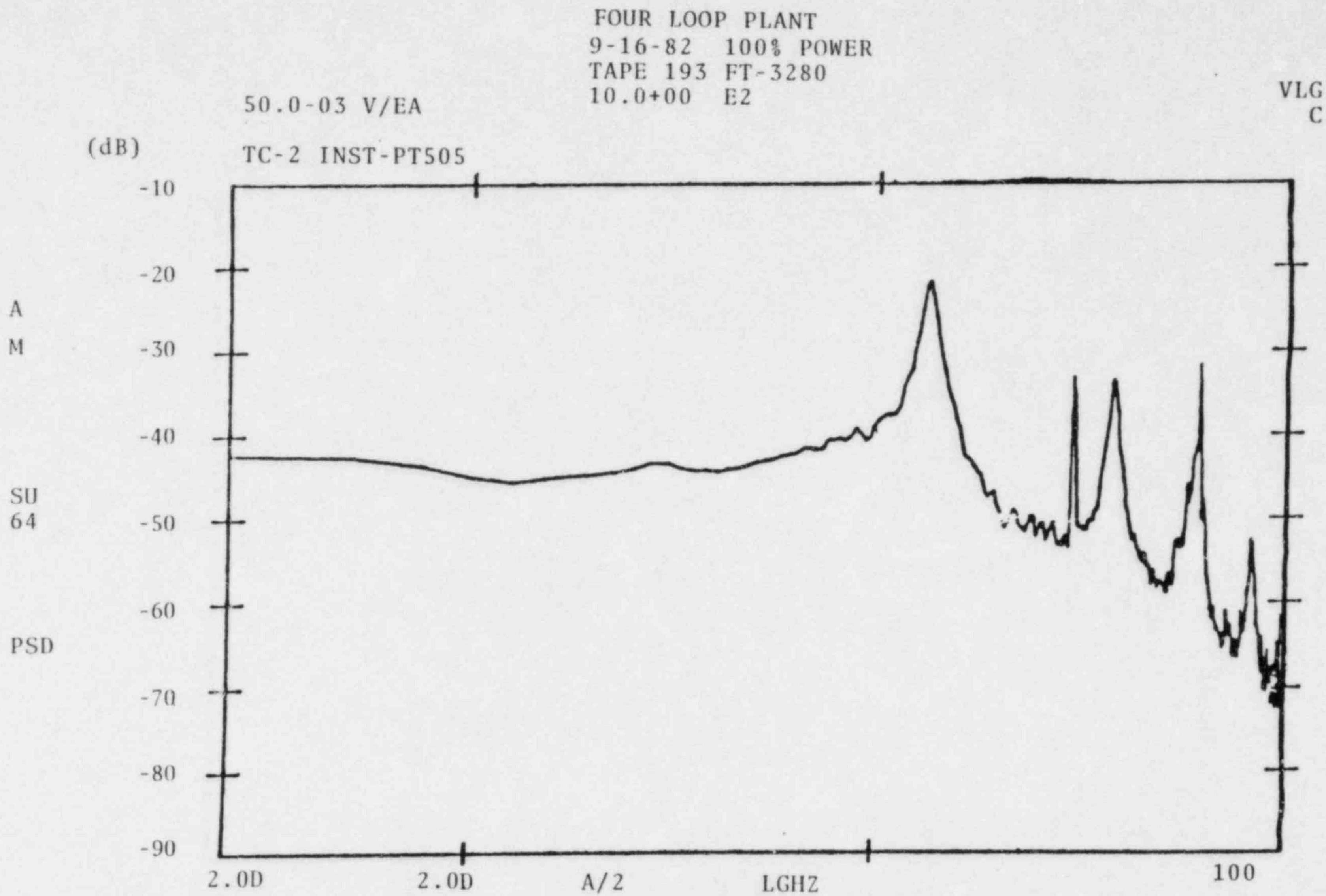


Figure 68:
9/16/82
100% Power, Steam Line Pressure, PSD

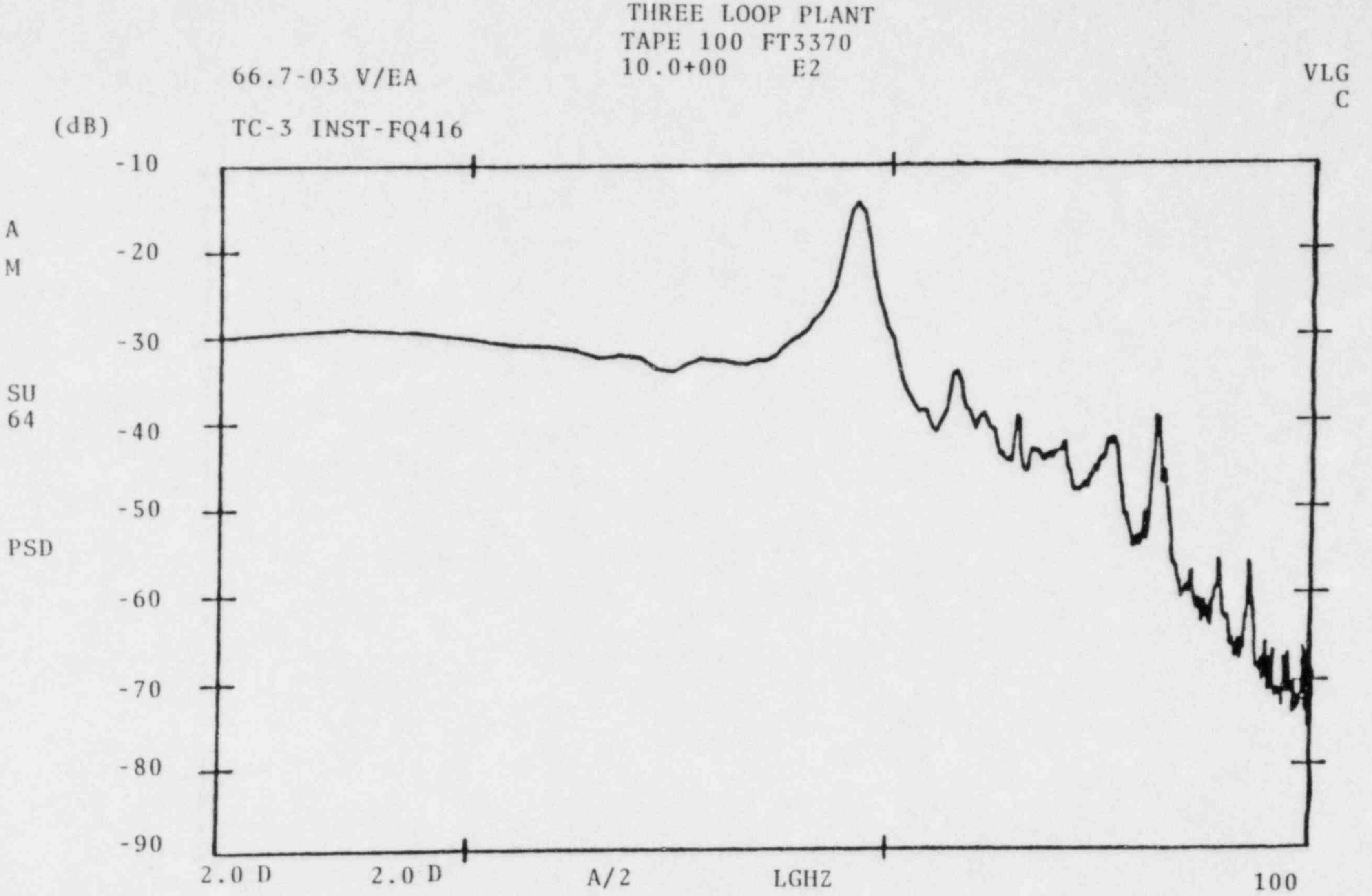


Figure 69: 3/17/78
100% Power, Reactor Coolant Flow III, PSD

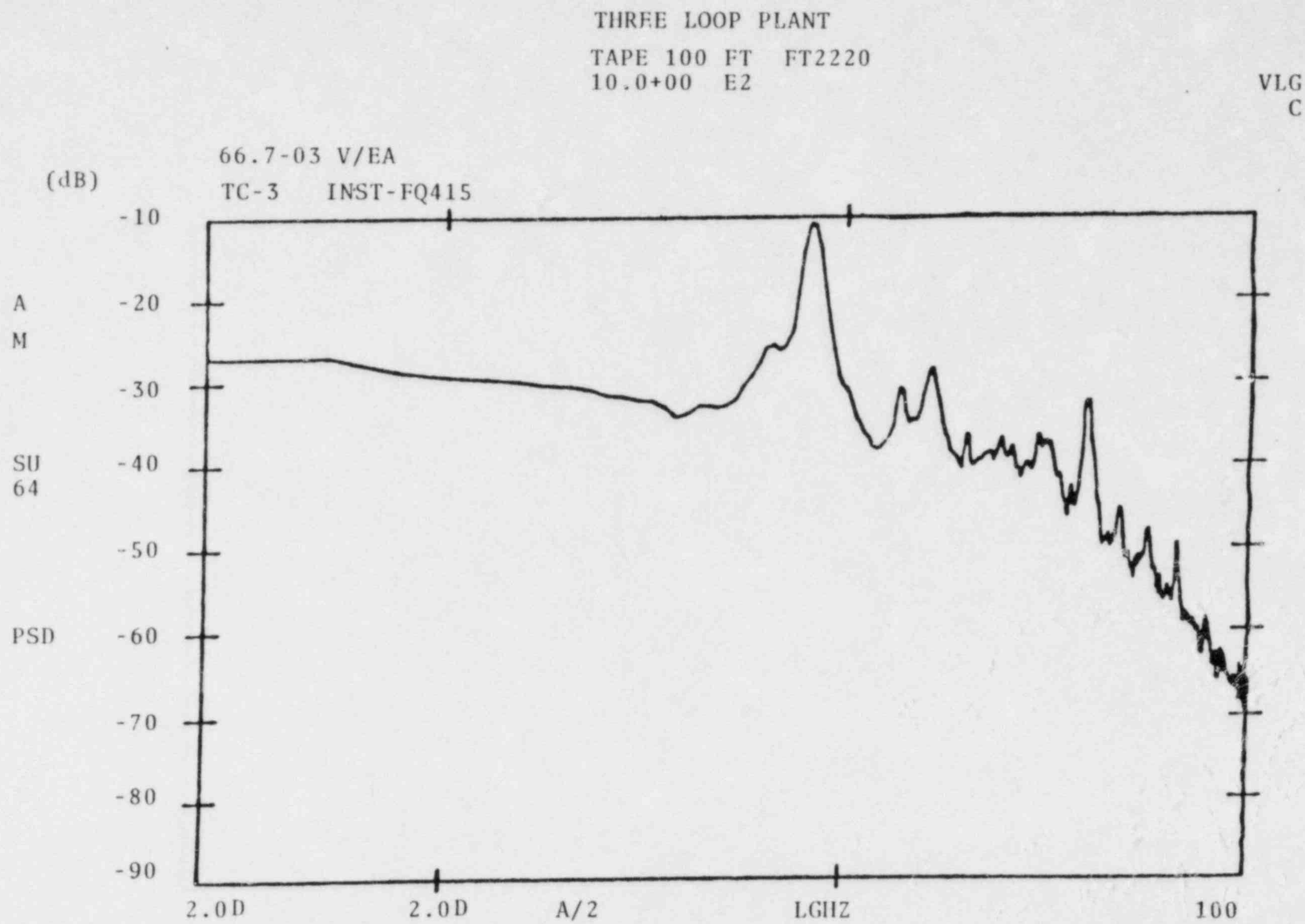


Figure 70:
3/17/78
100% Power, Reactor Coolant Flow II, PSD

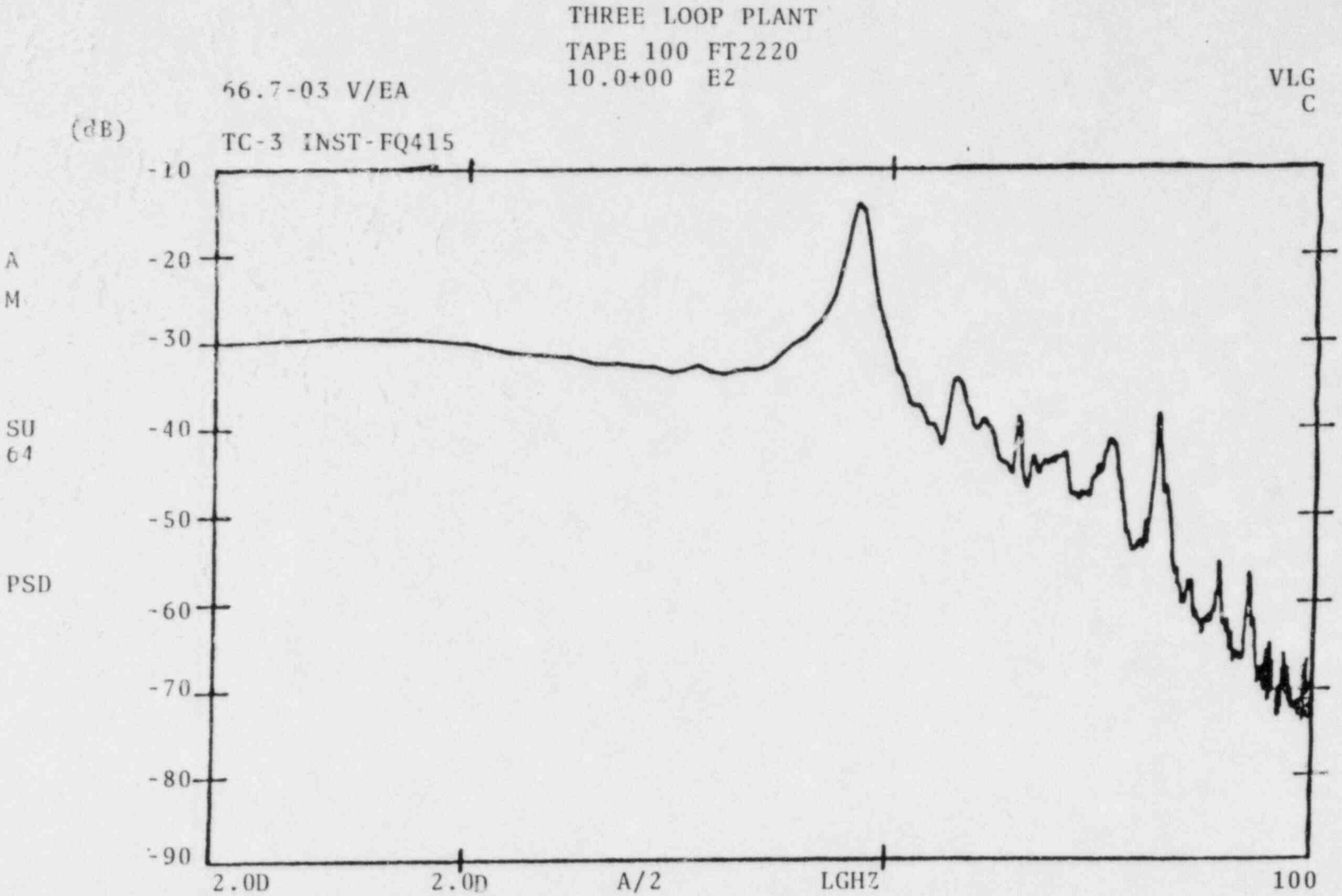


Figure 71:
3/17/78
100% Power, Reactor Coolant Flow II, PSD

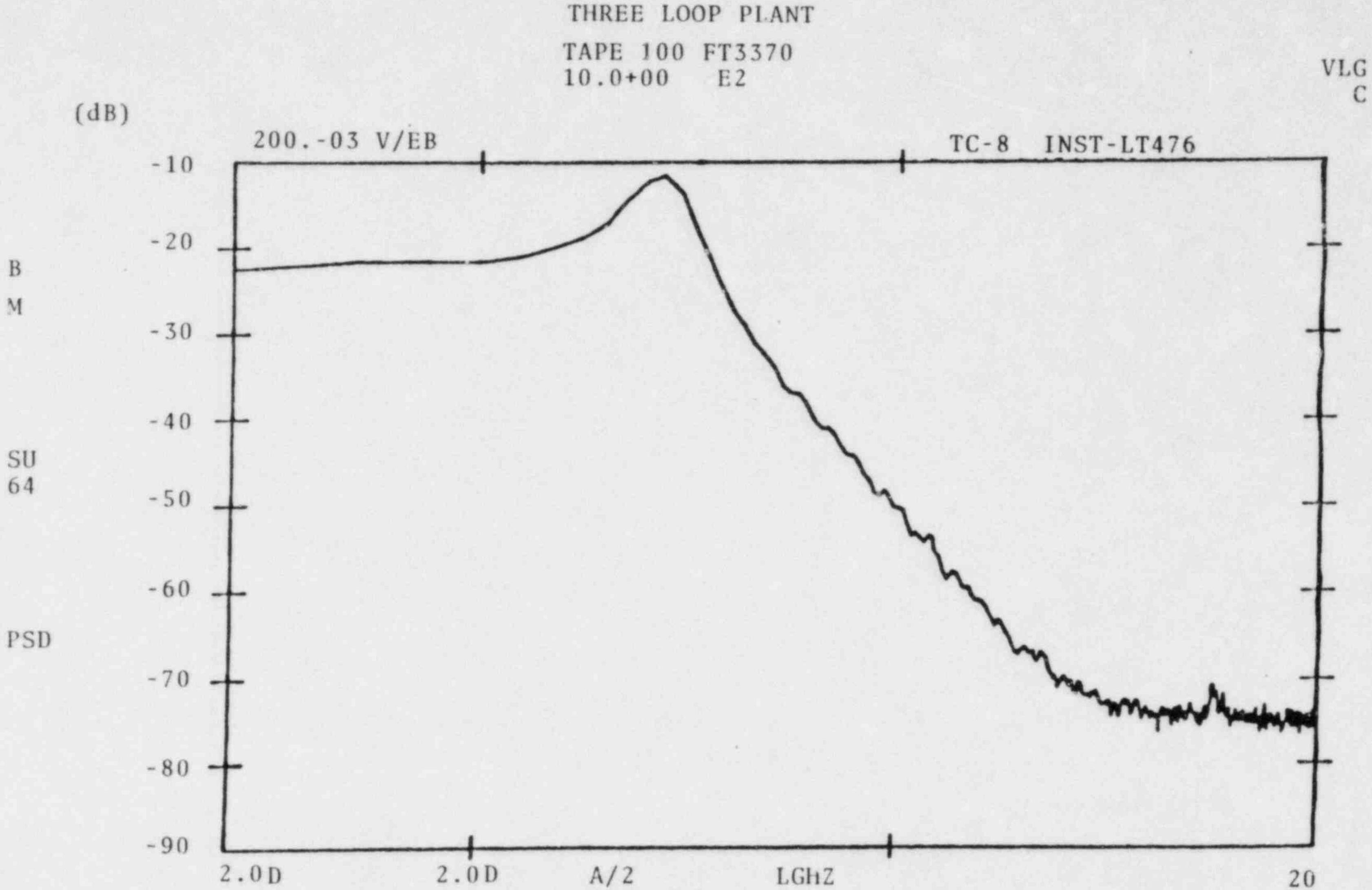


Figure 72:

3/17/78
100% Power, Pressurizer Level, PSD

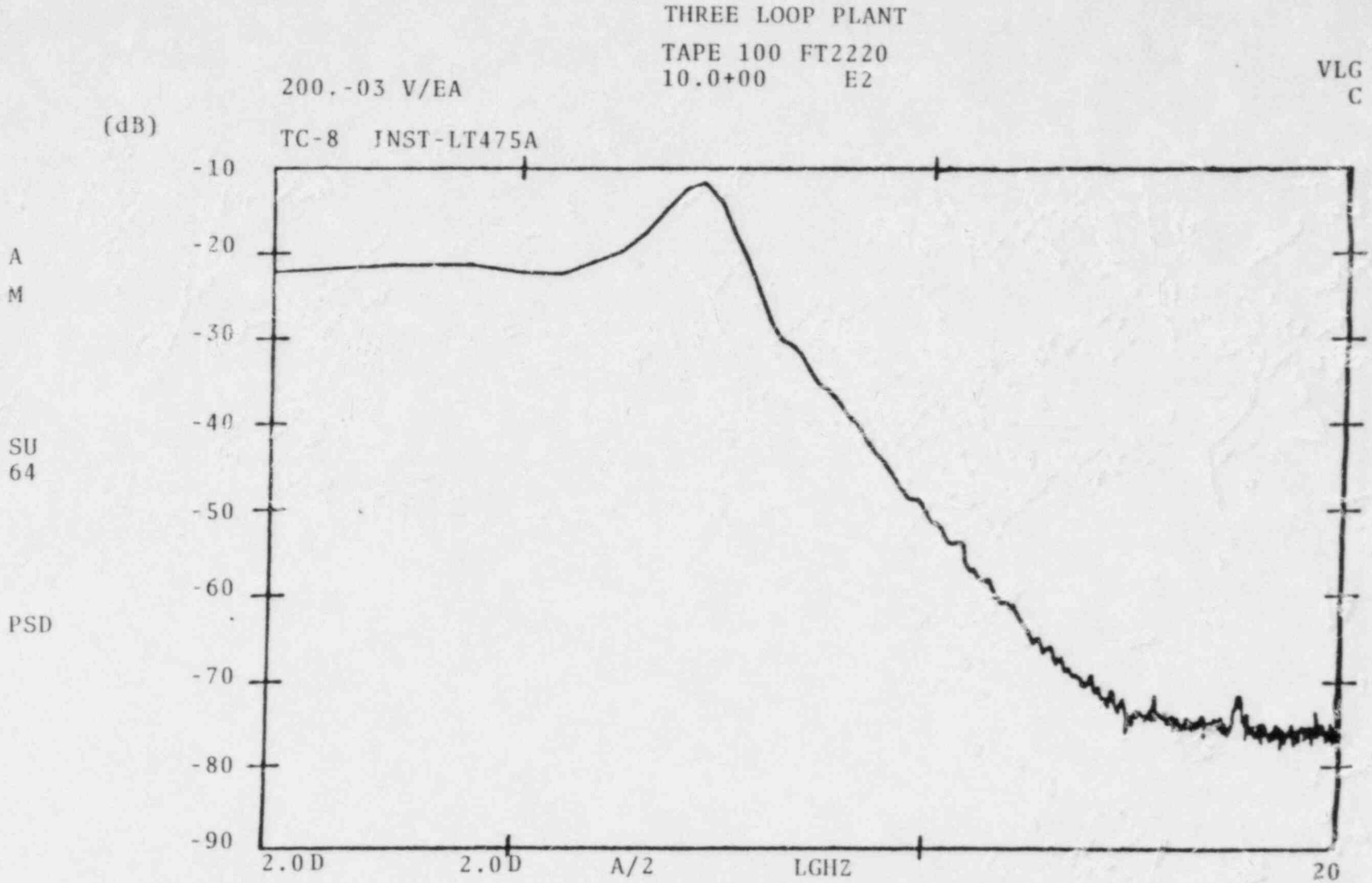


Figure 73: 3/17/78
100% Power, Pressurizer Level, PSD

THREE LOOP PLANT

TAPE 100 FT3370
10.0+00 E2

VLG
C

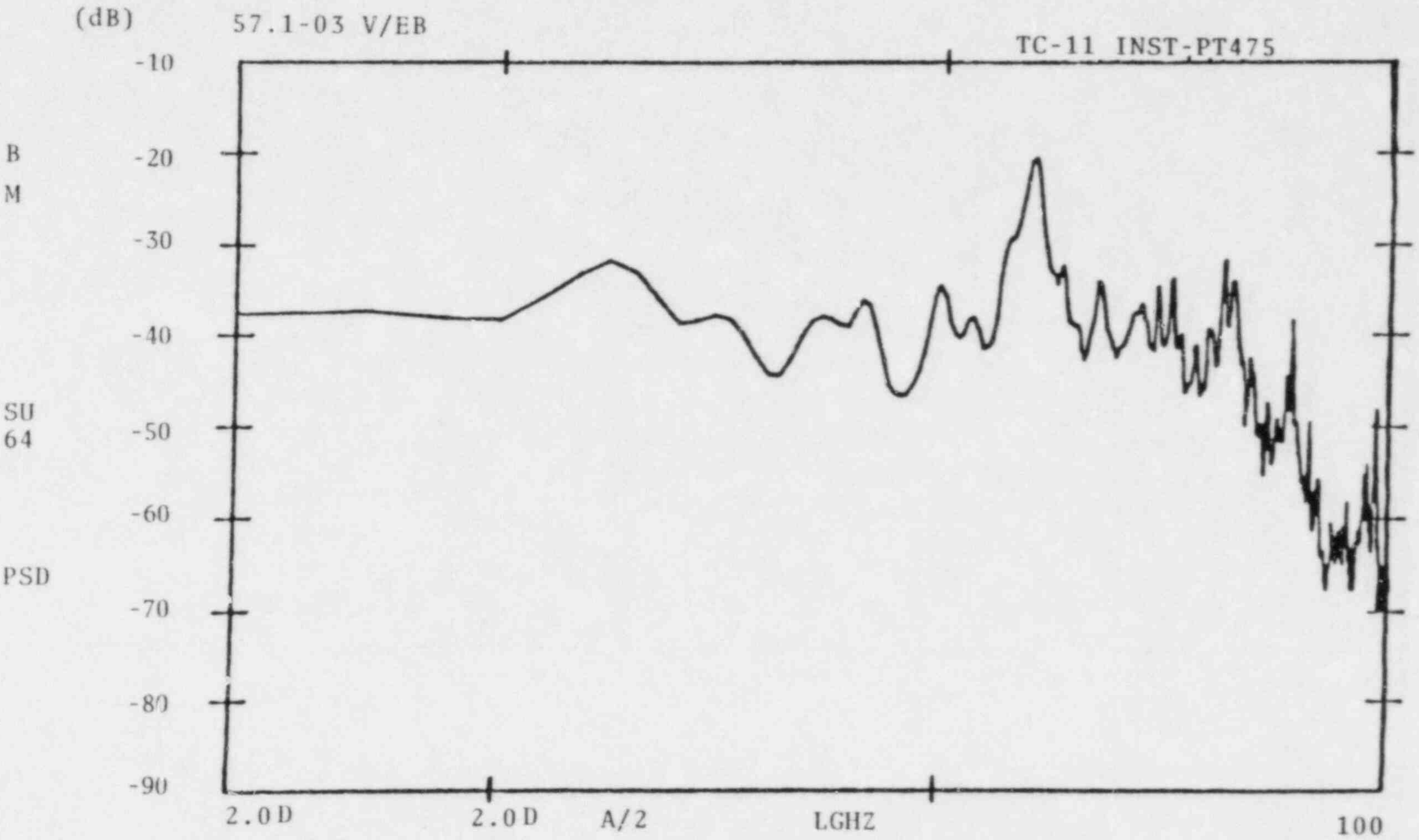


Figure 74: 3/17/78
100% Power, Pressurizer Pressure, PSD

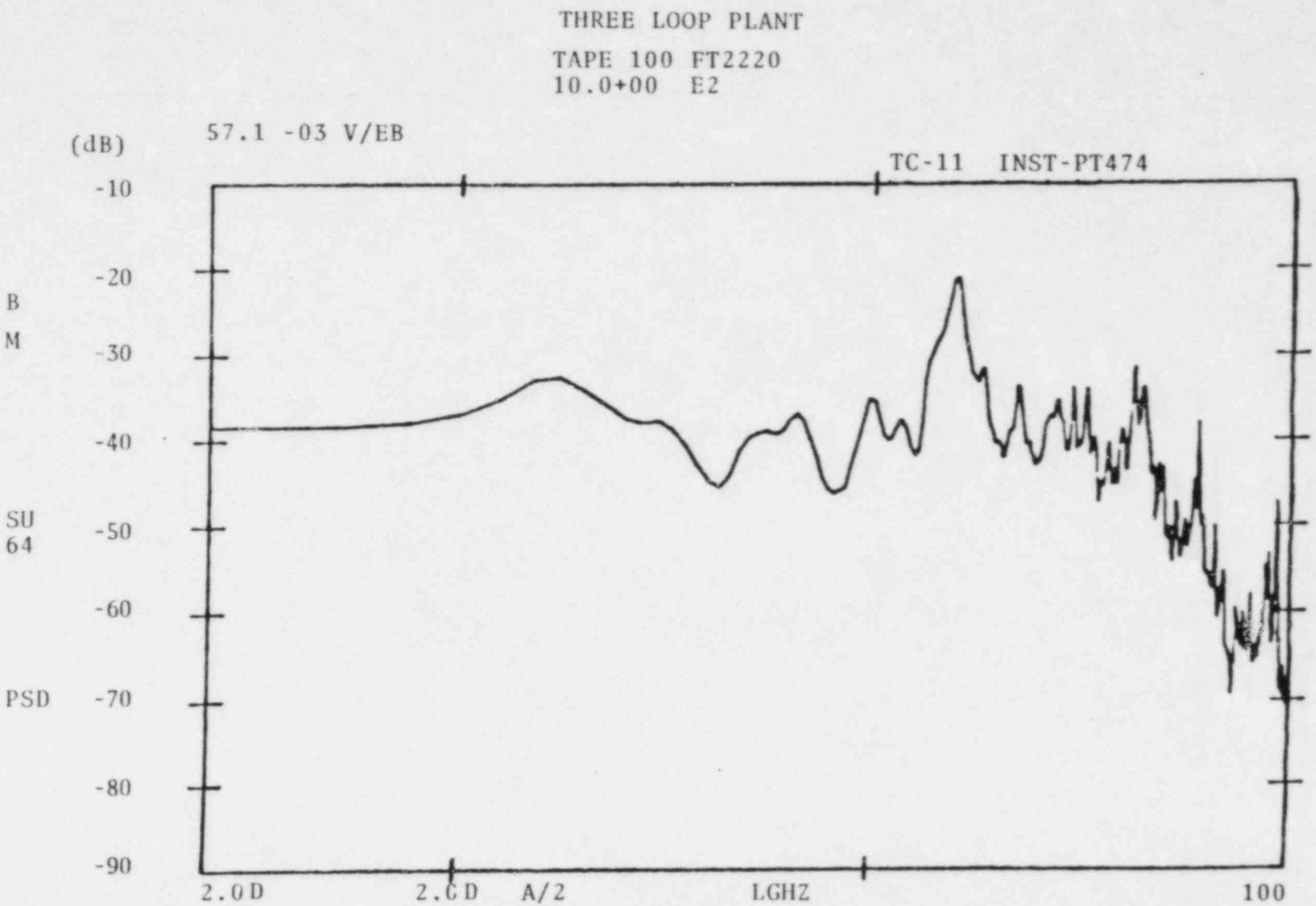


Figure 75: 3/17/78
100% Power, Pressurizer Pressure, PSD

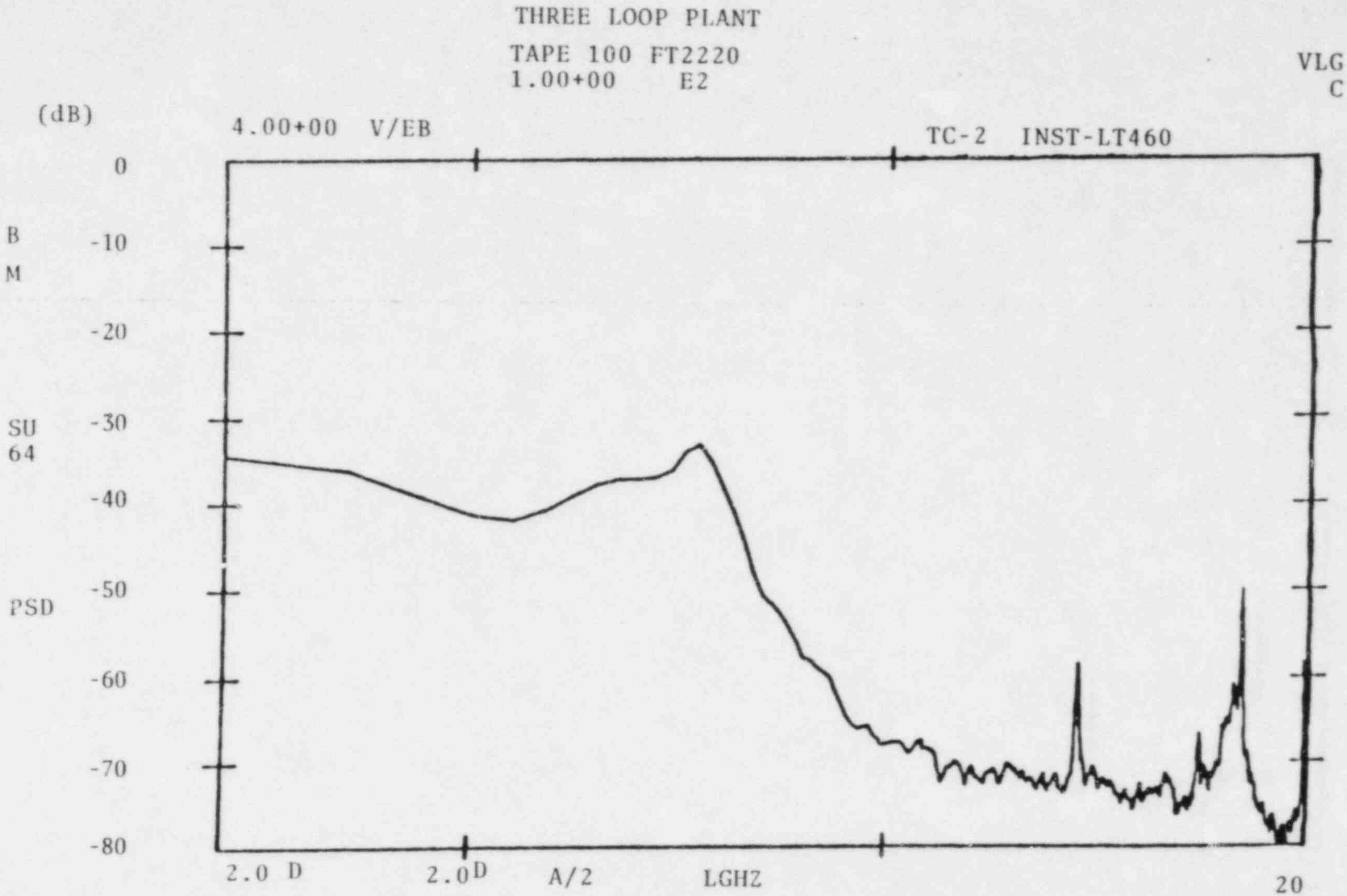


Figure 76: 3/17/78
100% Power, Pressurizer Level, PSD

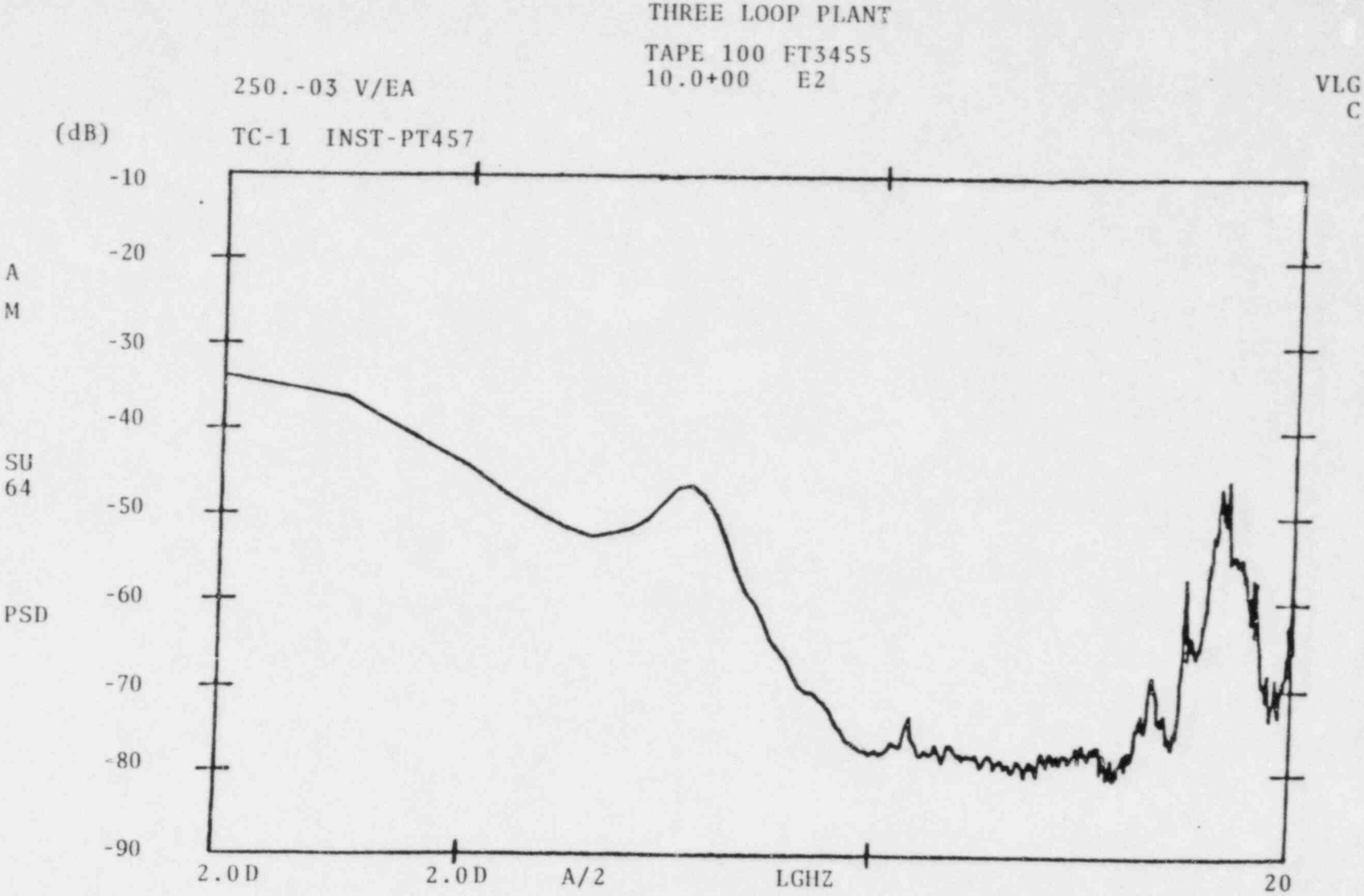


Figure 77: 3/17/78
100% Power, Pressurizer Pressure, PSD

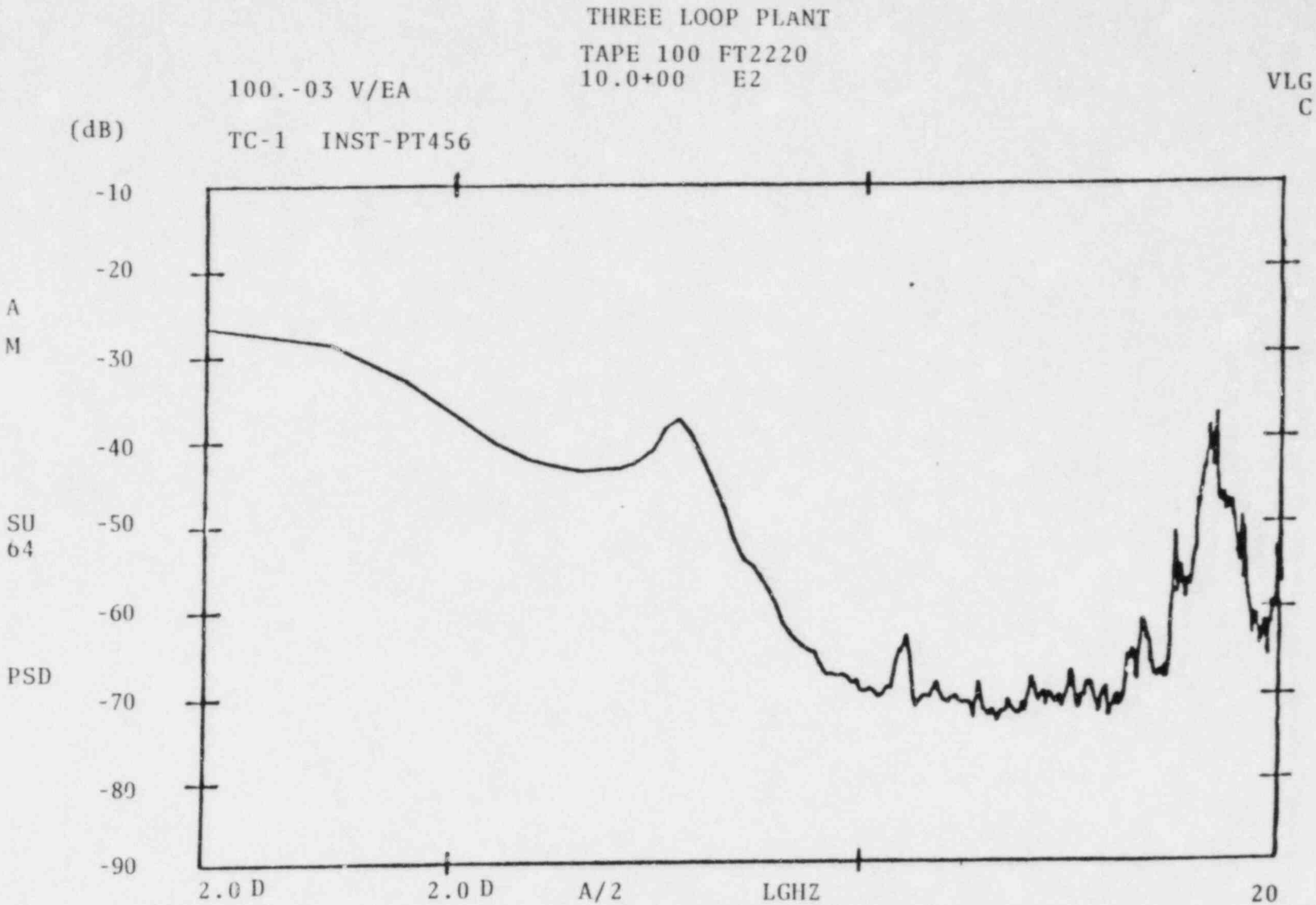


Figure 78: 3/17/78
100% Power, Pressurizer Pressure, PSD

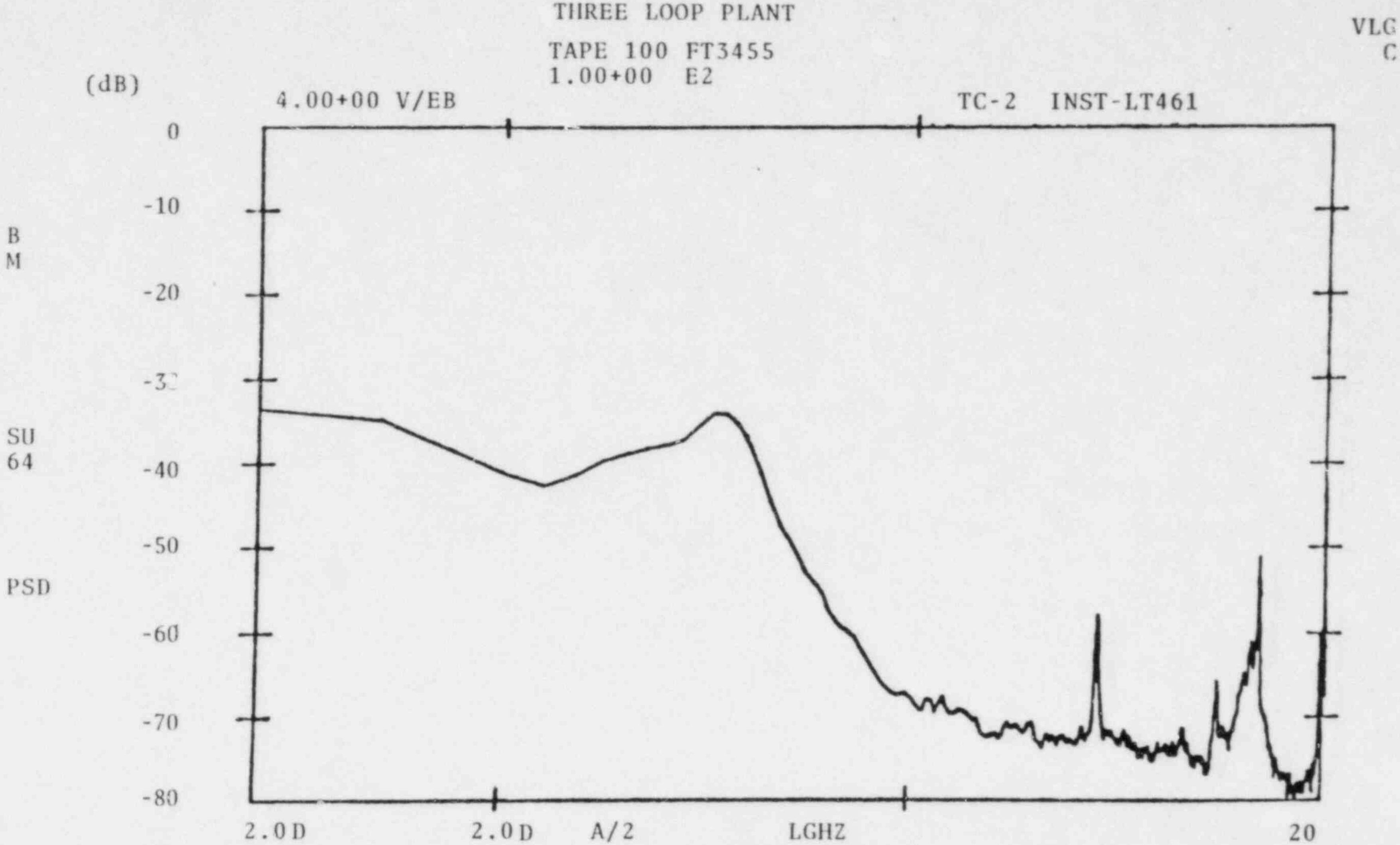


Figure 79: 3/17/78
100% Power, Pressurizer Level, PSD

APPENDIX B

RESPONSE CHARACTERISTIC DEGRADATION MEASUREMENTS OF PRESSURE SENSORS

W. CIARAMITARO
R. L. BURKHART

INTRODUCTION

The response characteristics of protection sensors in nuclear power plants could conceivably deteriorate because of the demanding environment in which they are installed. Although conservative estimates are used in the safety analysis, in event of an accident, a degraded sensor could jeopardize reactor safety. Therefore, it is important to be aware of any degradation. The objective of the test program is to demonstrate that noise analysis techniques, used in situ, can be used to detect pressure sensor degradation. Two types of effects were evaluated for changes: power spectral density noise signatures, which are due to constriction of the sensing line and the second due to various lengths.

Noise analysis technique is a well established procedure. The basic concept used to determine the time response of a sensor from its response to a noise input is straightforward. The sensor acts as a filter for the natural process variations or noise sensed at the input of the sensor. If the sensor has a relatively fast time response, it will pass the higher frequency components of the process noise.

If a sensor degrades it will decreasingly alternate the high frequency components of the input process fluctuation which indicates a change in response characteristics.

TEST LOOP DESCRIPTIONS

Mechanical

The test loop schematic is shown in Figure 1. The loop is constructed around a MTS hydraulic signal generator consisting of a hydraulic power supply, controller, fast acting servo valve, and hydraulic cylinder that generates small pressure fluctuations superimposed on a constant static pressure with no circulating flow. An electrical signal of random gaussion noise is connected to the controller to excite the servo valve. The loop was operated at 2200 psi static pressure with 2 - 50 psi pressure oscillation.

The test section was constructed of various lengths of 3/8" high pressure tubing and a series of high pressure Napro valves for changing the effective length of the section in steps of a 100 ft. The output of the test was attached to a common manifold for the sensors being evaluated. The high accuracy and fast response reference sensor was a Statham Model PA 822-2M thin film strain gage pressure sensor with a high natural frequency (approximately 500K Hz).

Electrical Instrumentation

Three pressure sensors were installed in a common manifold, Statham Model PA 822-2M, Barton Model 763, and Veritrak 59PH 4443 7050. The output of the Statlan along with the reference sensors were conditioned with Vishay 2310 strain gage conditioning amplifiers which provide the 10V excitation and high gain amplifier for the MV input signal. The Barton 763 and Veritrak

59PH 4443 7050 are pressure transmitters that provide a 4-20 ma outputs proportional to the operating range. The power supply for the current loop was a HP 6215A for each transmitter. The voltage was measured across a precision 100 delta resistor.

The voltage signal was connected into two stages of DC differential amplifiers in series. The first stage amplifier was used to null out the DC steady state voltage by means of an offset control. The second stage amplifier was used to amplify the AC noise signal. The output of the amplifier was connected into a dual channel Fast Fourier Transform Spectrum Analyzer Model Nicolet Scientific 660A. The spectrum analyzer calculated the power spectral density (PSD) curves. The spectra were then sent to the Textronic hardcopy unit for records.

TEST RESULTS

The input static pressure - 2200 psi and dynamic pressure fluctuations were generated to MTS hydraulic system. The electrical input signal was random white noise with a bandwidth of 500 Hz. Even though the input noise to the MTS controller was white, the MTS system could not respond at the high frequency. The input PSD measured by the reference sensor is shown in Figure 2. The input signature appears to have three real poles at approximately 1 Hz., approximately 30 Hz and approximately 100 Hz as noted by the roll of the 6dB/oct, 12 dB/oct, and 18 dB/oct slopes respectively.

Valve Test

The first test was to evaluate the effect of a construction in the impulse line. This was simulated by closing a high

pressure Nupro valve. Very little effect was noted until the last quarter turn of the valve, when the valve was closed in 1/12 turn increments. A composite of the PSD's is shown in Figure 3 for the last 1/12 turns of the valve plotted on a log-log scale. The loss of high frequency of the PSD is evident as the valve is closed as the ratio of high to low frequency changes. The two higher frequency poles also disappear as the valve is closed along with an approximately 20 dB decrease in the PSD background. This change corresponds to a decrease in cross sectional area of 14 percent.

Impulse Line Test

The second test was used to evaluate the effect of increased damping. This was accomplished by valving various length of 3/8" tubing into the test section and closing the bypass line valve. Data was collected using the 660A dual channel analyzer with the reference sensor in Channel A and the test sensor in Channel B. Data was collected from three pressure sensors; (1) Statham PA 8222M, (2) Barton 763, and (3) Varitrak 59PH 4443-7050. The four test configurations were recorded.

- Test Section valves closed and bypass section open
- 100 ft. length of line and bypass section valved out
- 200 ft. length of line and bypass section valved out
- 300 ft. length of line and bypass section valved out

Figure 4 through 6 are overlay of the PSD's plotted on a log-log scale for Statham, Barton and Veritrak respectively. The changes in the PSD signatures are evident as the line length

increases and indicates a loss of high frequency components. The shifting of transfer function poles to the left is noted as would be expected for system degradation.

When the PSD's are compared with valve closed PSD's, the significance of the reduction in noise is even more pronounced. Frequencies above 20 Hz. are completely attenuated.

Figure 7 is a composite plot of the coherence function between the reference Staham and the Statham in the test manifold as a function of line length. The coherence is defined as follows:

$$\frac{[G\ AB]2}{GAN\ \ GBB}$$

GAB = Cross power spectrum

GAA = Power Spectrum of A

GBB = Power Spectrum of B

AB = Coherence Function

The function values range from 0 - 1.0. If two channels or sensor signals are perfectly correlated, they have a coherence equal to 1.0. If the two signals are completely independent, the coherence is equal to 0.

Even though loss of coherence at low frequencies is not fully understood, indications are that it may be possible for the bypass time and valve to act as a short for the high frequency pressure waves. If this is true, the changes in the PSD signatures may be conservative. In other words, if the roll of the curve is a more pronounced effect, degradation is easier to detect.

CONCLUSIONS AND RECOMMENDATIONS

The sensor noise analysis is feasible as a sensor surveillance technique for detection of degradation in pressure sensors. Changes in PSD signatures were observed by degrading the sensor system by simulating a constricted sensing line and increased damping due to the addition of long line lengths.

It is not possible to interpret physically all the peaks on the PSD curves, especially in pressure sensors, which may be dependant on operating conditions. The underlying baseline PSD may provide information about changes in response time by detection of loss of frequency content.

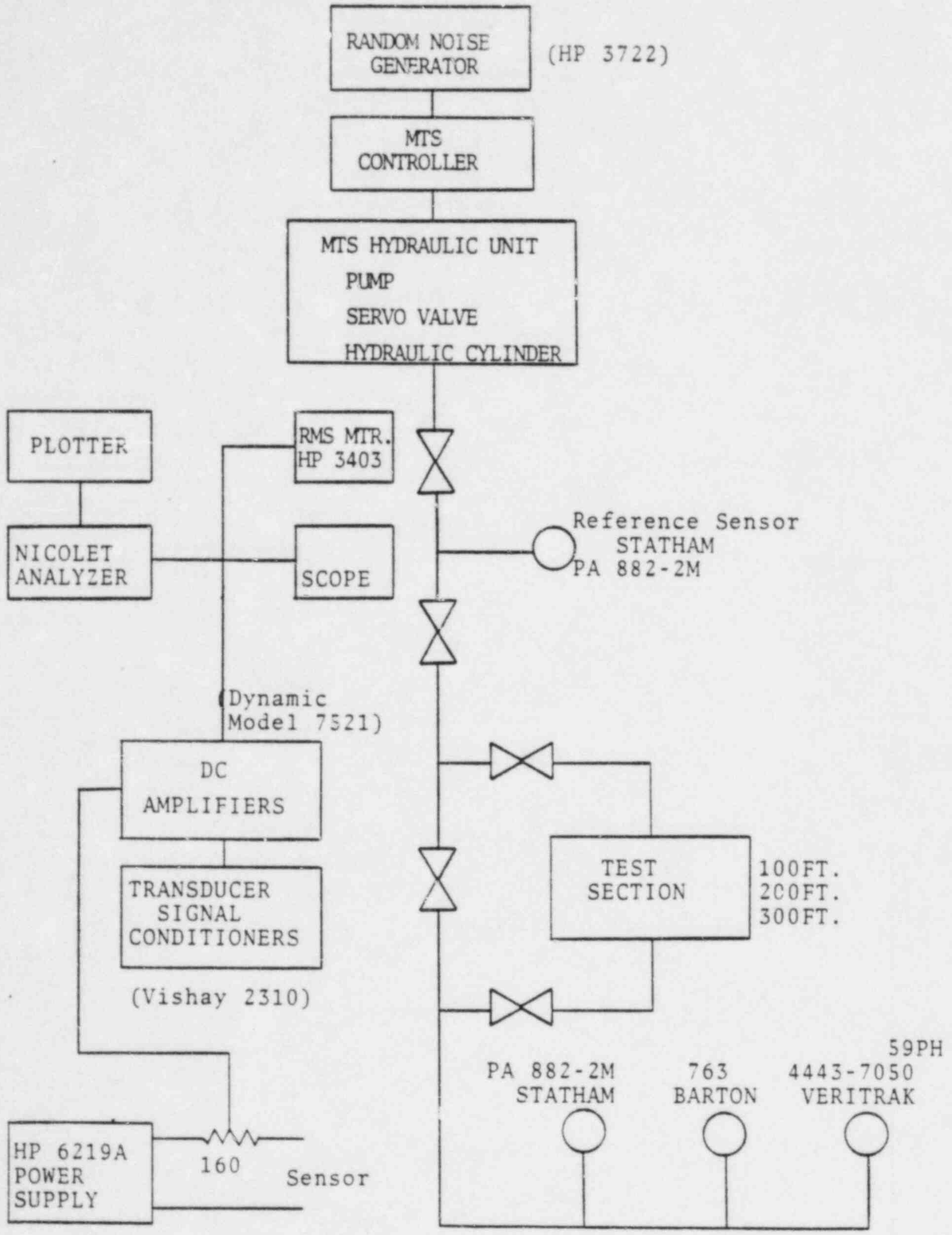


Figure 1: MTS Test System

RESPONSE CHARACTERISTIC DEGRATION
TEST RESULTS

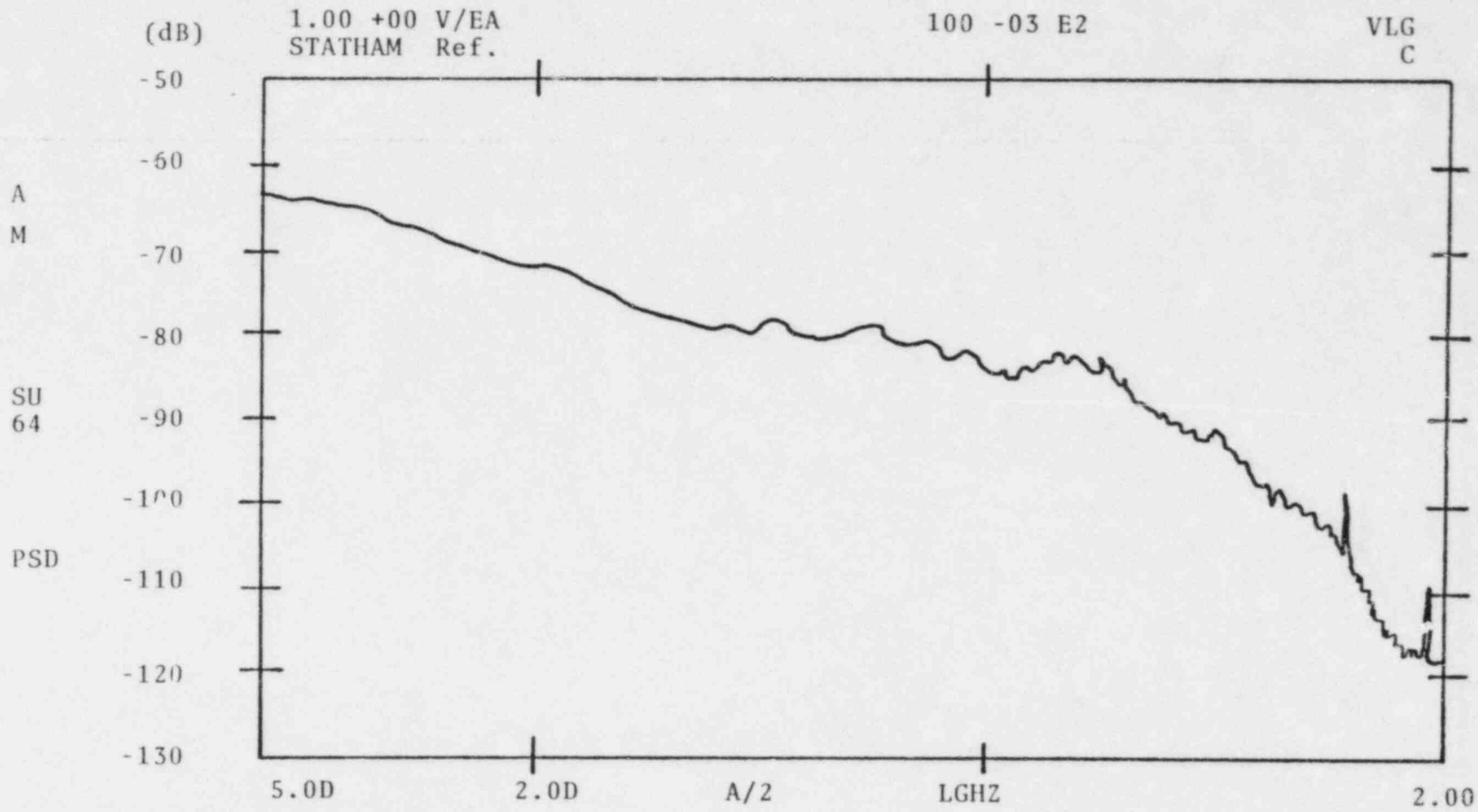


FIGURE 2

PSD VS
VALVE POSITION

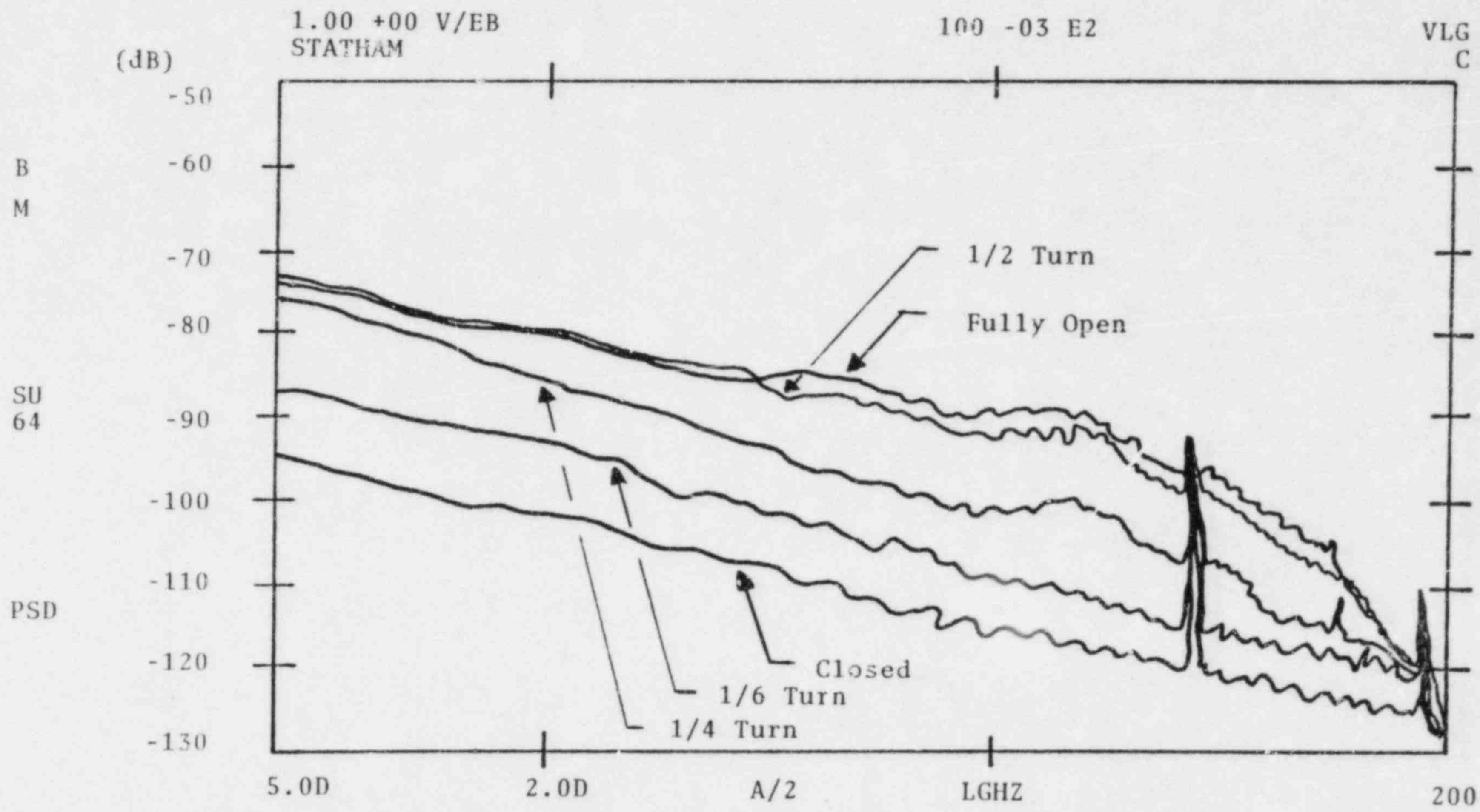


FIGURE 3

RESPONSE CHARACTERISTIC DEGRADATION
IMPULSE LINE TEST

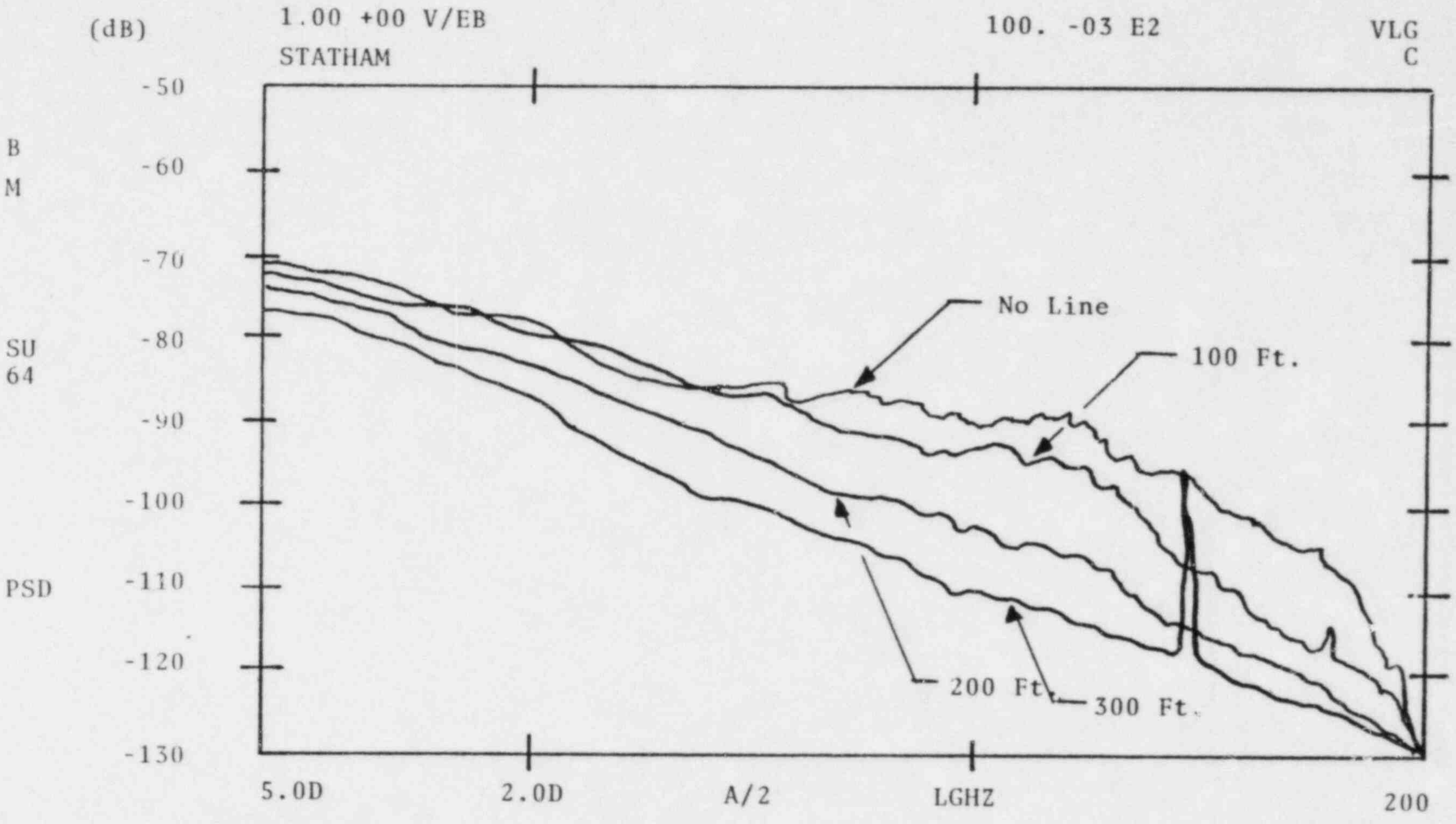


FIGURE 4

RESPONSE CHARACTERISTIC DEGRADATION
IMPULSE LINE TEST

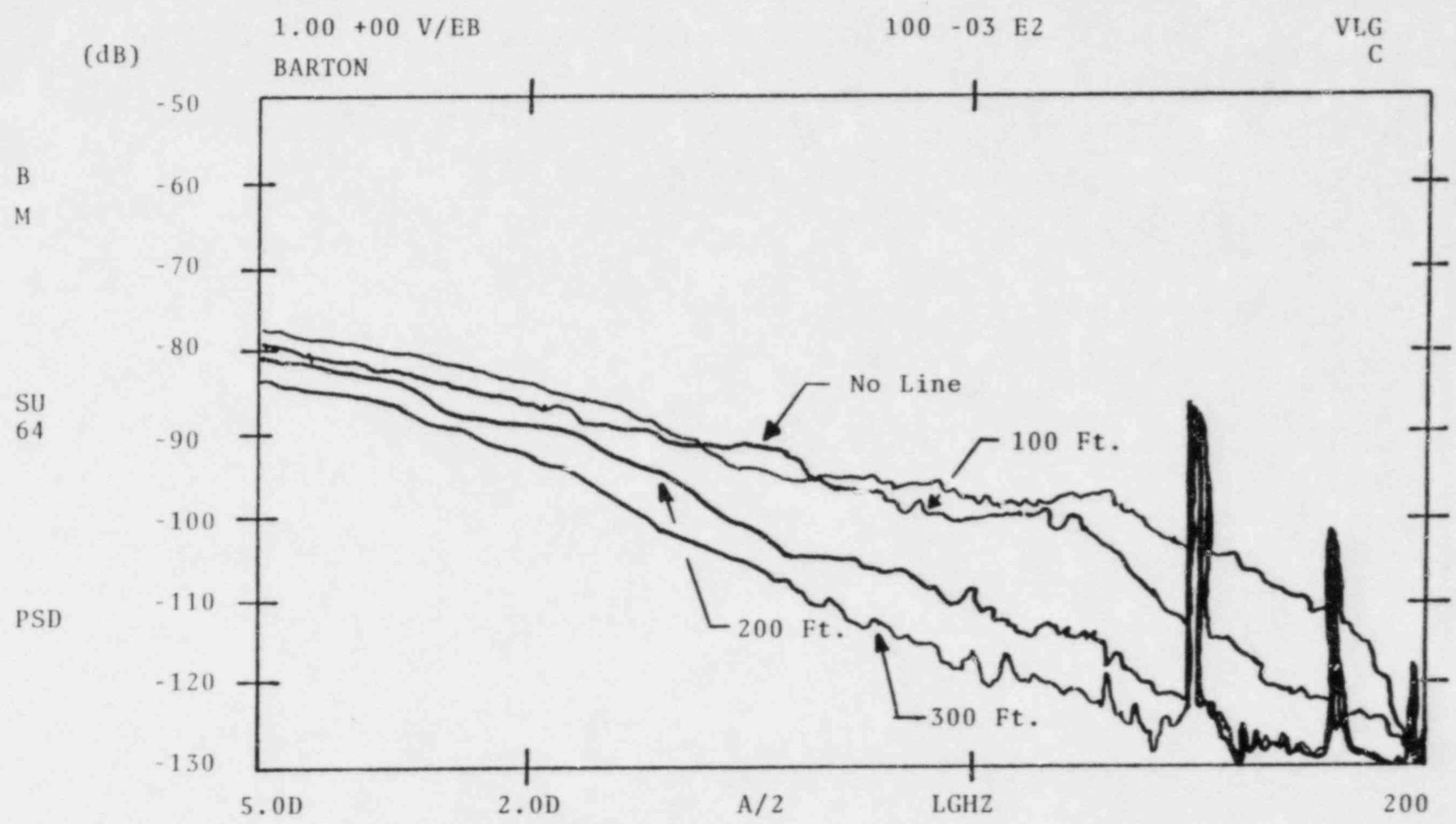


FIGURE 5

RESPONSE CHARACTERISTIC DEGRADATION
IMPULSE LINE TEST

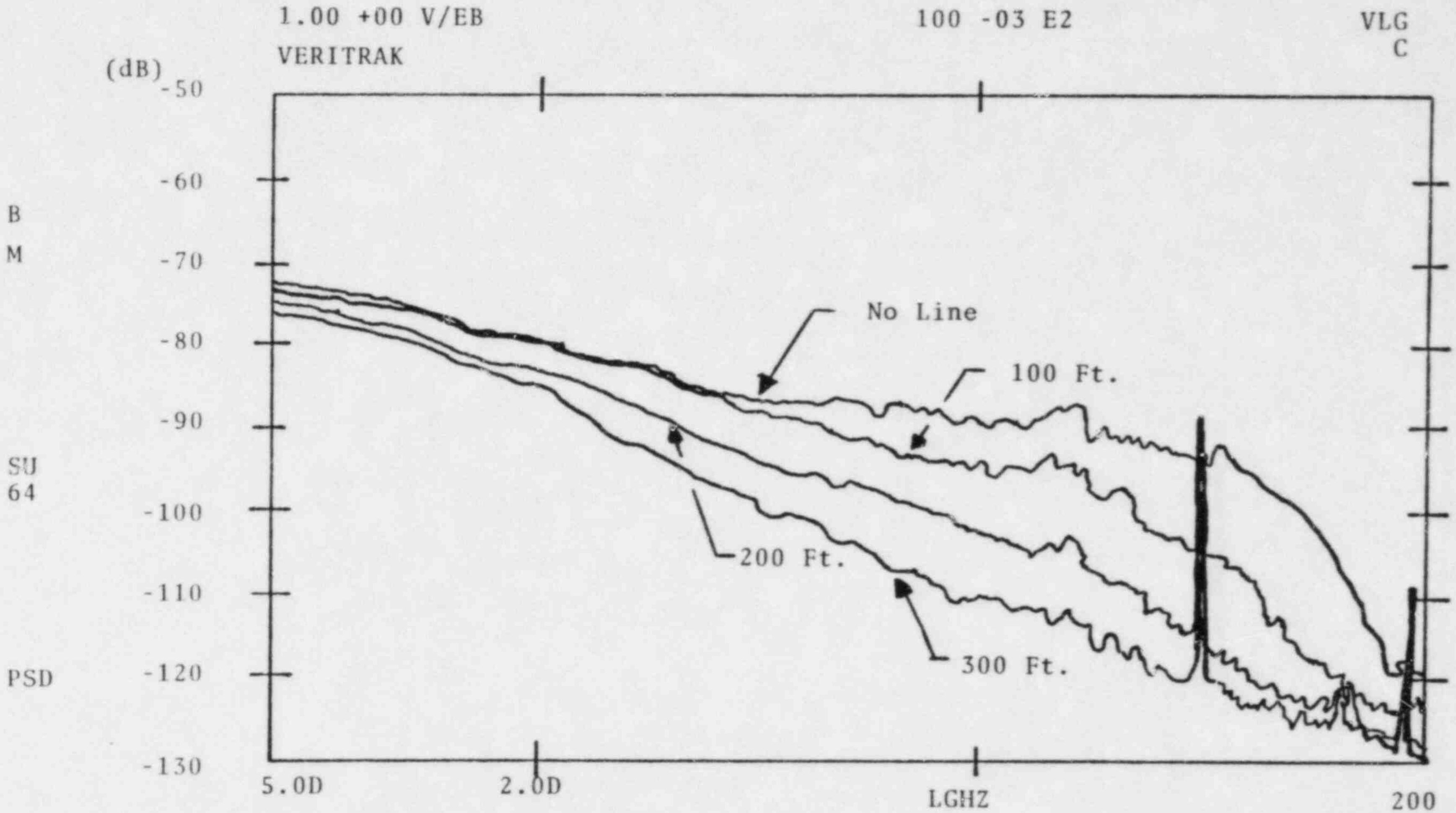


FIGURE 6

RESPONSE CHARACTERISTIC DEGRADATION
COHERENCE FUNCTION

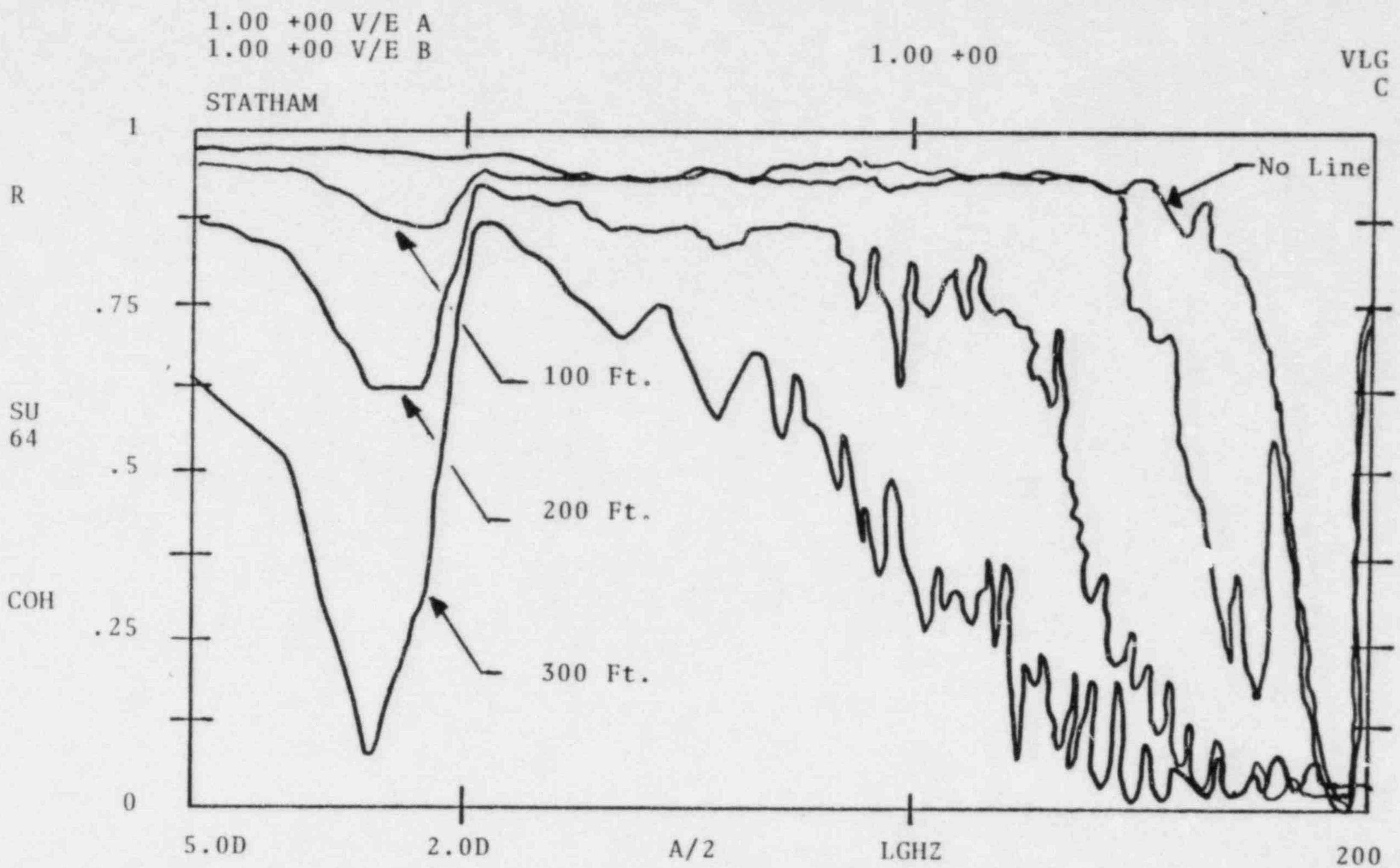


FIGURE 7

APPENDIX C

Regulatory Requirements

Over the last few years several criteria, regulatory guides, and standards have been issued which establish the requirements for response time testing of protection system sensors. These requirements have evolved to include testing of any connections to the process being measured, the sensing element, and the transmitter. The following is a listing of pertinent sections from most of the major regulatory requirements in this area.

A. IEEE Standard 279-1971

"Criteria for Protection Systems for Nuclear Power Generating Stations"

4.9 Capability for Sensor Checks

Means shall be provided for checking, with a high degree of confidence, the operational availability of each system input sensor during reactor operation.

This may be accomplished in various ways, for example:

1) by perturbing the monitored variable; or

2) within the constraints of paragraph 4.11, by introducing and varying, as appropriate, a substitute input to the sensor of the same nature as the measured variable; or

3) by cross checking between channels that bear a known relationship to each other and that have read-outs available.

B. Branch Technical Position ElCSB24

"Branch Technical Positions (Appendix 7-A) of Standard Review Plans for Nuclear Power Plants," U.S. Nuclear Regulatory Commission, 1974

Periodic tests for verification of system response

times of reactor trip systems and engineered safety feature actuation systems should include the response times of the sensors whenever practical.

In some cases, indirect means of verifying sensor response times may be used.

C. Standard Technical Specifications (STS) for Westinghouse Pressurized Water Reactors

"4.3.1.1.3 The Reactor Trip System Response Time of each reactor trip function shall be demonstrated to be within its limit at least once per 18 months. Each test shall include at least one logic train such that both logic trains are tested at least once per 36 months and one channel per function such that all channels are tested at least once every N times 18 months where N is the total number of redundant channels in a specific reactor trip function as shown in the "Total No. of Channels" column of Table (3.3-1)."

Reactor Trip System Response Time

1.22 The reactor Trip System Response Time shall be the time interval from when the monitored parameter exceeds its trip setpoint at the channel sensor until loss of stationary gripper coil voltage.

Engineered Safety Feature Response Time

1.23 The Engineered Safety Feature Response Time shall be that time interval from when the monitored

parameter exceeds its ESF actuation setpoint at the channel sensor until the ESF equipment is capable of performing its safety function (i.e., the valves travel to their required positions, pump discharge pressures reach their required values, etc.). Times shall include diesel generator starting and sequence loading delays where applicable.

D. Reg. Guide 1.68 Rev. 2, August 1978

"Initial Test Programs for Water-Cooled Reactor Power Plants"

Verify by test the response time of each of the protection channels, including sensors. Acceptance criteria for the response time of the protection channels should account for the response time of the associated hardware between the measured variable and the input to the sensor (snubbers, sensing lines, flow-limiting devices, etc.).

E. IEEE Standard 338-1977

"Standard Criteria for the Periodic Testing of Nuclear Power Generating Station Safety System"

Sufficient overlap shall be provided to verify overall system response. Where it is not practicable to include sensors in in-plant individual or system response time tests, the sensors may be periodically removed from their normal installations and tested. When this is done, the test installation shall simulate the relevant environment and configuration of the

actual installation.

Where the entire set of equipment from sensor to actuated equipment cannot be tested at once, verification of system response time shall be accomplished by measuring the response times of discrete portions of the system and showing that the sum of the response times of all is within limits of the overall system requirement.

F. Reg. Guide 1.118 Rev. 2, June 1978

"Periodic Testing of Electric Power and Protection Systems"

Section 6.3.4 of IEEE Standard 338-1977 should be supplemented by the following:

"For neutron detectors (1) tests of detector-cable assemblies for increased capacitance, (2) monitoring of noise characteristics of neutron detector signals, or (3) some other test that does not require removal of detectors from their installed location should be used to confirm neutron detector response time characteristics to avoid undue radiation exposure of plant personnel unless such tests are not capable of detecting response time changes beyond acceptable limits".

WCAP 632

APPENDIX D

OPERATING RESULTS OBTAINED IN A NUCLEAR POWER PLANT WITH A SENSOR SURVEILLANCE PROTOTYPE

(5th Power Plant Dynamics Control and Testing Symposium, Knoxville, March 21/23 1983)

by

J.P. JACQUOT*, A. POUJOL**, J. BEAUBATIE***, W. CIARAMITARO****

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ABSTRACT

Surveillance methods have been validated and specific equipment have been built to measure the response time of sensors from a nuclear power plant protection channel. The reason of the choice of this parameter is twofold : the sensor response time is representative of the sensor physical status and is also part of the overall channel response time .Two surveillance methods are used : noise analysis (by AR or PSD fit modeling), and loop current step response (for RTD's only). The methods were validated on test facilities and on nuclear power plants. Two test equipments were built and tested on plants. Results are presented and conclusions are drawn on the feasibility of such methods for sensor surveillance.

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1. - INTRODUCTION

The nuclear power plant safety is realized by protection channels whose response time is an essential characteristic. The periodic verification of these protection channels implies in particular the testing of the sensors which are the first element of the channel. Surveillance methods have been validated and specific equipement has been developed to measure the sensors response time (temperature, pressure, flow) in situ. The reason of the choice of sensor response time is twofold :

- first, it is part of the global response time of the protection channel. The US Nuclear Regulatory Commission requires that the sensor is included in the safety system periodic testing (NRC regulatory guide 1.118).

- second, this parameter is quite representative of the sensor physical status and can be used to detect possible degradation.

Therefore, considerable interest exists in developing an efficient method for response time verification that would not require plant shutdown or other inconvenient testing procedures.

Two possible techniques are passive and active methods

- The first uses the presence of natural plant perturbations in the process variables of nuclear power reactor for determining protection sensor response characteristics on-line and in situ during routine plant operation without the addition of complicated mechanisms. If the response characteristics of sensors to these plant perturbations could be translated into response times, there would be no need for intentional perturbations of the plant, removal of the sensors for laboratory testing, or valving of sensor to inject test signals. The natural plant perturbations under consideration are process noise due to normal plant operation.

- The second uses an active technique only applicable to RTD's : The principle of this technique is to increase suddenly the current into the sensor and to measure and analyse, the transient associated to the induced self heating.

After describing in more details these two techniques, this paper presents the results obtained on test facilities, gives a brief description of the test equipment and summarizes results from plant tests performed in France and United States. This analysis covers Resistance Thermometer Detectors (RTD's), pressure transmitters and differential pressure transmitters.

2. - TECHNIQUES AND VALIDATION ON LOOPS

2.1. - Passive method : Sensor noise analysis

2.1.1. - Principle of the analysis

The analysis uses the fluctuations of the electric signal around the continuous, constant value, related to the fluid temperature. These fluctuations are the noise of the physical process filtered by the sensor. If we assume that the process noise is stationary and white,

consequently we can deduce that the power spectrum of the sensor noise signal represents the modulus of the sensor transfer function H(s). If the process noise is bandlimited, a conservative value of the response time can be obtained.

These are two methods of analysis : the first one consists in carrying out a fit to the spectrum by a simple transfer function. The second one is based on time series modeling.

The response time is defined as the time required for a sensor to indicate 63.2 percent of the final response to a step input.

2.1.2. - Power spectrum fit method

A power spectrum is generated from a FFT algorithm used to process normal signal fluctuation detected from the sensor. The sensor response characteristics can be evaluated by a least squares fit to the power spectrum to obtain a transfer function. The empirically determined transfer function is used to calculate the response time of the sensor to a step input.

The application of this method to a resistance thermometer detector, shows that a transfer function without zero allows a good fit of the PSD. Its optimal order was found to be 3 and the response time of the sensor deduced was 300 ms (figure 1).

2.1.3. - Time-Series method (Autoregressive model) [1]

We assume that the analyzed fluctuations have the characteristics of a stationary and linear random process. In this case, it can be represented by the following model :

$$y_k = \sum_{i=1}^{n} b_i \, y_{k-i} + v_k \qquad (1)$$

where n is the order of the model, b_i are the coefficients to be estimated, y_k is the noise sequence analyzed, and v_k is the excitation white noise. The Yule-Walker equation allows to calculate the coefficients b_i from the autocorrelation function of the signal y_k. The step response of the sensor is deduced by applying a step input to the model calculated. Figure 2 shows a superposition of the PSD and of the associated models (oder 3 and 10). The corresponding step responses are also given. The response time obtained has a value of 300 ms.

2.2. - Active method : Loop Current Step Response (LCSR)

2.2.1. - Principle of the test [1]

The temperature measurement with a resistance sensor is done using a Wheatstone bridge. A 2 mA current is applied to the sensor. The current induces a internal self-heating which is generally negligible. The principle of this test is to increase suddenly this current and to analyze the transient associated to the induced selfheating.

2.2.2. - Response time determination using LCSR

The calculation is done using a thermal model of the sensor. If the heat transfer is radial (monodimensional model), it can be shown that :

- The transfer function associated with an external excitation (variation of the fluid temperature) is :

$$H_1(s) \quad K/\prod_i (s+p_i) \qquad (2)$$

- The transfer function associated with an internal excitation (heating by an electric current) is of the form :

$$H_2\,(s) = \prod_j (s+ z_j) \;/ \prod_i (s + p_i) \qquad (3)$$

The step responses associated with H_1 and H_2 are :

$$R_1(t) = A_o \quad + \sum_i A_i\, e^{-p_i t} \qquad (4)$$

$$R_2(t) = B_o + \sum_i B_i\, e^{-p_i t} \qquad (5)$$

The measured transient R2(t) is analyzed in order to find the poles p_i.

The knowledge of their values is sufficient to deduce the transfer function H_1 (which does not contain a zero), and thus the associated step response ($R_1(t)$).

This method is illustrated in fig. 3, where the transients $R_1(t)$ and $R_2(t)$ are shown. The estimation of the poles p_i was achieved using the least squares method.

2.3. - Test facilities results

Numerous test facilities were utilized to evaluate the performance of different sensors used in PWR reactors. The main characteristics of these test facilities are described in table 1. They allow different tests on RTD's, differential pressure (D P) and pressure transmitters.

In order to check the accuracy of the on line testing method (active or passive), base line measurement techniques were developped to estimate the response time of the sensors to a pressure or temperature step change.

Test Loop	Temp.Press.	Flow/Velocity	Sensors	Principle	Performance
<u>WESTINGHOUSE</u>					
Forest Hill Autoclave	288 °C (550° F) 151 bar (2200PSI)	0,11 l/s (1,8 gpm)	RTD Pressure	noise injection test	bandwidth = 0.1 Hz risetime = 50 ms
				natural noise	---
Water table Loop	RT	4,5 m/s (15 ft/s)	RTD	plunge test	risetime = 50 ms
MTS Hydraulic unit	RT 206 bar (3000 PSI)	0	Pressure	natural noise step test	bandwidth = 100 Hz risetime = 5 ms
Forest Hills	287°C(550°F 151 bar (2200 PSI)	252 l/s (4000 gpm)	Pressure	natural noise	reference sensor
<u>C.E.A.</u>					
BECAP Loop	20- 60 °C ~4 bar	2.5 m/s	RTD	plunge test	risetime = 50 ms
				injection test	risetime = 20 ms
			DP	natural noise	reference sensor
Pressure Loop	RT 90 bar	0	Pressure	step test	risetime = 10 ms
<u>E.D.F.</u>					
Main Loop Renardières	280 °C 160 bar		97 l/s		
Test Section Systherm Loop	idem	2 l/s 0 - 6 m/s	RTD	injection test	risetime = 40 ms
				pseudo-random noise	bandwidth = 6 Hz
				LCSR	---
			DP	natural noise	reference sensor
			Pressure	natural noise	reference sensor

Table 1 : Characteristics and performance of the loops

2.3.1. - Base line value

* Two kinds of techniques were used for generating a temperature step input for the RTD sensors :

a) Plunge test :
The sensor is plunged from room temperature air into water flowing in the test section.

b) Injection test :
Cold water is injected into the hot water stream to produce the desired temperature perturbation.

* Again, 2 techniques were developped for pressure sensor testing :

a) Step test :
The pressure of a tank is suddenly modified by a valve operation.

b) Transfer function technique :

This technique is based on identification principle and used the information from a fast reference sensors. The response time is deduced from the mathematical model of the sensor which is assimilated to a linear filter represented by its transfer function. The signal from the reference sensor connected on the loop is considered as the filter input and the signal from the tested sensor as the filter output.

* For Differential Pressure Sensors (DP), only the transfer function technique was used.

2.3.2. - On line values :

For RTD sensors, the loop current step response test was evaluated in laboratory and PWR operating conditions. For all sensors, the noise analysis test was performed using natural loop fluctuation or simulated noise. In this case, noise data were created by temperature or pressure excitation (with a PRBS generator).

2.3.3. - Loop test conclusion :

The main conclusions of these tests are as follows :

a) Temperature sensor [2]

The first conclusion indicates the velocity of the fluid (1 m/s to 6 m/s), around the sensor has a significant effect upon the response time (fig. 4). For slow response time sensors this effect is not as pronounced.

The second conclusion (table 2) indicates both on line techniques can detect degradation (loop current step response and noise analysis). The loop current response provides absolute response time whereas noise analysis provides a response time related to the bandwidth of the process noise.

Sensor	Base line (s)	Noise Analysis (s)	LCSR (s)
ROSEMOUNT 176 KF	0.175	0.160	0.150
Same, degraded	0.7	0.5	0.550
RDF	4	3.84	-
RDF degraded	5.5	5.67	-

Table 2 : RTD's response time : detection of degradation on loops

b) Pressure sensor

The response time obtained by transfer function method is directly related to the length of the impulse line (Fig. 5 : L = 15 m), normally the impulse line acts as a second order resonant low pass filter. The degradation can be readily detected using transfer function and noise signatures.

The table 3 shows the influence of degradations on the response time deduced from transfer function method.

c) Differential pressure transducers :

The transfer function shape indicates that the tested transducer associated to the two impulse lines is a second order system ,with two real poles and a damping factor equal to 1 (Fig. 6 : L = 15 m). The effect of the impulse line is smaller than it is for the pressure sensors. This remark has probably two origins :

- the ratio between the response time of the sensor itself and the response of the line,

- the constructive interference between the two sensing lines.

The degradation can be detected using transfer function technique and noise analysis. However, the detection of degradation is less sensitive than it is for pressure transmitter.

Type of degradation	Force balance Pressure sensor (ms)	Force balance DP sensor (ms)
Normal (linelength = 15 m)	10	102
Mass addition on the flail	10.5	100
Viscous damping	30	110
Paper insertion in the sensor coil	100	192
Friction	10	138
Linelength = 10 m	7	110
Low pressure impulse line closure	-	94
H pressure impulse line closure	-	2470

Table 3 : Pressure and DP sensors response time : detection of degradation on loops

3. - DESCRIPTION OF TEST EQUIPMENT

3.1. - French prototype [3]

This prototype is an automatic testing device using both LCSR and noise analysis method . It calculates on line the response of 30 sensors from the protection and control system. It is a fixed equipment divided in 3 modules :

- The main unit provides the functions of signal conditioning and data processing. It includes also a thermal printer which displays the results (fig. 7).

- The LCSR module connected to the main unit generates current step inside the selected RTD.

- The CRT displays PSD, LCSR curves and step response. The associated key board gives the possibility to modify some parameters.

The noise analysis is performed in the main unit. Both PSD and AR modeling are implemented and can be selected on the front panel. The analysis can be executed in a manual or automatic mode. In this configuration, the response of each connected sensor is calculated periodically.

The duration of the analysis of one sensor is around 30 minutes and the period between two tests on the same sensors is adjustable. The LCSR test is performed in a few minutes.

The LCSR test requires the connection of the RTD to the corresponding module. The operator selects the number of current steps to be averaged and initiates the test.

This prototype has been installed on a French 900 MWe PWR plant, since october 1981.

3.2. - Westinghouse prototype

The Sensor Response System Hardware is a multi-master, multiprocessor configuration implemented using standard single-board computer products. Data acquisition from the process-noise amplifier which filters and amplifies the signal is processed by a 12 bit A/D converter and a 16-bit microcomputer to generate a FFT. A 8 bit microcomputer handles terminal I/O via an on-board serial port and disk I/O via the disk controller (2-boards). The 8-bit microcomputer also performs curve fitting and step response calculations with the support of a high speed mathematical unit. The sensor response hardware includes an expansion RAM board which is shared by the two processors and a E PROM expansion board which contains the resident portion of the operating software. A graphics terminal and graphics printer is used for operator interaction and data presentation.

3.3. - Plant test results

Figures 8 to 15 present some results obtained from both prototypes for different sensors : hot and cold leg temperature (RTD's), primary coolant flow, steam generator level, turbine pressure (HP/first stage), pressurizer level, pressurizer pressure, steam pressure. Response time values are summarized on table 4. PSD curves, obtained from the same processing, are displayed on each figure. The mean values of response time are presented in Table 4, together with the standard deviation. RMS values in physical units are given, in the 0-20 Hz band, except for turbine and steam pressures (0 - 100 Hz).

The main conclusions of the tests done on plant are the following :

- the process noise is stationary at a given power level (except for pressurizer level),

- the response time values are conservative, due to the band limited process noise,

- the autoregressive model gives good results except in the case of pressure sensors. For these sensors, the response time is directly related to the highest resonance peak and not to the overall frequency content.

- for RTD's, the LCSR method gives absolute values for response time, similar to results obtained during the loop test.

Sensor	Westinghouse plants (PSD Fit) average (ms)	Westinghouse plants (PSD Fit) standard deviation (ms)	French plants (AR model) average (ms)	French plants (AR model) standard deviation (ms)
Cold leg temperature	345	15	450	40
Hot leg temperature	300	16	390	26
Primary flow	330	41	750	4[illegible]
Pressurizer level	330	85	214	12
Steam generator level	560	80	895	33
Pressurizer pressure	1200	280	723	16
Steam pressure	18	8	323	203
Turbine pressure	13	2	98	69

Table 4 : Sensors response time : plant results

4. - CONCLUSION

The sensor noise analysis is feasible as a sensor surveillance technique for a steady state plant operation. It is possible to detect incipient degradation of sensors. It has been demonstrated on loop test facilities. It occured two times during our data analysis on plant :

- detection of incipient failure of a pressurizer pressure sensor on an US plant, resulting from an intermittent electrical component,

- detection of impulse line valve closure on flow sensors on a French plant (feasability test).

It is not possible to interpret physically all the peaks on the PSD curves, especially in pressure sensors, which may be dependant on plant operating conditions. The underlying baseline PSD may provide information about changes in response time by detection of loss of frequency content. In the case for similar operating conditions, change in relative amplitude of peaks may be used to derive information about sensor degradation.

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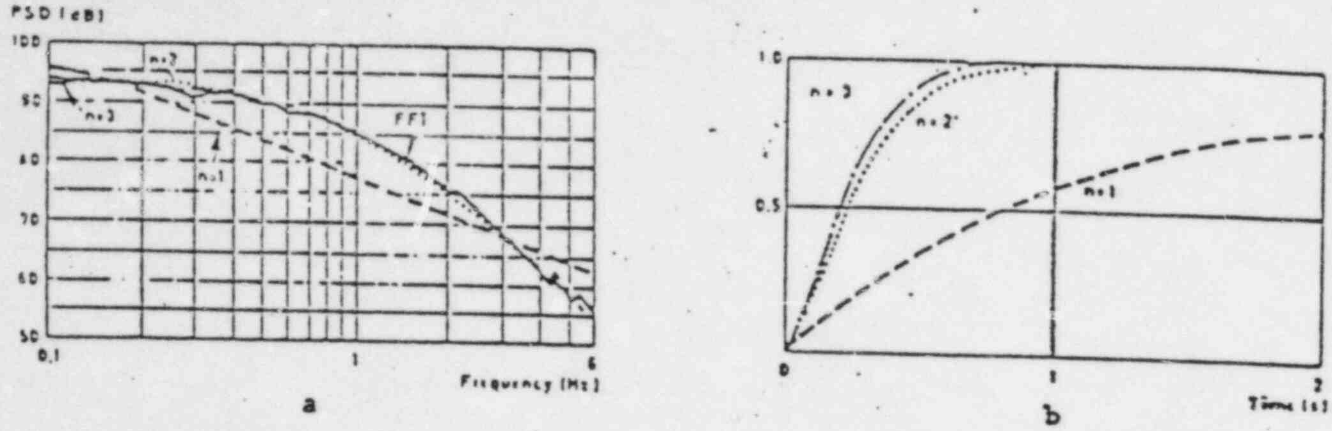
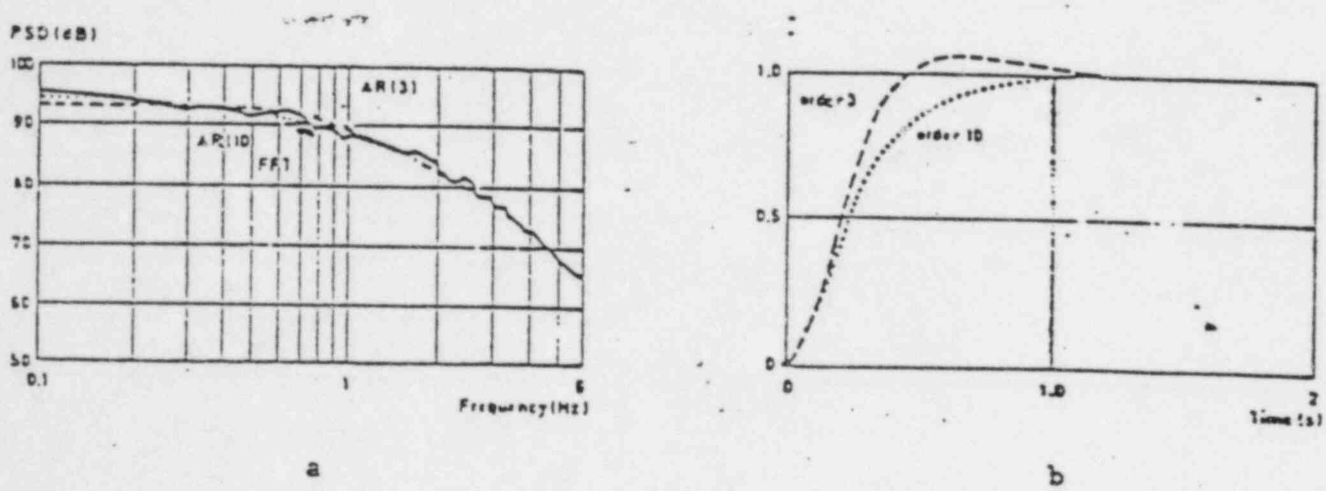


a - PSD and model

b - Step response

Fig. 1 : Power Spectrum fit Method.



a - AR Model

b - Step response

Fig. 2 : Time Series Analysis.

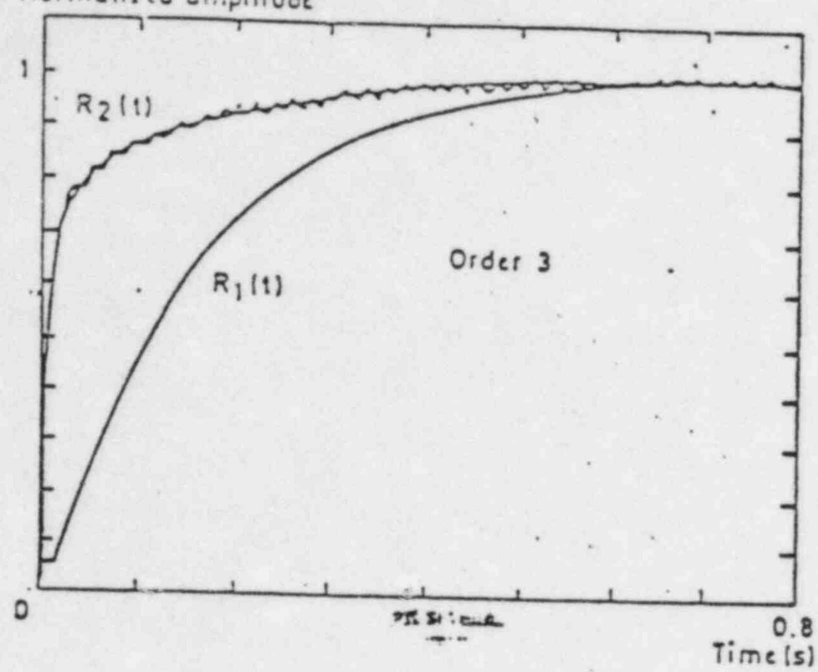


Fig. 3 : Active Method.
$R_2(t)$: Loop current Step Response.
$R_1(t)$: Temperature Step Response.

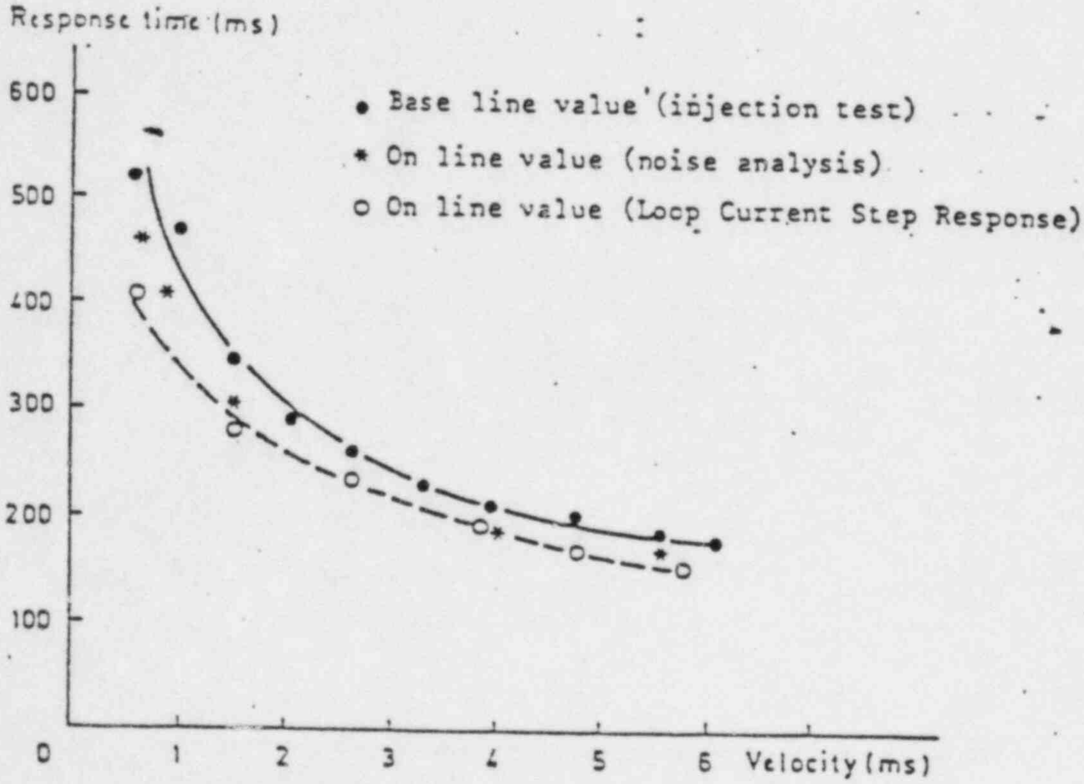


Fig. 4 : Facilities Results : Temperature Sensor Response time versus fluid velocity.

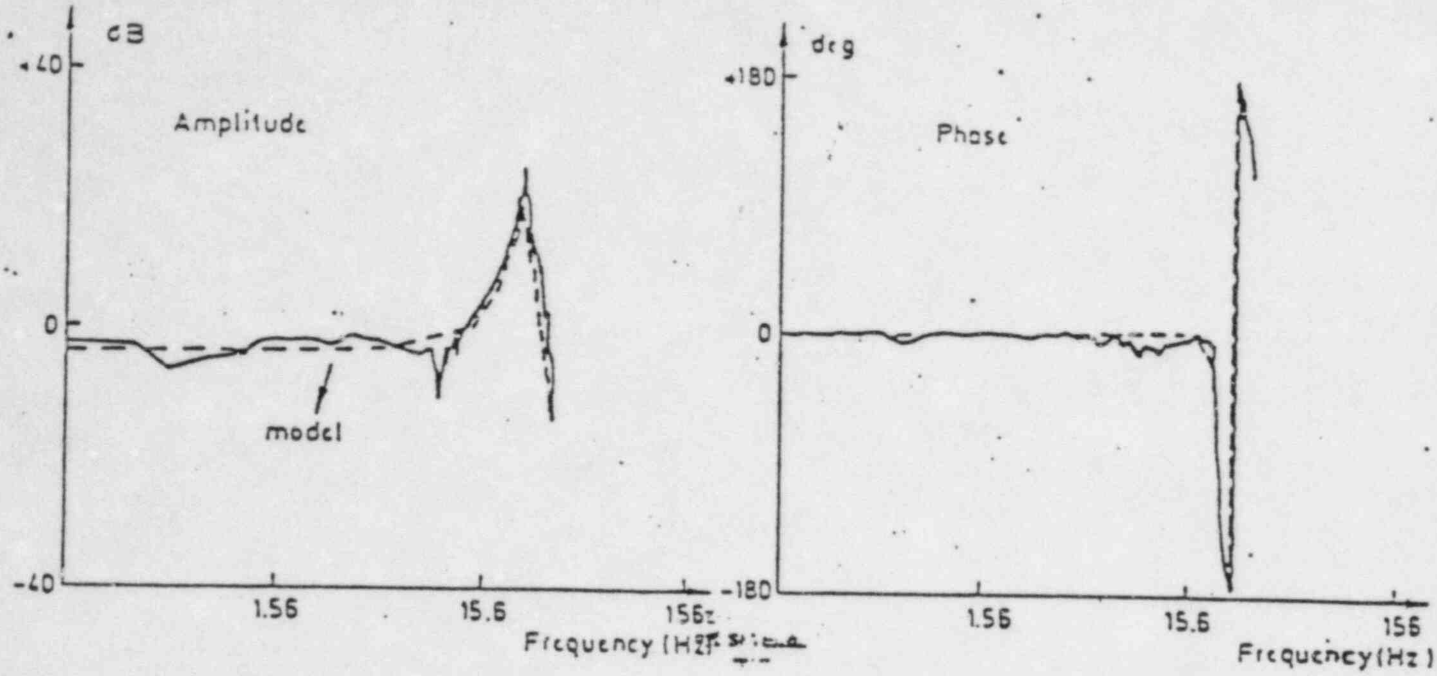


Fig. 5 : Test facilities results : transfer function of a pressure sensor and estimated model.

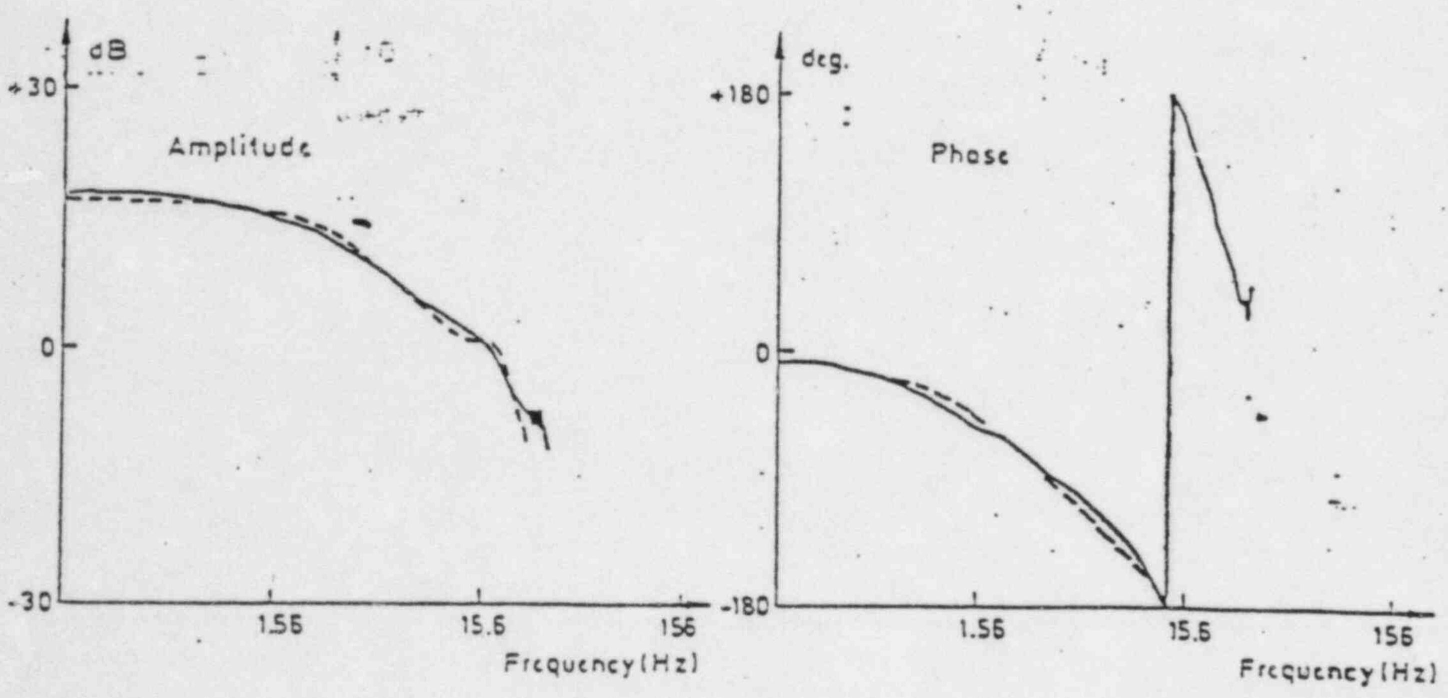


Fig. 6 : Test facilities results : transfer function of a flow sensor and estimated model.

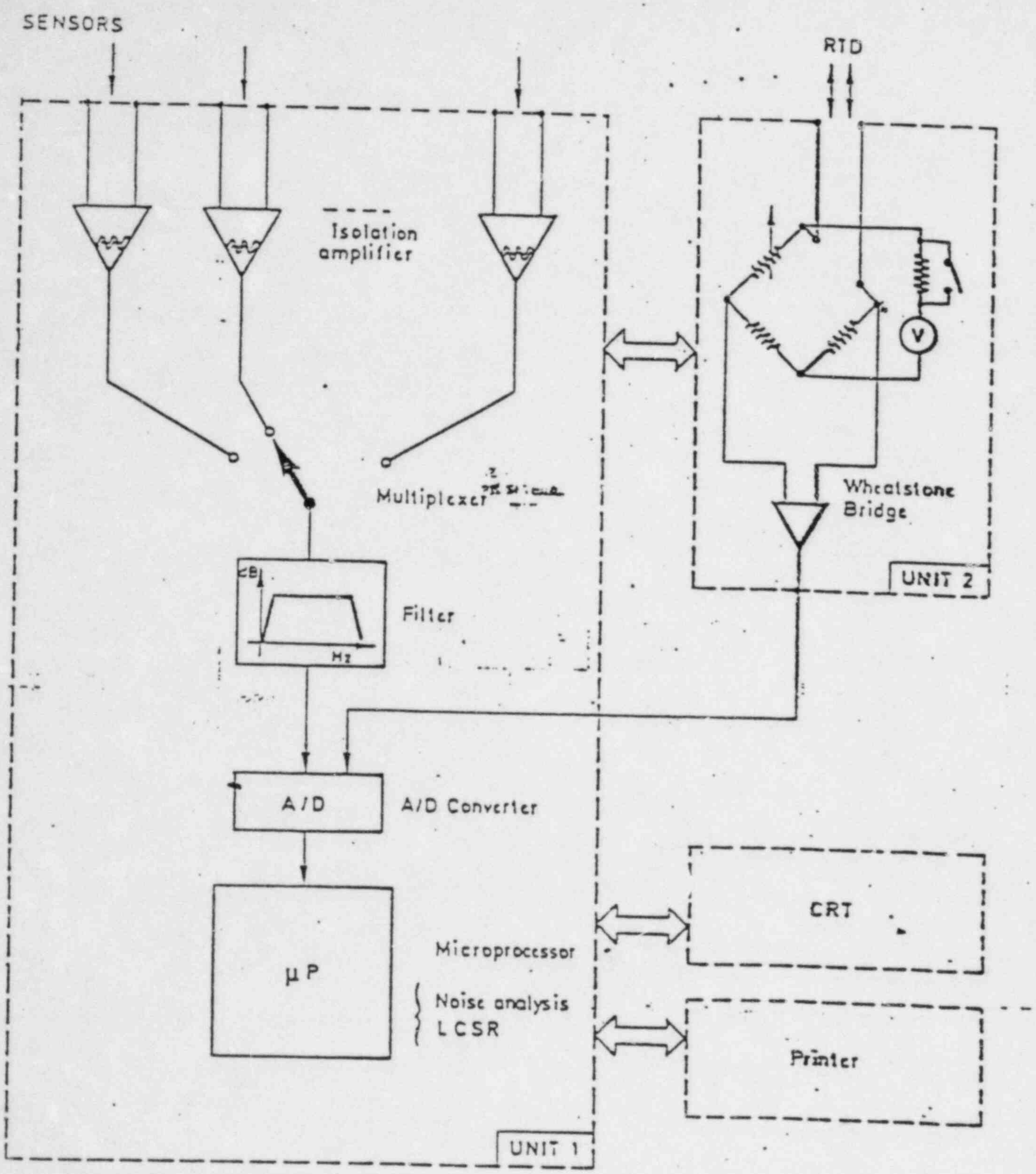
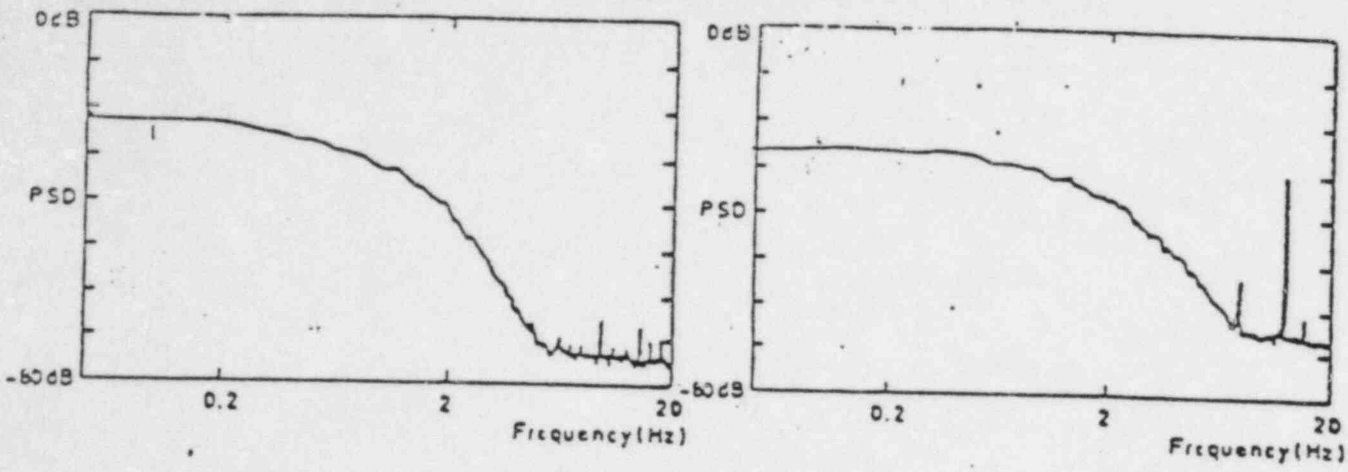


Fig. 7 : Schematic of the French test equipment



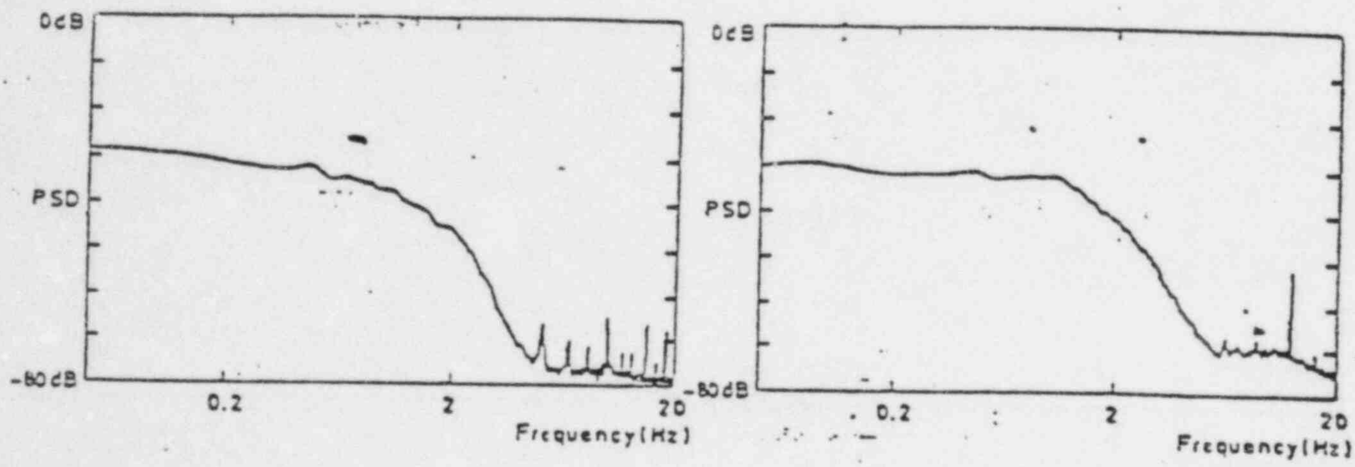
R.M.S. Value : 89 10^{-3} °C

3 loops French Plant

R.M.S. Value : 82 10^{-3} °C (147.10^{-3} °F)

4 loops U.S. Plant

Fig. 8 : Power Spectrum Density. Hot leg temperature.



R.M.S. Value : 46 10^{-3} °C

3 loops French Plant

R.M.S. Value : 52.4 10^{-3} °C (94 10^{-3} °F)

4 loops U.S. Plant

Fig. 9 : Power Spectrum Density. Cold leg temperature.

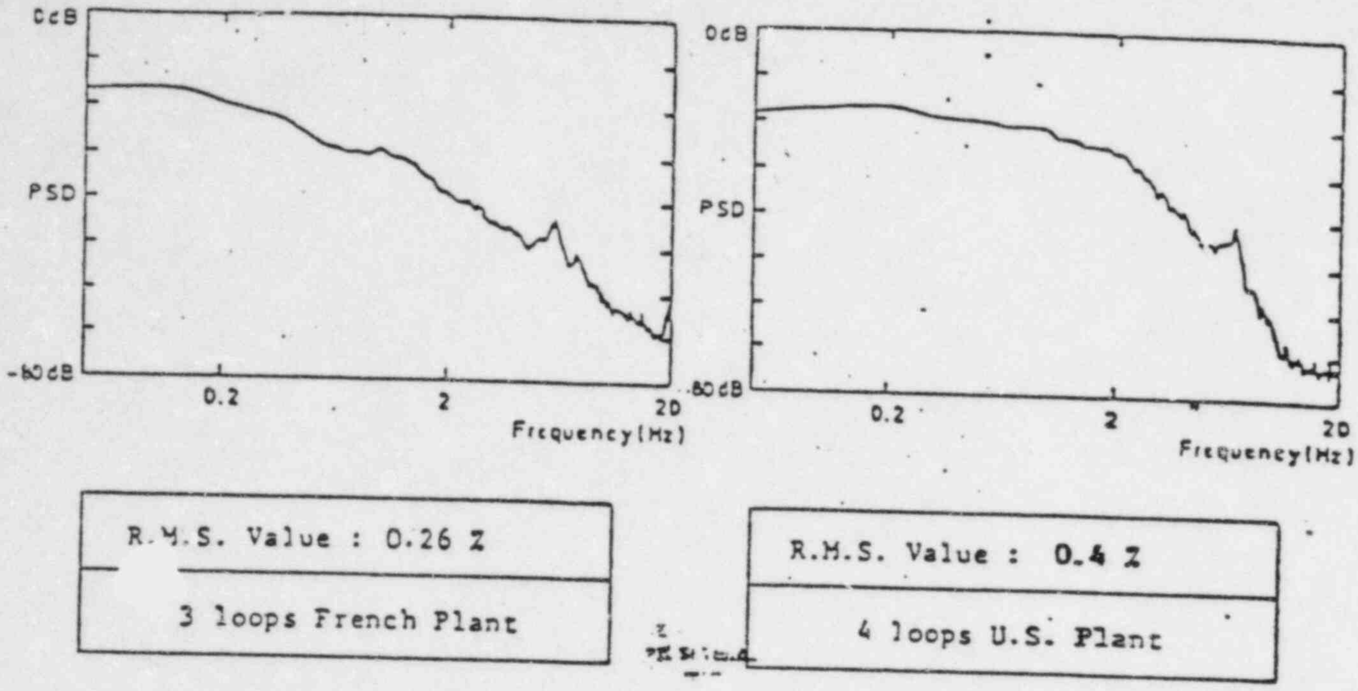


Fig. 10 : Power Spectrum Density. Reactor coolant Flow.

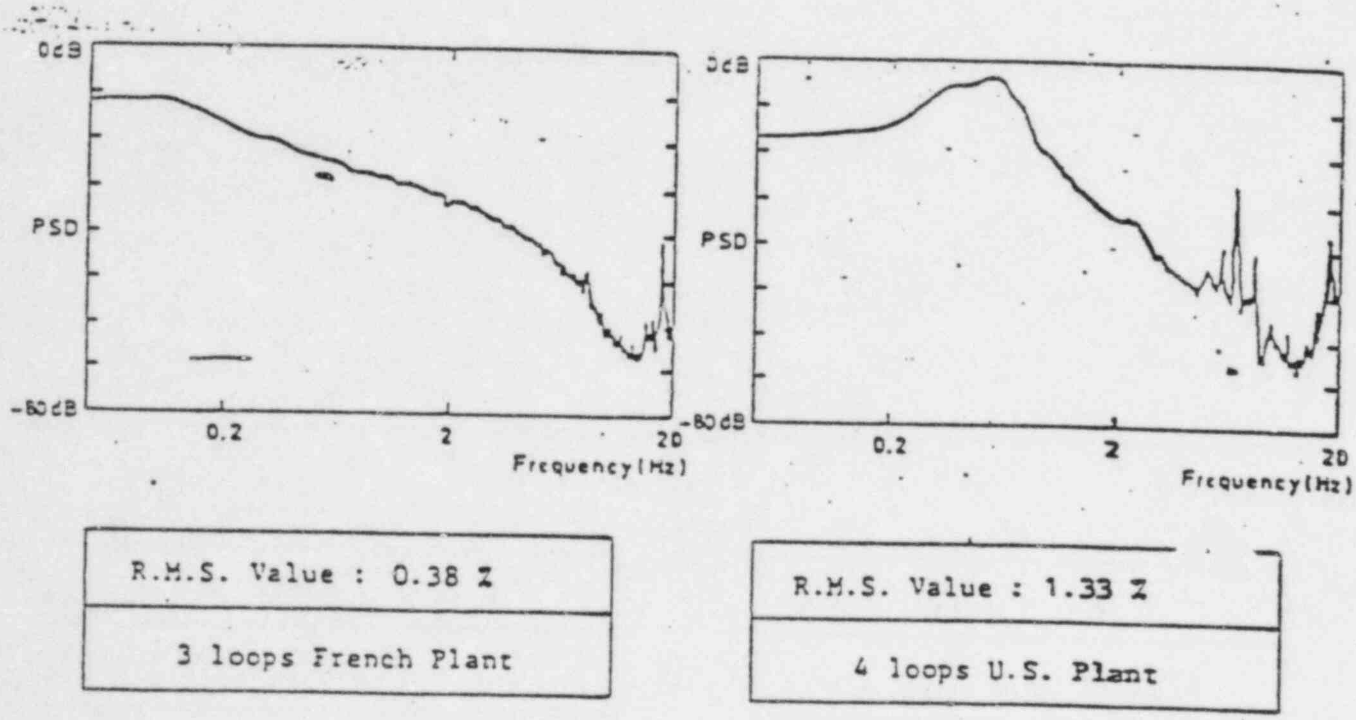
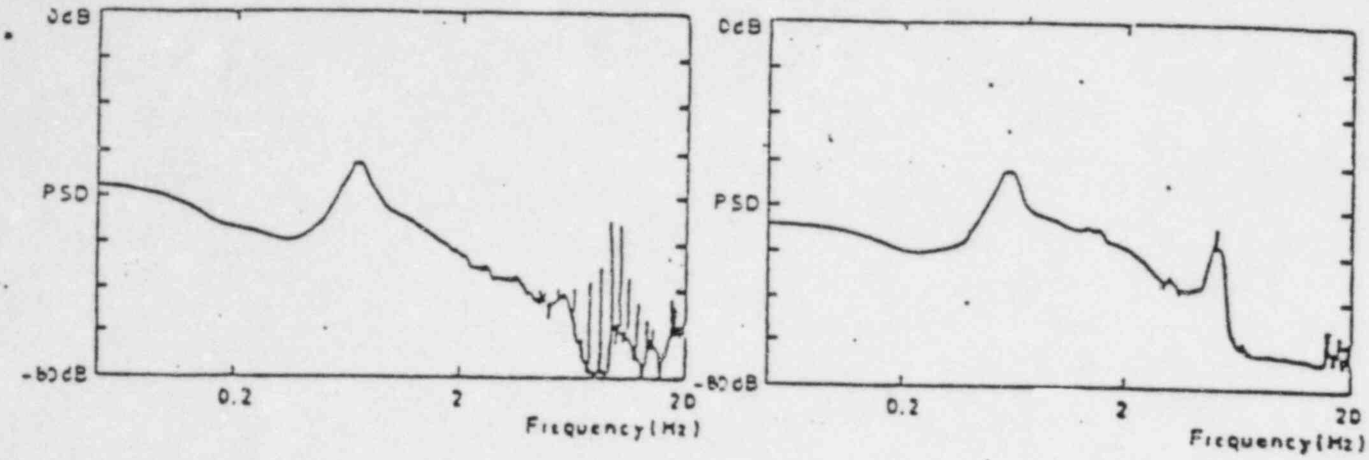
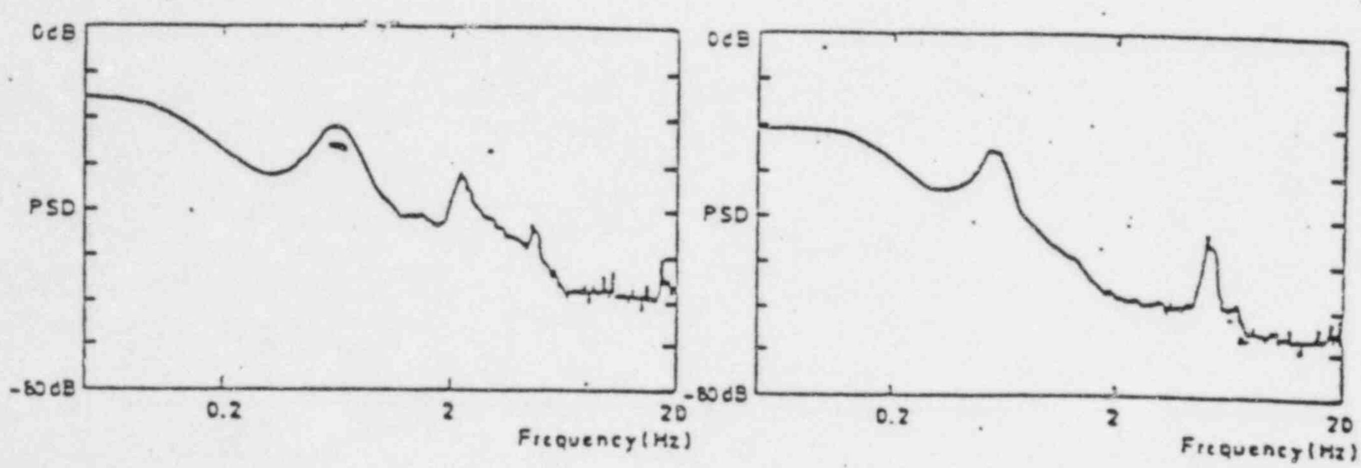


Fig. 11 : Power Spectrum Density. Steam Generator Level.



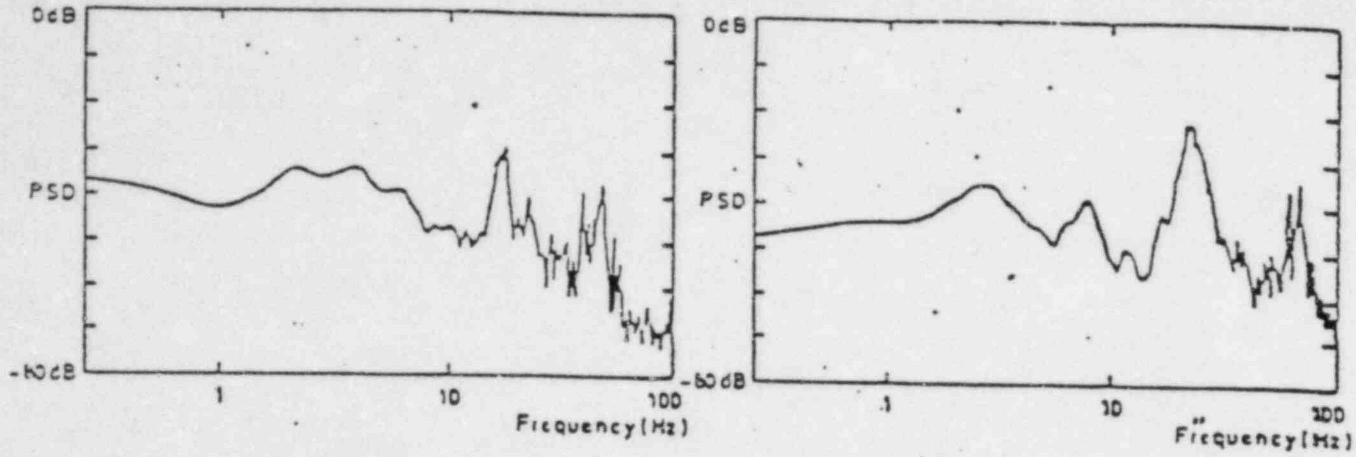
R.M.S. Value : $40.3\ 10^{-3}$ %	R.M.S. Value : 40.10-3 %
3 loops French Plant	4 loops U.S. Plant

Fig. 12 : Power Spectrum Density. Pressurizer Level.



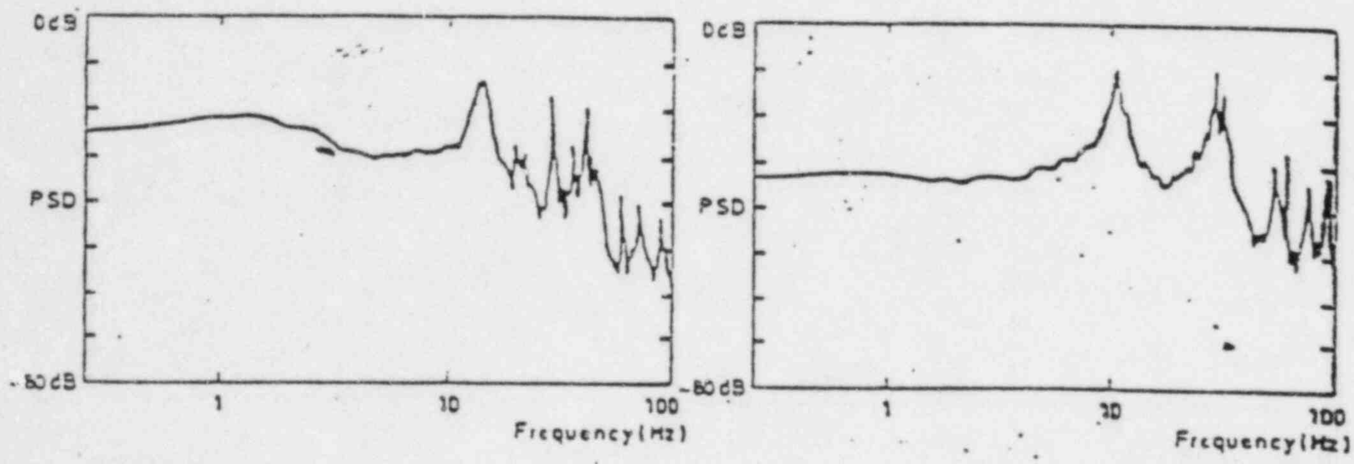
R.M.S. Value : $14\ 10^{+2}$ Pa ($14\ 10^{-3}$ bar)	R.M.S. Value : $9.2\ 10^{2}$ Pa ($133\ 10^{-3}$ PSI)
3 loops French Plant	4 loops U.S. Plant

Fig. 13 : Power Spectrum Density. Pressurizer Pressure.



R.M.S. Value : 46 10² Pa (0.046 bar)	R.M.S. Value : 97.10² Pa (1.4 PSI)
3 loops French Plant	4 loops U.S. Plant

Fig. 14 : Power Spectrum Density : Steam Pressure.



R.M.S. Value : 85 10² Pa (0.085 bar)	R.M.S. Value : 110.10² Pa (1.6 PSI)
3 loops French Plant	4 loops U.S. Plant

Fig. 15 : Power Spectrum Density : Turbine Impulse Pressure.