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Volume II

Optimization Study Report on Base Level Analyzer

Contract No. AF 33(657) 13866

Prepared for

Air Force Systems Command
U.S. Air Force
Wright Patterson Air Force Base, Ohio

6 January 1965

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7. SYSTEM ERROR ANALYSIS

7.1 Introduction

In the following paragraphs, the operation of the Base Level Analyzer will be examined and all sources of error will be identified and, if possible, described quantitatively. A final conclusion regarding the errors to be expected will be made, summarizing all calculations and error estimates in a conservative manner.

The error sources in the Base Level Analyzer operation fall into four main categories and are:

a. Oil Sample and/or Standard Errors

b. Source Variations

c. Optics Errors

d. Electronic Signal Processing or Readout Errors

Of these, the last two categories will be emphasized since they represent instrumental errors which are within the scope of the existing contract and since the greatest amount of quantitative data is available in these areas. Source variations would be covered in more detail except for a lack of firm quantitative data. The first category, that of oil sample and standard errors, is not strictly within the scope of the contract and is an extensive problem area in itself. It will be discussed briefly, but no quantitative error estimate will be made.

The Base Level Analyzer is an instrument which does not contain an internal reference standard but compares oil samples of unknown impurity level with supposedly known standards. As a result it is important to consider in this error analysis only those sources of error which affect the calibration repeatability or reproducibility of the instrument over a relatively short time span, say one day. Systematic errors which are either constant or very small are not of major concern. However, such errors will be identified where they exist and described as well as is possible.

Since many of the errors to be discussed in the optical category are wavelength dependent, being greatest for the spectral extremes, frequent mention in examples will be made of iron. Iron has been selected first because it is of prime interest to the sponsor; second, because the iron line being used falls near the low extreme of the spectrum considered; and third, because the working curve for iron is nearly linear.

7.2 Oil Sample and Standard Errors

Quantitative analysis of impurities in lubricating oil by spectrographic methods is based upon a comparison of the oil sample containing the unknown impurities with a set of known standards containing the impurities of interest at various levels of concentration. In order to obtain an accurate and meaningful result from the comparison, the sample must be representative of the whole body of oil from which it was extracted and the set of standards must be reliable.

Obtaining a representative sample is a matter of common sense and good chemical technique. Samples must be obtained in a uniform and careful manner considering oil temperature, time since last agitation, sampling level within the reservoir in the vehicle, and cleanliness of the glassware used. Also, the handling of the samples subsequent to extracting the oil from the vehicle must be such that no chemical reaction or sedimentation occur which might remove impurities from the sampled oil. Finally care must be taken to avoid contamination of the sample or source electrodes when setting up the source prior to burning the sample.

Sets of oil standards are prepared by adding known amounts of organic salts containing the metallic constituents plus solubilizing agents to a base oil assumed to be free of impurities. Generally the highest impurity levels are obtained directly in this way and the initial solution is diluted with additional oil to obtain standards at the lower impurity levels. The final standards can be in error as a result of inaccurate weighing and mixing of the organic salts, errors in diluting the initial high impurity level standard, failure of all the organic salts to dissolve and remain in solution, chemical reactions causing one or more metallic constituents to leave the solution, dirty glassware, and impurities contained initially in the base oil.

Of these sources of error, the most important and generally the hardest to detect are the failure of the organic salts to dissolve and remain in solution and chemical reactions causing impurities to leave solution. Weighing and diluting measurement errors can be kept small, of the order of two percent. Dirty glassware becomes more important at the lowest impurity levels but should not present a problem if good technique is employed.

Impurities in the base oil cannot be completely eliminated. Generally the assumption is made that an oil is impurity free as it comes from the refinery container despite the fact that it may contain minor amounts of impurities (of the order of 1 or 2 parts per million (ppm)). Larger amounts of impurity additives can be detected in the base oil by comparing supposedly pure oils of different types. Small amounts of impurities (1 or 2 ppm) cause an effective offset in the absolute calibration of the Base Level Analyzer but do not impede its successful use since it is always used as a comparative rather than an absolute measuring tool.

Since the subject of oil sample and oil standard errors is a major problem area outside the scope of the existing contract, no quantitative estimate of overall error has been attempted here.

7.3 Source Variations

Changes in source conditions may excite some unknown lines differentially with respect to reference background. No exact data is available as to the importance of this effect or the ultimate source stability requirements. However, data have been obtained on the Baird-Atomic Research Direct-Reader Spectrograph (RDRS) which indicate that the integrated intensity for a burn of fixed time duration does not vary by more than ± 10 percent and that the total reproducibility error from all causes, optical and electronic, is of the order of ± 10 percent. A source reproducibility error much less than ± 10 percent is indicated by this data despite the lack of a voltage regulated supply for the RDRS source. Hence it will be assumed arbitrarily that reproducibility errors resulting from variations in source conditions are small and are of the order of ± 1 percent or less for the Base Level Analyzer, which does use a regulated source power supply.

7.4 Optics Errors

The optical errors which are to be discussed in this section arise from changes in ambient atmospheric pressure, temperature and humidity which affect the index of refraction of air, the diffraction grating line spacing and the dimensions of the mechanical supporting structure in the optical head. These environmental parameters produce shifts of the spectral lines laterally with respect to the exit slits (dispersion errors) and changes in optical focus (line broadening). Errors are produced when the amounts of integrated power reaching the reference and unknown photomultipliers respectively vary by different scale factors.

In the Base Level Analyzer design discussed in this report the reference photomultiplier uses spectral background as a source of energy and hence its output will not be affected by minor discrepancies in optical alignment or dispersion or by minor focus errors. However, the output of a photomultiplier collecting light from a spectral line of unknown intensity will be affected. Percentage changes in the excitation of such a photomultiplier will produce equal error percentages in the output reading of element concentration in parts per million provided the working curve for the element in question is linear.

In order to have a specific example for use in the discussion which follows, the element iron has been selected. Iron is the element of greatest interest in this program and it has a linear working curve. Also, since the spectral line used for iron (2599 A) is at one extreme of the focal curve, iron will experience nearly all the peak errors discussed below which are a direct function of wavelength separation from the optical alignment servo wavelength.

7.4.1 Dispersion Errors

In an earlier section the dispersion errors in terms of lateral shifts for the extreme wavelengths were computed assuming extreme changes in temperature, pressure, and humidity plus an optical alignment servo for maintaining registration between a mean wavelength and the corresponding slit. These shifts for temperature, pressure, and humidity are respectively 1.9 microns, 14 microns, and 1 micron at 2208 A and 2.2, 16 and 0.8 microns at 4254 A assuming the alignment servo operates at 3126 A.

An additional error of as much as ± 5 microns can be caused by dispersion in the calcium fluoride plate used in the optical alignment servo. A 5-micron shift is produced at the short wavelength end of the focal curve (2200 A) when the full 100-micron deflection of the calcium fluoride plate is being employed. Since the shift is a direct function of deflection, it normally will be much less than 5 microns, even at 2200 A. Also the maximum shift at 4500 A is only 1.2 microns at full deflection while no shift is experienced at 3147 A.

Dispersion errors can result in important output errors. The amount of each in terms of percentage error at the photomultiplier output can be determined by considering the widths of exit and entrance slits and the spectral line shape.

The Base Level Analyzer entrance slit is 50 microns in width and is imaged by a 1-meter grating onto 25-micron wide exit slits. The intensity profile of the spectrum line has an approximately Gaussian shape as shown in figure 7-1. Translation of the line relative to the slit causes a decrease in the integrated intensity passing through the slit. The power on the photomultiplier is P where

$$P = \int_{X_1}^{X_2} \phi(x)\, dx$$

In this equation X_1 and X_2 represent the boundaries of the exit slit and

$$\phi(x) = \frac{1}{\sqrt{2}\ \sigma} \exp\left[-1/2\ \frac{x^2}{\sigma 2}\right]$$

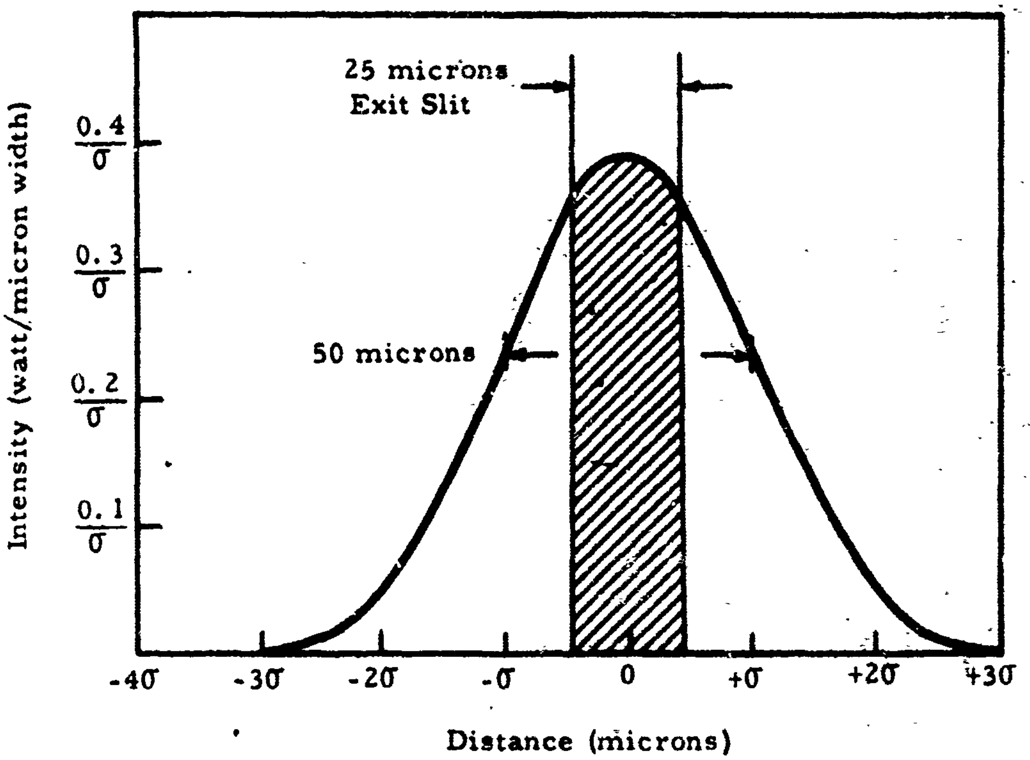

Figure 7-1. Intensity Profile of Spectrum Line (approximate)

Using the cumulative distribution function

$$P = \Phi(X_2) - \Phi(X_1) \quad .$$

where

$$\Phi(x) = \int_{-\infty}^{X} \phi(x)\, dx$$

The values X_2 and X_1 always differ by the width of the exit slit σ, or 25 microns. The graph in figure 7-2 shows the effect on the photomultiplier tube output for shifts of various amounts.

It can be seen from figure 7-2 that the maximum dispersion shift of 2 microns caused by temperature, changes in index of refraction of air and grating line spacing produces less than a 0.5 percent change in photomultiplier output. Humidity variations produce a still smaller percentage change, about 0.2 percent. Since the reference channel will not be affected by these environmental effects, a maximum change in calibration in the iron channel of 0.5 or 0.2 percent will be observed for the complete temperature or humidity excursion.

Pressure changes cause a much greater shift, about 15 microns, in the position of the spectral line relative to the exit slit. Figure 7-2 shows that this shift is equivalent to a 15 percent change in photomultiplier output (or error) in the case of iron. An error of this size is intolerable. Consequently, a mechanism has been provided whereby the grating is moved manually toward the center of the focal curve as pressure is reduced so that compensation for the line shift is achieved. A total movement of 0.003 inch is needed to compensate from 0 to 10,000 feet altitude. Provided the grating is exactly adjusted for ambient pressure no error will exist. In practice, however, only an average pressure setting for the height above sea level of the instrument will be used. Weather changes can cuase rms atmospheric pressure variations

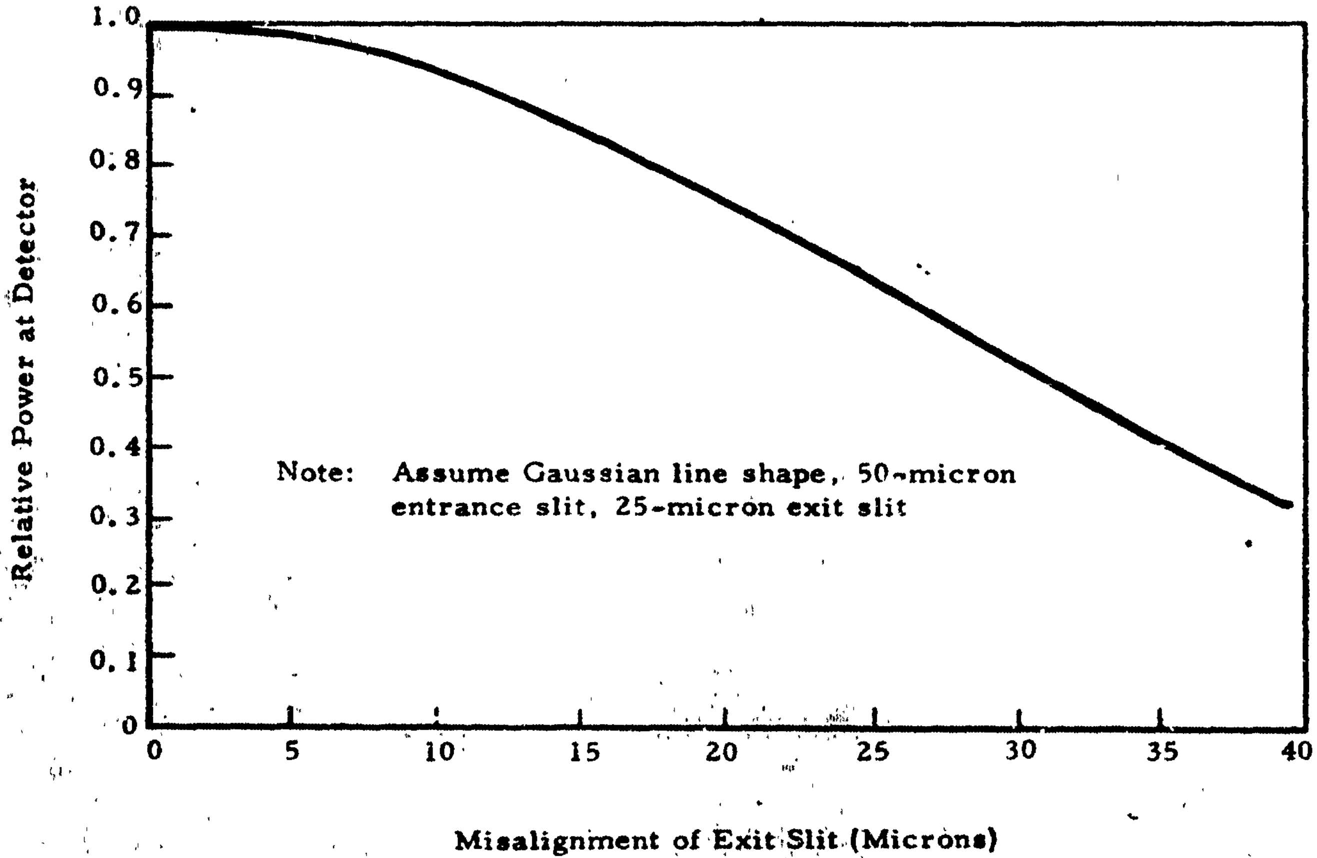

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Figure 7-2. Effect of Misalignment of Exit Slit about the average pressure setting of the order of 15 millimeters of mercury and corresponding line shifts of 0.8 micron rms. Errors from this source in a reading of iron concentration can therefore be as much as 0.2 percent rms.

The calcium fluoride deflection plate used in the optical alignment servo can produce as much as a ± 5-micron alignment error, equivalent to a ± 1.6 percent output error. The amount of this error is proportional to the difference between the wavelength in question and 3126 A as well as to the amount of correction supplied by the servo. Pressure changes from 0 to 10,000-foot altitude produce a + 50-micron correction requirement. Temperature changes of ± 30°C require ± 6.6-micron corrections while the total range of humidity change from minimum or normal conditions to high temperature wet conditions (23°C and 72 percent relative humidity to 55°C and 100 percent relative humidity) gives only a + 3-micron correction. The ± 1.6-percent error stated above corresponds to the maximum correction that can be made by the servo which is ± 100 microns.

7.4.2 Line Broadening Errors

In the preceding section errors caused by shifts of a spectral line of constant width relative to an exit slit were discussed. This section is concerned with errors produced when the optics become defocused and the width of the spectral line is increased without any lateral shift. If the line is broadened relative to the exit slit width, a smaller fraction of the total light will pass through to the photomultiplier. The decrease in photomultiplier output can once again be estimated assuming a Gaussian line shape. If the exit slit is 25 microns wide and the line is 50 + δ microns wide, then the slit width in terms of standard deviations (σ) is

$$w = \frac{50}{50 + \delta} \sigma$$

The power on the photomultiplier is

$$P = \int_{-\bar{X}}^{+\bar{X}} \phi(x)\, dx$$

$$= 2\int_{0}^{X} \phi(x)\, dx$$

where

$$X = \frac{w}{2} = \frac{25}{50 + \delta}\ \sigma$$

Figure 7-3 shows the relative photomultiplier output plotted versus the broadening δ. The relative photomultiplier output is

$$\frac{P_{(50+\delta)\mu}}{P_{50\mu}} = \frac{\int_{0}^{X} \phi(x)\, dx}{\int_{0}^{0.5} \phi(x)\, dx}$$

The focus errors which produce the broadening δ result basically from changes in ambient temperature. These errors occur in addition to the dispersion errors produced by temperature effects on the air and grating which have already been analyzed in paragraph 4.3.5. No additional registration errors result from temperature changes provided the complete optical structure including focal plane is fabricated of the same material so that it has a uniform temperature coefficient of expansion and is maintained at a uniform temperature throughout.

In order to correct the focusing errors which can result from temperature changes, a servo has been provided to adjust the optical path between entrance slit and diffraction grating. This servo operates by inserting a variable thickness plate of calcium fluoride so that correct focus is maintained despite ±30°C temperature changes and resulting changes in the size of the mechanical structure.

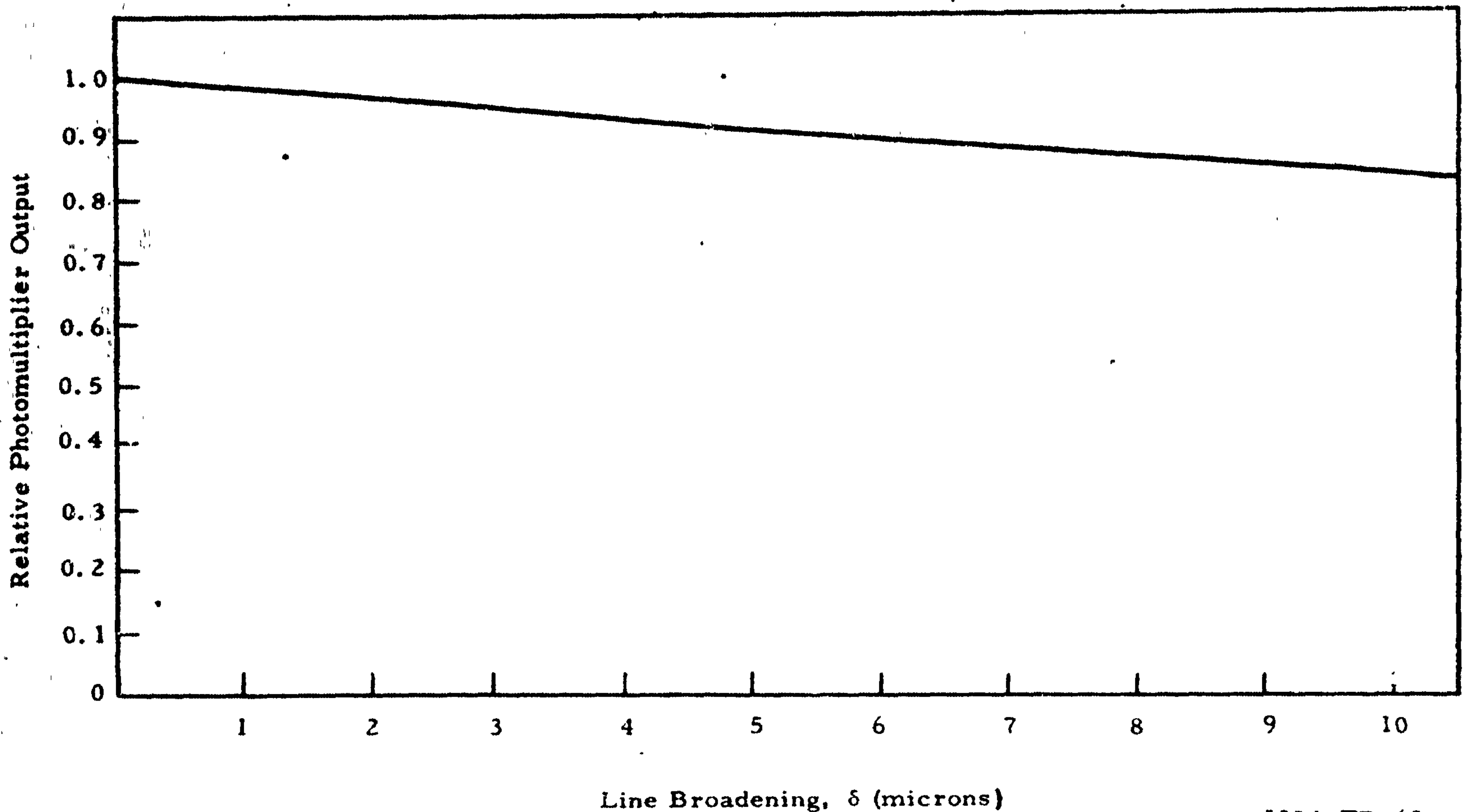

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Figure 7-3. Relative Photomultiplier Output versus Spectral Line Broadening

These changes result from the fact that the optical head assembly will be a casting of A 356 aluminum. This material has a linear coefficient of expansion of 11×10^{-6} inches per inch/°C or ± 0.011 inch over 40 inches with a ± 25°C temperature change, results in an increase shift of ± 0.044 inch over a ± 25°C temperature range. This is due to the fact that the entrance slit moves 0.022 inch relative to the grating and the grating moves 0.022 inch relative to the focal curve.

No appreciable error would result from line broadening due to poor focusing if the servo were designed to operate in a proportional manner and if equal focus correction were provided for all wavelengths. However, neither of these conditions are met. The servo operates stepwise covering the total range of correction in 10 equal steps and the calcium fluoride has noticeable dispersion over the spectral band of interest.

First, consider the error caused by the stepwise servo adjustment. The total servo focus correction is ± 0.044 inch. Each servo step is therefore 0.0088 inch. Since it is equally probable that the error lies anywhere within this range, the rms focus error is $0.0088/2\sqrt{3}$ or 0.0025 inch (63.5 microns). In an f/20 optical system the line broadening to be expected is about 1/20 of this value or 3.2 microns. Reference to figure 7-3 shows that 3.2 micron broadening causes a 5.5 percent error in the photomultiplier output or in the concentration reading of an element such as iron.

These calculations are considerably pessimistic since actual measurement shows that an f/20 one meter diffraction grating system with the entrance slit displaced by 0.050 inch has but 13 microns of line broadening. Linear extrapolation from this value leads to an rms broadening of only 0.75 micron and a corresponding error of 1.1 percent.

Second, consider the errors in focus produced by the dispersion of calcium fluoride focus corrector plate. A plate ranging in thickness from about 3.9 to 11 millimeters will be required. Such a plate has the ability to shift the focal plane by a distance x where

$$x = d\left(1 - \frac{1}{n}\right)$$

and

d = the plate thickness

n = the index of refraction

Assuming an 11 millimeter thickness and taking the indices of calcium fluoride at 2200 and 4300 A of 1.48112 and 1.43950 respectively, the focal plane shifts at these wavelength are 3363 and 3574 microns. The difference of 211 microns can be split so that the maximum error in focus at the extreme wavelengths is ± 106 microns. A linear extrapolation of the line broadening measurement previously mentioned leads to a maximum value of line broadening of 1.1 microns and a maximum error (figure 7-3) of 2.0 percent. Typically, of course, the error at the extreme wavelengths is less since the focus correction actually used in a normal temperature environment is about half the maximum.

7.5 Electronic Signal Processing Errors

The light emitted by the source during the burn period is dispersed by the diffraction grating and focused on the reference and unknown exit slits. The light passing through each of these slits is detected by a photomultiplier tube whose output current charges an integrating capacitor. Provision is made in the charging circuit for photomultiplier dark current cancellation. At the conclusion of the burn, namely when the reference capacitor voltage reaches a specified level, the capacitors are disconnected from the photomultipliers and their voltages are measured sequentially using a non-linear measurement circuit utilizing the working curves for the elements. The digitized outputs of the non-linear circuits are converted to 9 bit digital numbers and stored in registers whose contents can be displayed at will on a 3-decimal digit set of Nixie tubes.

The whole apparatus is illustrated in block diagram form in figure 7-4 in order to facilitate the following error analysis. In the analysis, each error producing block will be discussed in turn. Those subjects to be covered are:

a. Photomultipliers

b. Integrating Capacitors

c. Reference Capacitor Cutoff Voltage

d. Dark Current Cancellation

e. Analog Circuits

   1. Unity Gain Amplifier

   2. Nonlinear Amplifiers

   3. Analog-to-Digital Converters

f. Digital Circuits

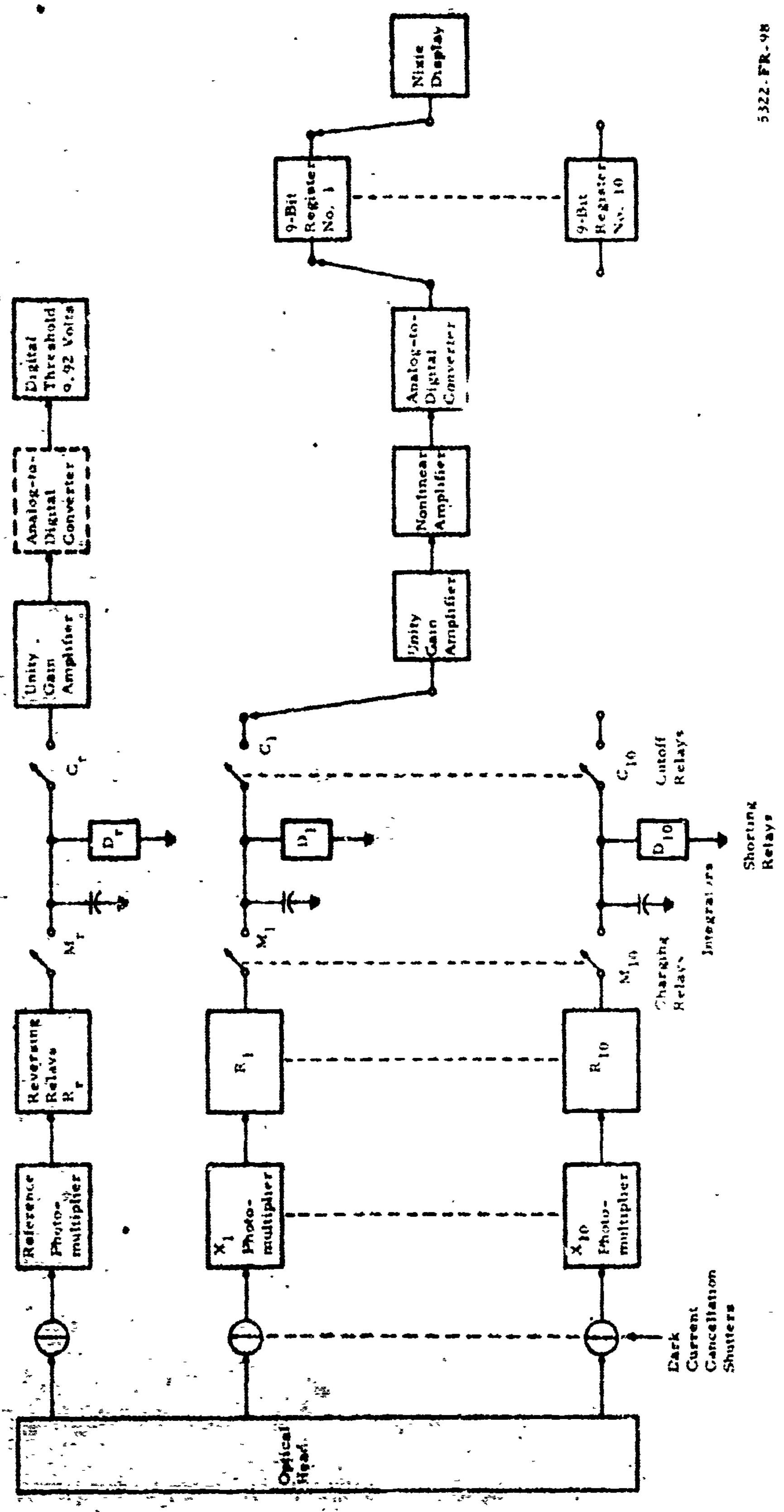

Figure 7-4. Base Level Analyzer, Block Diagram

7.5.1 Photomultiplier Errors

The photomultipliers used in the Base Level Analyzer are 1P28 9-stage units operated from a common 1000-volt regulated supply (an Arnold Magnetic Corp. Model SMU). Three types of errors can be considered to arise from the combination of photomultiplier and supply. These result from

a. Changes in Supply Voltage
b. Changes in Individual Photomultiplier Tubes
c. Photomultiplier Dark Current

The discussion of dark current problems will be deferred to paragraph 7.5.3.

Small changes in the photomultiplier supply voltage tend to make large changes in photomultiplier current gain and anode sensitivity. The current gain G is

$$G = \delta^9$$

where

δ = the secondary emission ratio of the dynodes (approximately 3).

In the region of interest, δ is approximately proportional to the voltage per stage (V).

$$\delta = K'V$$

so that

$$G = KV^9$$

if

$$K = (K')^9$$

If the voltage changes by a factor X then,

$$\frac{G_x}{G} = \frac{K X^9 V^9}{K V^9} = X^9$$

A ± 1 percent change in voltage, which can be expected from the photomultiplier voltage supply over the design temperature range, can therefore give about a ± 10 percent change in gain.

However, because of the use of a common supply voltage for all tubes, each should experience the same gain change, at least to a first approximation, so that the ratio of unknown capacitor voltage to reference capacitor voltage should remain constant. It is possible that not all dynodes in the various tubes will have exactly the same gain versus voltage characteristic and that a second order error will result. However, since no data is available upon which to base a quantitative error estimate, it will be assumed arbitrarily that such errors are negligibly small.

Differential aging of the photomultiplier tubes, if it occurred following calibration of the instrument, could have a major effect on the useability of the Base Level Analyzer. Differential aging is important for some types of photomultipliers, especially during the first 100 hours of operation. However, it is believed that this effect has not been observed with 1P28 tubes. In any case a burn-in program can be conducted to achieve good photomultiplier stability. Consequently, no assignment of error will be made to account for aging phenomena.

7.5.2 Integrating Capacitor Errors

7.5.2.1 Charging Errors -- The voltage across a capacitor C being charged from a current source I is given by

$$V = R_L I \left[1 - e^{-\frac{t}{R_L C}}\right] \simeq \frac{I t}{C} \left[1 - \frac{t}{2 R_L C}\right] \quad \text{for } R_L C \gg t$$

where

R_L = the leakage resistance

t = the time

The capacitors being used have an intrinsic time constant of 25,000 seconds, except for the reference capacitor which is always shunted by a unity gain amplifier having less than 1.0-nanoampere leakage current, and the charge time is of the order of 10 seconds so that the approximation is valid.

The voltage on the i^{th} capacitor after burning the oil sample is

$$V_i \simeq \frac{I_i t_f}{C_i} \left[1 - \frac{t_f}{2 R_{L_i} C_i} \right] \tag{7-1}$$

and the time at the end of burn, t_f, is found from the equation

$$V_R \simeq \frac{(I_R - I_L) t_f}{C_R} \left[1 - \frac{t_f}{2 R_{L_R} C_R} \right] \tag{7-2}$$

where V_R is the reference threshold voltage and I_L is the leakage current of the unity gain amplifier. It should be pointed out that leakage phenomena included in these two equations do not of themselves cause output errors. If all leakage phenomena were constant, no output errors would result. It is only when either I_L or R_L varies that errors occur. Naturally a large variation in a quantity having only a vanishingly small effect on the output in the first place cannot cause a serious error. Therefore it is desirable to keep leakage currents small as well as constant.

The rms output error, again using iron as our example, is identical to

$$\overline{\Delta V_i^2}^{\,1/2}$$

where

$$\left[\overline{\Delta V_i^2}\right]^{1/2} = \left\{ \left(\frac{\partial V_i}{\partial I_R}\right)^2 \overline{\Delta I_R^2} + \left(\frac{\partial V_i}{\partial V_R}\right)^2 \overline{\Delta V_R^2} + \left(\frac{\partial V_i}{\partial I_L}\right)^2 \overline{\Delta I_L^2} + \left(\frac{\partial V_i}{\partial R_{L_i}}\right)^2 \overline{\Delta R_L^2} \right\}^{1/2} \quad (7\text{-}3)$$

The value of V_i in this equation is obtained by eliminating t_f from equation (7-1) with equation (7-2).

$$V_i = \frac{k_1 I_R V_R k_2}{(I_R - I_L)} \left[1 - \frac{V_R k_2}{2 (I_R - I_L) R_{L_i}} \right] \quad (7\text{-}4)$$

$$k_1 = \frac{I_i}{I_R}$$

$$k_2 = \frac{C_R}{C_i}$$

The ratio of the currents charging the reference and unknown capacitors has been replaced by a constant k_1. This has been done since, for a given unknown element, source variations and photomultiplier power supply variations affect both currents and their ratio remains constant. In other words the current errors are functionally related and correlated and are not statistically independent. The same reasoning applies to the values of the reference and unknown capacitors which are primarily affected by temperature and hence have a constant ratio. All remaining parameters in equation (7-4) have statistically independent random errors so that the averaging operation removes all but the squared terms from equation (7-3). Evaluating equation (7-3) we find that

$$\left[\overline{\Delta V_i^{\,2}}\right]^{1/2} = \left\{ \frac{I_L^{\,2} k_1^{\,2} V_R^{\,2} k_2^{\,2}}{(I_R - I_L)^4} \overline{\Delta I_R^{\,2}} + \frac{k_1^{\,2} I_R^{\,2} k_2^{\,2}}{(I_R - I_L)^2} \overline{\Delta V_R^{\,2}} \right.$$

$$\left. + \frac{k_1^{\,2} I_R^{\,2} V_R^{\,2} k_2^{\,2}}{(I_R - I_L)^4} \overline{\Delta I_L^{\,2}} + \frac{k_1^{\,2} I_R^{\,2} V_R^{\,4} k_2^{\,4}}{4 (I_R - I_L)^4 R_{L_i}^{\,4}} \overline{\Delta R_{L_i}^{\,2}} \right\}^{1/2} \qquad (7\text{-}5)$$

Assuming as values for the preceding equation

$I_L = 10^{-9}$ ampere

$I_R = 10^{-6}$ ampere

$k_1 = 1$

$C_R = 10^{-6}$ farad

$C_I = 10^{-7}$ farad

$\left[\dfrac{\overline{\Delta R_{L_i}^{\,2}}}{R_{L_i}}\right]^{1/2} = \pm 20$ percent

$C_i R_{L_i} = 25{,}000$ seconds

$V_R = 10$ volts

$\left[\dfrac{\overline{\Delta I_L^{\,2}}}{I_L}\right]^{1/2} = \pm 20$ percent

$\left[\dfrac{\overline{\Delta V_R^{\,2}}}{V_R}\right]^{1/2} = \pm 0.07$ percent*

$\left[\dfrac{\overline{\Delta I_R^{\,2}}}{I_R}\right]^{1/2} = \pm 10$ percent

*See paragraph 7 5.2

we find that

$$\left[\overline{\Delta V_1^2}\right]^{1/2} = 7.4 \times 10^{-2} \quad .$$

If a typical value of V_1 corresponding to a current of 10^{-7} amperes is 10 volts, the rms output error is

$$\frac{\left[\overline{\Delta V_1^2}\right]^{1/2}}{V_1} = \pm 0.74 \text{ percent}$$

Of the four terms in the expression for

$$\left[\overline{\Delta V_1^2}\right]^{1/2}$$

the second contributes the major portion of the error. The second term represents the effect of uncertainty in the reference capacitor cut-off voltage.

7.5.2.2 Leakage Errors -- In addition to the errors which occur during the charging of the integrating capacitors, which have just been discussed, there can be a variable amount of discharge between the time the capacitor charging is complete and the time that the charge is read out. Ten unknown capacitors are read at intervals of 100 milliseconds. Each of these 0.1 microfarad capacitors has a 25,000 second leakage time constant. Since the voltage during the time the capacitor is allowed to leak is

$$v = V_i \exp\left[\frac{-t}{R_{L_i} C_i}\right] \simeq V_i'\left(1 - \frac{t}{R_{L_i} C_i}\right) \text{ for } t \ll T_L$$

the rms error in v for a particular V_i and t is

$$\left[\overline{\Delta v^2}\right]^{1/2} = \left\{\left(\frac{\partial v}{\partial R_{L_i}}\right)^2 \overline{\Delta R_{L_i}^{2}} + \left(\frac{\partial v}{\partial C_i}\right)^2 \overline{\Delta C_i^{2}}\right\}^{1/2}$$

$$= \frac{V_i t}{R_{L_i} C_i} \left\{\frac{\overline{R_{L_i}^{2}}}{R_{L_i}^{2}} + \frac{\overline{\Delta C_i^{2}}}{C_i^{2}}\right\}^{1/2}$$

This equation can be evaluated using the most pessimistic parameter values, namely:

V_i = 10 volts

t = 10 x 100 milliseconds = 1 second

$R_{L_i} C_i$ = 25,000 seconds

$$\frac{\left[\overline{\Delta R_{L_i}^{2}}\right]^{1/2}}{R_{L_i}} = \pm 20 \text{ percent} \qquad \frac{\left[\overline{\Delta C_i^{2}}\right]^{1/2}}{C_i} = \pm 0.5 \text{ percent}$$

The result is that

$$\frac{\left[\overline{\Delta v^2}\right]^{1/2}}{V_i} \cong 0.01 \text{ percent},$$

a very small rms variable-capacitor-leakage error.

An additional leakage error can occur as each unknown capacitor is read. A single high input impedance readout system is used to read all 10 capacitors. After connection is made to a particular capacitor, 30 milliseconds are allowed to pass to assure that all relay contact and amplifier transients have ended and then the capacitor voltage is sampled for 30 milliseconds. The remaining 40 milliseconds of the 100-millisecond cycle is used to disconnect the amplifier from the capacitor. During the sampling operation the voltage leakage increment is

$$\Delta v_L = -\frac{V_i}{T_a} t$$

where

$$T_a = R_a C_i$$

R_a = the amplifier input impedance

The variation in Δv_L as a result of changes in amplifier input impedance and sampling time is the error in this case.

$$\frac{\left[\overline{\Delta v_L^{\,2}}\right]^{1/2}}{V_i} = \frac{\left\{\left(\frac{\partial \Delta v_L}{\partial R_a}\right)^2 \overline{\Delta R_a^{\,2}} + \left(\frac{\partial \Delta v_L}{\partial C_i}\right)^2 \overline{\Delta C_i^{\,2}} + \left(\frac{\partial \Delta v_L}{\partial t}\right)^2 \overline{\Delta t^2}\right\}^{1/2}}{V_i}$$

$$= \frac{t}{T_a}\left\{\frac{\overline{\Delta R_a^{\,2}}}{R_a^{\,2}} + \frac{\overline{\Delta C_i^{\,2}}}{C_i^{\,2}} + \frac{\overline{\Delta t^2}}{t^2}\right\}^{1/2}$$

The rms error during capacitor readout is 0.01 percent for the parameters

$t = 60$ milliseconds

$T_a = R_a C_i = 10^9$ ohm x 10^{-7} farad = 10^2 second

$$\frac{\left[\overline{\Delta R_a^2}\right]^{1/2}}{R_a} = \pm 20 \text{ percent}$$

$$\frac{\left[\overline{\Delta C_i^2}\right]^{1/2}}{C_i} = \pm 0.5 \text{ percent}$$

$$\frac{\left[\overline{\Delta t^2}\right]^{1/2}}{t} = \pm 10 \text{ percent}$$

7.5.3 Reference Capacitor Final Voltage Errors

The voltage on the reference capacitor at the end of the burn period is ideally a constant value of the order of 10 volts. However, because of errors occurring in the Adage HA-150 unity gain amplifier, analog-to-digital converter and digital threshold used to monitor the reference capacitor voltage, there will be some small inconsistencies in the final value. These inconsistencies, considered on an rms error basis, represent an output error for an element having a linear working curve. The effect of this type of error was included in the previous section in the form of the term

$$\left(\frac{\partial V_i}{\partial V_R}\right)^2 \overline{\Delta V_R^2} \quad \text{in equation (7-3).}$$

The unity gain amplifier has errors due to gain stability and drift or offset variations. The output voltage, V_o, is given by

$$V_o = KV_i + \Delta$$

where

K = the gain

V_i = the input voltage

Δ = the offset voltage.

Using this equation the rms error in output is

$$\left[\overline{\Delta V_o^2}\right]^{1/2} = \left\{\left(\frac{\partial V_o}{\partial K}\right)^2 \overline{\Delta K_2} + \left(\frac{\partial V_o}{\partial \Delta}\right)^2 \overline{\Delta \Delta^2}\right\}^{1/2}$$

$$= \left\{V_i^2 \ \overline{\Delta K^2} + \overline{\Delta \Delta^2}\right\}^{1/2}$$

Using the values

$$V_i = 10 \text{ volts}$$

$$\left[\overline{\Delta \Delta^2}\right]^{1/2} = \pm \frac{100 \text{ microvolt}}{\sqrt{3}} = \pm 58 \text{ microvolts rms}$$

$$\frac{\left[\overline{\Delta K^2}\right]^{1/2}}{K} = 10^{-6}$$

$$V_o = 10 \text{ volts}$$

the equation gives for the unity gain amplifier error

$$\frac{\left[\overline{\Delta V_o^2}\right]^{1/2}}{V_o} = 6 \times 10^{-4} \text{ percent rms}$$

The analog-to-digital converter has errors due to its finite sampling interval, drift in its voltage-reference, and the resolution of the digital output.

Since the sampling interval is 10 milliseconds and since the ramp input to the converter has a slope of 10 volts in 10 seconds or 1 volt per second, the voltage change between samples is 10^{-2} volt or 0.1 percent of full scale. The rms error is 0.1 percent$/2\sqrt{3}$ or 0.03 percent as a result of the finite sampling interval. The digital resolution is one part in 512 for a 9-bit system, an rms error of 0.06 percent and the drift in the voltage reference is 0.01 percent rms.

Combining all errors for both analog-to-digital converter and unity gain amplifier, the total uncertainty in the reference capacitor cutoff voltage is approximately 0.07 percent rms*.

7.5.4 Dark Current Cancellation Error

Reversing relays and a dark current cancellation shutter for the source are provided in the Base Level Analyzer for the elimination of dark current contributions to the charge sto[illegible] on the integrating capacitors. Charge is stored over a number of regular cycles, light source produced photocurrent plus dark current being added to the capacitor in one half cycle and dark current alone being subtracted in the next half cycle. Figure 7-5 shows the approximate effect on dark current alone. Starting with one-half of a positive dark current pulse assures that the mean dark current charge increment will be zero, since it is equally likely that the threshold will be reached and shutoff will occur at anytime during the positive dark current pulse, a result of the decision to control the final reference capacitor voltage rather than the source burn time.

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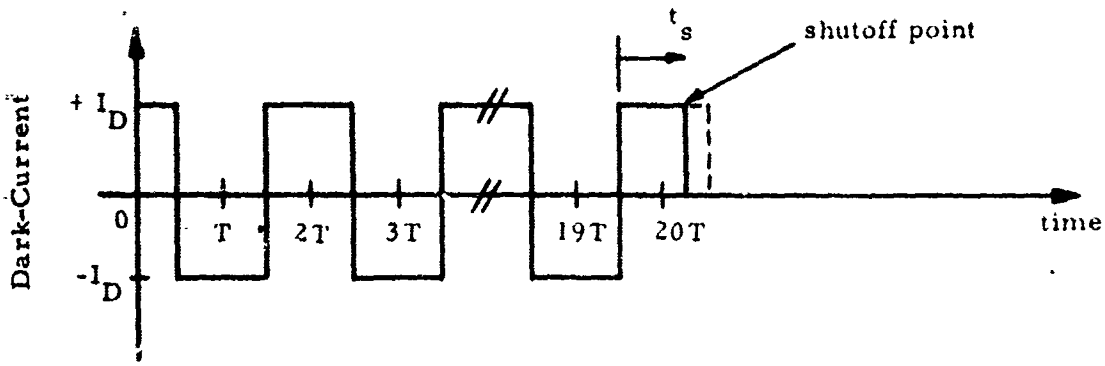
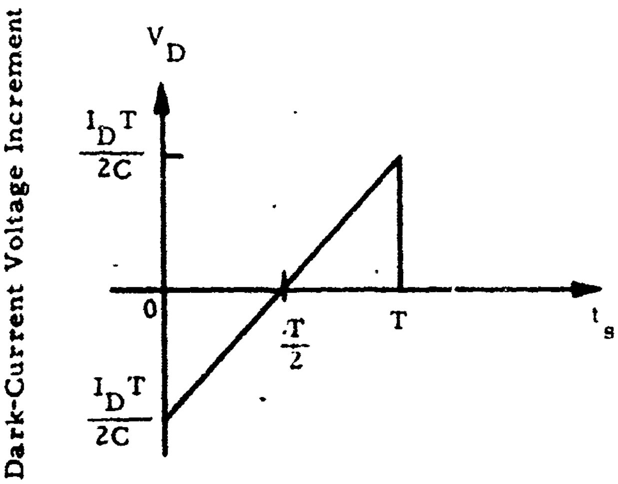
*The effect of this error is included in paragraph 7.5.2.1 and need not be considered again separately.

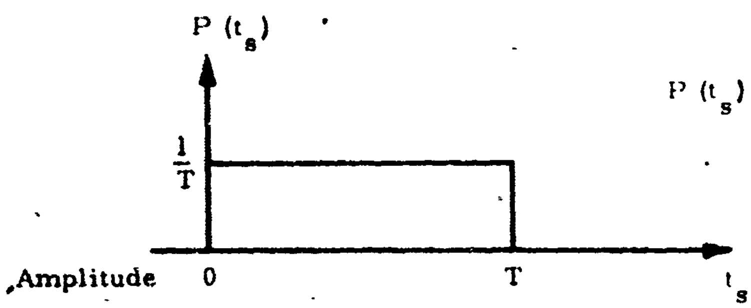


a) Dark-Current Only Applied to Integrating Capacitor



$$V_D = \frac{I_D}{C}\left[-\frac{T}{2} + t_s\right]$$

b) Dark-Current Voltage Increment



$$P(t_s) = \frac{1}{T} \quad 0 \le t_s \le T$$
$$= 0 \text{ elsewhere}$$

c) Probability Distribution of t_s

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Figure 7-5. Dark-Current Cancellation

Although the mean dark current voltage increment shown in figure 7-5(b) is zero, the rms increment is non-zero

$$\left[\overline{V_D^2}\right]^{1/2} = \left[\int_{-\infty}^{+\infty} P(t_s)\, V_D^2 \, dt_s\right]^{1/2}$$

$$= \left\{\frac{1}{T}\int_0^T \frac{I_D^2}{C^2}\left[\frac{T}{2} - t_s\right]^2 dt_s\right\}^{1/2} = \frac{I_D T}{4\sqrt{3}\,C} \qquad (7\text{-}6)$$

The full rms voltage increment given in equation (7-6) does not represent an output error since comparable errors of different magnitude appear in both reference capacitor voltage and unknown capacitor voltage and it is the ratio of these voltages which is of interest. If the subscripts, i and R represent unknown and reference respectively then the fractional error in the voltage ratio is

$$\epsilon = \frac{\dfrac{V_i + V_{D_i}}{V_R + V_{D_R}} - \dfrac{V_i}{V_R}}{\dfrac{V_i}{V_R}} = \frac{\dfrac{V_{D_i}}{V_i} - \dfrac{V_{D_R}}{V_R}}{1 + \dfrac{V_{D_R}}{V_R}} \simeq \frac{V_{D_i}}{V_i} - \frac{V_{D_R}}{V_R} \qquad (7\text{-}7)$$

Using rms values of dark current voltage increment

$$\epsilon \simeq \frac{\left[\overline{V_{D_i}^{2}}\right]^{1/2}}{V_i} - \frac{\left[\overline{V_{D_R}^{2}}\right]^{1/2}}{V_R}$$

and since

$$V_i = \frac{N T I_i}{C_i}$$

where N is the number of dark current reversals

$$\epsilon \simeq \frac{I_D}{4\sqrt{3}\,N}\left[\frac{1}{I_i} - \frac{1}{I_R}\right] \qquad (7\text{-}8)$$

Equation (7-8) can be evaluated using as pessimistic values of the parameters, typical values for low unknown impurity concentrations and maximum dark currents

$I_D = 10^{-8}$ amperes

$N = 10$

$I_i = 10^{-9}$ amperes (5 ppm impurity level)

$I_R = 10^{-6}$ amperes

These values lead to an rms error, ϵ, of ± 14.4 percent at maximum levels of dark current and low levels of signal current for the unknown. If lower dark current values can be achieved by selection of photomultipliers, say 10^{-9} amperes, the error is decreased to 1.4 percent. Additional improvement can be achieved by increasing the number of reversing cycles, N. Since this decreases relay life, only a modest increase, say a factor of two, is possible.

A problem of accuracy exists at the high operating temperature levels which may be experienced (130°F). At these temperatures dark current in photomultipliers may increase as much as a factor of six* over room temperature values which are typically around 10^{-9} amperes in selected tubes. At the 10-ppm impurity level, the error would be increased from 0.7 percent, the room temperature value, to 4.2 percent at 130°F.

7.5.5 Readout Circuit Errors

In order to measure the voltage stored on an unknown integrating capacitor after the source burn and to convert this voltage nonlinearly to a new voltage proportional to unknown concentration, a special readout circuit is employed. This circuit consists of a high input impedance unity gain amplifier, an operational amplifier with non-linear feedback networks and an analog-to-digital converter. In addition digital storage registers and readout are used.

The error contribution of the Adage HA-150 unity gain amplifier results from variations or drifts in offset voltage, noise and gain instability. The offset voltage can vary between ± 100 microvolts so that the rms error is 58 volts. The amplifier noise is 70 microvolt peak-to-peak or 10 microvolts rms. In addition the gain variations are 1 ppm. Assuming that all these errors are statistically independent and Gaussian they may be combined by taking the square root of the sum of the squares. If a 500-ppm impurity level is equivalent to a 10-volt charge on the unknown capacitor, the combined errors of the unity gain amplifier at a 500-ppm level are 0.006 percent. At 10 ppm, the unity gain amplifier error becomes 0.03 percent and at 1 ppm, 0.3 percent.

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* RCA Technical Manual PT-60, "Phototubes and Photocells", p. 96, Radio Corporation of America, Lancaster, Pa., 1963.

The operational amplifier error contribution arises from gain instability and offset voltage drifts with changing temperature and supply voltage. The gain stability is determined by the stability of the resistances in the feedback loop. If these have 25-ppm stability, then the gain stability is 0.004 percent. The temperature produced offset is 3 microvolts per °C or ± 90 microvolts over the temperature range. The supply voltage produced offset is ± 200 microvolts per volt. Since the 28-volt supply used has a 0.05 percent per °C temperature coefficient, an additional 72 microvolts can be added for a total offset voltage variation with temperature of ± 162 microvolts. At the 500-ppm impurity level the total operational amplifier error is 0.004 percent rms and results from gain instability. At the 10-ppm impurity level, the operational amplifier drift gives a ± 0.1 percent error over the temperature range while at the 1-ppm level there is a ± 1 percent error over the temperature range.

The analog-to-digital converter errors result from the instability of its voltage reference, which is known to be ± 0.01 percent, and from the digital resolution of a 9 bit binary system The latter is a one part in 512 peak-to-peak error or a 0.06 percent of full scale rms error so that it predominates The total analog-to-digital converter error is 0.06 percent rms or 0 3 ppm at 500 ppm, 3 percent rms or 0.3 ppm at 10 ppm, and 30 percent rms or 0.3 ppm at 1 ppm.

The digital portion of the readout system, including registers and Nixie tubes is assumed to be error free

7.6 Summary of Base Level Analyzer Errors

A summary of the errors calculated in the previous paragraphs is given in table 7-1. No attempt has been made to combine all errors since many reach meaningful levels only under particular adverse environmental conditions However, the most important error sources are imperfect dark current

Table 7-1

Summary of Base Level Analyzer Errors

Paragraph	Description of Source of Error	Variation of Error: Temperature	Variation of Error: Pressure	Variation of Error: Relative Humidity (percent)	Variation of Error: Wavelength	Variation of Error: Other	Error
7.2	Oil Sample and Oil Standards						No Estimate
7.3	Source Variations						[illegible] Over Range
7.4.1	Optics Errors in Dispersion [illegible] Index of Refraction [illegible] Air	±1 Range			Error ∝ λ - λ avg (λ [illegible] 200 Å)		± [illegible]% Over Range
				[illegible] and [illegible]	Error ∝ λ [illegible] (λ [illegible] Å)		[illegible]% Over Range
			Weather Changes (5 mm Mercury) rms		Error ∝ λ - λ avg (λ [illegible] Å)		[illegible]% rms
	Optics Errors in Dispersion [illegible] Optical Alignment Servo Deflection Plate				Error ∝ λ - λ avg (λ [illegible] 200 Å)	Error ∝ Servo Plate Deflection (Deflection ± 300 [illegible])	± [illegible] Maximum
7.4.2	Optics, Line Broadening or Focus Error Stepwise Focus Servo						[illegible] rms
	Optics Line Broadening [illegible] Errors Dispersion of [illegible] Plate [illegible]	Maximum error at [illegible] Plate [illegible] temperature			Maximum error at extreme [illegible] (λ [illegible] 230 Å)	Error ∝ Plate Thickness, d [illegible] meters	[illegible]% Maximum
7.5.1	Photomultiplier Errors						No Estimate
7.5.2.1	Integrating Capacitor Charging Errors						[illegible] rms
7.5.2.2	Integrating Capacitor Leakage Errors and Read Errors						[illegible] rms
7.5.4	Photomultiplier Dark Current [illegible] Error	Error increases [illegible]				Error ∝ Dark Current and (Signal Current)[illegible] [illegible] amperes	[illegible] rms at [illegible] ppm [illegible]
7.5.5	Readout Errors [illegible] operational amplifier [illegible] digital [illegible] digital [illegible] errors)					Error ∝ (Signal Current [illegible] amp [illegible] amperes or [illegible] ppm impurity level)	[illegible] rms [illegible] ppm

cancellation and electronics readout errors (primarily digital resolution error). Both of these sources of error are most important at impurity concentrations below 10 ppm and together can produce a 5 percent rms error at high temperatures at the 10-ppm impurity level.

One of the worst possible combinations of conditions is found in a high altitude, hot, humid location. If the maximum limit of the temperature, pressure and humidity specifications all occur together, iron (λ = 2599 A) experiences a 5.5 percent rms or 0.55 ppm error at the 10 ppm level plus offset errors totaling 2 percent The offset error remains constant at lower impurity levels while the rms error is inversely proportional to concentration. Thus, at the 1-ppm level of iron the error will be about 55 percent rms or or 0.55 ppm. The error for low concentrations of lead may well exceed that of iron since the lead line used is also at short wavelengths (2203 A) and the sensitivity shown by the lead working curve is less than that for iron.

8. RELIABILITY

8.1 Reliability Program Plan

8.1.1 Basic Philosophy

The basic philosophy of the Base Level Analyzer Reliability Program is to emphasize adequate reliability controls during the design phase of the project. These controls reflect the requirements of the procuring agency's work statement and are the cornerstone of the reliability structure. Baird-Atomic takes the position that reliability, by definition, must be inherent in the basic design, as no amount of reliability controls in areas other than the design phase can ever correct or make up for basic design defects.

As a support or a back up function to the design control phase, the reliability effort will also be directed toward ensuring that the procurement, manufacturing, safety, human factors, and maintainability elements of the total program are integrated to that point where each element contributes a minimum degradation to the reliability of the analyzer.

8.1.2 Reliability Organization

The organization structure of reliability, and its immediate access to top management, is as shown in figure 8-1.

8.1.3 General Reliability Requirements

The Baird-Atomic Reliability Program requirements are as specified in the following documents:

a. MIL-STD-441

b. MIL-R-26484A except that MIL-T-21200D shall be substituted for MIL-E-5400, in accordance with RFQ 33-657-65-5001, dated 31 July 1964

In general the Reliability Program will consist of the following basic elements:

a. Design Review Program

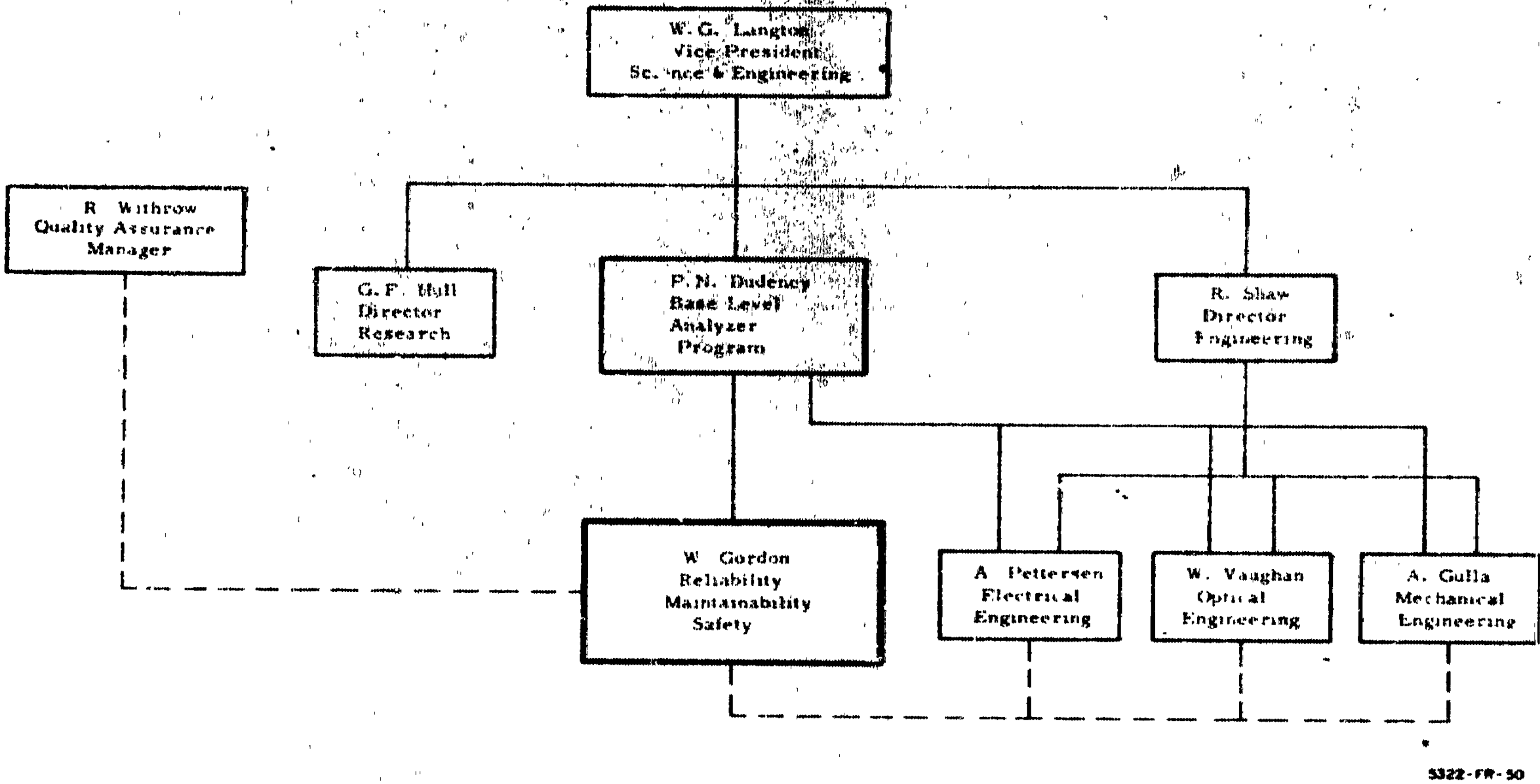

Figure 8-1. Reliability Organization

b. Parts Program

c. Milestone Identification and Schedule

d. Monitoring Program

e. Failure Analysis and Reporting

f. Reporting

8.1.4 Design Review Program

During the design phase of the project, the reliability of each subsystem proposed is carefully considered before final design decisions are made. The reliability design review shall take into consideration the following factors:

a. Concept and Design Approach

b. System and Component Design and Performance Requirements

c. Environmental Requirements

d. Maintainability Requirements

e. Safety Requirements

In the area of mechanical design, stress analyses will be performed to assure that the critical mechanical structures will not fail in the environment specified or will not fail under the shock and vibration tests specified. In the area of optical design, tolerance studies will be made to assure that the manufactured optical system will have the same performance as the computed requirements. Also, in the electronic design area, preferred parts and circuits will be selected for their reliability aspects and will be employed with proper derating. Circuits will be simple, have a minimum number of parts, and incorporate redundancy where it appears de irable.

The design review program will consist of a cricital failure mode analysis of each major subassembly. A system diagram will be used for the initial prediction. Each subassembly will be assigned a reliability apportionment,, and a detailed analysis of all parts comprising each subassembly will be made relative to the apportionment. Updating and reliability trade-offs will be made as required by the program position.

The analyzer reliability shall be assumed to be in accordance with an exponential distribution; that is,

$$R = e^{-\lambda_s t}$$

where

R_s = system reliability ≥ 0.9989

λ_s = system failure rate = $1/MTBF \leq 1/150$ failures/HR

t = required operational time, 10 minutes

As a basis for total life requirements, maintainability, etc., it will be assumed that the longevity (total operating life) requirement, in accordance with MIL-R-2648A, shall be 3000 hours, minimum. It is implicit that at any time the equipment is operated during this 3000 hour operational period, the probability of it completing a 10-minute run will be 0.9989.

RADC Reliability Notebook, AD-148868, and MIL Handbook 217 will be used in the assignment of failure rates when documented evidence from the supplier of a specific part or subassembly is not available upon demand. It is understood that both the RADC Notebook and MIL Handbook 217 offer only engineering estimates of failure rates and as such do not constitute proof of a failure rate specified. Moreover, it is also understood that a failure rate specified by a vendor of a component or subassembly for the analyzer may be an average failure rate attained over a period of time when the vendor has controlled manufacturing and testing techniques. The failure rate specified by the vendor does not have to necessarily reflect the lot from which the component or subassembly supplied to Baird-Atomic was selected.

8.1.5 Parts Program

Baird-Atomic reliability shall sign off all requisitions relative to end item procurement of all major parts and/or subassemblies of the analyzer. In this way, complete control is maintained by the reliability organization.

8.1.6 Milestone Identification and Schedule

Milestone identification and schedule will be in accordance with figure 8-2.

8.1.7 Monitoring Program

Reliability monitoring will be involved with the following:

a. Procurement

b. Development Testing

c. Manufacturing

d. Acceptance Testing

e. Maintainability Evaluation

8.1.7.1 Procurement -- Where possible, each part and/or subassembly of the analyzer will be a "preferred" item and will be purchased in accordance with the pertinent specification Qualified Parts List (QPL).

When a required item does not conform to either the RADC Notebook or MIL Handbook 217, the project manager will be so informed by Reliability. The supplier of this item will be requested to inform Baird-Atomic Reliability as to a failure rate relative to our specific usage. A reliability report will be compiled on each of these items outlining all judgments as to predicted reliability.

8.1.7.2 Development and Acceptance Testing -- Development and acceptance testing will supply all data relative to justification of the design reliability prediction. All data gathered during these tests will be used to verify the reliability prediction by means of a sequential test analysis technique.

Milestone Number	1	2	3	4	5
PERT Corresponding Event	System Layout Complete (Design Review)	Mid Design and Development	System Assembly Drawings Complete (Design Review)	Acceptance Tests Complete	Summary Report
Reliability and Maintainability Action	Initial Prediction	Updated Prediction No 1	Updated Prediction No. 2	Demonstration Tests	Final Report

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Figure 8-2 Milestone Identification and Schedule

8.1.7.3 Manufacturing -- Techniques of manufacturing and assembly of each analyzer will be monitored by reliability in close cooperation with Quality Assurance personnel in order to insure a minimum degradation of the analyzer design reliability.

8.1.7.4 Maintainability Evaluation -- During the prototype testing phase, the maintainability shall be verified by simulations in accordance with paragraph 40.1.1 of MIL-M-26512B.

8.1.8 Failure Analysis and Reporting

A test summary tabulated against consecutive failure numbers shall be made including both relevant and nonrelevant failures. The test summary shall contain the following items:

a. Failure Number
b. Failure Analysis Number
c. Date
d. Part Name
e. Part Number and Symbol
f. Subassembly
g. Major Assembly
h. Serial Number of Equipment
i. Hours of Operation (both equipment and total accumulated)
j. Mode of Operation
k. Manufacturer of Failed Part
l. Symptom of Failure
m. Cause of Failure
n. Corrective Action for Test Continuation
o. Diagnosis Time for Each Skill Level
p. Repair and Retest Time for Each Skill Level
q. Categorization of Failure
r. Result of Failure (catastrophic abort, degradation, etc.)

A full tabulation of failures will be submitted with every monthly report.

8.1.9 Reliability Reporting

Baird-Atomic Reliability will submit a progress report each month as part of the Contract Progress Report.

Each monthly report will contain a complete treatment of any trouble areas and will emphasize corrective action required and/or completed. Updated system reliability prediction will be submitted in accordance with the timing specified in figure 8-2. Each updated prediction will include an updated electronic parts list in accordance with figure 8-3.

The final report, at the end of each phase of the program, will consist of a complete analysis and prediction of the probability of success of the analyzer.

8.2 Reliability Analysis and Prediction

8.2.1 Introduction

In accordance with the parameters as specified in RFQ 33-657-65-5001 and the basic reliability requirements as outlined in MIL-R-26484A (USAF), this report includes those aspects relative to the predicted reliability of the Base Level Analyzer design.

The operational life of the instrument is defined as 3000 hours minimum in accordance with MIL-R-26484A (USAF). It is assumed that the 3000-hour operational life of the instrument is defined as system ON time, not specimen analysis time.

Throughout this analysis, failure rate assignments are made in accordance with the following:

a. The failure rate quoted by the proposed supplier, (where documentary evidence to justify the supplier's claim is available to Baird-Atomic upon demand).

Project Identification ______________________________

Subassembly ______________________________

Drawing Number ______________________________

Component	[illegible]	[illegible]	Vendor Specification	Mil Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$

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Figure 8-3. Reliability Data Sheet

b. MIL-Handbook 217, where component will be purchased to the appropriate MIL specification.

c. Best engineering estimate of the proposed supplier.

8.2.2 Summary

The required reliability of the proposed design is 0.9989 over an operational use period of 10 minutes. These criteria specify an MTBF of 150 hours.

In accordance with the positions outlined in the Reliability Program Plan, the Base Level Analyzer design has a predicted reliability and associated Mean Time Between Failures (MTBF) as shown in figure 8-4.

Figure 8-4 shows that the reliability and MTBF of the analyzer design ranges from a 0.999799 and 820 hours respectively at 60 runs per hour to 0.999928 and 2270 hours respectively at 8.4 runs per hour, this being the maximum-minimum number of estimated runs per hour on the basis of a one man operation.

On a design basis, therefore, the Base Level Analyzer exceeds the required MTBF of 150 hours by a minimum factor of 5.5 at 60 runs per hour and a maximum factor of 15.0 at 8.4 runs per hour.

For completeness, Baird-Atomic Reliability has investigated the concept of treating the 10 integration X channels as a parallel system and has determined the increased reliability of the system assuming some X-channels may fail without system degradation. Paragraph 4.3 gives a complete treatment of the analysis which shows an increased system MTBF of from 114.5 to 131.3 percent.

It is the conclusion of Baird-Atomic Reliability that the analyzer design as reflected in deliverable hardware will more than meet requirements.

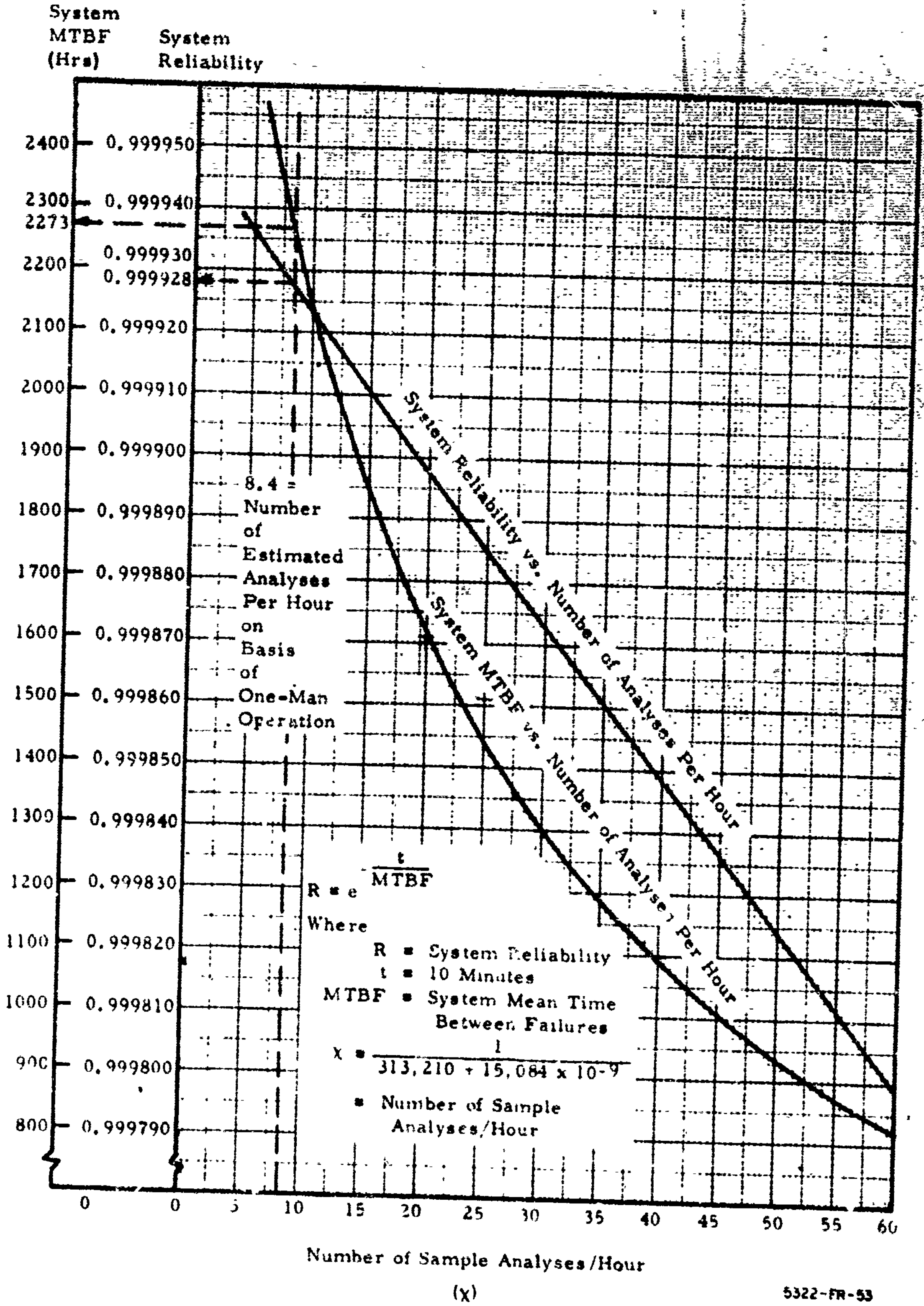

Figure 8-4. Reliability and MTBF versus Number of Sample Runs per Hour

8.2.3 Reliability Prediction

8.2.3.1 General Introduction -- In accordance with MIL-R-26484A (USAF) the exponential distribution is assumed for the proposed design. Therefore

$$R_s = e^{-\lambda_s t}$$

where

R = system reliability = 0.9989

λ_s = system failure rate = $\frac{1}{MTBF} = \frac{1}{150}$

t = operational time period = 10 minutes

Since the required MTBF = 150 hours, the failure rate design goal of the Base Level Analyzer system is as follows:

$$\lambda_s = \frac{1}{150} = 6,667,000 \times 10^{-9} \text{ failures per hour}$$

8.2.3.2 Functional Operation of the Base Level Analyzer -- The first step in the reliability analysis was to generate a reliability functional operation diagram of the proposed system (figure 8-5).

8.2.3.3 Reliability Block Diagram -- The second step in the reliability analysis was to generate a reliability block diagram of the proposed system (figure 8-6). It will be noted that there are 10 major subdivisions of the analyzed system as follows:

R_1 = structures
R_2 = miscellaneous electrical components
R_3 = excitation source system
R_4 = source shutter mechanism
R_5 = optical system

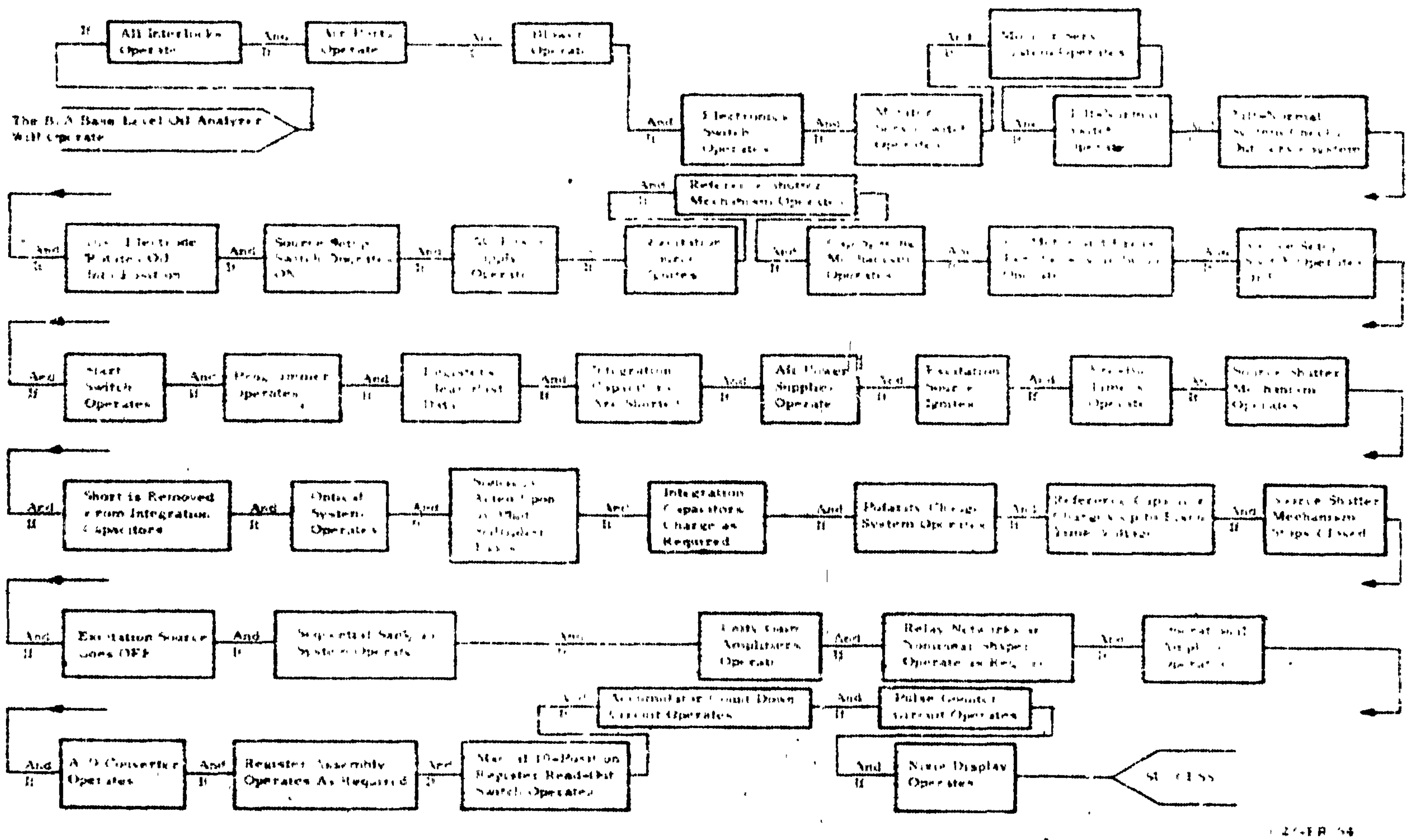

Figure 8-5. Reliability Functional Operation Diagram

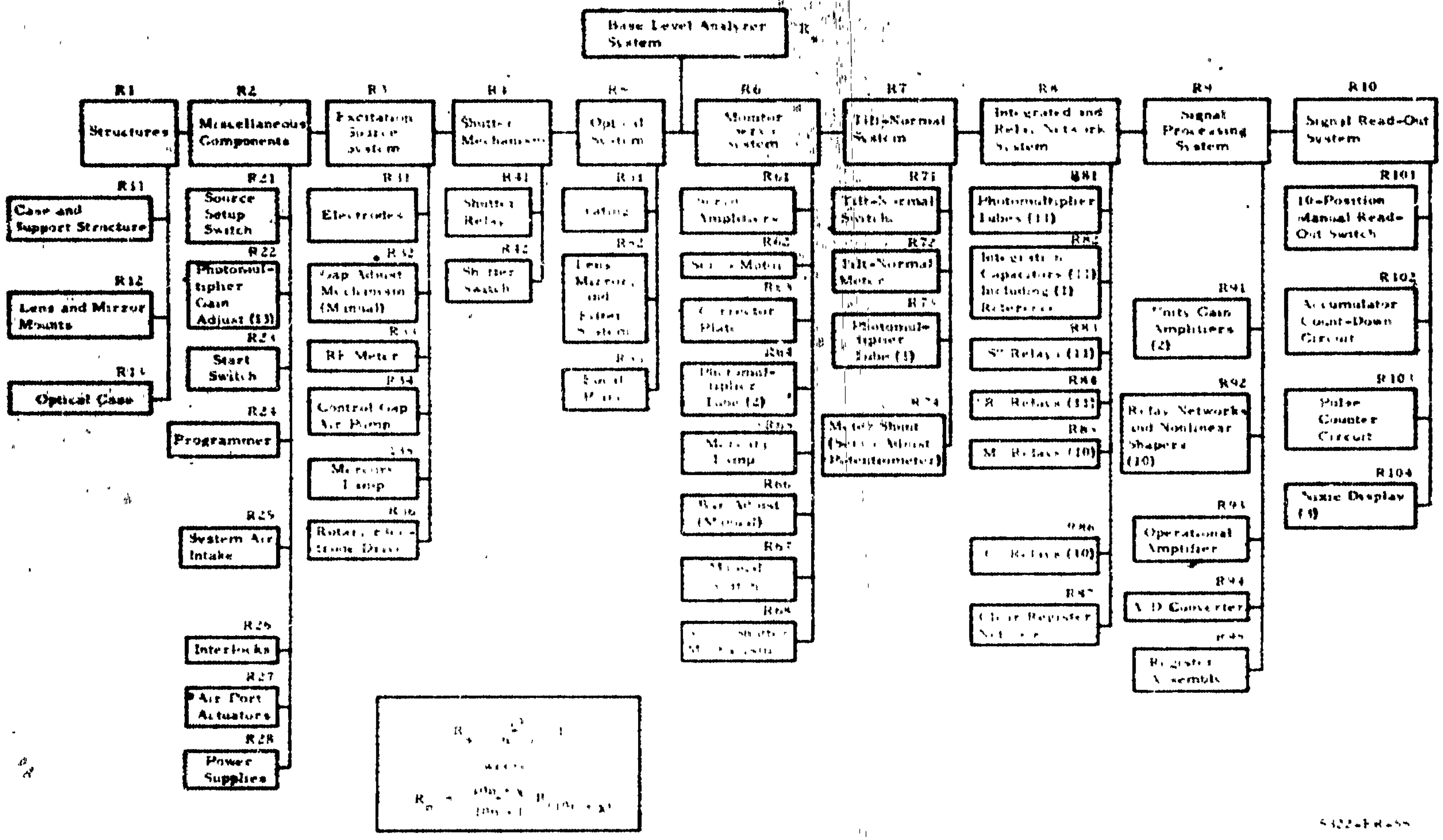

Figure 8-6. Reliability Block Diagram

R_6 = monitor servo system

R_7 = tilt-normal system

R_8 = signal receiving system

R_9 = signal processing systems

R_{10} = signal readout system

The following analysis takes each of the above major subdivisions specified together with their associated subassemblies and fully outlines the position taken relative to each failure rate assignment.

8.2.3.4 Subsystem Analysis -- In paragraphs 8.2.3.4.1 through 8.2.3.4.10 and tables 8-1 through 8-6, all subassemblies are noted for the sake of continuity. However, when a particular subassembly and its operation is a function of the number of analyses made per hour, the failure rate is not stated. Paragraph 8.2.3.4.11 and table 8-7 contain all failure rate assignments as a function of analyses made per hour.

8.2.3.4.1 Structures -- Structures used in the Base Level Analyzer design include the following:

R_{11} = case and support structure

R_{12} = exit/entrance slits, lens and mirror mounts

R_{13} = optical encasement

It is assumed that all structures reflect a mature design with the incorporation of proper safety factors as determined by structural analyses. Therefore, all structures are defined as being represented by a rectangular failure density function, and the apportioned reliability value is assumed to be 1.00, or

$$\lambda_{11} = \lambda_{12} = \lambda_{13} = \lambda_1 = 0$$

8.2.3.4.2 Miscellaneous Electrical Components -- There are eight subgroups under miscellaneous electrical components, R_2 as follows:

R_{21} = source setup switch
R_{22} = photomultiplier gain adjust
R_{23} = start switch
R_{24} = programmer
R_{25} = system air intake
R_{26} = interlocks
R_{27} = air port actuators
R_{28} = power supplies

In accordance with table 8-1 for that part of the total failure rate, λ_2, which is not effected by the number of analyses per hour, is as follows:

$$\lambda_2 = 110,380 \times 10^{-9}$$

8.2.3.4.3 Excitation Source System -- There are six subgroups under excitation source system, R_3 as follows:

R_{31} = electrodes
R_{32} = gap adjustment mechanism
R_{33} = RF meter
R_{34} = control gap air pump
R_{35} = mercury lamp
R_{36} = rotary electrode drive

Since the analytical electrodes are replaced every run and the control gap adjustment mechanism is manually operated, it is assumed that R_{31} and R_{32} can be defined as a rectangular failure density function, and the apportioned reliability value is assumed to be 1.00 or $\lambda_{31} = \lambda_{32} = 0$.
Note: See paragraph 8.2.3.4.6 for a full treatment of the mercury lamp.

Table 8-1

Reliability Data Sheet. Miscellaneous Electrical Components, R_2

R No.	Component	Description	Qty	Supplier	Vendor Specification	MIL Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{9}$
21	Switch	Source Setup	1	Micro-Switch	Series 102PB1-T	MIL-S-6743, 4	30%	0 to 70°C	Micro-Switch	867
22	Photomultiplier Gain Adjust Potentiometer	Potentiometer	11			MIL-R-11	50%	0 to 70°C	MIL HDBK 217	800
23	Switch	Start	1	Micro-Switch	Series 102PB1-T	MIL-S-6743, 4	50%	0 to 70°C	Micro-Switch	See Table 8-7
24	Programmer	Logic Module	1	Packard Bell	TF-200	MIL-E-5400		0 to 70°C	Packard Bell	
		Logic Module	1	Packard Bell	TO 200			0 to 70°C	Packard Bell	
		Logic Module	2	Packard Bell	DG-200	MIL-E-16400		0 to 70°C	Packard Bell	See Table 8--
		Logic Module	2	Packard Bell	DD 200	MIL-E-5272		0 to 70°C	Packard Bell	
		Program Timer	4	Baird Atomic		MIL-E-5272		0 to 70°C	MIL HDBK 217	
25	System Air Intake	Blower	1	Rotron Mfg	Model D Type KS-4502 Motor Series 413AS	MIL-E-5272*		0 to 70°C	Rotron Mfg	10,000
26	Interlocks	Reset Door Type	10	Micro-Switch	MS 25253-4	MIL-S-6743	33%	0 to 70°C	Micro-Switch	1500
27	Airport-Actuators		1	Globe	Fractional Horsepower	MIL-E-5272*		0 to 70°C	Globe	3000
28	Power Supplies (a) Electronics Power Supplies	Power Supplies	2	Philbrick	SPR 30			0 to 70°C	Philbrick	12,000
		Power Supplies	1	Packard Bell	MPS 22			0 to 70°C	Packard Bell	5000
		Power Supplies	1	Burroughs	VC 28/200			0 to 70°C	Burroughs	5000
	(b) Photomultiplier Tube Power Supply	(1000v)	1	Grafix, Inc	HVS-1000/28	MIL-E-5400		0 to 70°C	Grafix, Inc.	1000
	(c) Relay Power Supply	28v	1	Elec. Research, Inc.	MS 284	MIL-E-5400		0 to 70°C	Electric Corporation of America	25,000
	(d) Nixie Power Supply		1	Baird Atomic				0 to 70°C	MIL HDBK 217	5000
	(e) High Voltage Power Supply									
	Line Filter	25a, 250v, 0-60cps/600v dc	1	Genistron	GF-5060-25D	MIL-F-1573	84%	0 to 70°C	Genistron	500
	Interlock Switch	Reset Door Type	2	Micro-Switch	MS-25253-4	MIL-S-6743	33%	0 to 70°C	Micro-Switch	1500
	Circuit Breaker	2pole, 240v ac, 25 amp	1	Heinemann	PAM-33MG	MIL-E-5272	80%	0 to 70°C	Heinemann	200
	Transformer	2-1/2 KVA	1			MIL-T-27A		0 to 70°C	MIL HDBK 217	308
	Voltage Regulator	115v 25a 40v/sec	1	General Radio	1570-AL515	MIL-E-4158		0 to 70°C	General Radio	31,000
	Contactor	3PST, 115, 60~, 50a	1	Cutler-Hammer	MS-24376-A2	MIL-R-6106C	67%	0 to 70°C	Cutler-Hammer	200
	HV Transformer	115/12000 115 KVA	1			MIL-T-27A		0 to 70°C	MIL HDBK 217	300
	Capacitor	500µµfd 20 KV	3	Aerovox, Hi-Q	HV-500AA 20	MIL-C-11015	84%	0 to 70°C	MIL HDBK 217	450
	Capacitor	4000µµfd 30 KV	1	Aerovox, Hi-Q	HV-4000AA 30	MIL-C-11015	85%	0 to 70°C	MIL HDBK 217	140
	Resistor	5k 210 watt	1	Ohmite	RW47V502	MIL-R-26C	72%	0 to 70°C	MIL HDBK 217	50
	Resistor	1 meg. 20 KV 10 watt	1	IRC	MVK-15		50%	0 to 70°C	IRC	70
	Inductance	350µh	1	Barker & Williamson	40695	MIL-C-15305	50%	0 to 70°C	MIL HDBK 217	300
	Contactor	SPST 28v dc 50A	1	Cutler-Hammer	MS-24181-1	MIL-R-6106B	67%		Cutler-Hammer	200

$\lambda_2 = 119,300 \times 10^{-9}$

*Component not qualified but is built in accordance to the MIL Specification as noted.

In accordance with table 8-2 the total failure rate for that part of λ_3, which is not effected by the number of analyses per hour, is as follows:

$$\lambda_3 = 0 \times 10^{-9}$$

8.2.3.4.4 <u>Shutter Mechanism</u> -- There are two subgroups under the shutter mechanism, R_4, as follows:

R_{41} = shutter relay
R_{42} = shutter switch

Since both R_{41} and R_{42} are a function of the number of analyses made per hour, the failure rate, λ_4, which is not effected by the number of analyses made per hour, is as follows:

$$\lambda_4 = 0 \times 10^{-9}$$

8.2.3.4.5 <u>Optical System</u> -- There are three subgroups under the optical system, R_5, as follows:

R_{51} = grating
R_{52} = lens, mirror, and filter systems
R_{53} = focal plane

Since the optical elements will be structurally sound and the transmission and reflectance characteristics are not expected to degrade over the 3000-hour operational period, a rectangular failure density function is assumed and the apportioned reliability values are assumed to be 1.00 for each of the subgroups. Therefore,

$$\lambda_5 = \lambda_{51} = \lambda_{52} = \lambda_{53} = 0$$

Table 8-2
Reliability Data Sheet, Excitation Source System

R No	Component	Description	Qty	Supplier	Vendor Specification	Mil Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$
33	RF Meter		1	Weston	[illegible] *	Mil M 10304	100%	0 to 70°C	Weston	See Table 8-[illegible]
34	Auxiliary Gap Blower	Pump and Blower *	[illegible]				[illegible]	[illegible]	assumed	See Table 8
35	Mercury Lamp	Mercury Vapor	1	Westinghouse	[illegible]	none	100%	[illegible]	Westinghouse	See Table 8-[illegible]
36	Rotary Electrode Drive		1	A. W. Haydon	22100 Series	MIL F [illegible]	[illegible]	[illegible]	A. W. Haydon	See Table [illegible]

$\lambda_{(}$ [illegible] $\times 10^{-9}$

*Component not qualified but is built in accordance to the Mil Specification as noted

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Table 8-3
Reliability Data Sheet, Monitor Servo System R_6

R No	Component	Description	Qty	Supplier	Vendor Specification	Mil Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$
41	Amplifier	Servo Amplifier	1	Kearfott	Kearfott Special	Mil E 5400		[illegible]	Kearfott	5000
61a	Amplifier	Servo Amplifier	1	Baird Atomic				[illegible]	MIL HDBK 21	5000
62	Motor	Servo Motor	1	Kearfott	Kearfott Special	MIL-F [illegible]		[illegible]	Kearfott	See Table 8-[illegible]
64	Photomultiplier Tube	Photomultiplier Tube	2	RCA	1P21	none		[illegible]	RCA	10000
64a	Photomultiplier Tube Receptacle		2	Baird Atomic	B. A. [illegible]			[illegible]	MIL HDBK 21	1900
65	Mercury Lamp	Mercury Vapor	1	Westinghouse	[illegible]	none		[illegible]	Westinghouse	3 [illegible]
66	Manual Switch	Push Button	1	Micro-Switch	1021PB1-1	MIL [illegible]		[illegible]	Micro-Switch	See Table 8-7
68	Servo Shutter Mechanism		1	same as R_4	Shutter mechanism					See Table 5

λ_6 59,300 $\times 10^{-9}$

*Components not qualified but are built in accordance to the Mil Specification as noted

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Baird Atomic

8.2.3.4.6 Monitor Servo System -- There are eight subgroups under the monitor servo system, R_6, as follows:

R_{61} = servo amplifiers
R_{62} = servo motor
R_{63} = corrector plate
R_{64} = photomultiplier tubes and recepticles
R_{65} = mercury lamp
R_{66} = bar adjust (manual)
R_{67} = manual ON-OFF switch
R_{68} = servo shutter mechanism

It is assumed that all structure mechanisms reflect a mature design with the incorporation of proper safety factors as determined by a structural analysis. Therefore, all structures are defined as being represented by a rectangular failure density function, and the apportioned reliability value for R_{63} and $R_{66} = 1$, or $\lambda_{63} = \lambda_{66} = 0$.

In accordance with table 8-3 (page 8-19), the total failure rate for that part of the monitor servo system, λ_6, which is not effected by the number of analyses per hour, is as follows:

$$\lambda_6 = 59,100 \times 10^{-9}$$

The mercury lamps (one in the high voltage supply near the auxiliary gap and the other the reference mercury line source in the monitor servo system) are purchased from the commercial division of Westinghouse as their type 794H.

Westinghouse has supplied Baird-Atomic with their best engineering estimate of lamp life characteristics as follows:

Random Failure Rate	80 percent probability that any lamp will attain a life of 6000 hours

Mean Life — 6000 hours with a standard deviation of approximately 1400 hours

The random failure rate is computed as follows:

$$0.80 = e^{-6000\,\lambda_{random}}$$

where

$$\lambda_{random} \cong 37,200 \times 10^{-9}$$

Assuming four standard deviations from the mean, the wearout probability at (6000 - 4 x 1400) = 400 hours is 0.000032 or the probability of no wearout is 0.999968. This probability of no wearout when considered at a time of 400 hours converts to a wearout, λ_ω, of zero.

Therefore, the failure rate for the mercury lamp is 37,200 x 10^{-9} when the lamp is replaced every 400 hours. This will be considered a basic maintainability requirement.

8.2.3.4.7 Tilt-Normal System -- There are four subgroups under the tilt-normal system, R_7, as follows:

R_{71} = tilt-normal switch
R_{72} = tilt-normal meter
R_{73} = photomultiplier tube and recepticle
R_{74} = meter shunt

The tilt-normal switch failure rate is identical with item R_{21} failure rate. Therefore, from table 8-1,

$$\lambda_{71} = 860 \times 10^{-9}$$

The tilt-normal meter failure rate is identical with item R_{33} failure rate but with a duty cycle of 1/120. Therefore, from table 8-2,

$$\lambda_{72} = \frac{1}{120} \times 5100 \times 10^{-9}$$

or

$$\lambda_{72} = 40 \times 10^{-9}$$

The photomultiplier tube and recepticle failure rate is equal to one-half of item R_{64} failure rate. Therefore, from table 8-3,

$$\lambda_{73} = 5950 \times 10^{-9}$$

The meter shunt is a standard potentiometer and MIL-HDBK-217 defines such as follows:

$$\lambda_{74} = \frac{1}{120} \times 300 \times 10^{-9}$$

or

$$\lambda_{74} \cong 0$$

The failure rate for that part of the tilt-normal system λ_7 which is not effected by the number of analyses made per hour is as follows:

$$\lambda_7 = \lambda_{71} + \lambda_{72} + \lambda_{73} + \lambda_{74}$$

or

$$\lambda_7 = 6850 \times 10^{-9}$$

8.2.3.4.8 Integrated relay network -- There are seven subgroups under integrated relay network, R_8, as follows:

R_{81} = photomultiplier tubes and recepticles
R_{82} = integration capacitors
R_{83} = "S" relays
R_{84} = "R" relays
R_{85} = "M" relays
R_{86} = "C" relays
R_{87} = clear register network

In accordance with table 8-4, the total failure rate for that part of λ_8, which is not effected by the number of analyses made per hour, is as follows:

$$\lambda_8 = 65,450 \times 10^{-9}$$

8.2.3.4.9 Signal Processing System -- There are five subgroups under signal processing system, R_9, as follows:

R_{91} = unity gain amplifiers
R_{92} = relay network and nonlinear shapers
R_{93} = operational amplifier
R_{94} = analog-to-digital converter
R_{95} = register assembly

In accordance with table 8-5 the total failure rate of that part of λ_9, which is not effected by the number of analyses per hour, is as follows:

$$\lambda_9 = 71,430 \times 10^{-9}$$

8.2.3.4.10 Signal Readout System -- There are four subgroups under signal readout system, R_{10}, as follows:

R_{101} = 10-position manual readout switch
R_{102} = accumulator count-down circuit

Table 8-4
Reliability Data Sheet Integrated and Relay Network

R No.	Component	Description	Qty	Supplier	Vendor Specification	MIL Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$
81	Photomultiplier Tube	Photomultiplier & Receptacle	11	RCA	1P21	none		0 to 70 C	RCA	15,450
82	Integration Capacitor	Metalized Capacitor	11	Gudeman Co.	MRG-[illegible]	MIL-C-[illegible]	10%	0 to 70 C	Gudeman Co.	See Table 8
83	"S" Relays		11	Leach	M 250	MIL-R-5757/9A		0 to 70 C	Leach	See Table 8
84	"R" Relays		11	Leach	M 250	MIL-R-5757/9A		0 to 70 C	Leach	See Table 8
85	"M" Relays		10	Leach	M 250	MIL-R-5757/9A		0 to 70 C	Leach	See Table 8
86	"C" Relays		10	Leach	M 250	MIL-R-5757/9A		0 to 70 C	Leach	See Table 8
87	Clear Register	Switch	1	Micro Switch	[illegible]	MIL-S-[illegible]	[illegible]	0 to 70 C	Micro Switch	See Table 8

λ_R = 65,450 x 10^{-9}

[illegible]

Table 8-5

Reliability Data Sheet, Signal Processing System, R_9

R No.	Component	Description	Qty	Supplier	Vendor Specification	MIL Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$
91	Unity Gain	Amplifier	[illegible]	Philbrick	[illegible]	MIL F 5400*		0 to 70 C	Philbrick	4,900
92	Relay Network and Nonlinear Shapers		(35)							
	Diodes		70			to be specified	50%	0 to 70 C	MIL HDBK 217	
	Resistors		50			to be specified	50%	0 to 70 C	MIL HDBK 217	
	Potentiometers*		40			to be specified	50%	0 to 40 C	MIL HDBK 217	See Table 8-
	Relays, "C"		18	Leach	M [illegible]	MIL-R-5757/9A		0 to 70 C	Leach	
93	Operational Amplifier		[illegible]	Philbrick	5305*	MIL F 5400*		0 to 90 C	Philbrick	5,430
94	A/D Converter	Modules	1	Intercontinental Instrument	SCI 103	MIL-E-5400		0 to 70 C	Intercontinental Instrument	
		Modules	1	Intercontinental Instrument	SCP 21	MIL-E-5400		0 to 70 C	Intercontinental Instrument	
		Modules	1	Intercontinental Instrument	STN, 805	MIL E-5400*		0 to 70 C	Intercontinental Instrument	See Table 8-7
		Modules	[illegible]	Intercontinental Instrument	D/A Converter	MIL E 5400		0 to 70 C	Intercontinental Instrument	
		Modules	1	Intercontinental Instrument	Comparator	MIL E 5400		0 to 70 C	Intercontinental Instrument	
		Modules	1	Intercontinental Instrument	[illegible] Supply	MIL E-5400*		0 to 70 C	Intercontinental Instrument	
95	Register Assembly	Modules	26	Packard Bell	18-100	See Table 8-1		0 to 70 C	Packard Bell	6,100

*Component not qualified but is built in accordance with the MIL Specification as noted.

$\lambda_9 = 71,430 \times 10^{-9}$

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Table 8-6

Reliability Data Sheet, Signal Readout System, R_{10}

R No.	Component	Description	Qty	Supplier	Vendor Specification	MIL Specification Reference	Derating Factor	Ambient Temperature C	Failure Rate Reference	$\lambda \times 10^{-9}$
101	Switches	Read-out Manual	10	Micro Switch	102PB1-3	MIL-S-6743, 4	1/33, 6	0 to 70°C	Micro-Switch	See Table 8-7
102	Accumulator	Count-Down Circuit								
103	Pulse Counter Circuit	Logic Modules	25	Packard Bell	DG 200			0 to 70°C	Packard Bell	
		Logic Modules	24	Packard Bell	11-200	See Figure 8-6		0 to 70°C	Packard Bell	See Table 8-7
		Logic Modules	1	Packard Bell	SCG-200			0 to 70°C	Packard Bell	
104	Nixie Display Assembly	Nixie Tubes	13	Burroughs	BF/50-7-18	none		0 to 70°C	Burroughs	See Table 8-7
		Counters	3	Burroughs	BID-A001A	none		0 to 70°C	Burroughs	

$\lambda_{10} = 0 \times 10^{-9}$

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R_{103} = pulse counter circuit

R_{104} = nixie display assembly

In accordance with table 8-6 (page 8-25), and since all four items are effected by the number of analyses made per hour, the failure rate, λ_{10}, which is uneffected by the number of analyses made per hour is as follows:

$$\lambda_{10} = 0 \times 10^{-9}$$

8.2.3.4.11 <u>Failure Rates Effected by Number of Analyses per Hour</u> -- Table 8-7 presents a complete analysis of those items effected by the number of analyses made per hour on the Analyzer.

8.2.4 <u>Conclusions</u>

8.2.4.1 <u>Predicted MTBF</u> -- A summary of the predicted failure rates is in accordance with table 8-8. The resulting system failure rate is as follows:

System failure rate, $\lambda_s = [313,210 + 15,084\ X] \times 10^{-9}$ failure per hour

where

X = number of analyses made per hour

$$\text{Predicted MTBF} = \frac{1}{\lambda_s} = \left[\frac{1}{313,210 + 15,084\ X} \right] \times 10^{9}$$

8.2.4.2 <u>Predicted Reliability</u> -- Using the exponential,

$$R_s = e^{-\lambda_s t}$$

Table 8-7

Reliability Data Sheet, All Assemblies Effected by Number of Analyses Per Hour

R No.	Description	Operating Data and Supplier Reference Figure Number	Qty Per Assy	Effected Failure Rate: Failures/Hr. x 10^{-9}	Effected Failure Rate: Failures/Operation x 10^{-9}	Operating Time Per Analysis (Hrs)	Number of Operations Per Analysis	Failures Per Analysis x 10^{-9}	
R23	Start Switch	Table 8-1	1		(1) x 102.6 = 102.6				
R24	Programmer						1	102.6	
	Logic Module	Table 8-1	3	(3) x 2353 = 7060					
	Logic Module	Table 8-1	1	(1) x 2000 = 2000		28/3600 = 0.00778		54.9	
	Logic Module	Table 8-1	2	(2) x 300 = 600		28/3600 = 0.00778		15.6	
	Logic Module	Table 8-1	2	(2) x 2000 = 4000		28/3600 = 0.00778		4.7	253.4
	Program Timer	Table 8-1	4	(4) x 1100 = 4400		28/3600 = 0.00778		31.1	
R26	Interlock (Electrode Door)	Table 8-1	1			28/3600 = 0.00778		34.2	
R33	RF Meter	Table 8-2	1		(1) x 10.3 = 10.3		1	10.3	
R34	Control Gap Air Pump	Table 8-2	1	(1) x 10,500 = 10,500		0.00778		81.6	
R35	Mercury Lamp (Source)	Table 8-2	1	(1) x 10,000 = 10,000		30/3600 = 0.00833		83.3	
R36	Rotary Electrode Drive	Table 8-2	1	(1) x 37,200 = 37,200		0.00778		289.4	513.8
R41	Shutter Relay		1	(1) x 7650 = 7650		0.00778		59.5	
R42	Shutter Switch	Ledex BD-3E-R	1		(1) x 66.4 = 66.4		10	664.0	
R62	Servo Monitor Motor	Table 8-3	1	(1) x 8000 = 8000	(1) x 20.54 = 20.54		10	205.4	869.4
R67	ON-OFF (Manual Switch)	Table 8-3	1			178.4 (worst case)		952.4	
R68	Servo Shutter Mechanism	Table 8-3	1		(1) x 102.6 = 102.6		1	102.6	1490.0
R82	Integration Capacitors	Table 8-4	11	(11) x 10 = 110	(1) x 435.0 = 435.0		1	435.0	
R83	"S" Relays	Table 8-4	11			20/3600 = 0.00555		0.0	
R84	"R" Relays	Table 8-4	11		(11) x 66.4 = 730.4		1	730.4	
R85	"M" Relays	Table 8-4	10		(11) x 66.4 = 730.4		10	7304.0	9465.0
R86	"C" Relays	Table 8-4	10		(10) x 66.4 = 664.0		1	664.0	
R87	Clear Register Switch	Table 8-4	1		(10) x 66.4 = 664.0		1	664.0	
R92	Relay Network and Nonlinear Shapers	Table 8-5			(1) x 102.6 = 102.6		1	102.6	
	Diodes	Table 8-5	20	(20) x 100 = 2000					
	Resistors	Table 8-5	50	(50) x 70 = 3500		0.1/3600 = 0.000028		0.056	
	Potentiometers	Table 8-5	60	(60) x 300 = 18,000		0.000028		0.098	
	"C" Relays	Table 8-5	14			0.000028		0.504	
R94	A/D Converter	Table 8-5			(14) x 66.4 = 929.6		1	929.6	
	Modules	Table 8-5	3	(3) x 5900 = 17,700					
	Modules	Table 8-5	1	(1) x 8000 = 8,000		9/3600 = 0.0025		44.25	
	Modules	Table 8-5	1	(1) x 4000 = 4,000		0.0025		20.00	1071.5
	Modules	Table 8-5	2	(2) x 6700 = 13,400		0.0025		10.00	
	Modules	Table 8-5	1	(1) x 6700 = 6,700		0.0025		33.50	
	Modules	Table 8-5	1	(1) x 6700 = 6,700		0.0025		16.75	
R101	10-Position Readout Switch	Table 8-6	10			0.0025		16.75	
R102	Accumulator Countdown Circuit	Table 8-6			(10) x 102.6 = 1026.0		1	1026.0	
R103	Pulse Counter Circuit	Table 8-6							
	Logic Modules	Table 8-6	13	(13) x 300 = 3900					
	Logic Modules	Table 8-6	4	(4) x 2350 = 9400		30/3600 = 0.00833		32.49	
	Logic Modules	Table 8-6	1	(1) x 2000 = 2000		0.00833		78.30	
R104	Nixie Display Assembly	Table 8-6				0.00833		16.66	1420.8
	Nixie Tubes	Table 8-6	3	(3) x 2700 = 8100					
	Counters	Table 8-6	3	(3) x 8000 = 24,000		0.00833		67.47	
						0.00833		199.92	

Σ Failures/Analysis = 15,084 x 10^{-9}

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Table 8-8
Failure Rate Summation

R No.	Subgroup Identification	Failure Rates Unaffected by Number of Analyses/Hr		Failure Rates Affected by Number of Analyses/Hr	
		Reference	$\lambda_u \times 10^{-9}$	$\lambda_a X \times 10^{-9}$	λ_a Reference
R1	Structures	Para 8.2.3.4.1	0	0	Para 8.2.3.4.1
R2	Miscellaneous electronic components	Table 8-1	110,380	253.4X	Table 8-7
R3	Excitation source system	Table 8-2	0	513.8X	Table 8-7
R4	Shutter mechanism	Para 8.2.3.4.4	0	869.4X	Table 8-7
R5	Optical system	Para 8.2.3.4.5	0	0	Para 8.2.3.4.5
R6	Monitor servo system	Table 8-3	59,100	1,490.0X	Table 8-7
R7	Tilt-normal system	Para 8.2.3.4.7	6,850	0	Table 8-7
R8	Signal receiving system	Table 8-4	65,450	9,465.0X	Table 8-7
R9	Signal processing system	Table 8-5	71,430	1,071.5X	Table 8-7
R10	Signal readout system	Table 8-6	0	1,420.8X	Table 8-7
		Totals	$\Sigma\lambda_u = 313,210 \times 10^{-9}$	$\Sigma\lambda_a X = 15,084X \times 10^{-9}$	

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where

λ_u = failure rate of those systems UNAFFECTED by the number of analyses per hour, failures per hour

X = number of analyses made per hour

λ_a = failures per analysis

$\lambda_a X$ = failure rate of those systems AFFECTED by the number of analyses per hour, failures per hour

System failure rate $\lambda_s = \Sigma\lambda_u + \Sigma\lambda_a X$ or $\lambda_s = [313,210 + 15,084X] \times 10^{-9}$ failures per hour

where

R_s = system reliability

λ_s = system failure rate = $[313,210 + 15,084\ X] \times 10^{-9}$ failures per hour

t = operational use period = 10 minutes

then

$$R_s = \exp\left[-\frac{1}{6}(313,210 + 15,084\ X) \times 10^{-9}\right]$$

Figure 8-4 is a plot of both MTBF and R_s as a function of X, where X is the number of analyses made per hour.

If for a one-man operation it is assumed that each analysis takes five minutes and the operator exhibits a 70 percent efficiency, then the number of analyses made per hour will be as follows:

$$\frac{1 \text{ analysis}}{5 \text{ minutes}} \times \frac{60 \text{ minutes}}{\text{hour}} \times 0.70 = 8.4 \text{ analyses per hour}$$

On this basis, that is, X = 8.4 analyses per hour,

R_s = 0.999928

MTBF = 2273 hours

at 8.4 analyses per hour

If the Analyzer is operated at 60 analyses per hour,

R_s = 0.999799

MTBF = 820.9 hours

at 60 analyses per hour

Relative to the predicted design MTBF, the Analyzer design exceeds the requirement of 150 hours by a factor ranging from

Minimum Excess = 820.9/150 ≅ 5.5

Maximum Excess = 2273/150 ≅ 15.0

8.2.4.3 Parallel Channel Considerations -- The purpose of this section is to determine the magnitude of increased system reliability if some failures are permissable in the ten X-channels.

There will be three cases considered:

a. Case I -- The operation of three specific X-channels will be assumed to be mandatory. This investigation will determine what increase in reliability will be attained assuming one up to seven failures are permitted in the balance of seven X-channels.

b. Case II -- The operation of four specific X-channels will be assumed to be mandatory. This investigation will determine what increase in reliability will be attained assuming one up to six failures are permitted in the balance of six X-channels.

c. Case III -- The operation of five specific X-channels will be assumed to be mandatory. This investigation will determine what increase in reliability will be attained assuming one up to five failures are permitted in the balance of five X-channels.

Those portions of the system that are included in a parallel channel are in accordance with table 8-9.

From paragraph 8.2.4.1, the system failure rate (with no permissable failures) is defined as follows:

$$\lambda_{system} = [313,210 + 15,084\ X] \times 10^{-9}$$

Table 8-9

X-Channel Breakdown

Item	Channel Component and Breakdown	$\lambda_u \times 10^{-9}$	$\lambda_a X \times 10^{-9}$	Table Reference
1 Photomultiplier Tube 1 Photomultiplier Receptacle		5950		8-4
Relay Network and Integrator	1 "R" Relay 1 "S" Relay 1 "M" Relay 1 "C" Relay		66.4X 66.4X 66.4X 66.4X	8-7
Relay Network and Nonlinear Shapers	1.4 "C" Relays 2 Diodes 5 Resistors 6 Potentiometers		93.0X 0.006X 0.010X 0.050X	8-7
Register	2 Modules	4700		8-5
Photomultiplier Gain Adjust		800		8-1
	Totals	$\sum \lambda_u = 11,450 \times 10^{-9}$	$\sum \lambda_a X = 358.7X \times 10^{-9}$	

The failure rate for one of the ten channels under parallel circuitry consideration is as follows:

$$\lambda_1 = \left[11,450 + 358.7X\right] \times 10^{-9}$$

where X = number of analyses made per hour.

From table 8-9, the failure rate for one channel under the parallel circuitry consideration is

$$\lambda_1 = [11,450 + 358.7 X] \times 10^{-9}$$

and for the ten channels, the total failure rate is

$$10\,\lambda_1 = [114,500 + 3587 X] \times 10^{-9}$$

If the system that is not included in the parallel circuitry is defined as the series portion, R_{series}, then R_{series} is defined as follows:

$$R_{series} = e^{-\lambda_{series} t}$$

where

t = 10 minutes

$$\lambda_{series} = \lambda_{system} - 10\,\lambda_1 = [313,210 + 15,084 X] \times 10^{-9} - [114,500 + 3587 X] \times 10^{-9}$$

or

$$\lambda_{series} = [198,710 + 11,497 X] \times 10^{-9}$$

For system reliability, when considered from the parallel circuitry point of view,

$$R_{system} = R_{parallel} \times R_{series}$$

where

$$R_{series} = e^{-[198,710 + 11,497 X]\, t \times 10^{-9}}$$

$R_{parallel}$ is determined relative to the particular case involved.

a. Case I -- Case I requires that three specific X-channels of the ten available operate. Therefore, $R_{parallel}$ is that probability of success of the seven remaining channels operating when one or more these seven channels may fail.

$$R_{parallel} = \sum_{k=0}^{r} \binom{n}{k} (R_p)^{n-k} (1 - R_p)^k$$

where

n = seven channels

r = maximum number of channel failures permitted

k = failures considered, ranging from $0 \rightarrow r$

R_p = the probability of successful operation of one channel = $e^{-\lambda_1 t}$

or

$$R_p = e^{-\frac{1}{6} [11,450 + 358.7 X] \times 10^{-9}}$$

If we consider 60 analyses per hour as the worst case,

$$R_p = e^{-\frac{1}{6} [11,450 + 358.7 \times 60] \times 10^{-9}} = e^{-5495 \times 10^{-9}}$$

or

$$R_p = 0.99999455$$

Since R_p = 0.99999455 is so close to 1.0, even one permitted failure will make $R_{parallel}$ be equivalent to 1.00 by observation.

Therefore, for Case I

$$R_{system} = R_{series} \times R_{3\ channels}$$

$$= e^{-[198,710 + 11,497\ X]\frac{1}{6} \times 10^{-9}} \times e^{-3\ [11,450 + 358.7\ X]\frac{1}{6} \times 10^{-9}}$$

or

$$R_{system} = e^{-[38,843 + 2,096\ X] \times 10^{-9}}$$

and

$$MTBF_{system} = \frac{1}{[233,060 + 12,573\ X] \times 10^{-9}}$$

b. Case II -- Case II requires that four specific X-channels of the ten available operate. Using the same arguments as in Case I, $R_p = 0.99999455$ and therefore $R_{parallel} = 1.0$ when at least one failure is permitted.

$$R_{system} = R_{series} \times R_{4\ channels}$$

$$= e^{-[198,710 + 11,497\ X]\frac{1}{6} \times 10^{-9}} \times e^{-4\ [11,450 + 358.7\ X]\frac{1}{6} \times 10^{-9}}$$

or

$$R_{system} = e^{-[40,752 + 2,155\ X] \times 10^{-9}}$$

and

$$MTBF_{system} = \frac{1}{[244,510 + 12,932\ X] \times 10^{-9}}$$

a. Case III -- Case III requires that five specific X-channels of the ten available operate. Again using the same arguments of Case I.

$$R_{system} = R_{series} \times R_{5\ channels}$$

$$= e^{-[198,710 + 11,497\ X] \frac{1}{6} \times 10^{-9}} \times e^{-5[11,450 + 358.7\ X] \frac{1}{6} \times 10^{-9}}$$

or

$$R_{system} = e^{-[42,660 + 2,215\ X] \times 10^{-9}}$$

and

$$MTBF_{system} = \frac{1}{[255,960 + 13,291\ X] \times 10^{-9}}$$

Looking at the effects of Cases I, II, and III, with respect to the extremes of X, (the number of analyses per hour), the system Reliability and system MTBF are in accordance with table 8-10.

The minimum excess factor = 6.3 at 60 operations per hour

The maximum excess factor = 19.7 at 8.4 operations per hour

Therefore, the parallel circuitry approach will increase the MTBF of the analyzer as follows:

$$\frac{6.3 - 5.5}{5.5} = 14.5 \text{ percent minimum}$$

$$\frac{19.7 - 15}{15} = 31.3 \text{ percent maximum}$$

The minimum and maximum increase in MTBF is therefore, 114.5 and 131.3 percent respectively.

Table 8-10

Derivation of λ_s, System Failure Rate

Case		I	II	III
Number of X-Channels that must operate		3	4	5
Basic Reliability Equation		$e^{-\left[38,843 + 2,096X\right] \times 10^{-9}}$	$e^{-\left[40,752 + 2,155X\right] \times 10^{-9}}$	$e^{-\left[42,660 + 2,215X\right] \times 10^{-9}}$
System Reliability	X = 8.4	0.999944	0.999942	0.999939
	X = 60	0.999837	0.999832	0.999826
Basic MTBF Equation		$\frac{1}{\left[233,060 + 12,573X\right] \times 10^{-9}}$	$\frac{1}{\left[244,510 + 12,932X\right] \times 10^{-9}}$	$\frac{1}{\left[255,960 + 13,291X\right] \times 10^{-9}}$
System MTBF (hours)	X = 8.4	2953	2832	2720
	X = 60	1013	980	949
Factor of Improvement over 150 MTBF requirement	X = 8.4	19.7	18.9	18.1
	X = 60	6.7	6.5	6.3

9. MAINTAINABILITY PLAN

9.1 Basic Philosophy

The basic philosophy of the Baird-Atomic maintainability program is to introduce within the design frame work concepts and techniques that will ensure ease of maintenance and operation within the limitations specified by the procuring activity.

9.2 Maintainability Organization

The organization structure of maintainability, and its immediate access to top management, is in accordance with figure 9-1.

It will be noted that reliability, maintainability, and safety engineering come under one head. Baird-Atomic takes the position that because of the interrelationship of these three groups, combining them will unify their effort and best serve the customer.

9.3 General Maintainability Requirements

The Baird-Atomic Maintainability Program requirements are as specified in the following documents:

a. AFSC Manual 80-5 (Ground Equipment)

b. AFSC Manual 80-6 (Ground Support Equipment)

c. MIL-M-26512C, except that maintainability demonstration shall be in accordance with paragraph 40.1 1 of MIL-M-26512B

d. MIL-STD-803 (Human Engineering)

In general the Maintainability Program will consist of the following basic elements:

a. Operational and Support Concepts and Requirements

b. Design Assistance, Review, and Analysis Program

c. Milestone Identification and Schedule

d. Maintainability Controls

e. Maintainability Demonstration

f. Records

g. Reporting

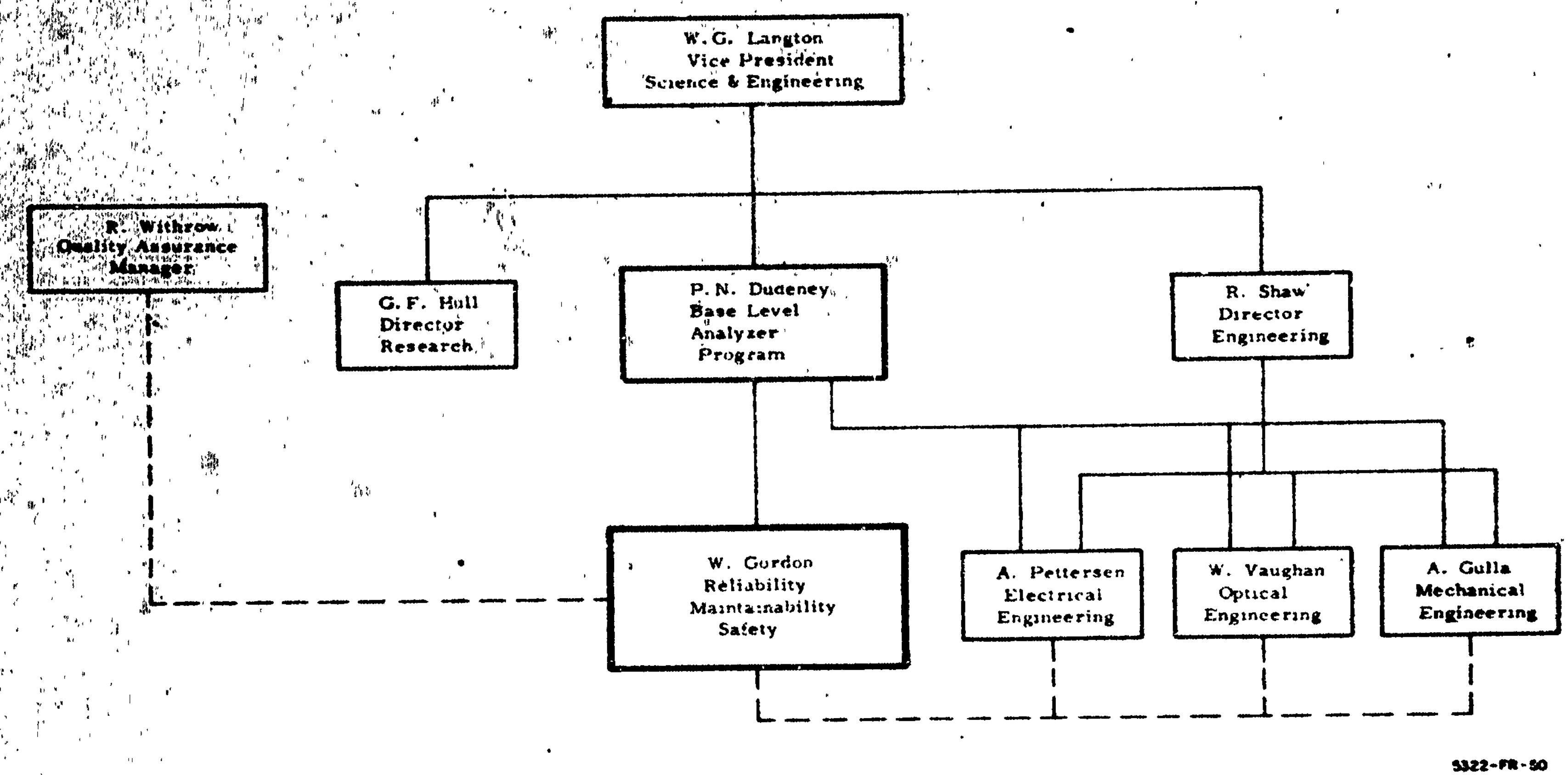

Figure 9-1. Organization Structure of Maintainability

9.4 Operational and Support Concepts and Requirements

Baird-Atomic maintainability shall be responsible for the review and delineation of the import of the referenced manuals and specifications relative to the maintainability requirements of the Base Level Analyzer design. Specific design guides shall be made known to design engineering and monitored as to effective usage.

It is understood that the maintenance manpower goal is 4 percent of the operating hours of the equipment with the minimum operating hour requirement of the equipment defined as 3000 hours.

9.5 Design Assistance, Review, and Analysis Program

9.5.1 Design Assistance

Maintainability shall assist design engineering by specifying design guides and monitoring their usage. The minimum design guide listing is as follows:

a. Every component or subassembly used in the proposed design shall, where possible, be MIL approved.

b. Every component or subassembly used in the proposed design shall, where possible, have a document of failure rate available to Baird-Atomic upon demand.

c. Every phase of the design shall be, where possible, in accordance with design and construction techniques as specified in MIL-T-21200D.

d. Each major portion of the equipment shall contain, where applicable, a suitable elapsed time indicator to provide appropriate data for maintenance records during the testing program.

e. Every failure in any type of development or final test shall be recorded including an analysis of cause, description of the defective part, and corrective action recommended.

f. Every major portion of the design shall be provided with test points in such a manner as to provide the means to locate a defective subassembly in the least possible time.

g. All parts and subassemblies shall be so arranged that they are easily accessible for testing and replacement.

h. Every consideration shall be given to keeping the cost of modules and subassemblies at a minimum to allow for the possibility of disposal at failure.

9.5.2 Design Review

The maintainability design review phase of the project will be in accordance with that specified in the Reliability Program Plan.

9.5.3 Maintainability Analysis

The maintainability analysis phase of the project will include the determination of the following:

a. Inherent mean and maximum downtime.

b. Inherent availability.

c. A schedule of all preventive maintenance tasks with an estimate of the time to accomplish such tasks computed on the basis of one man per task.

The basic work sheet used in accomplishing the maintainability analysis shall be in accordance with figure 9-2.

9.6 Milestone Identification and Schedule

The milestone identification and schedule shall be in accordance with that specified in figure 9-3.

9.7 Maintainability Controls

In order to effect control of maintainability principles in the design of the analyzer, the maintainability organization will participate in all of the design reviews as organized by design engineering, and will be on the distribution list for all design changes.

9.8 Maintainability Demonstration

Maintainability demonstration shall be in accordance with paragraph 40.1.1 of MIL-M-26512B.

Item	A	B	C				D	E
	Parts or Subassemblies	Failure Rate (Failures/Hour)	Estimate of Active Maintenance Time/Failure (Hours/Failure)				Duty Cycle	Maint nance Time Total (Hours)
			Loc. Time	Repair	Check	Total		
							Total:	

$E_n = B_n \times C_{tn} \times D_n$

Figure 9-2. Maintenance Estimate Format

Milestone Number	1	2	3	4	5
PERT Corresponding Event	System Layout Complete (Design Review)	Mid Design and Development	System Assembly Drawings Complete (Design Review)	Acceptance Tests Complete	Summary Report
Reliability and Maintainability Action	Initial Prediction	Updated Prediction No. 1	Updated Prediction No. 2	Demonstration Tests	Final Report

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Figure 9-3. Milestone Identification and Schedule

9.9 Records

The maintainability records to be established and maintained are as follows:

a. Description of Changes Caused by Maintainability Recommendations
b. Maintainability Design Recommendations Rejected or Trade-Offs
c. Design Review Results and Current Status
d. Progress and Deviation Reports
e. Supporting Documents
f. Documented Sign-Off of Design Specifications and Drawings

9.10 Reporting

Baird-Atomic Maintainability will submit a progress report each month that will be a part of the Contract Progress Report.

Each monthly report will contain a complete treatment of any trouble areas and emphasize corrective action required and/or completed.

10. SAFETY ENGINEERING PLAN

10.1 Basic Philosophy

The basic philosophy of the Base Level Analyzer Safety Engineering Program is to specify the requirements and establish the responsibility for achieving a comprehensive system safety effort. Safety engineering is considered a prime effort.

The system safety effort shall be integrated with system design, development, manufacture, test, checkout, installation and operation by the procuring agency.

Every effort shall be made to obtain the highest degree of inherent safety through the selection of appropriate design features, proven qualified components, and operating principles.

10.2 Safety Engineering Organization

The organization structure of safety engineering, and its immediate access to top management, is in accordance with figure 10-1.

It will be noted that safety, maintainability, and reliability engineering come under one head. Baird-Atomic takes the position that because of the interrelationship of these three groups, combining them will unify their effort and best serve the customer.

10.3 Safety Engineering Requirements

The Baird-Atomic Safety Engineering Program requirements are as specified in MIL-S-38130 (USAF), dated 30 September 1963.

In general, the Safety Engineering Program will consist of the following elements:

a. Subsystem Safety Analysis
b. System Safety Analysis
c. Safety Recommendations
d. Safety Procedures
e. Reporting

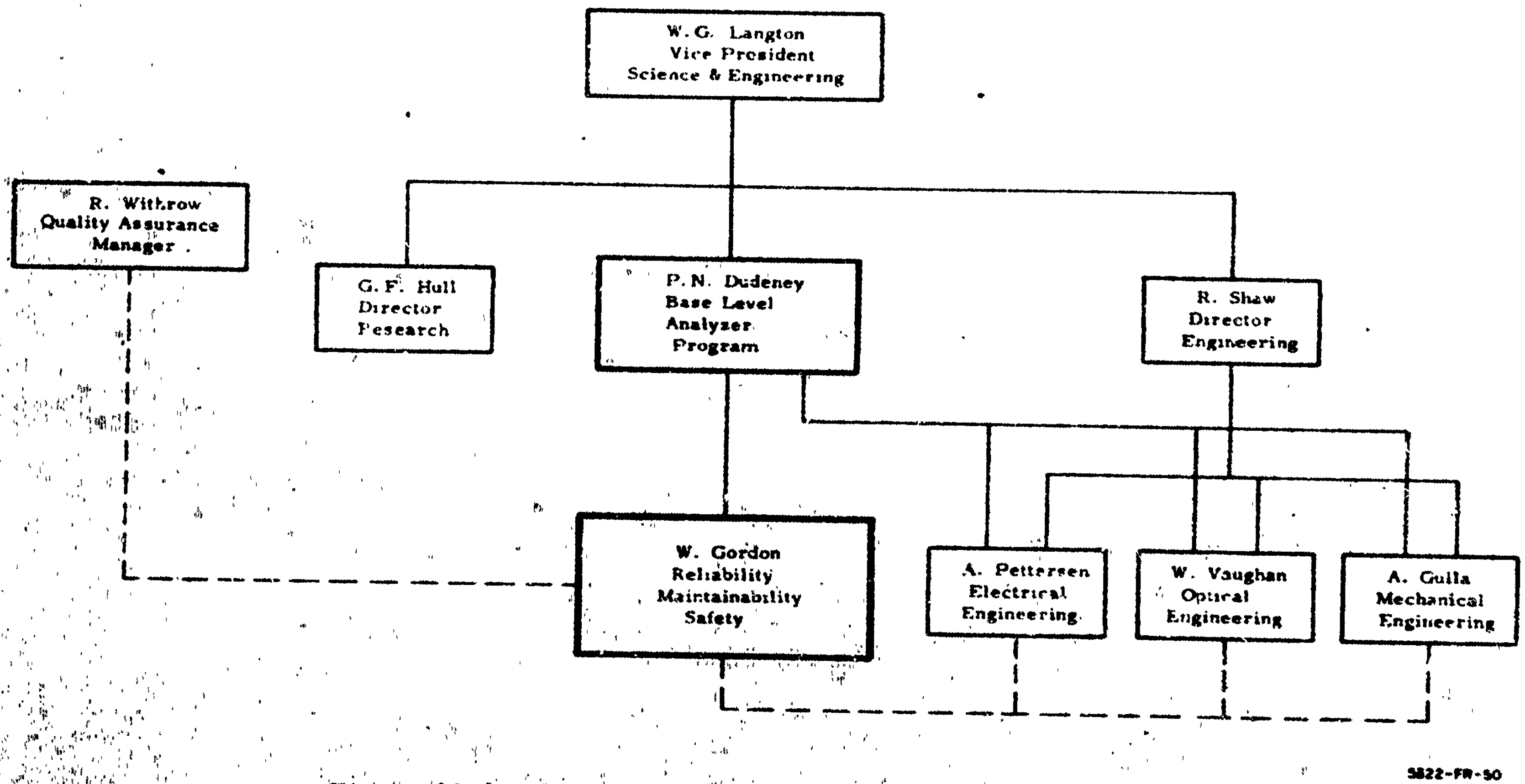


Figure 10-1. Organization Structure of Safety Engineering

10.4 Subsystem Safety Analysis

Each major subsystem of the analyzer shall be reviewed in order to identify all potential hazards and determine their criticalness. Hazardous failure modes shall be identified and probability of occurrence predicted on the basis of the reliability analysis of parts and subassemblies. As a result of this subsystem, safety analysis the system safety analysis will be performed.

10.5 System Safety Analysis

The system safety analysis utilizes the results from the subsystem safety analysis and develops these results as to their effect on the interface safety aspects of the total system. The combined system design is then reviewed in detail in order to define likely modes of failure including personnel error and the effects on system safety.

10.6 Safety Recommendations

Upon completion of the system safety analysis a review of the design precepts will be made in order to eliminate all classes of hazard exceeding class II.

Suitable safety and warning devices will be employed, where required, in order to effect class II as the maximum hazard condition.

Recommendations shall include all aspects relative to personnel, procedures, and equipment for conducting maintenance, support, and test operations.

10.7 Safety Procedures

Safety Engineering will be responsible for initiating or review of all safety procedures in the operation, maintenance, or test of the Analyzer.

10.8 Reporting

At the end of the program a safety engineering report will be submitted relative to safety engineering aspects of the Analyzer.

A. 1 RESEARCH DIRECT READER SPECTROGRAPH (RDRS) DATA REDUCTION PROGRAM

A. 1. 1 Object

Take RDRS data from analysis of standard samples and convert from concentration versus clock time to concentration versus capacitor voltage format. with voltages normalized to a 10 volt charge on the reference capacitor.

A. 1. 2 Equations

$$V_i = 1.50\, e^{\left[\frac{t_{cv} - t_i}{20}\right]} \qquad \text{(A-1)}$$

where

V_i = voltage on capacitor for i^{th} element

t_{cv} = time in clock units require to discharge reference capacitor to 1.5 volts

t_i = time in clock units required to discharge reference capacitor to i^{th} element capacitor voltage

$$V_o = 1.50\, e^{\left[\frac{t_{cv}}{20}\right]} \qquad \text{(A-2)}$$

where

V_o = initial voltage on reference capacitor

The values obtained from equations (A-1) and (A-2) are scaled so that all values are normalized to V_o = 10 volts. All averaging operations and all computer data printouts are done subsequent to conversion from clock units to voltage and normalization.

A. 1. 3 Computer Printout

Three numbers are printed by the computer for each concentration of each impurity type. These are the mean $\overline{V}$, the maximum difference $V_{max} - V_{min}$ and the rms, v. These are obtained as follows

$$\overline{V} = \frac{\sum_{j=1}^{N} V_j}{N} \qquad \text{(A-3)}$$

$$v = \frac{\left[\sum_{j=1}^{N} (V_j - \overline{V})^2\right]^{1/2}}{N^{1/2}} \qquad \text{(A-4)}$$

On the output data sheets, (which follow) line 1 gives the average, line 2 the maximum minus the minimum, and line 3 the standard deviation.

Table A-1

7808/GB/BA Standard A, Normalized Output Data (Sheet 1 of 2)

OSC. TYPE 7808/GB/BA Standard A DATE

REF. CAP. VALUE 1.0 MFD.

X CHANNEL CAP. VALUE 0.1 MFD.

BREAKS PER HALF CYCLE 5

RF AMPS. 4

ENTRANCE SLIT 50 MICRONS

EXIT SLIT 25 MICRONS

TEMPERATURE

CNCTRATN PPM	MG 1	CR 2	AL 3	PB 4	SI 5	AG 6	NI 7	FE 8	CU 9	SN 10	CV	DIVSR
500A	6.670	5.931	8.077	2.946	6.450	8.042	7.231	5.584	6.169	6.768	10.00	1.312
	.613	.678	3.740	.449	.986	2.423	.879	1.085	1.512	.705		
SPREAD	.242	.230	1.215	.185	.367	.763	.293	.385	.462	.245		
400A	5.704	5.365	7.122	2.386	5.129	7.560	6.295	4.467	6.152	5.852	10.00	1.319
	.679	.921	3.378	.411	.565	2.333	.904	1.323	1.370	.616		
SPREAD	.236	.307	.970	.139	.224	.687	.252	.400	.474	.223		
300A	4.958	4.489	5.901	1.939	4.078	6.456	5.161	3.686	5.273	4.624	10.00	1.407
	.822	.714	2.504	.304	.685	1.254	.965	.843	1.027	.629		
SPREAD	.266	.223	.778	.092	.188	.428	.291	.272	.344	.193		
200A	3.730	3.534	4.369	1.259	2.713	5.117	3.748	2.451	3.958	3.056	10.00	1.242
	.443	.675	2.100	.278	.369	1.185	.543	.291	.332	.630		
SPREAD	.175	.234	.656	.089	.106	.394	.157	.085	.115	.181		
100A	2.493	2.221	[illegible]	.797	1.321	[illegible]	2.417	[illegible]	[illegible]	1.741	10.00	[illegible]
	.441	.439	1.001	.127	.220	.756	.468	.284	.627	.249		
SPREAD	.152	.141	.311	.045	.093	.315	.146	.112	.225	.086		
50A	1.587	1.385	1.505	.593	.984	2.096	1.608	.825	1.643	1.050	10.00	1.254
	.297	.327	.892	.091	.208	.768	.169	.090	.423	.120		

Table A-1

7808/GB/BA Standard A, Normalized Output Data (Sheet 2 of 2)

7808/GB/BA Standard A

SPREAD	.088	.095	.271	.029	.067	.236	.055	.032	.137	.040		
20A	.797	.788	.790	.448	.599	1.150	1.153	.521	.928	.696	10.00	1.236
	.106	.128	.494	.054	.081	.255	.159	.187	.587	.037		
SPREAD	.030	.041	.157	.019	.032	.074	.050	.062	.179	.011		
10A	.470	.561	.566	.386	.486	.721	.918	.349	.538	.572	10.00	1.332
	.137	.085	.208	.050	.068	.114	.078	.070	.138	.043		
SPREAD	.043	.025	.056	.016	.027	.041	.030	.025	.042	.015		
5A	.245	.460	.460	.366	.429	.543	.840	.264	.365	.503	10.00	1.366
	.045	.034	.177	.074	.104	.115	.081	.048	.056	.045		
SPREAD	.016	.012	.049	.023	.033	.035	.024	.014	.020	.014		
1A	.000	.359	.332	.359	.390	.326	.729	.183	.175	.442	10.00	1.267
	.000	.044	.083	.126	.080	.036	.054	.028	.027	.046		
SPREAD	.000	.013	.025	.039	.025	.011	.014	.009	.008	.015		
[illegible]	.000	.330	.295	.344	.353	.248	.676	.153	.118	.422	10.00	1.242
	.00C	.055	.103	.050	.069	.022	.073	.039	.032	.044		
SPREAD	.000	.016	.032	.016	.021	.007	.022	.015	.010	.014		

Table A-2

7808/GB/BA Standard A, Input Data, Concentration versus Clock Readings
(Sheet 1 of 3)

Input Data 7808/GB/BA Standard A

		MG	CR	AL	PB	SI	AG	NI	FE	CU	SN	CV
		1	2	3	4	5	6	7	8	9	10	
1	500A	9.7	11.7	.7	25.3	10.6	3.6	8.3	.	.	.	32.6
			9.9	3.2	25.5	9.5	3.1	6.6	13.7			33.7
				10.5	23.4	8.7	8.1	6.2	11.6	12.6		34.5
					22.6	7.7	4.8	5.8	11.0	9.8	7.3	33.3
		7.9				7.5	5.2	5.8	9.8	9.8	8.2	33.6
		7.8	10.6				1.9	5.9	10.1	7.6	6.9	33.1
		9.2	10.7	4.3				6.9	13.0	9.9	7.7	32.3
		9.0	9.4	3.9	25.6				12.7	8.6	9.0	32.5
1	400A	12.1	13.4	3.5	29.7	14.3	6.2	8.8				34.4
			12.8	5.9	29.6	14.0	5.2	10.9	19.6			32.3
				13.8	27.9	12.6	7.2	9.1	16.4	10.6		33.9
					26.7	12.2	8.1	9.5	14.8	11.7	11.0	33.0
		10.9				12.4	5.2	9.4	17.6	10.1	9.6	31.9
		10.2	11.1				2.1	8.0	15.1	7.3	9.6	33.9
		11.0	11.8	5.7				9.2	16.3	9.9	11.2	32.3
		10.3	11.2	5.6	27.8				13.6	7.8	11.2	32.8
		11.[illegible]	14.6	7.6	29.0	13.7				11.0	10.8	31.6
		12.6	12.5	6.9	30.1	14.4	5.7				11.7	32.4
1	300A	15.6	18.4	8.4	34.8	19.9	9.8	14.7				31.7
			15.1	9.5	32.6	17.7	7.2	12.8	19.7			33.8
				18.0	33.2	17.8	10.8	13.3	20.9	14.8		34.1
					31.6	17.6	9.6	12.8	19.8	14.7	15.5	32.7
		12.3				16.5	8.5	11.1	13.4	10.9	14.8	33.9
		14.3	16.1				8.1	13.7	21.1	12.0	17.4	33.8
		14.0	15.8	10.1				14.4	22.4	12.3	15.6	31.0
		12.8	15.4	9.8	32.0				17.8	12.4	15.2	32.1
		14.8	16.2	10.6	32.4	18.0				12.8	15.0	32.4
		14.6	15.3	8.9	33.2	18.2	6.9				14.6	31.1
1	200A	20.4	21.4	13.3	42.2	25.8	14.0	19.6				33.7
			18.8	14.6	40.3	24.6	11.8	18.2	28.3			34.2
				23.8	40.6	25.8	15.6	19.8	29.5	19.6		33.0
					39.2	26.7	14.4	19.2	27.1	18.3	24.5	33.1
		19.2				26.6	14.6	20.3	28.4	18.1	26.2	33.6
		18.8	21.3				12.8	19.3	27.5	18.1	22.0	31.3
		19.1	22.6	18.2				21.1	28.2	19.2	23.7	29.5
		18.7	21.6	16.9	41.7				27.9	18.6	23.4	30.5
		21.1	21.2	16.8	42.8	26.4				17.9	23.1	32.8
		20.9	19.0	14.1	43.6	27.3	11.0				23.3	33.6
1	100A	29.3	33.4	25.8	51.8	39.1	23.2	30.5				32.9
			29.5	24.8	51.6	38.3	19.5	28.8	41.6			33.8

Table A-2

7808/GB/BA Standard A, Input Data, Concentration versus Clock Readings
(Sheet 2 of 3)

Input Data 7808/GB/BA Standard A

				33.3	49.1	36.2	22.8	26.6	37.7	26.3		34.8
					48.9	37.3	23.6	28.7	37.7	28.4	36.7	33.6
		25.8	29.2				19.2	27.4	37.5	24.1	33.8	33.6
		28.1	29.9	25.4				28.1	40.4	28.8	34.9	32.4
		26.9	29.8	27.5	50.2				37.7	26.4	34.4	31.4
		27.8	29.3	27.2	51.5	36.2				24.9	34.2	34.0
		29.1	29.8	25.9	51.1	39.1	20.1				35.9	33.1
1	50A	39.0	41.8	34.3	58.1	43.7	31.3	37.5				32.5
			37.1	35.4	56.0	45.6	29.1	35.4	50.2			34.7
				48.0	55.6	47.4	36.5	36.9	49.0	39.8		34.4
					55.0	47.5	32.5	37.3	50.7	37.3	46.0	32.7
		35.2				46.1	28.7	36.4	49.3	35.1	44.9	33.4
		36.5	40.3				30.8	35.9	48.9	35.4	46.3	34.3
		36.2	40.2	37.1				36.5	51.1	34.8	44.0	31.5
		36.7	39.5	37.3	57.0				50.1	36.5	44.3	31.5
		37.8	38.6	36.4	57.5	47.8				34.4	45.3	34.3
		36.5	39.5	39.4	56.4	46.8	30.8				44.8	33.4
1	20A	50.8	52.0	45.9	62.9	54.7	43.3	44.1				32.0
			50.5	49.6	61.8	57.3	42.1	43.7	60.7			33.6
				55.5	60.8	56.8	45.8	44.0	60.7	51.4		34.3
					61.1	57.0	43.5	43.2	59.1	49.6	52.9	33.9
		49.5				56.2	43.3	41.4	59.0	49.6	53.2	32.9
		50.3	50.7				43.7	43.3	60.7	48.5	53.3	32.1
		50.6	50.2	49.9				42.8	54.1	47.9	54.0	33.9
		50.1	59.2	50.5	63.2				60.1	47.9	53.4	32.5
		52.2	52.8	59.4	62.4	57.4				40.0	53.3	31.6
		50.7	49.5	47.6	62.6	54.7	41.3				52.9	33.7
1	10A	63.5	58.8	54.2	00.0	58.9	54.2	48.4				33.8
			58.3	57.2	65.4	61.6	52.4	48.4	67.4			32.6
				61.7	63.6	59.8	54.3	48.1	68.2	62.1		33.0
					64.9	59.1	52.4	46.7	68.1	58.3	57.7	34.1
		62.0				61.1	52.4	48.0	68.8	59.4	57.2	32.1
		57.8	57.8				51.1	46.8	65.2	57.4	56.3	32.3
		59.8	57.3	57.5				47.9	64.8	57.4	56.7	33.1
		60.7	55.8	56.8	66.2				67.6	58.2	57.7	32.8
		62.4	58.1	57.8	64.8	61.4				56.7	57.8	33.5
		62.3	57.2	57.4	65.7	61.7	51.4				57.1	32.2
1	5A	75.5	61.8	57.4	66.6	63.7	58.5	49.5				33.0
			61.1	61.7	66.5	63.7	57.1	49.9	74.2			33.1
				64.9	65.1	59.6	60.6	50.1	73.7	67.8		34.2
					63.8	62.8	57.7	48.2	70.6	66.3	59.4	33.9
		74.2				62.9	59.1	49.8	72.7	66.7	59.7	33.4

Table A-2

7808 GB BA Standard A, Input Data, Concentration versus Clock Readings

(Sheet 3 of 3)

Input Data 7808/GB/BA Standard A

		72.2	62.2				58.3	49.5	72.2	64.7	59.8	33.2
		75.3	61.3	61.4				49.7	72.6	64.7	60.6	33.2
		73.4	62.2	62.7	67.1				72.5	67.2	58.8	30.9
		72.6	61.6	61.9	67.8	64.2				66.2	60.4	33.9
		75.9	60.7	61.6	66.2	64.1	58.6				59.8	31.7
1	1A	0.0	68.1	64.8	62.3	63.8	69.2	53.2				34.4
			66.5	67.9	68.8	66.9	68.0	52.2	0.0			32.6
				68.8	65.4	64.1	69.3	52.3	78.8	82.9		32.8
					66.5	62.8	68.8	52.5	82.0	80.5	61.6	32.3
		00.0				65.9	68.4	51.7	79.3	80.3	62.6	33.4
		00.0	66.1				68.3	52.3	79.4	81.3	62.9	33.1
		00.0	66.1	68.2				52.4	80.7	80.8	62.7	32.8
		00.0	65.6	69.0	69.0				79.8	80.8	63.2	33.6
		00.0	67.0	68.5	67.6	65.0				79.7	62.5	33.4
		00.0	66.4	69.6	66.7	65.8	67.1				61.1	33.2
1	0A	00.0	70.1	66.0	67.7	67.7	73.9	55.3				35.0
			68.8	72.6	67.6	66.9	73.4	54.3	00.0			33.6
				70.6	65.6	64.2	73.2	53.9	81.4	87.8		33.8
					67.2	68.0	74.1	53.4	85.2	88.0	63.4	33.1
		00.0				67.6	75.0	53.8	85.6	91.5	64.3	34.6
		00.0	68.2				74.4	53.1	84.7	91.8	63.6	32.9
		00.0	68.6	71.1				53.4	84.0	88.8	62.8	32.9
		00.0	67.4	69.9	68.4				80.6	87.7	62.2	30.9
		00.0	66.7	71.7	66.8	67.0				86.3	62.8	33.1
		00.0	67.8	71.8	68.5	66.7	73.3				63.7	33.6

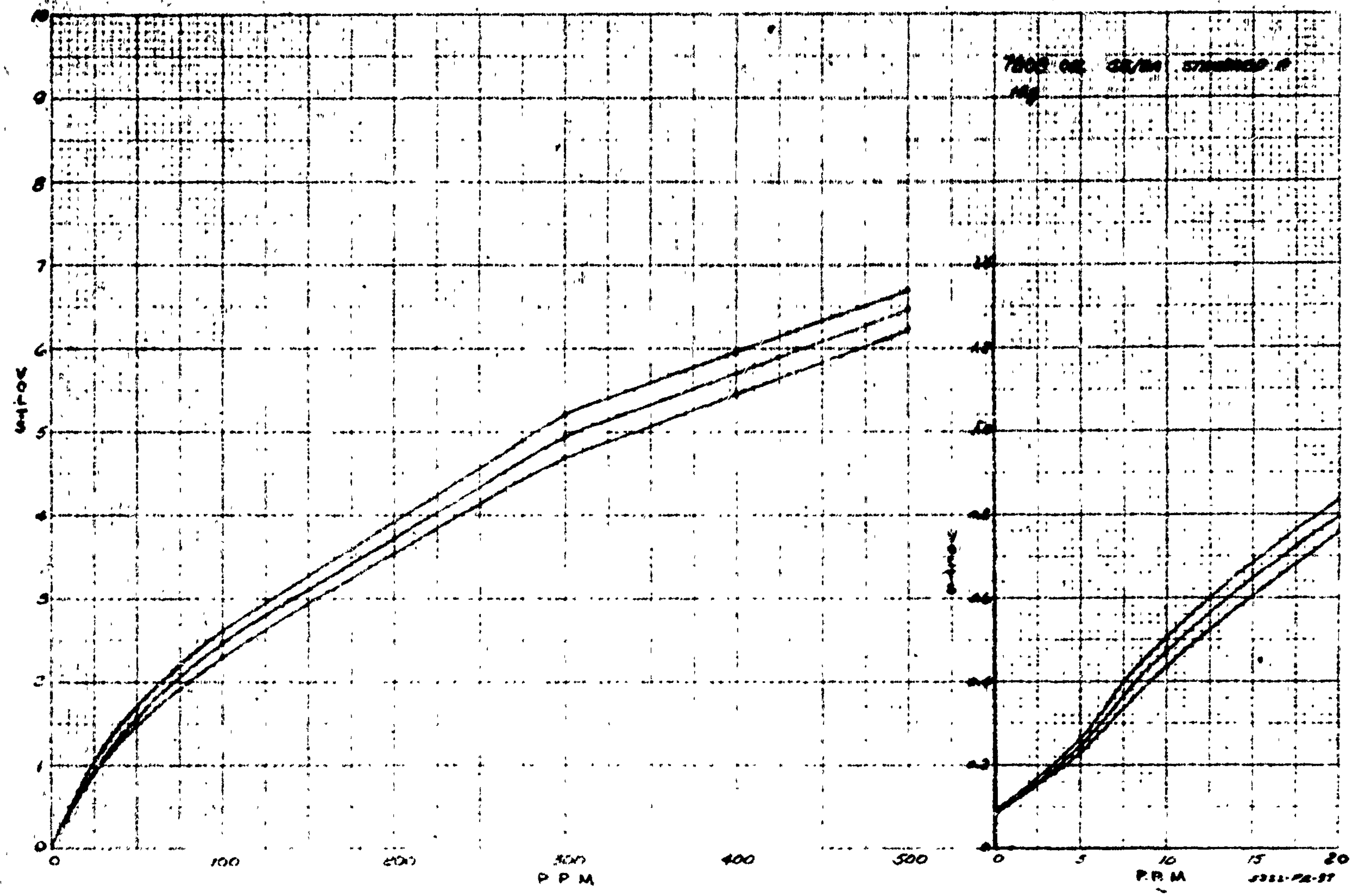


Figure A-1. Oil Type 7808 GB/BA Standard A, Magnesium

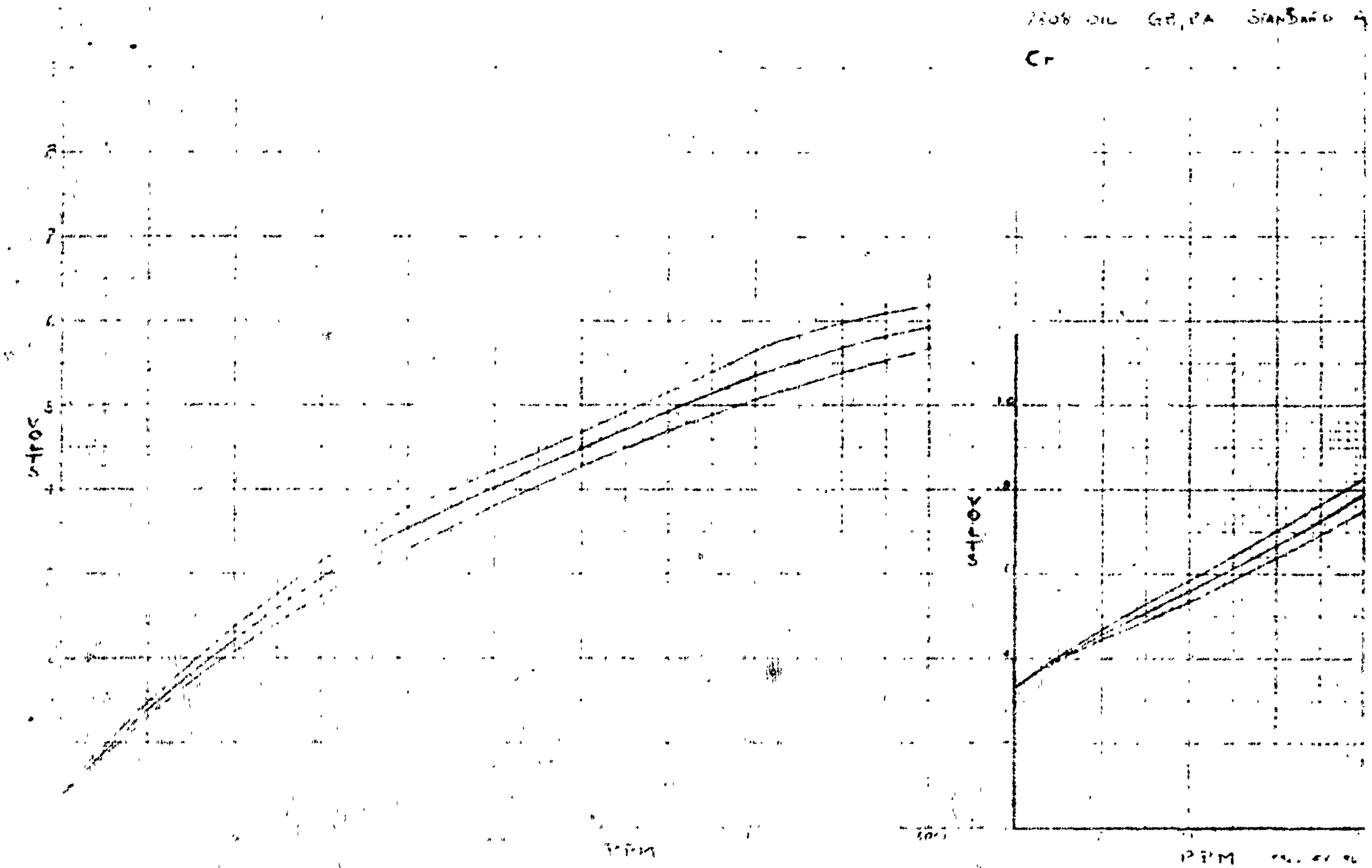


Fig. A-2. Oil Type 7808 GB/BA Standard A, Chromium.

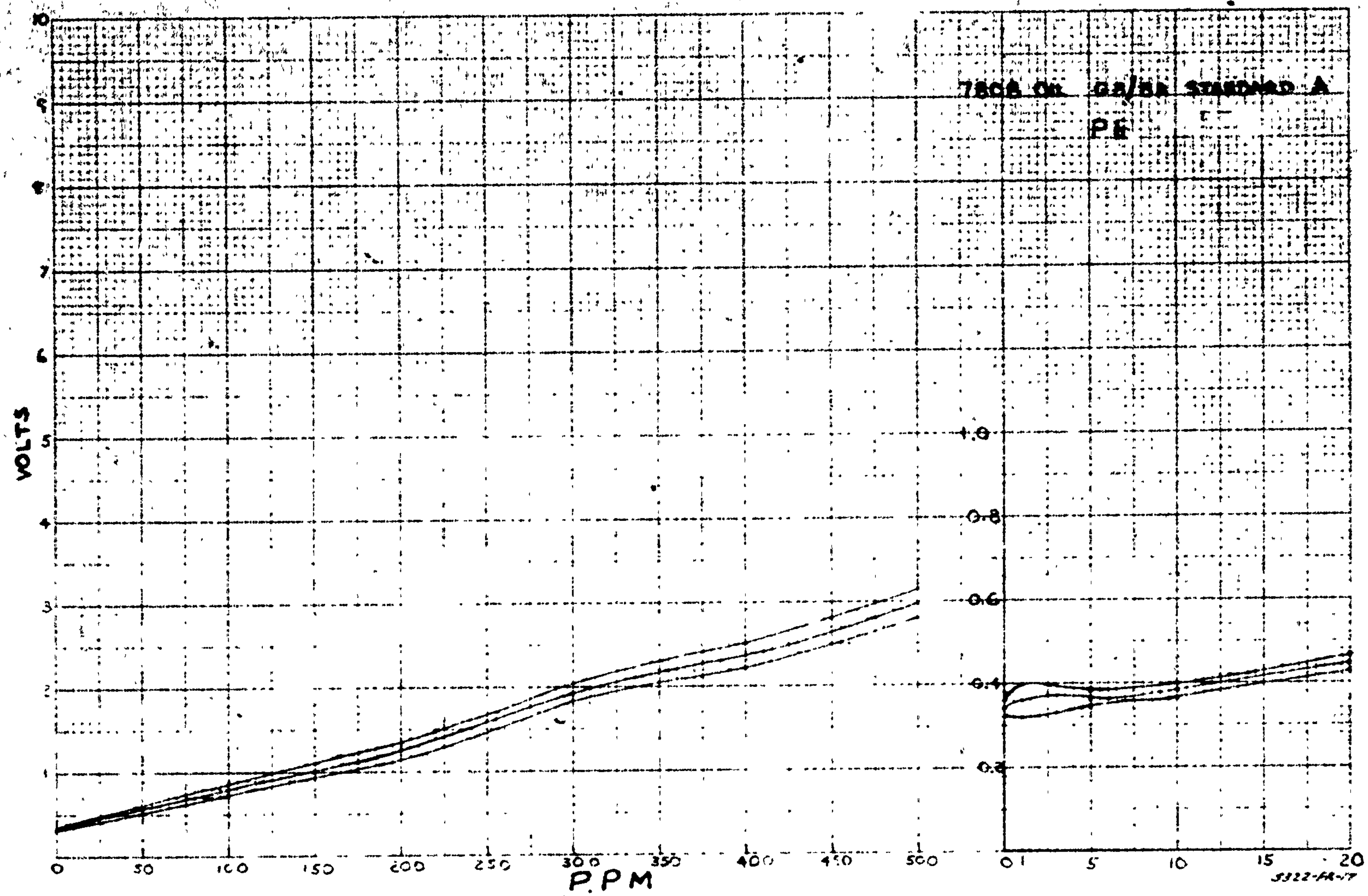


Figure A-3. Oil Type 7808 GB/BA Standard A, Lead

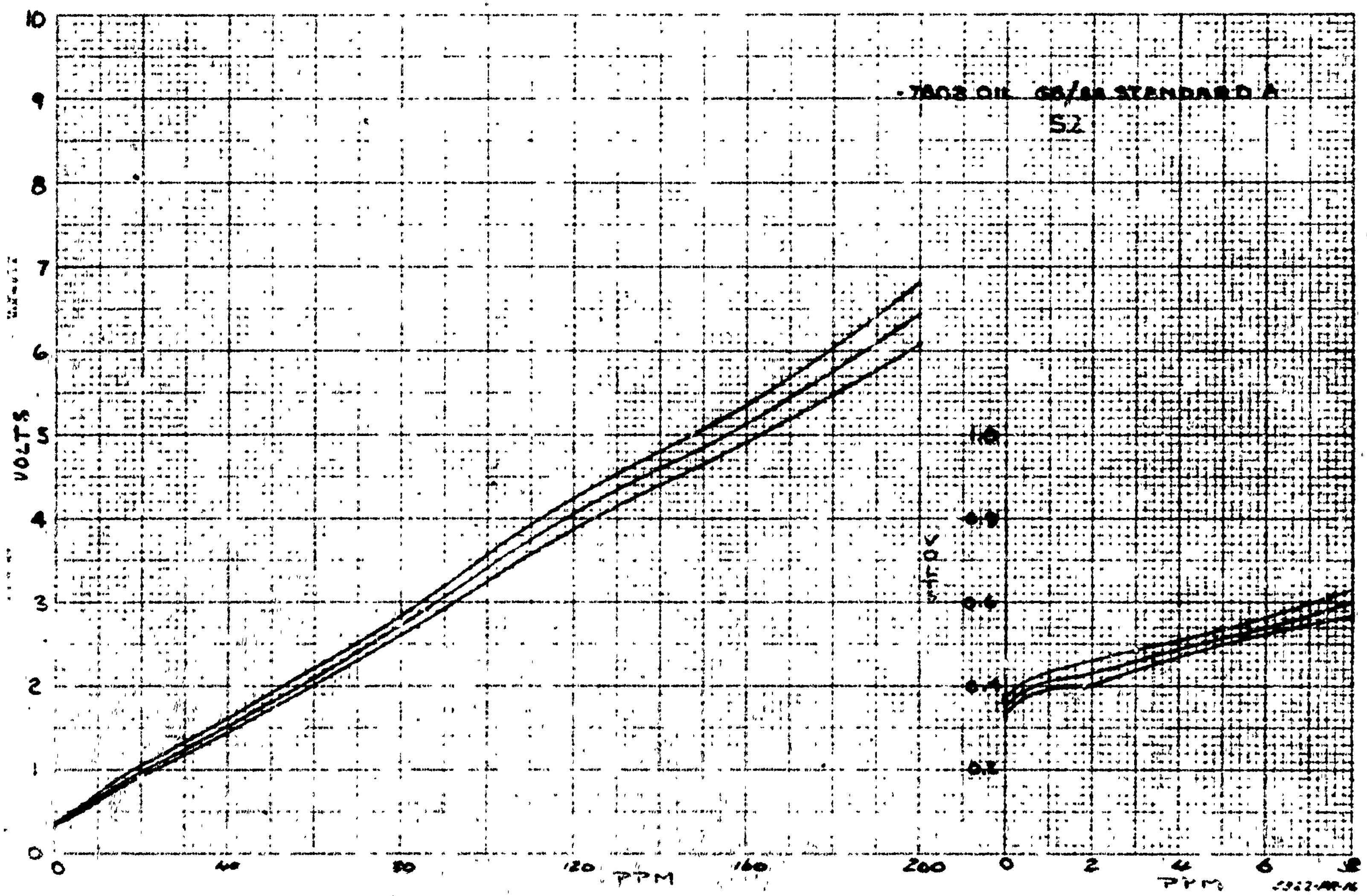


Figure A-4. Oil Type 7808 GB/BA Standard A, Silicon

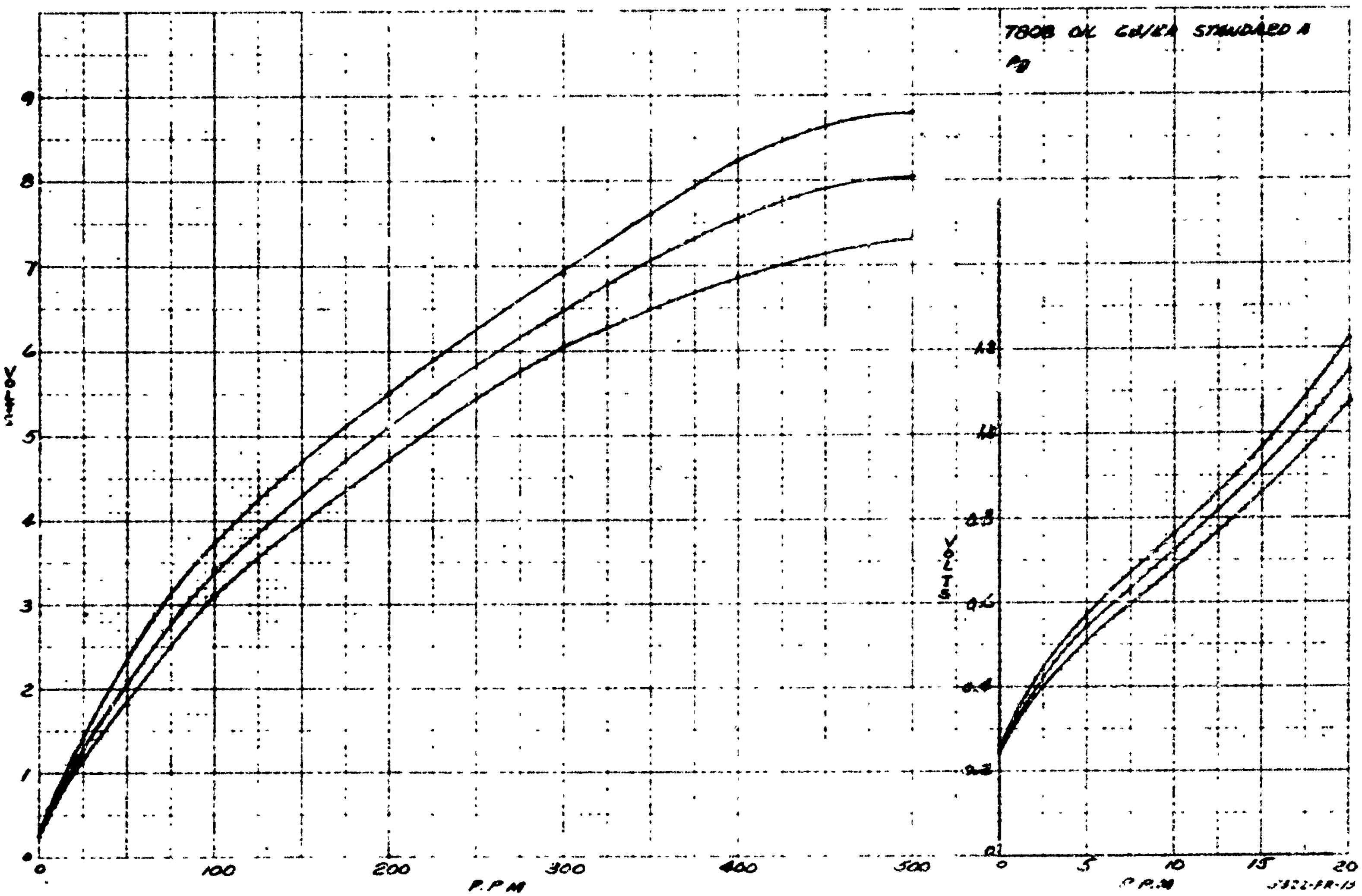


Figure A-5. Oil Type 7808 GB/BA Standard A, Silver

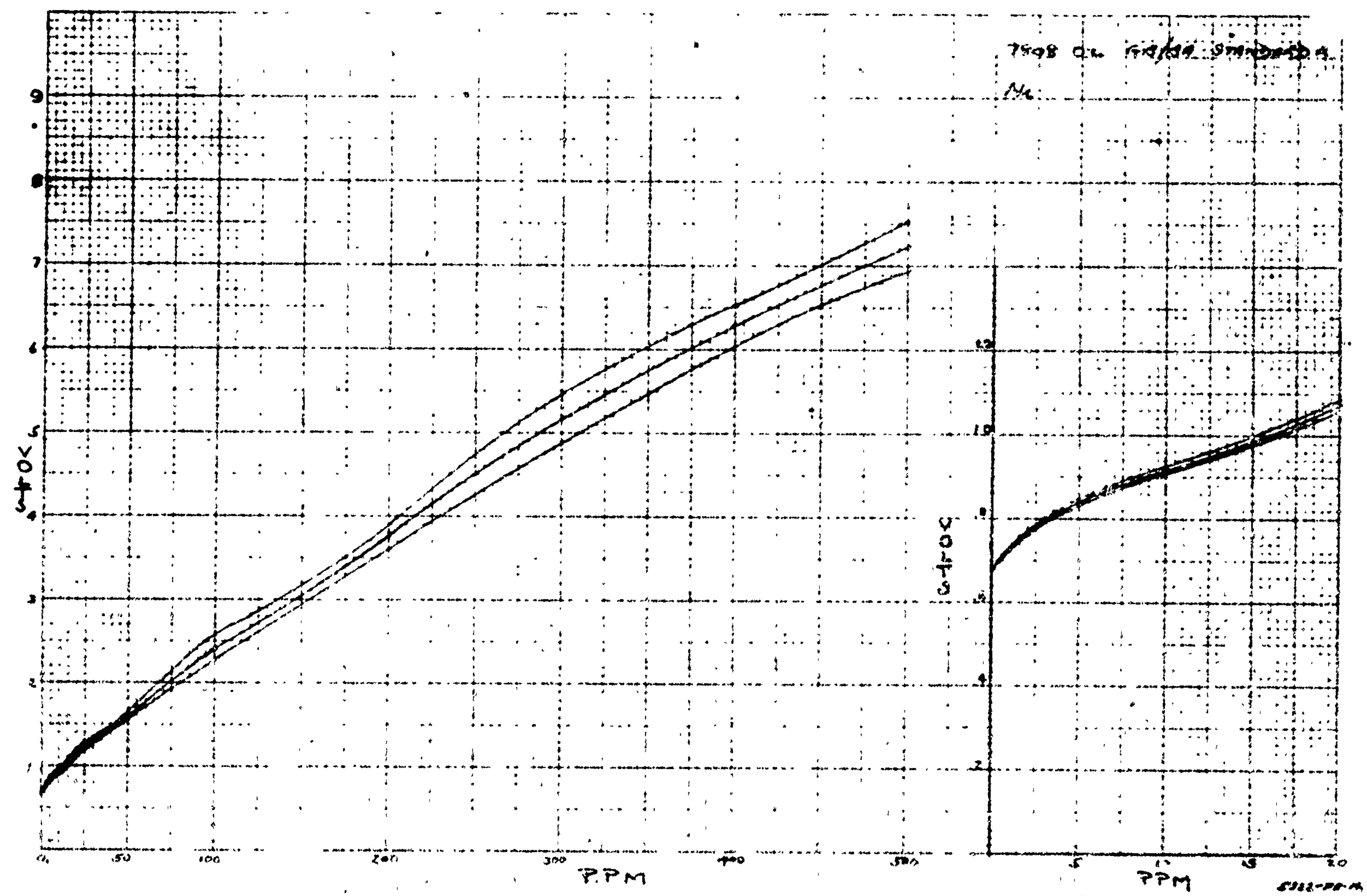


Figure A-6. Oil Type 7808 GB/BA Standard A, Nickel

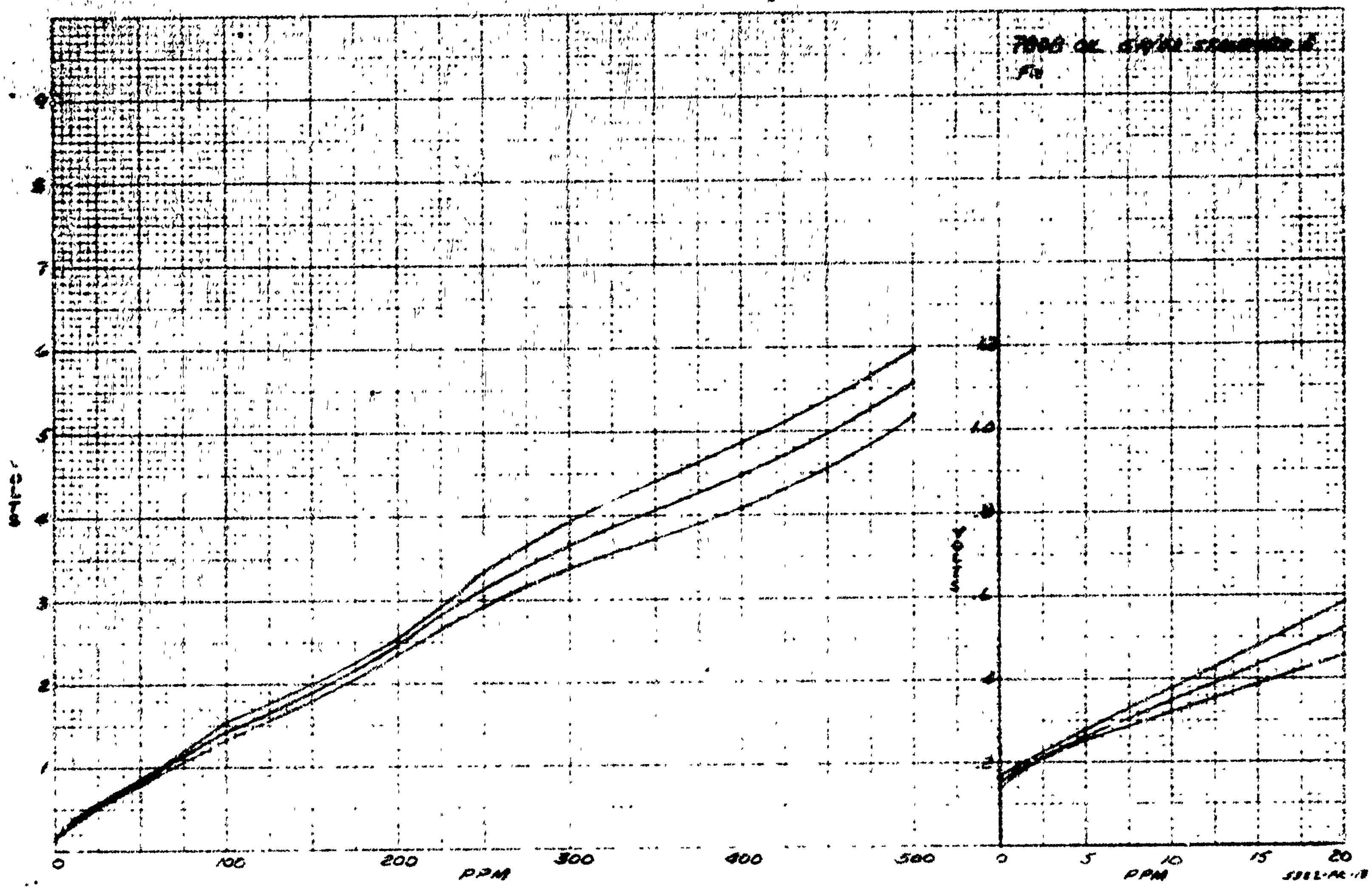


Figure A-7 Oil Type 7808 GB-BA Standard A. Iron

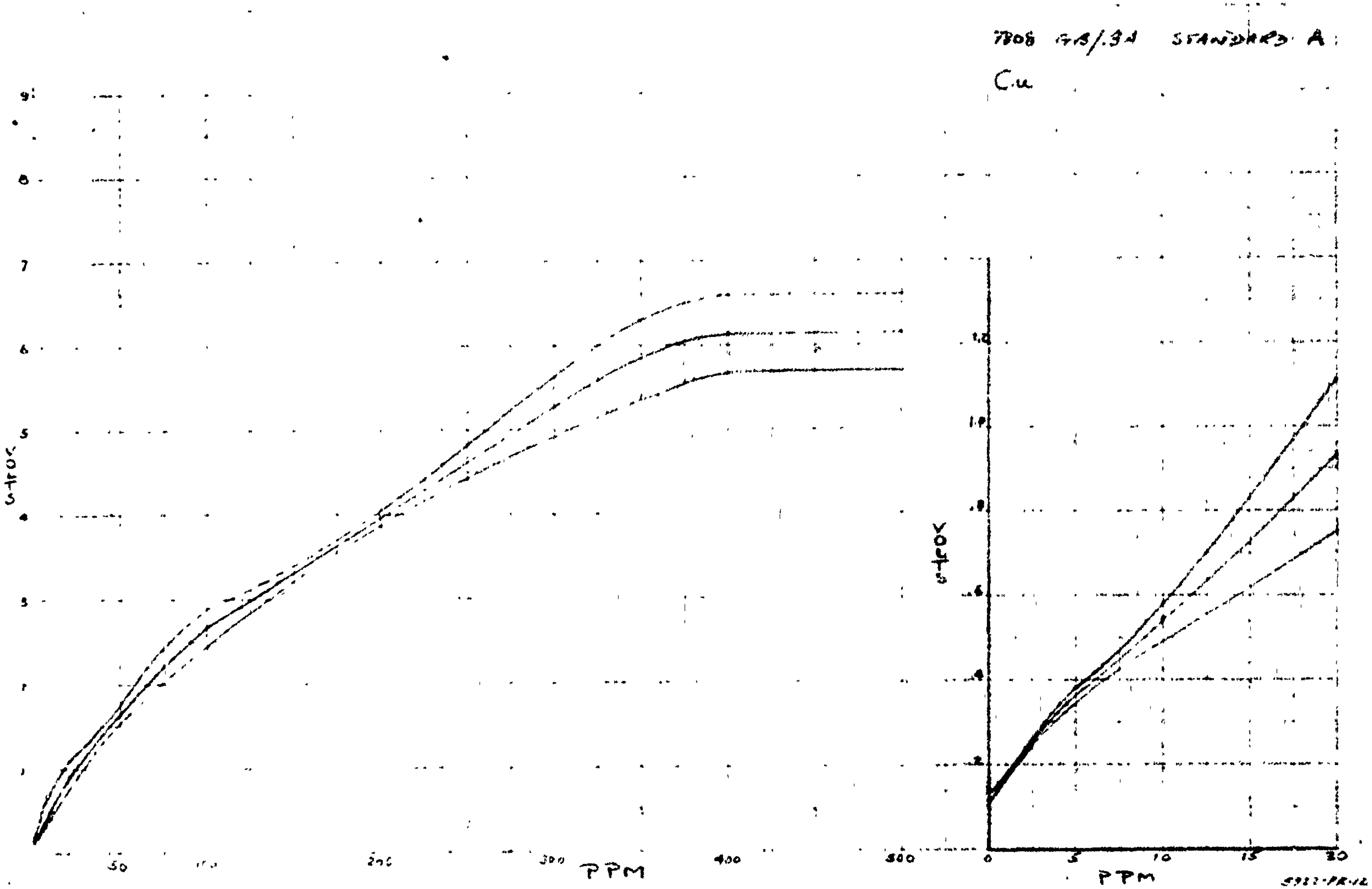


Figure A-8. Oil Type 7808 GB/BA Standard A, Copper

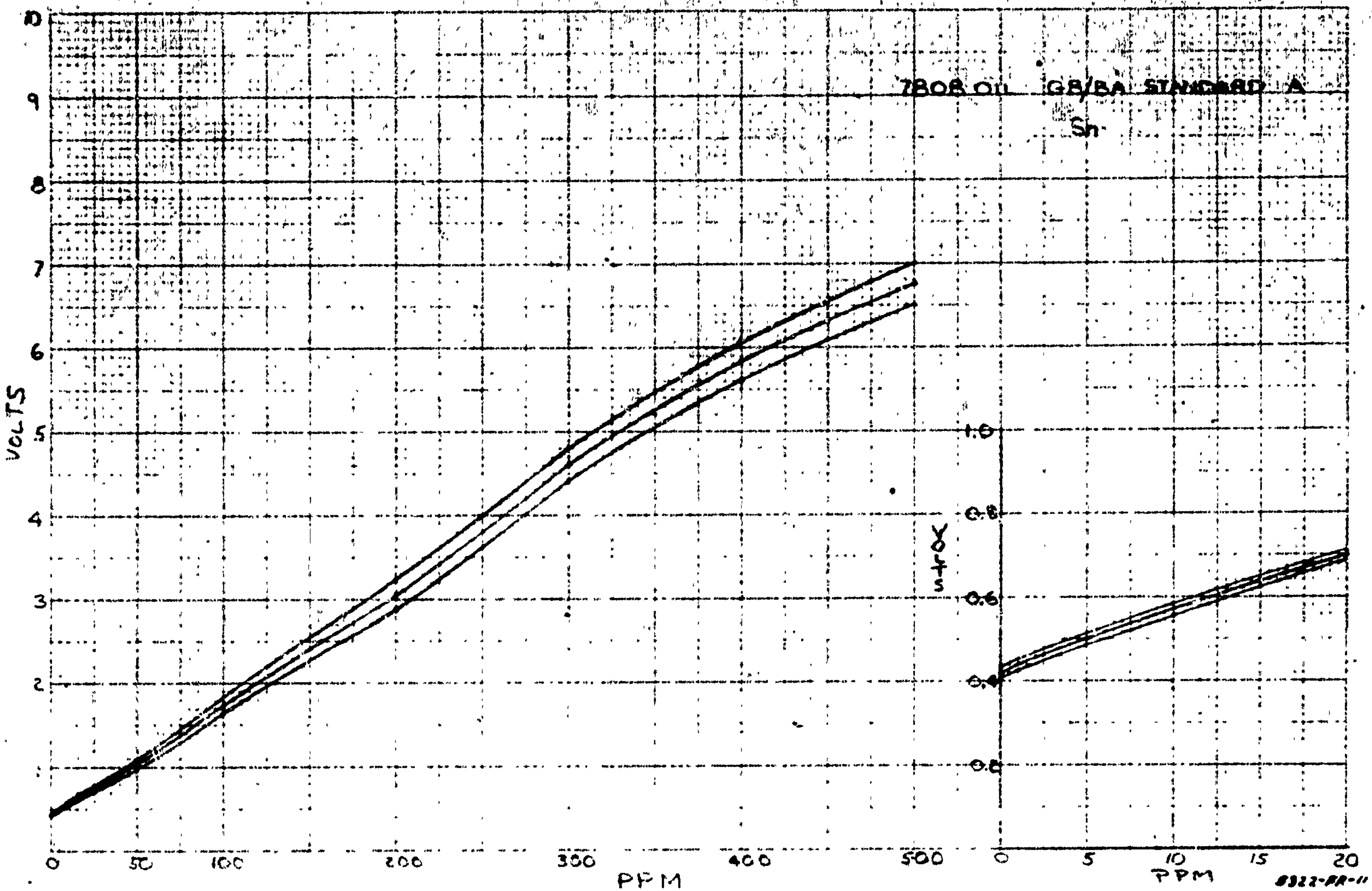


Figure A 9. Oil Type 7808 GB/BA Standard A, Tin

Table A-3

7806/GB/BA Standard B, Normalized Output Data (Sheet 1 of 2)

7808/GB/BA Standard B

OIL TYPE

DATE

REF. CAP. VALUE 1.0 MFD.

X CHANNEL CAP. VALUE 0.1 MFD.

BREAKS PER HALF CYCLE 5

RF AMPS. 4

ENTRANCE SLIT 50 MICRONS

EXIT SLIT 25 MICRONS

TEMPERATURE

CNCTRATN PPM	MG 1	CR 2	AL 3	PB 4	SI 5	AG 6	NI 7	FE 8	CU 9	SN 10	CV	DIVSR
500B	6.697	6.093	8.175	3.052	6.496	8.093	7.429	5.791	6.644	7.002	10.00	1.293
	.951	1.712	3.976	.609	.996	1.841	1.428	1.322	1.294	.764		
SPREAD	.321	.625	1.403	.248	.370	.755	.388	.396	.506	.249		
400B	5.813	5.485	7.106	2.460	5.258	7.439	6.393	4.882	6.205	5.804	10.00	1.373
	.796	1.302	3.485	.419	.969	1.641	1.391	.912	1.512	.471		
SPREAD	.279	.380	1.017	.129	.286	.473	.457	.282	.466	.166		
300B	4.916	4.571	5.820	1.922	4.004	6.442	[illegible]	3.665	5.375	4.522	10.00	1.339
	.463	.793	[illegible]	.429	.896	1.143	[illegible]	1.081	.767	.475		
SPREAD	.180	.252	.789	.141	.292	.380	.238	.336	.273	.172		
200B	3.811	3.469	4.346	1.297	2.712	5.163	3.743	2.359	4.021	3.034	10.00	1.293
	.548	.506	2.018	.385	.351	1.384	.452	1.051	.447	.449		
SPREAD	.187	.189	.595	.116	.130	.462	.158	.330	.136	.140		
100B	2.481	2.258	2.641	.818	1.572	3.567	2.432	1.478	2.688	1.793	10.00	1.254
	.362	.324	1.536	.127	.239	.883	.400	.216	.754	.246		
SPREAD	.119	.121	.457	.041	.077	.329	.153	.073	.237	.081		
50B	1.603	1.414	1.584	.615	.938	2.133	1.648	.857	1.719	1.067	10.00	1.261
	.239	.310	1.123	.198	.065	.645	.190	.108	.453	.139		

Table A-3

7808/GB/BA Standard B, Normalized Output Data (Sheet 2 of 2)

7808/GB/BA Standard B

SPREAD	.105	.090	.312	.065	.026	.207	.059	.033	.147	.045		
20B	.915	.758	.796	.456	.677	1.265	1.207	.546	.976	.732	10.00	1.299
	.914	.145	.288	.047	.409	.951	.577	.423	.892	.332		
SPREAD	.295	.044	.085	.015	.126	.300	.185	.133	.288	.112		
10B	.484	.561	.579	.406	.498	.736	.929	.344	.535	.572	10.00	1.181
	.046	.070	.230	.020	.135	.301	.082	.046	.093	.025		
SPREAD	.016	.023	.066	.006	.044	.090	.024	.013	.029	.008		
5B	.251	.449	.433	.363	.492	.529	.829	.258	.342	.523	10.00	1.242
	.052	.079	.131	.081	.448	.063	.053	.011	.074	.054		
SPREAD	.015	.026	.039	.023	.149	.024	.018	.004	.021	.019		
1B	.000	.362	.325	.328	.384	.311	.710	.178	.173	.444	10.00	1.236
	.000	.047	.122	.071	.115	.022	.056	.023	.038	.050		
SPREAD	.000	.016	.035	.022	.046	.008	.017	.008	.015	.014		
0B	.000	.337	.301	.318	.353	.247	.692	.150	.116	.419	10.00	1.299
	.000	.042	.096	.104	.075	.026	.051	.013	.024	.044		
SPREAD	.000	.013	.028	.031	.023	.008	.016	.004	.008	.013		

Table A-4

7808 GB BA Standard B Input Data, Concentration versus Clock Readings
(Sheet 1 of 3)

7808/ GB/BA Standard B

	MG	CR	AL	PB	SI	AG	NI	FE	CU	SN	CV
	1	2	3	4	5	6	7	8	9	10	
1 5008	9.9	13.9	2.4	25.8	10.4	5.7	8.2				31.2
		8.[illegible]	1.1	25.3	9.2	1.8	5.8	13.9			35.1
			12.0	24.0	8.9	6.3	5.6	12.0	9.6		34.8
				21.8	7.3	6.1	5.9	10.4	9.4	7.1	33.4
	7.7				7.5	3.9	5.9	10.7	8.6	6.8	32.9
	8.[illegible]	8.9				2.1	4.3	10.2	5.8	8.4	35.4
	7.6	10.8	4.0				6.1	10.4	9.4	7.2	32.1
	7.0	8.5	2.4	22.1				9.2	6.6	6.2	32.8
[illegible]	1[illegible].7	14.2	3.6	29.7	14.8	6.2	9.9				33.2
		1[illegible].7	6.0	28.0	13.2	5.6	9.3	[illegible]6.6			33.6
			14.4	27.8	12.2	8.6	9.0	15.3	12.6		33.6
				26.3	12.2	5.3	8.0	13.7	9.3	10.5	34.2
	9.9				11.1	6.6	7.4	12.8	10.3	11.4	34.2
	10.5	11.6				4.1	11.9	14.4	7.9	11.4	34.3
	10.0	9.5	4.8				7.5	14.4	7.6	9.8	33.4
	1[illegible].1	11.6	6.7	27.3				13.4	9.8	11.4	32.7
	11.1	13.1	7.1	28.2	13.2				9.7	10.6	32.9
	11.8	12.7	6.9	29.2	13.5	5.3				11.1	31.6
1 3008	15.3	17.6	8.9	34.8	20.7	9.8	13.7				33.7
		14.3	9.2	33.6	19.1	7.3	12.8	21.5			34.3
			18.3	31.9	16.9	10.9	12.1	18.9	14.2		34.9
				30.5	16.2	9.5	10.9	16.9	12.7	15.6	34.8
	13.7				18.8	7.6	13.6	22.7	11.6	16.9	33.2
	14.3	15.8				8.3	12.9	20.7	12.2	16.8	33.8
	14.0	14.1	8.6				12.5	21.2	11.3	15.0	33.4
	13.4	16.3	11.0	32.8				19.2	13.6	15.8	31.5
	13.5	15.9	10.7	32.7	17.4				11.5	14.8	33.5
	15.3	[illegible]5.8	10.6	34.9	19.4	8.4				16.3	32.1
1 2008	20.9	22.5	19.8	44.5	26.7	14.7	20.4				33.2
		19.6	15.1	41.3	25.2	11.9	18.6	28.2			33.[illegible]
			24.1	39.3	24.9	15.7	18.3	26.4	19.1		34.9
				40.9	27.3	15.0	20.7	36.4	18.8	25.6	33.4
	19.4				25.7	13.2	20.2	29.3	18.4	24.3	32.3
	18.8	22.2				12.2	19.7	27.7	17.8	23.4	31.6
	19.6	21.4	16.2				19.8	29.3	18.9	24.2	31.3
	18.	20.8	16.4	40.1				26.5	16.9	22.9	31.5
	20.3	22.1	17.1	42.	27.5				18.1	24.1	33.
	18.2	19.8	15.5	38.4	25.5	10.4				22.6	32.8
1 1008	28.4	30.9	22.8	50.6	37.9	22.3	29.5				33.3
		28.5	24.8	49.5	36.7	18.8	27.4	38.[illegible]			34.7

Table A-4

7808/GB/BA Standard B, Input Data, Concentration versus Clock Readings
(Sheet 3 of 3)

7808/GB/BA Standard B

		71.9	62.7				57.8	49.5	72.9	65.2	59.8	32.8
		73.2	62.9	64.4				50.2	72.8	67.4	60.2	33.3
		73.9	61.4	62.9	68.1				73.6	68.3	58.1	30.6
		73.5	61.0	62.8	63.7	62.7				66.6	58.8	31.6
		74.4	60.7	62.5	65.9	63.4	57.9				59.6	33.6
1	18	00.0	67.4	64.3	67.4	66.8	69.7	53.1				33.8
			65.9	69.1	68.8	66.9	63.8	52.7	00.0			33.5
				68.6	69.4	61.8	69.8	52.4	80.8	83.3		33.2
					66.7	61.7	69.8	53.9	78.8	82.8	62.1	34.1
		00.0				66.8	69.5	52.3	80.5	79.8	63.6	34.9
		00.0	66.8				68.4	52.7	81.4	79.7	61.8	33.0
		00.0	67.6	71.6				53.1	80.1	83.8	61.3	32.6
		00.0	65.5	69.8	67.7				81.4	79.3	62.4	32.2
		00.0	65.0	67.4	71.2	67.5				79.8	62.3	31.7
		00.0	66.2	69.4	67.4	65.6	69.8				62.6	33.7
1	0B	00.0	68.7	66.0	68.7	63.9	74.3	54.2				34.4
			69.1	71.0	66.8	66.7	73.8	53.1	00.0			31.9
				70.2	67.4	66.9	72.7	53.4	82.6	87.3		31.8
					73.8	67.7	73.4	53.4	83.9	88.7	63.4	32.9
		00.0				68.0	74.8	54.0	84.2	91.1	64.5	34.7
		00.0	67.4				74.3	52.7	84.4	91.5	62.9	31.8
		00.0	67.2	70.6				53.1	84.4	88.9	62.4	31.8
		00.0	67.5	70.3	68.7				84.4	87.6	63.3	32.4
		00.0	68.2	72.1	68.2	67.5				88.2	64.1	34.4
		00.0	66.6	70.5	69.6	67.4	74.6				63.6	32.7

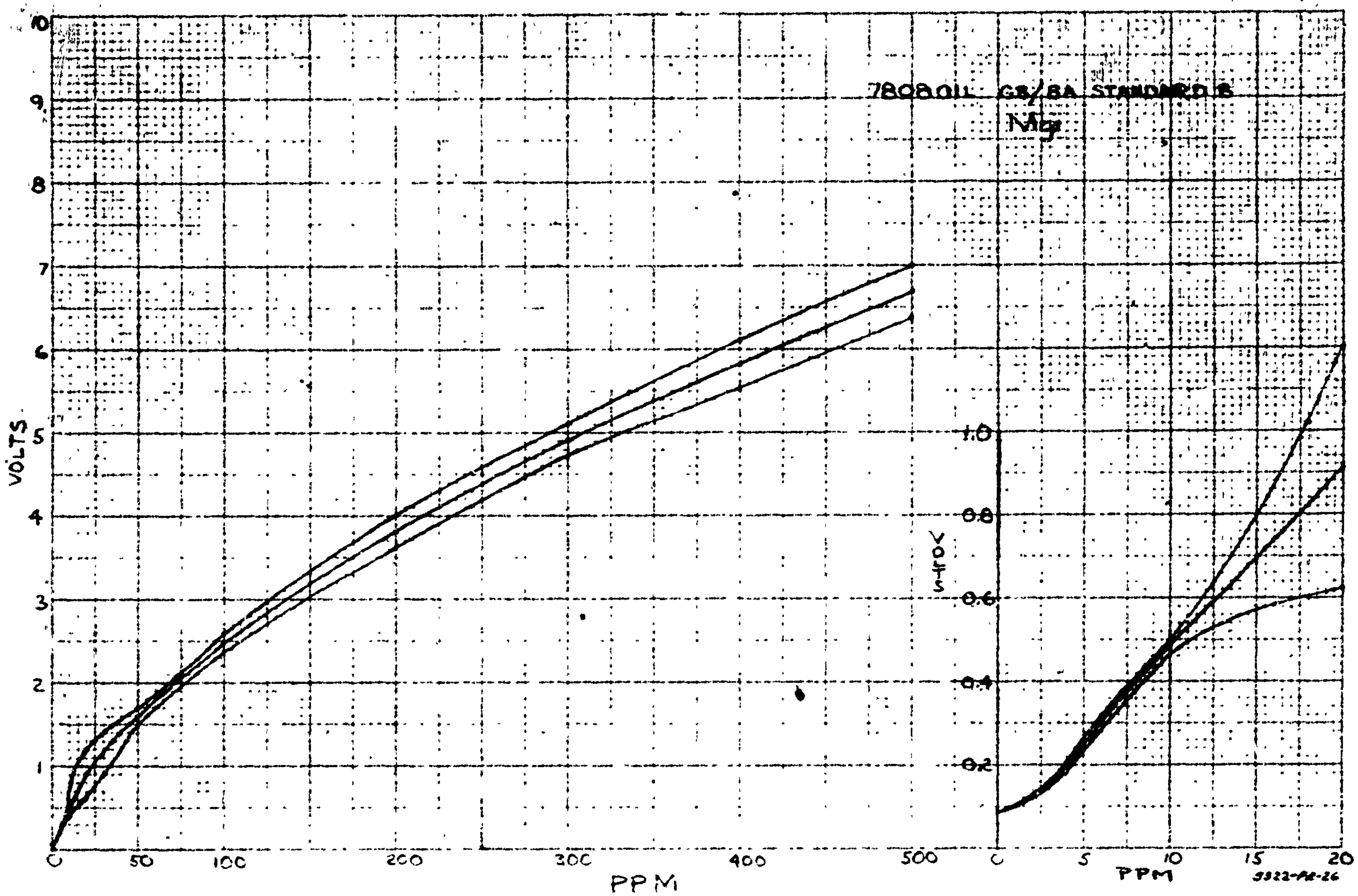


Figure A-10. Oil Type 7808 GB/BA Standard B. Magnesium

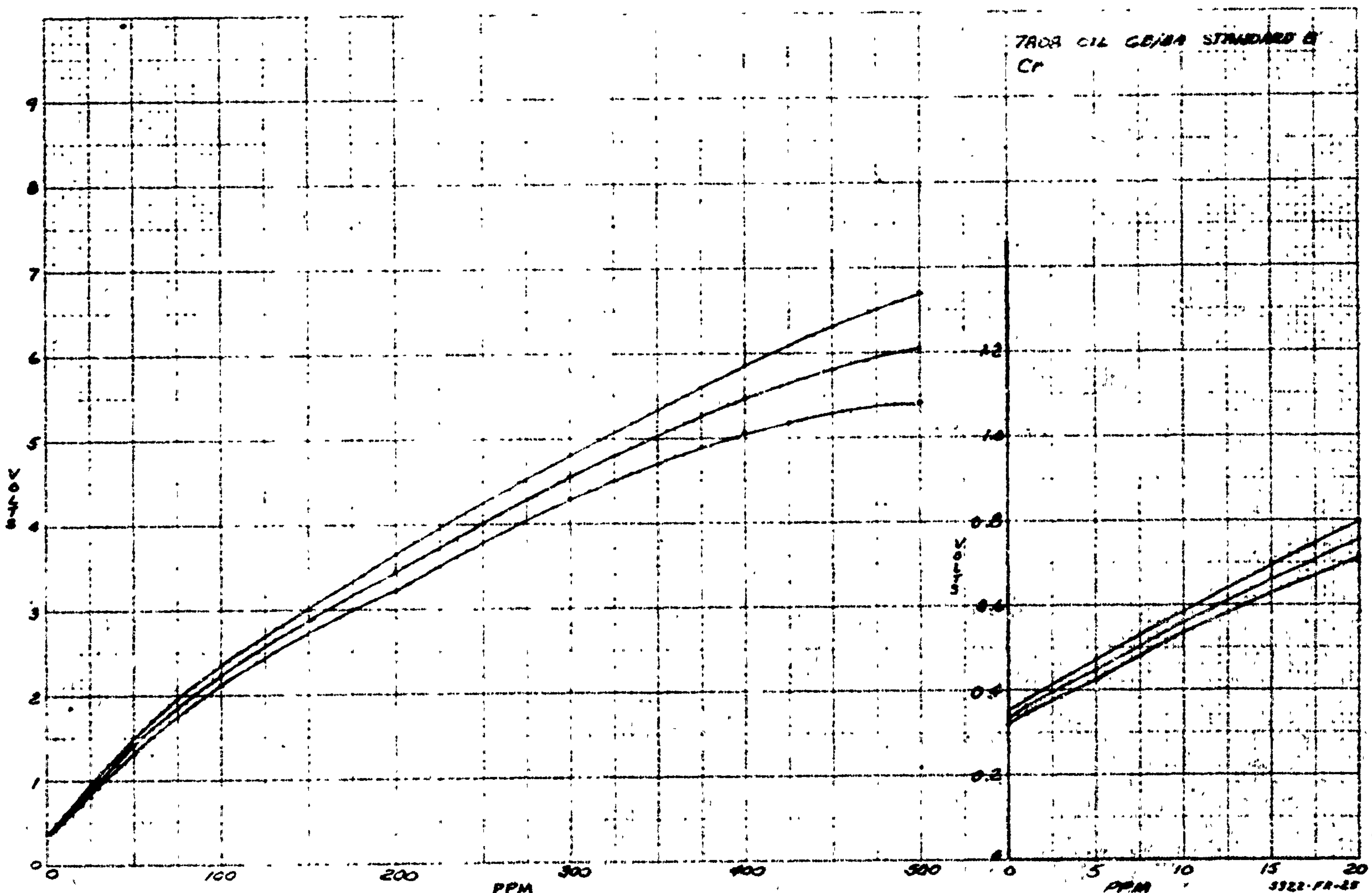


Figure A-11. Oil Type 7808 GB/BA Standard B Chromium

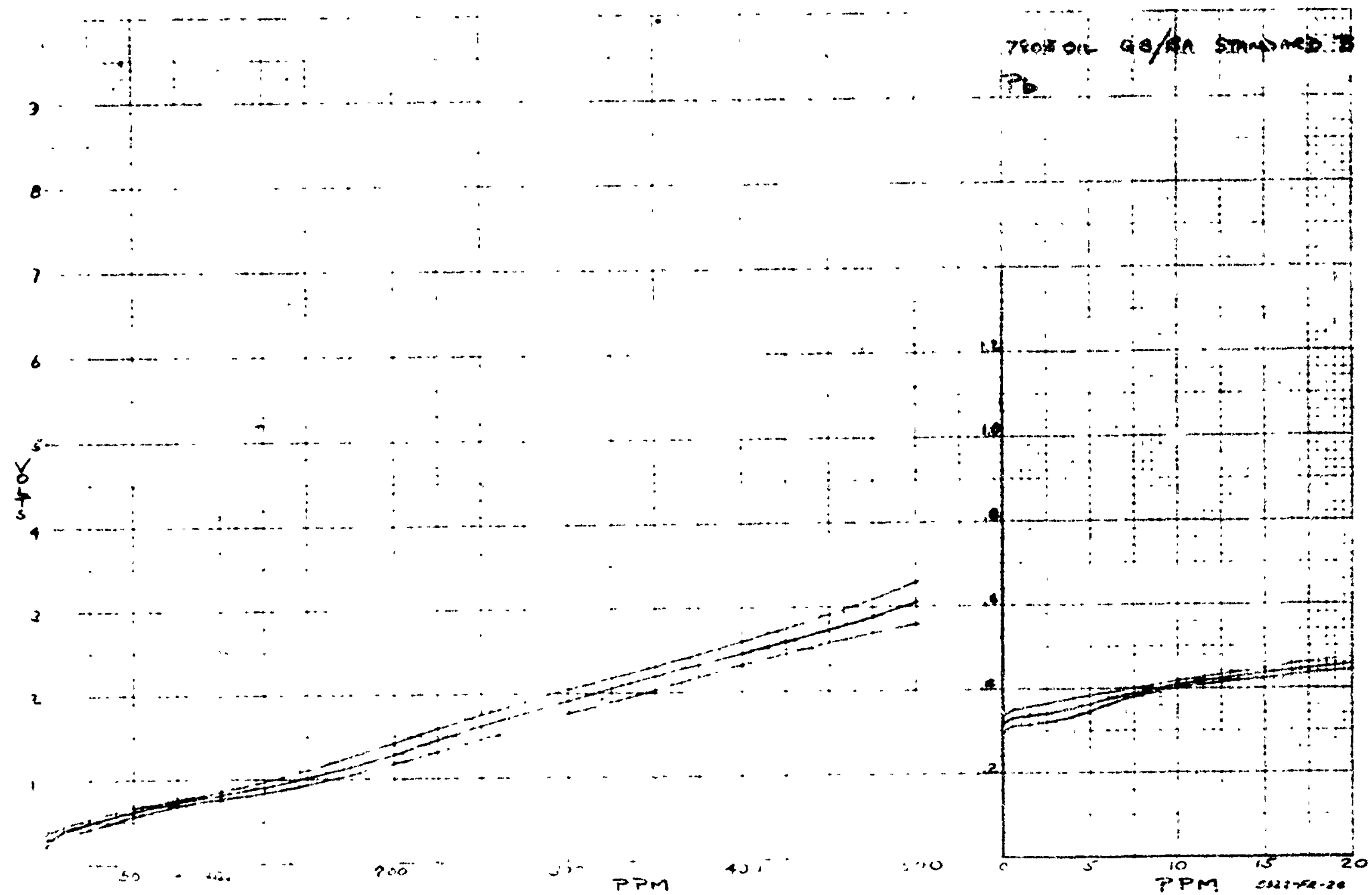


Figure A-12 Oil Type 7808 GB/BA Standard B, Lead

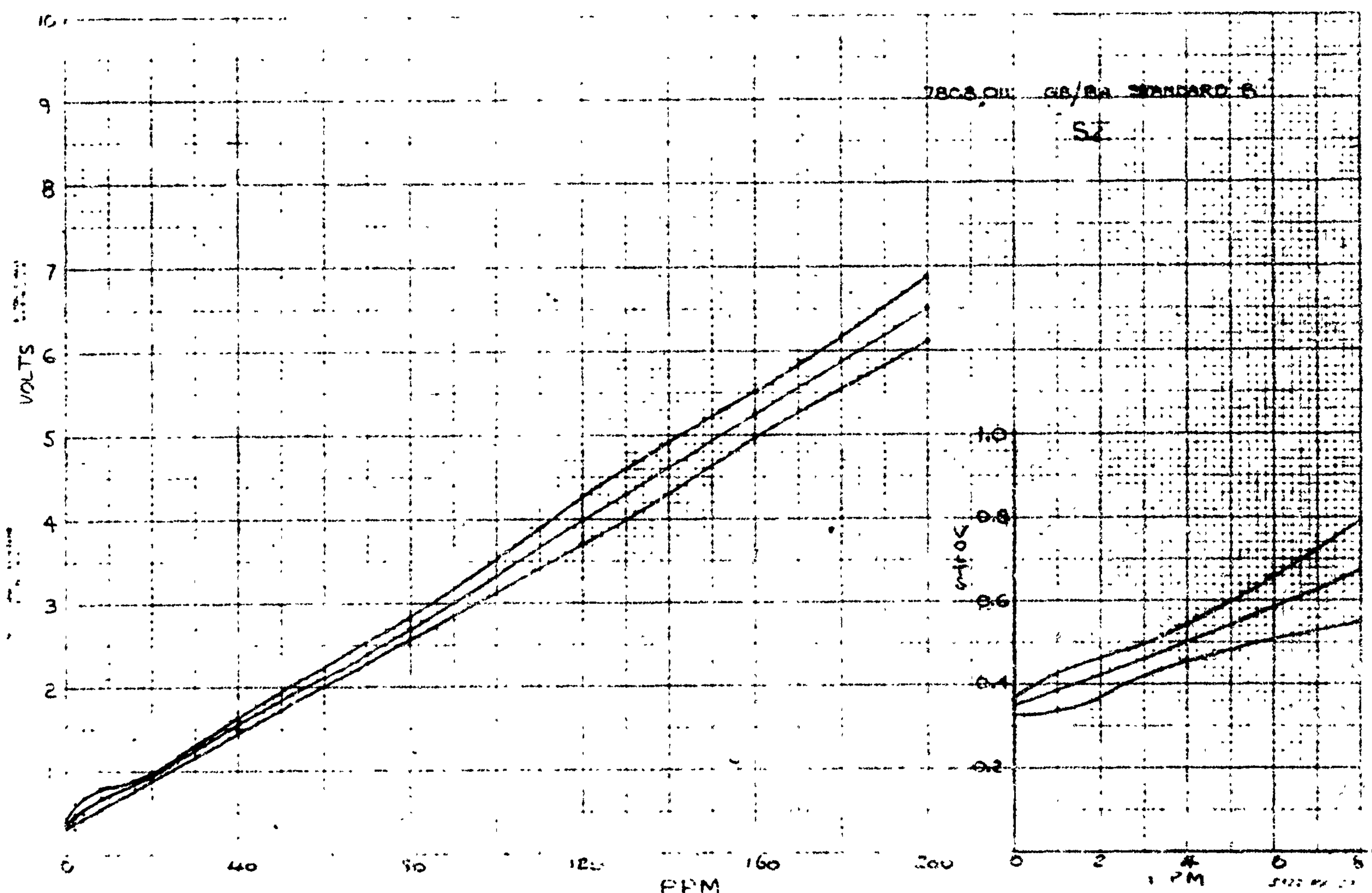


Figure A-13. Oil Type 7808 GB/BA Standard B, Silicon

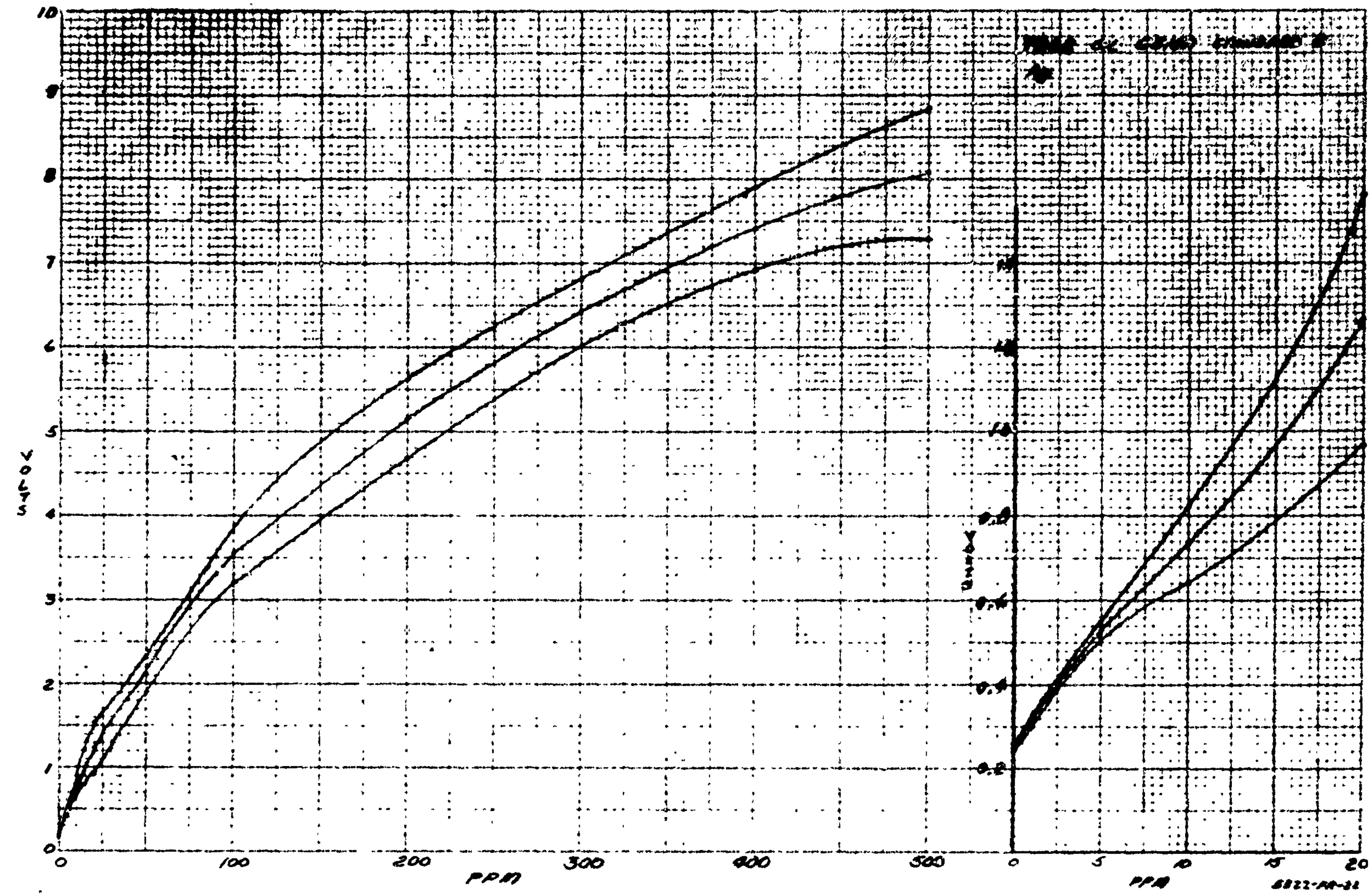


Figure A-14. Oil Type 7808 GB/BA Standard B, Silver

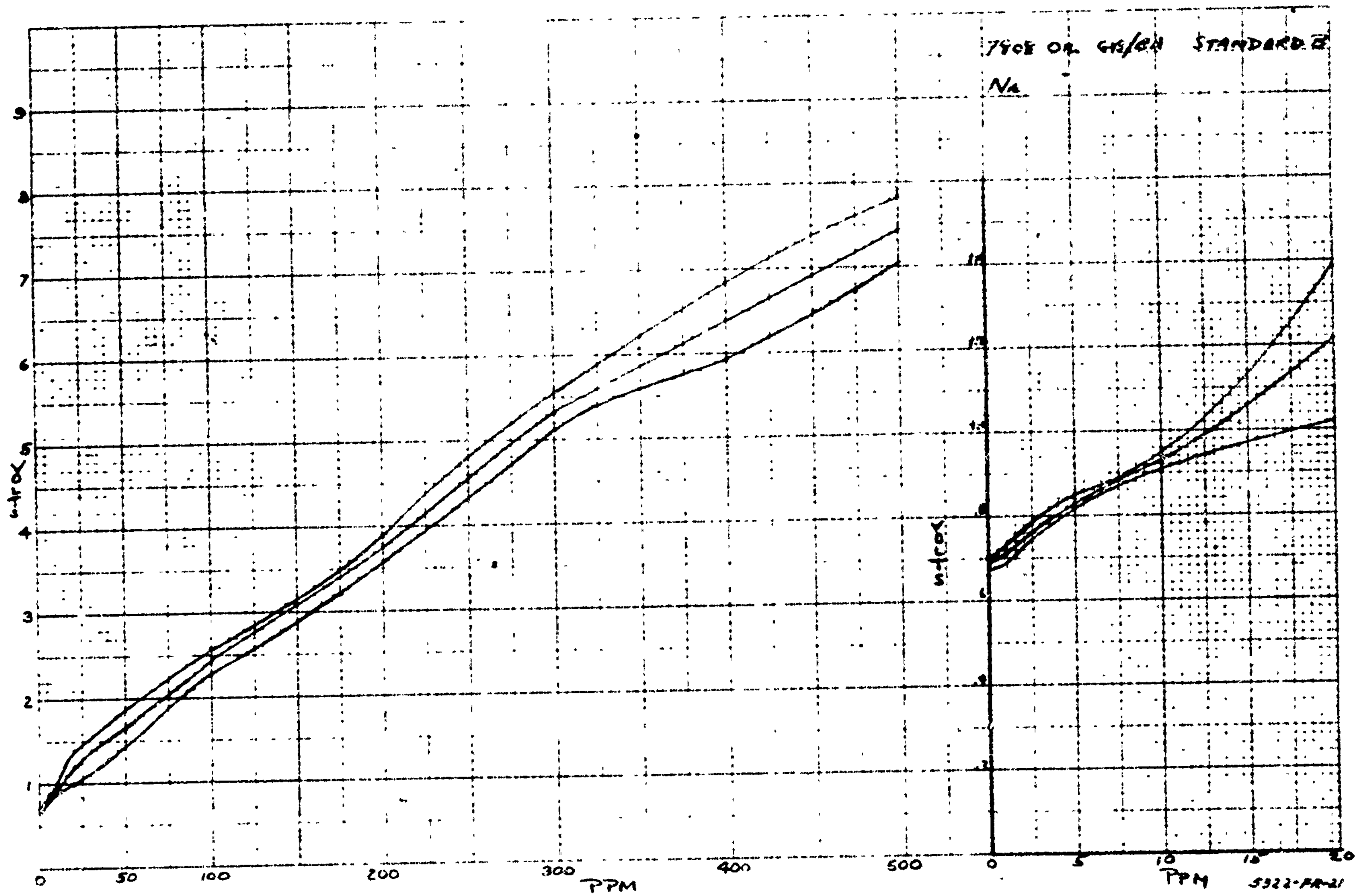


Figure A-15. Oil Type 7808 GB/BA Standard B, Nickel

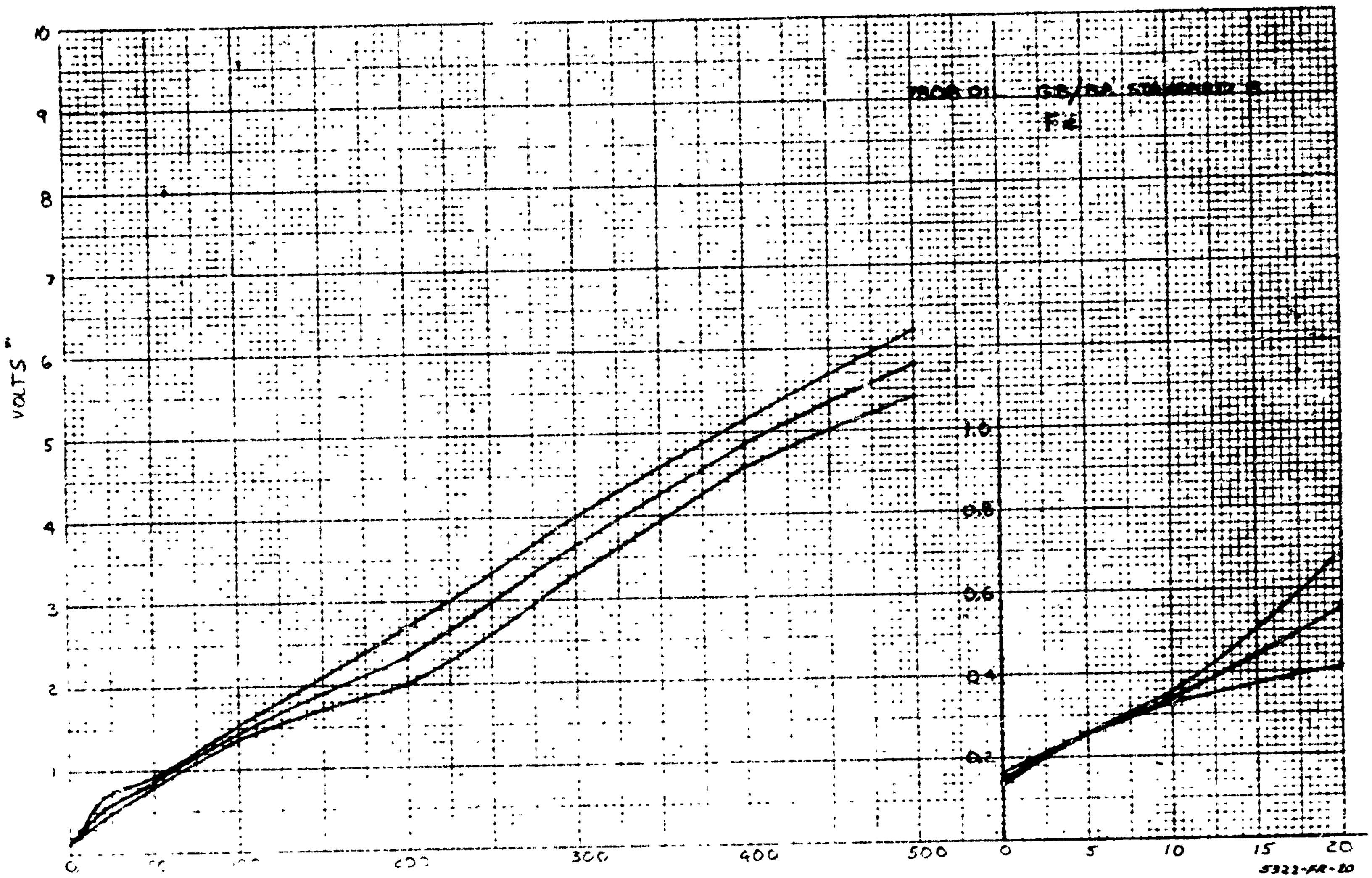


Figure A-16. Oil Type 7808. GB/BA Standard B

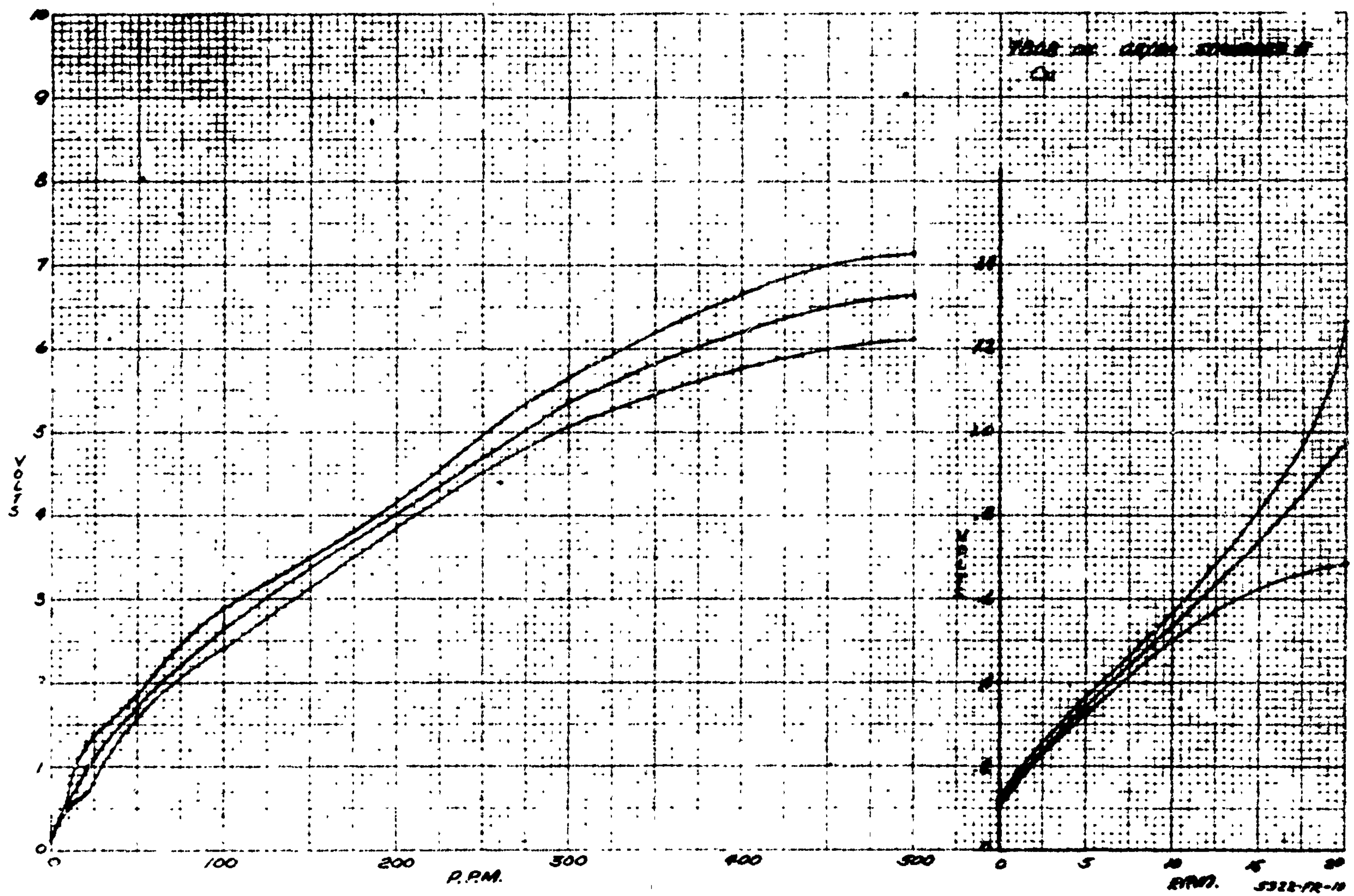


Figure A-17. Oil Type 7808 GB/BA Standard B, Copper

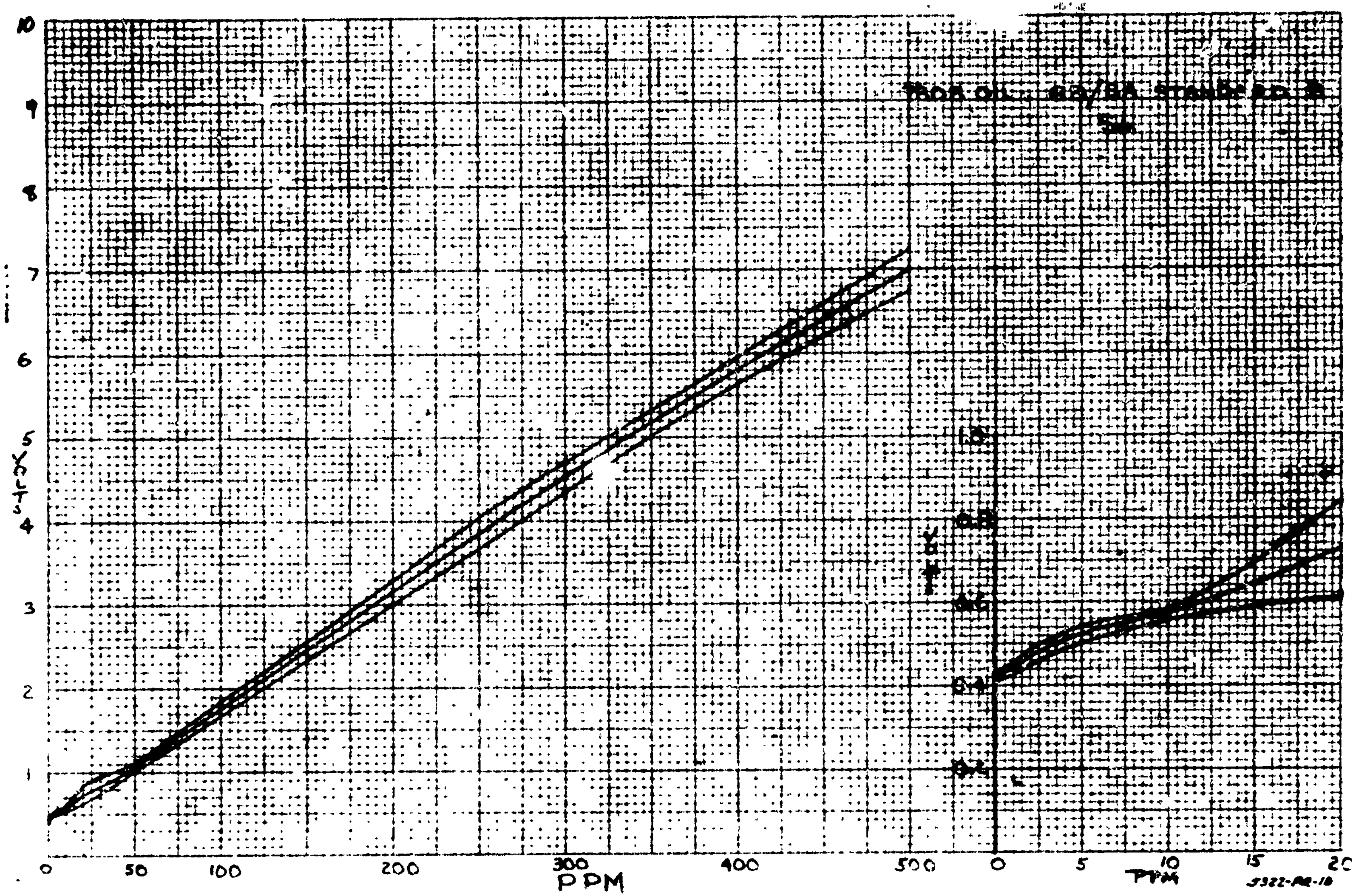


Figure A-18. Oil Type 7808 GB/BA Standard B, Tin

Table A-5

7808/GB/BA Standard C, Normalized Output Data (Sheet 1 of 2)

7808/GB/BA Standard C

OIL TYPE — DATE

REF. CAP. VALUE — MFD.

X CHANNEL CAP. VALUE — MFD.

BREAKS PER HALF CYCLE

RF AMPS.

ENTRANCE SLIT — MICRONS

EXIT SLIT — MICRONS

TEMPERATURE

CNCTRATN PPM	MG 1	CR 2	AL 3	PB 4	SI 5	AG 6	NI 7	FE 8	CU 9	SN 10	CV	DIVSR
500C	6.690	6.429	8.509	3.140	6.508	8.662	7.667	5.903	6.696	7.231	10.00	1.286
	.846	1.837	4.081	.649	1.356	2.405	1.053	1.211	1.073	.896		
SPREAD	.314	.588	1.419	.236	.452	.841	.319	.330	.359	.308		
400C	5.781	5.438	7.415	2.446	5.247	7.590	6.402	4.676	5.993	5.829	10.00	1.286
	.866	.378	3.576	.406	.696	1.396	.712	.877	.906	.527		
SPREAD	.306	.120	1.011	.129	.218	.488	.203	.301	.345	.159		
300C	4.823	4.602	5.915	1.870	4.029	6.500	5.198	3.664	5.097	4.525	10.00	1.230
	.671	.822	2.853	.408	.561	1.499	.669	.806	.799	.560		
SPREAD	.205	.275	.871	.129	.180	.608	.194	.259	.316	.168		
200C	3.897	3.534	4.367	1.314	2.744	5.283	3.957	2.586	4.078	3.138	10.00	1.339
	.541	.500	2.343	.197	.461	1.644	.432	.728	.656	.310		
SPREAD	.202	.139	.664	.076	.140	.552	.158	.251	.227	.098		
100C	2.491	2.268	2.618	.796	1.505	3.549	2.374	1.361	2.710	1.744	10.00	1.199
	.327	.462	1.257	.088	.090	1.032	.351	.236	.597	.158		
SPREAD	.119	.150	.413	.033	.030	.373	.120	.086	.376	.053		
50C	1.634	1.456	1.561	.604	1.000	2.237	1.657	.843	1.789	1.106	10.00	1.273
	.290	.232	.623	.087	.216	.599	.154	.085	.346	.123		

Table A-5

7808/GB/BA Standard C, Normalized Output Data (Sheet 2 of 2)

7808/GB/BA Standard C

SPREAD	.109	.080	.199	.031	.062	.217	.059	.028	.117	.040		
20C	.737	.703	.747	.440	.578	1.038	1.039	.445	.802	.662	10.00	1.380
	.176	.152	.158	.048	.167	.248	.320	.095	.079	.046		
SPREAD	.052	.049	.049	.016	.057	.083	.103	.033	.024	.017		
10C	.492	.559	.574	.407	.519	.723	.932	.354	.523	.578	10.00	1.373
	.054	.067	.295	.048	.199	.292	.110	.059	.107	.046		
SPREAD	.021	.019	.082	.013	.071	.095	.034	.019	.038	.016		
5C	.251	.450	.449	.363	.409	.483	.812	.248	.322	.499	10.00	1.450
	.072	.121	.154	.069	.022	.303	.109	.148	.230	.084		
SPREAD	.022	.038	.044	.020	.008	.088	.035	.041	.075	.025		
1C	.000	.369	.340	.345	.383	.307	.642	.170	.172	.438	10.00	1.293
	.000	.027	.079	.109	.133	.062	.577	.032	.038	.035		
SPREAD	.000	.009	.025	.035	.048	.019	.196	.010	.012	.008		
0C	.000	.334	.300	.328	.358	.290	.689	.154	.113	.430	10.00	1.319
	.000	.040	.116	.027	.100	.014	.062	.012	.025	.042		
SPREAD	.000	.013	.034	.007	.032	.005	.021	.004	.009	.012		

Table A-6

7808/GB/BA Standard C, Input Data, Concentration versus Clock Readings (Sheet 1 of 3)

7808/GB/BA Standard C

	MG	CR	AL	PB	SI	AG	NI	FE	CU	SN	CV
	1	2	3	4	5	6	7	8	9	10	
1 500C	9.9	12.1	1.6	25.6	11.4	4.2	7.1				32.9
		6.3	0.3	24.0	8.2	0.3	4.3	12.6			35.4
			11.0	23.3	8.2	5.9	4.6	10.6	9.1		35.4
				21.4	8.3	3.8	5.4	10.7	9.6	7.9	33.5
	7.3				7.1	2.8	5.3	10.3	8.2	6.4	32.9
	8.1	8.6				0.8	4.9	11.0	6.4	6.9	35.2
	7.7	9.2	2.7				5.7	10.3	7.7	5.4	32.8
	7.3	8.4	2.2	21.8				8.5	7.3	5.9	32.9
[illegible]00C	11.1	13.0	2.8	28.0	12.9	5.7	8.8				33.8
		11.6	5.1	28.5	13.2	4.6	9.2	16.8			33.6
			13.4	27.4	12.4	7.4	8.8	15.8	11.8		34.2
				27.9	13.5	7.5	9.8	16.7	12.3	11.6	32.3
	10.0				11.2	4.9	07.6	14.3	09.3	10.3	34.0
	11.1	12.3				3.8	09.2	15.7	09.4	11.1	32.8
	10.3	12.0	05.8				09.1	14.3	09.2	10.8	32.4
	09.5	11.7	05.4	26.4				13.1	09.5	09.8	32.3
	12.5	12.5	05.6	29.4	13.8				10.3	10.9	33.4
	12.4	12.2	5.3	29.7	13.4	5.0				11.1	32.9
300C	15.2	16.5	7.6	34.6	19.7	9.9	13.1				33.7
		14.7	8.6	32.8	17.4	6.3	12.5	20.6			33.8
			18.4	32.9	17.7	10.9	13.1	20.8	14.5		34.2
				31.5	16.9	9.5	12.0	17.5	13.2	15.5	33.9
	13.9				18.2	10.7	13.5	20.3	14.7	17.3	32.8
	14.2	14.9				6.4	12.9	21.3	11.7	15.6	33.8
	14.5	16.6	10.5				14.6	21.8	13.9	16.4	30.5
	13.7	14.8	9.9	32.7				18.8	11.8	15.4	32.8
	16.1	17.5	11.5	35.9	19.1				14.8	16.1	31.9
	15.0	13.9	8.8	34.6	18.4	7.2				14.8	33.8
[illegible]00C	18.8	21.1	12.6	40.4	25.5	12.7	18.0				32.7
		20.6	16.1	41.9	26.4	12.6	19.6	29.6			33.6
			24.2	39.1	25.4	16.6	18.3	26.6	20.1		34.4
				39.3	25.5	14.9	18.8	26.5	18.8	23.6	33.8
	17.5				24.4	12.8	17.8	25.2	17.0	23.4	34.1
	18.3	19.2				10.3	17.6	27.6	16.8	22.4	33.8
	19.3	22.0	17.1				19.8	30.2	18.5	24.4	31.3
	17.6	20.9	16.6	39.9				24.5	16.9	22.6	32.2
	20.1	21.1	16.7	42.1	26.6				17.7	22.8	32.9
	20.4	20.8	14.5	41.6	27.8	10.2				23.1	32.1
1 [illegible]	28.9	32.4	24.8	51.3	37.9	22.8	29.8				32.8
		28.5	24.9	51.4	37.2	19.6	28.1	40.6			34.2

Table A-6

7808/GB/BA Standard C, Input Data, Concentration versus Clock Readings (Sheet 2 of

7808/GB/BA Standard C

				36.2	49.4	37.7	24.8	29.5	40.9	28.3		33.4
					49.5	37.7	19.9	29.2	40.3	26.3	35.7	33.1
		26.3	28.6				18.7	26.9	37.8	23.9	33.9	33.8
		28.1	30.2	25.9				29.2	41.2	26.5	34.5	31.0
		26.8	29.7	25.8	50.3				38.7	25.7	35.4	32.1
		28.6	30.4	27.1	51.6	38.4				20.2	34.8	32.7
		28.2	28.2	25.1	50.8	38.3	19.2				35.3	34.3
1	50C	38.3	40.9	35.2	56.9	43.8	32.6	37.3				32.8
			37.8	35.5	57.6	46.4	28.8	35.4	49.7			33.6
				44.2	56.0	46.5	33.7	35.7	49.5	37.1		34.4
					54.7	46.6	29.6	35.9	49.8	35.9	44.9	33.2
		34.7				45.2	28.1	35.4	48.3	34.1	43.9	34.6
		36.2	37.6				28.4	35.4	50.3	33.8	43.5	34.3
		35.7	38.6	36.4				36.6	50.0	33.1	44.3	33.7
		35.2	39.5	37.8	54.9				48.7	33.6	44.1	31.8
		38.[illegible]	37.8	36.1	57.1	48.1				33.6	44.9	34.7
		35.6	37.7	36.1	55.8	45.9	29.1				42.7	33.1
1	20C	55.6	56.6	51.0	61.4	59.6	48.3	46.2				31.8
			52.8	50.8	63.2	58.8	43.8	44.4	64.4			31.4
				55.3	62.4	58.1	46.4	43.7	62.0	50.8		34.9
					62.8	55.4	46.6	44.2	62.7	51.6	55.1	34.9
		52.3				58.2	44.3	44.8	64.2	50.1	53.7	34.3
		51.6	52.0				44.8	44.0	60.8	50.3	54.8	33.4
		51.1	52.3	51.7				50.4	60.1	50.1	54.4	32.7
		50.6	53.6	51.4	62.1				61.9	59.6	53.7	30.6
		52.4	52.7	51.5	63.6	55.7				50.8	54.6	32.8
		51.8	5[illegible].0	51.8	61.6	53.9	43.4				53.8	31.5
1	10C	59.1	57.4	51.8	63.8	60.8	49.4	46.6				31.8
			58.7	57.8	64.3	61.4	51.3	47.5	66.7			32.5
				61.8	63.6	56.4	54.4	49.0	65.9	61.6		33.4
					64.2	54.4	54.5	47.4	66.3	60.9	56.8	32.6
		59.7				60.5	57.0	47.4	65.4	58.2	57.9	35.1
		59.4	58.2				50.9	47.8	68.6	57.7	57.3	33.0
		59.9	57.6	58.4				46.6	00.0	57.4	56.9	33.2
		61.2	57.6	57.6	65.2				67.7	58.2	57.6	32.6
		61.1	57.9	57.8	64.1	60.2				59.4	56.3	32.2
		61.3	56.3	56.1	62.8	61.6	50.6				56.3	31.6
1	5C	77.1	62.1	59.2	66.4	00.0	59.9	50.4				34.4
			61.5	62.7	66.3	64.3	58.0	49.9	73.4			33.2
				66.3	63.9	63.4	50.3	50.2	69.8	68.7		33.4
					66.5	63.6	59.7	49.5	73.6	65.3	59.7	33.8
		72.5				64.5	62.3	49.7	72.5	65.4	59.6	32.7

Table A-6

7808/GB/BA Standard C, Input Data, Concentration versus Clock Readings (Sheet 3 of 3)

7808/GB/BA Standard C

		00.0	66.4				70.4	52.9	83.1	83.8	62.3	33.2
		73.6	61.7	60.9				49.5	73.5	68.6	59.8	31.8
		74.1	61.5	62.8	66.8				73.7	69.1	59.3	31.6
		73.[illegible]	60.6	61.8	67.6	64.1				65.4	60.3	33.9
		71.2	60.7	61.3	66.8	63.7	56.3				58.8	30.5
1	1C	00.0	66.8	64.3	63.0	65.7	72.4	53.1				34.5
			66.4	68.2	67.5	66.4	69.4	52.4	00.0			31.8
				68.7	67.4	60.9	69.4	52.7	79.3	82.4		34.6
					68.3	62.6	68.4	52.1	81.4	79.3	62.8	34.1
		00.0				66.8	69.5	82.5	81.0	81.0	62.5	33.7
		00.0	66.4				70.4	52.3	83.1	83.8	62.3	33.2
		00.0	65.9	68.3				52.7	81.8	82.3	62.3	32.6
		00.0	65.7	68.5	67.7				82.5	79.8	61.9	32.4
		00.0	65.4	67.4	68.9	67.5				80.3	63.3	32.8
		00.0	65.3	68.0	68.9	67.5	68.2				62.6	32.8
1	0C	00.0	68.5	65.5	68.4	62.6	73.9	54.1				34.2
			69.0	70.0	67.6	67.6	73.8	54.0	00.0			33.7
				70.0	68.7	67.6	73.5	54.4	84.0	91.6		34.4
					68.4	66.8	73.2	53.1	83.2	87.2	62.7	33.6
		00.0				67.1	74.4	53.3	82.6	91.7	62.8	33.4
		00.0	68.1				73.4	53.0	82.9	88.1	62.8	33.1
		00.0	67.2	71.2				52.6	83.9	90.4	62.8	31.7
		00.0	67.4	70.5	69.3				84.2	90.3	62.3	31.1
		00.0	68.8	72.9	68.3	67.9				88.0	64.3	33.4
		00.0	66.6	71.3	68.5	66.9	74.2				62.8	32.4

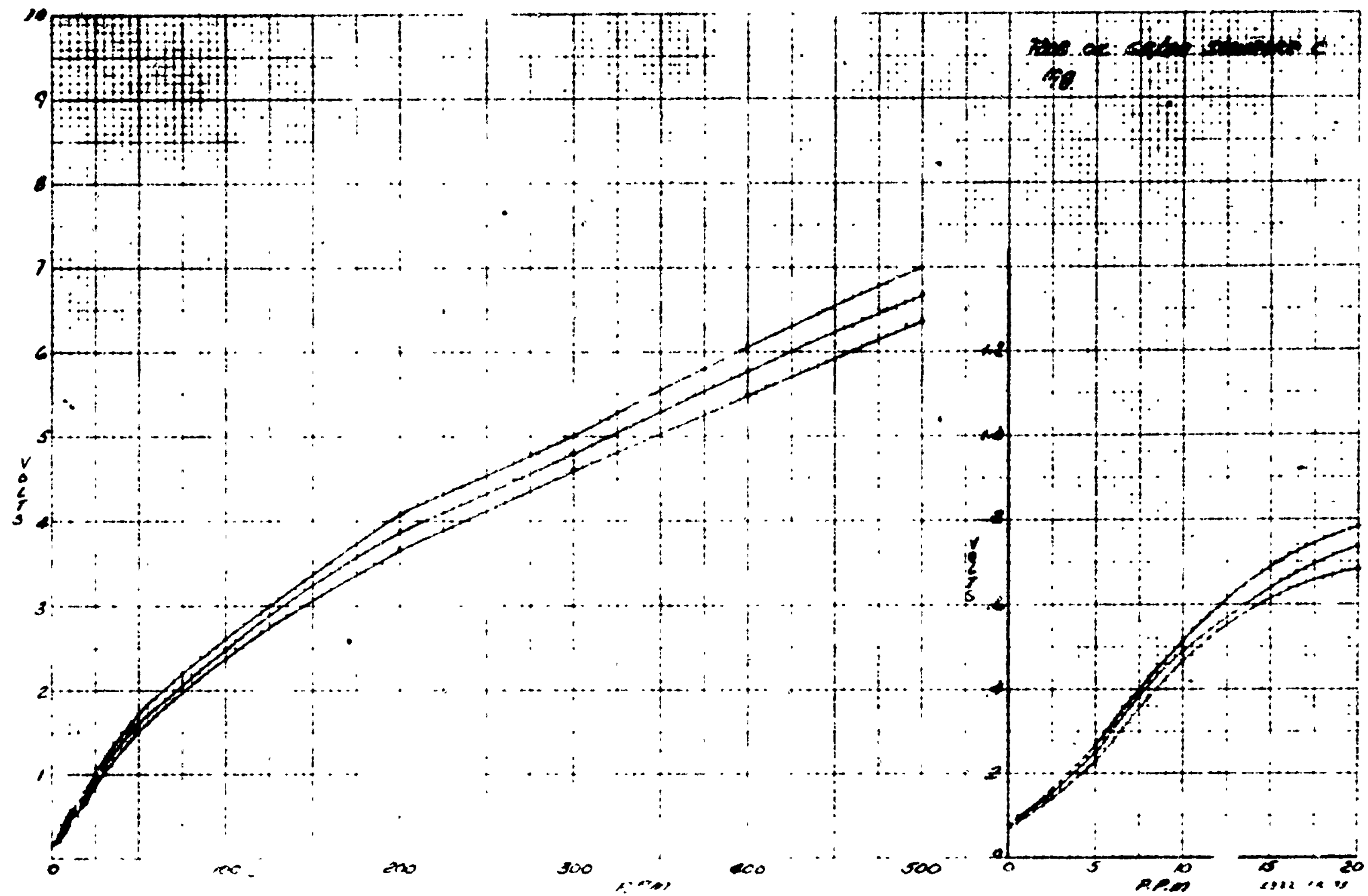


Figure A-19. Oil Type 7808 GB/BA Standard C, Magnesium

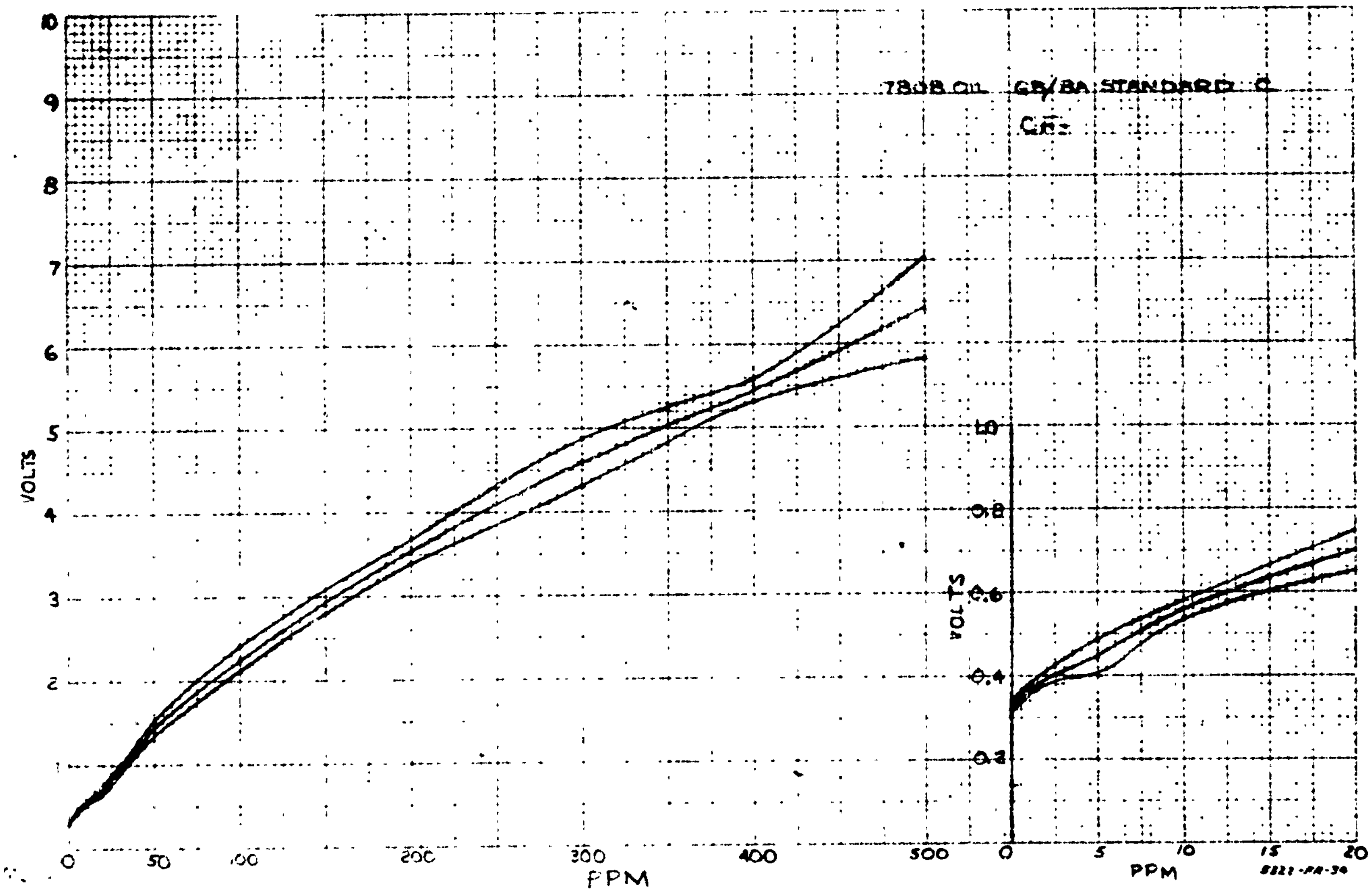


Figure A-20. Oil Type 7808 GB/BA Standard C. Chromium

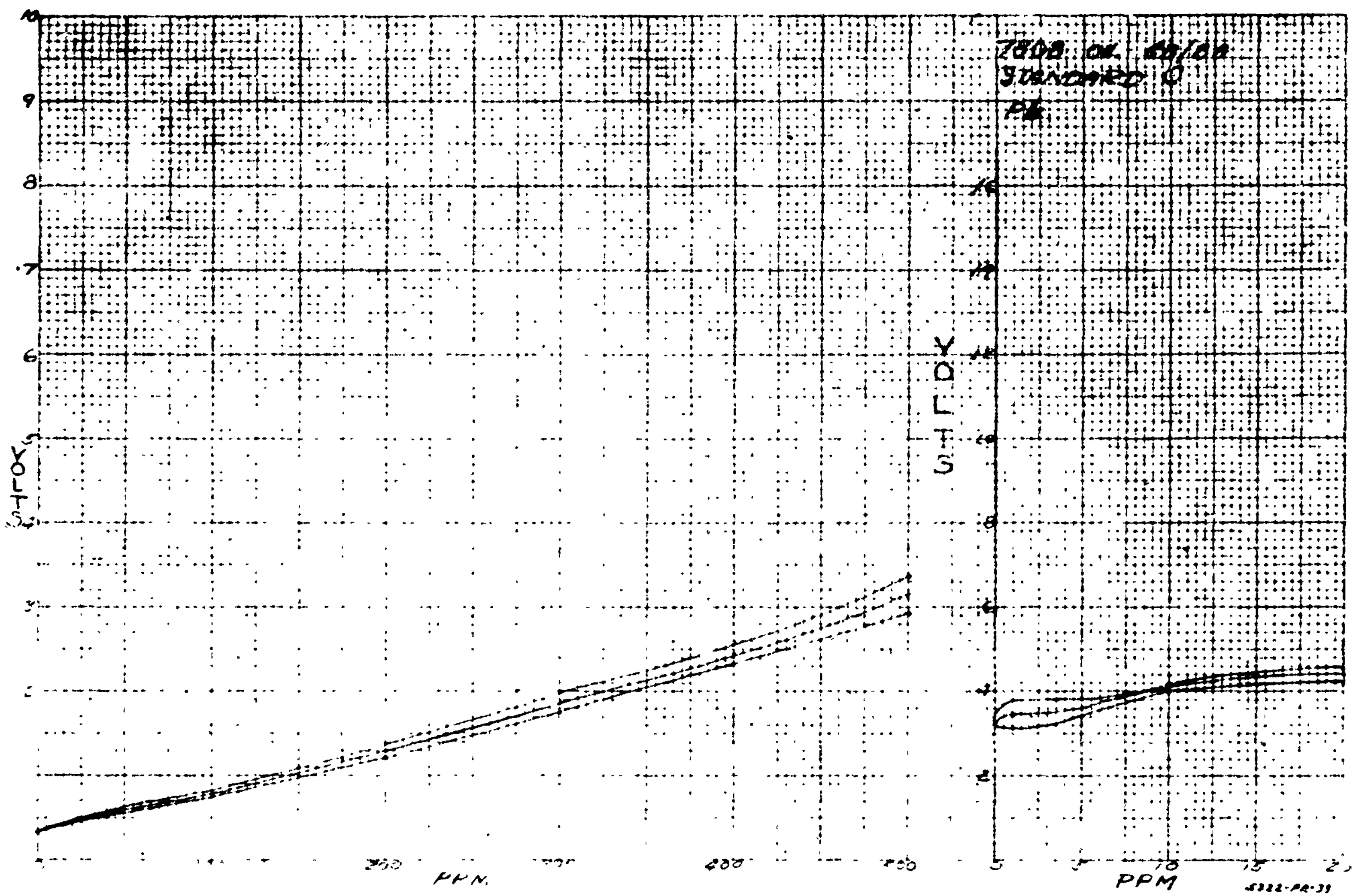


Figure A-21 Oil Type 7808 GB/BA Standard C, Lead

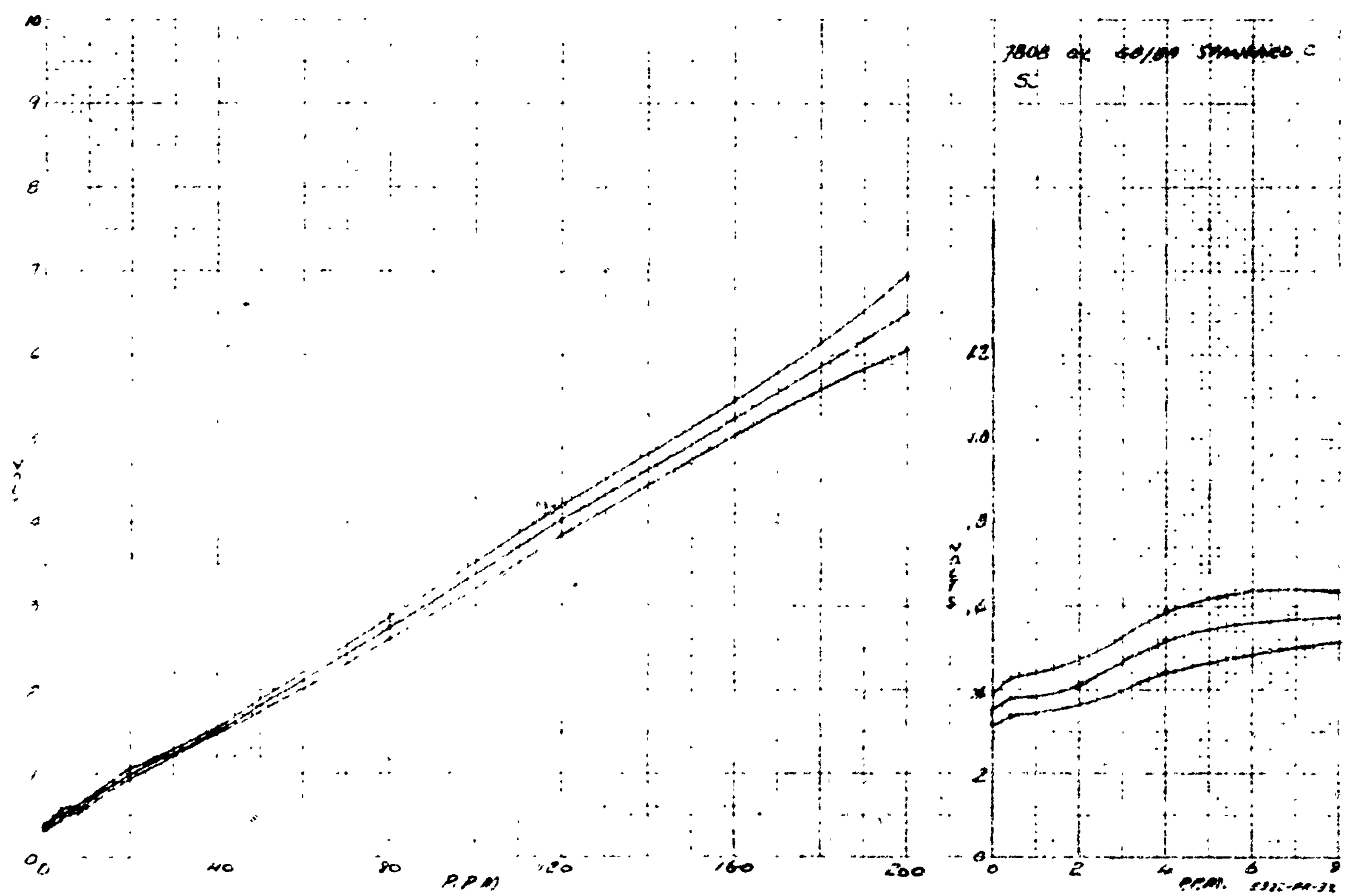


Figure A-22. Oil Type 7808 GB/BA Standard C. Silicon

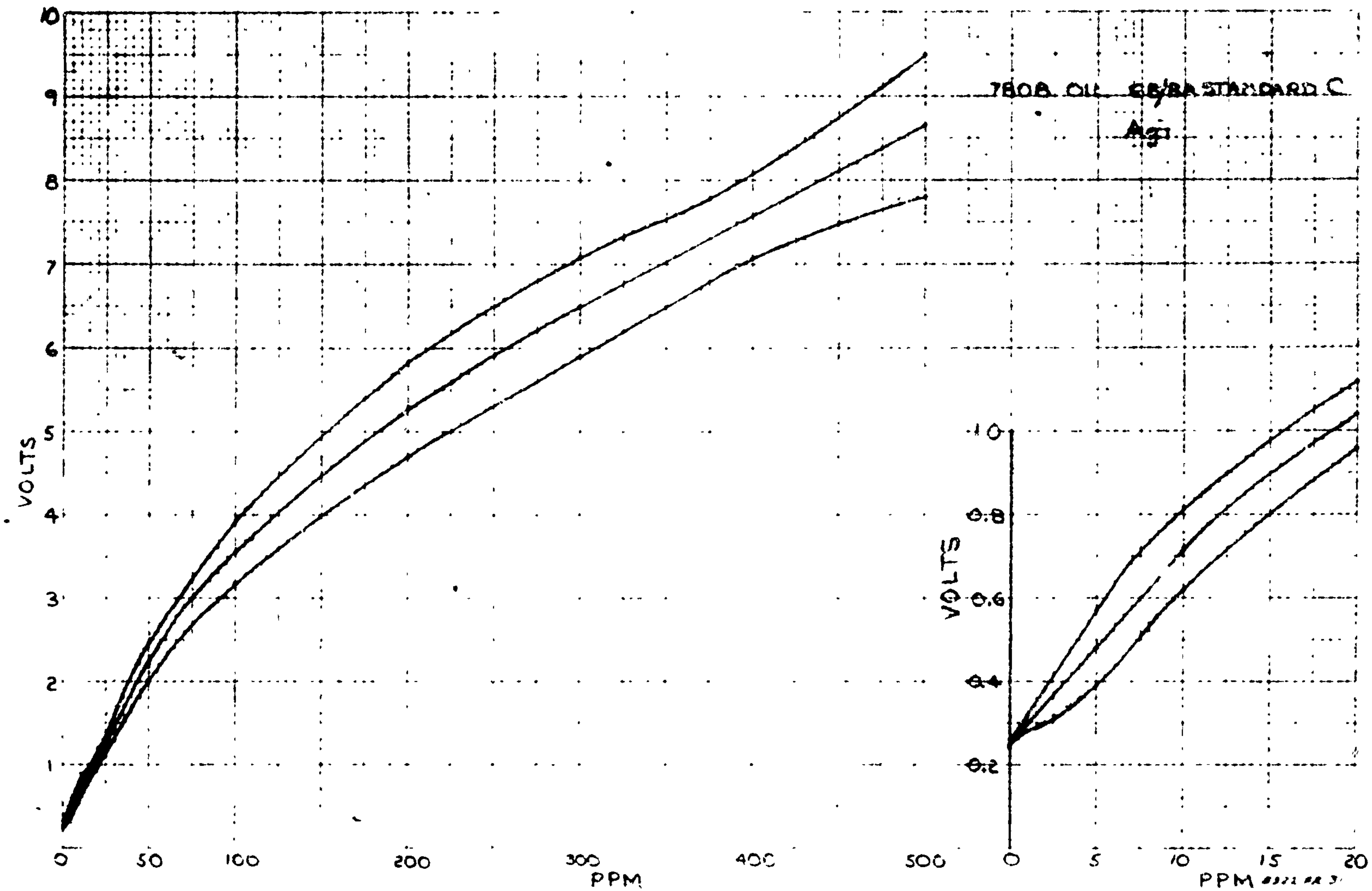


Figure A-23 Oil Type 7808 GB/BA Standard C Silver

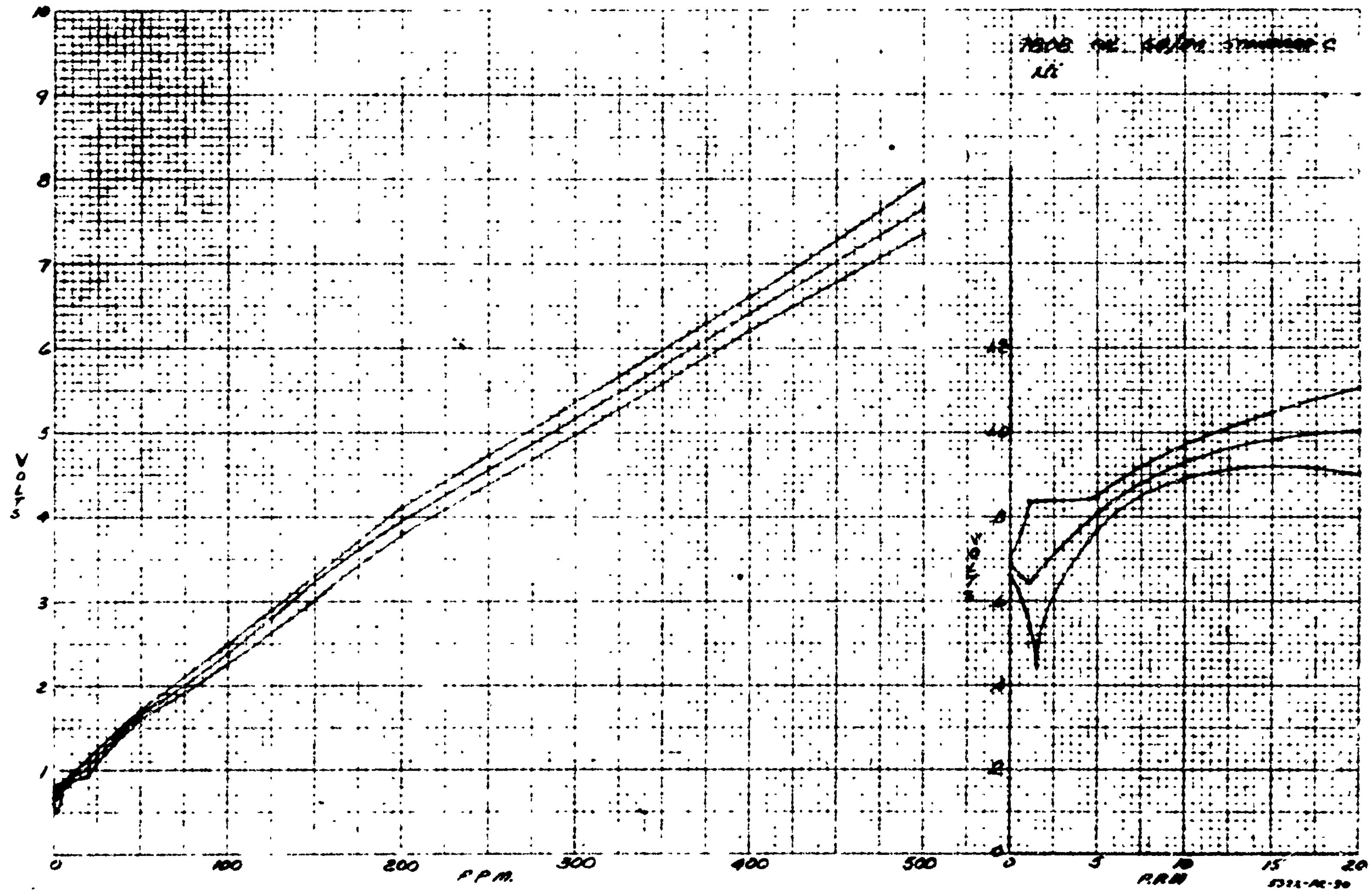


Figure A-24. Oil Type 7808 GB/BA Standard C, Nickel

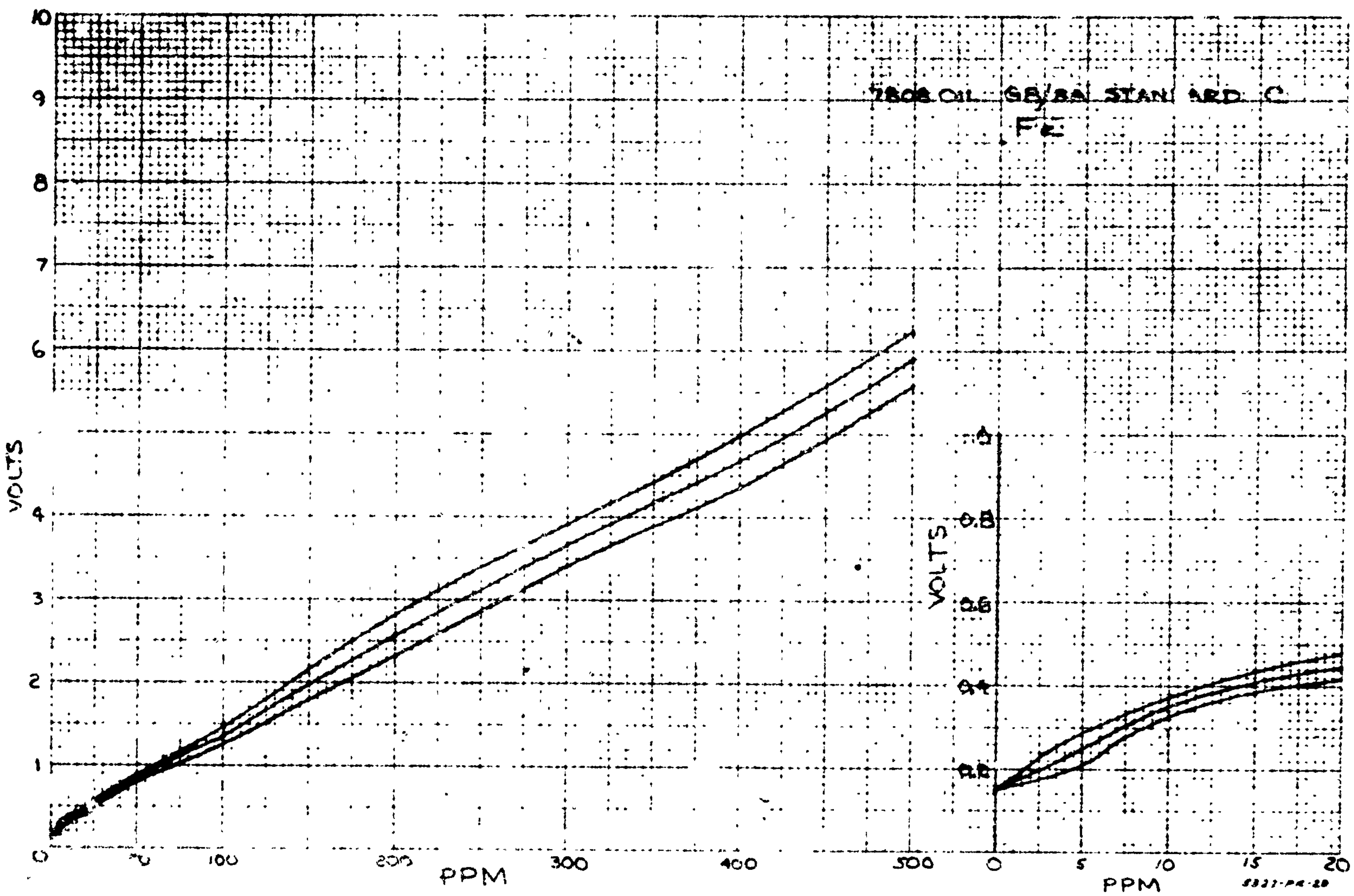


Figure A-25. Oil Type 7808 GB/BA Standard C, Iron

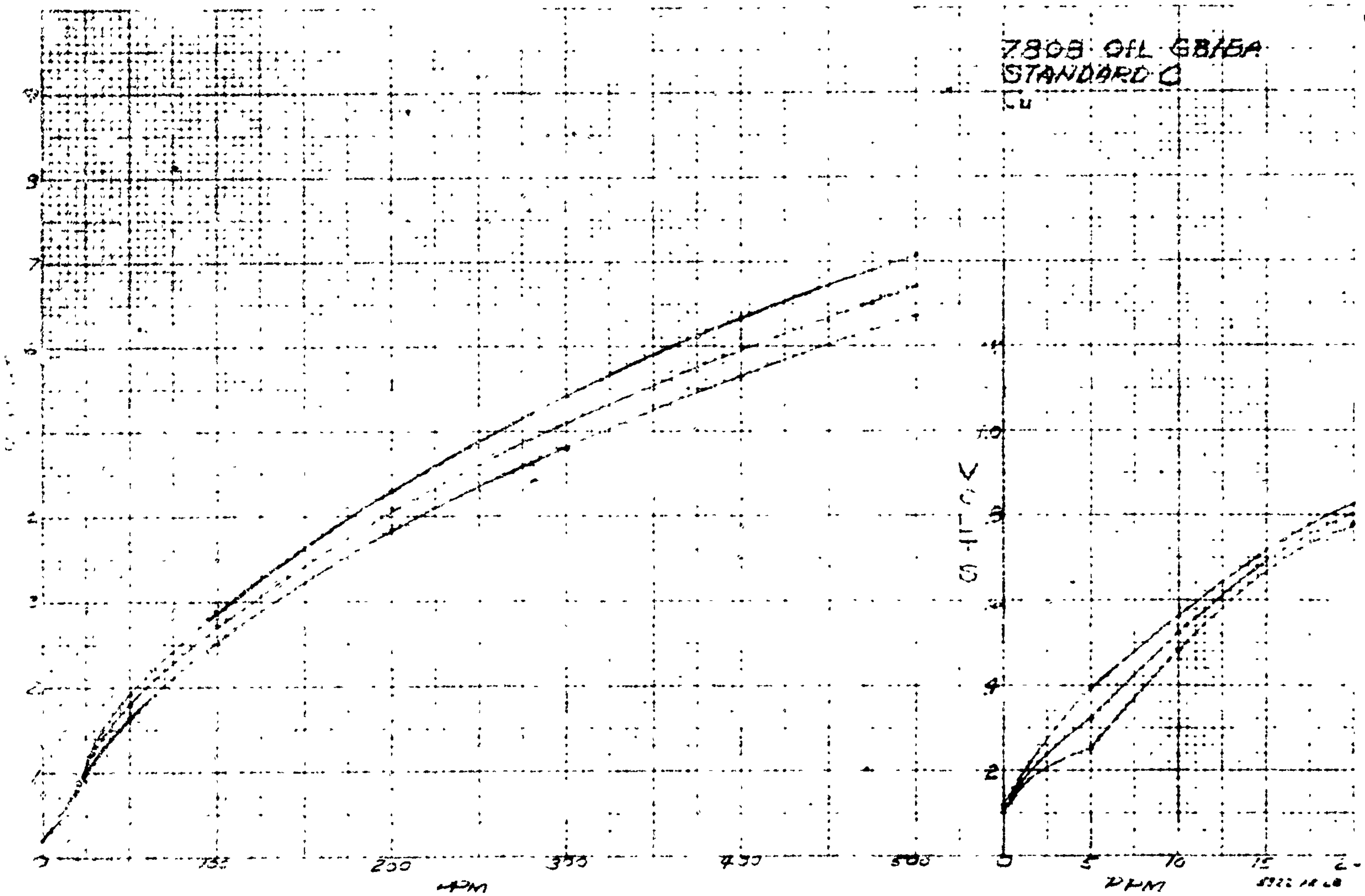


Figure A-26. Oil Type 7808 GB/BA Standard C, Copper

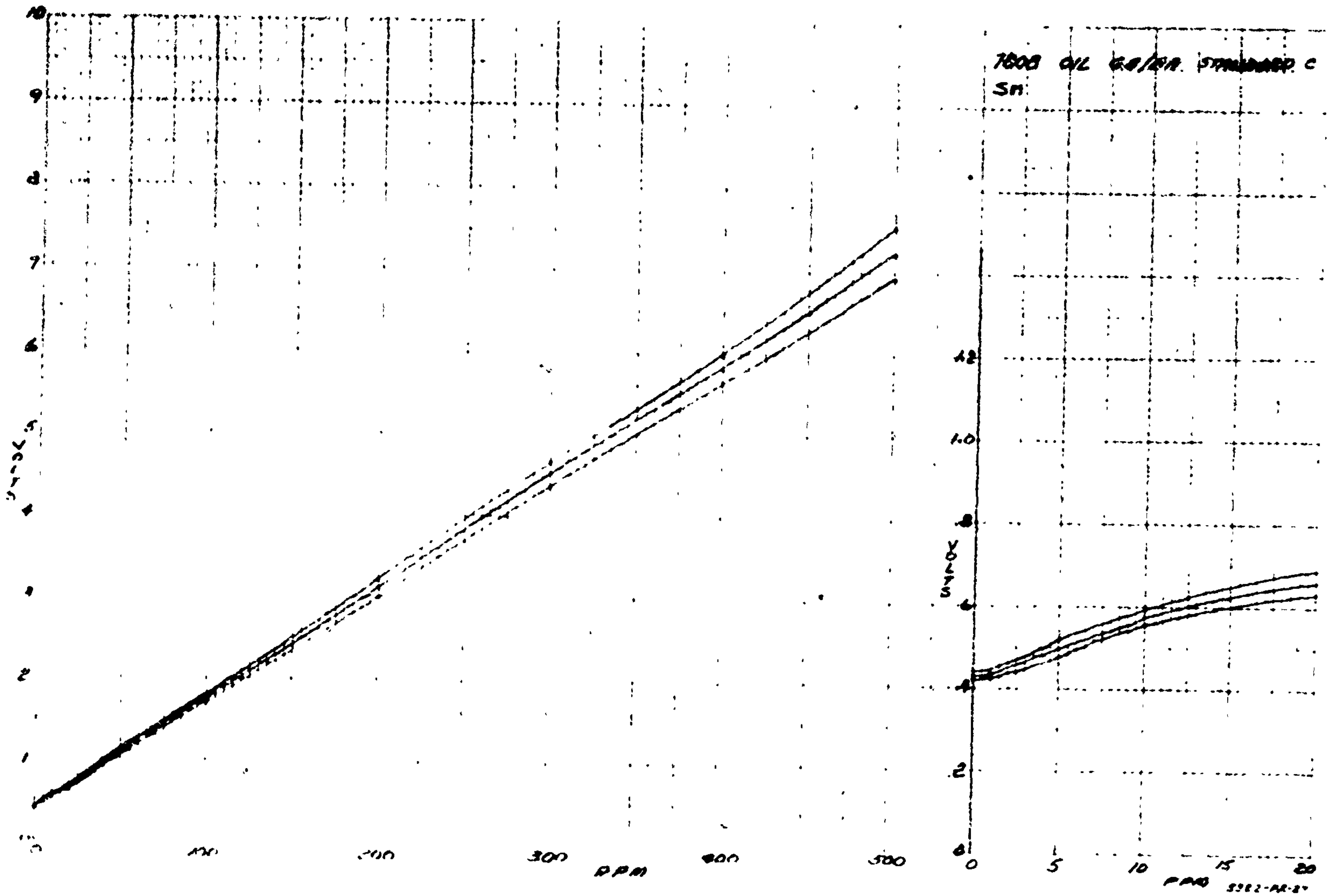


Figure A-27.. Oil Type 7808 GB/BA Standard C, Tin

Table A-7

7808 GB/BA Standards B and C, Normalized Output Data (Sheet 1 of 3)

7808 GB/BA Standard B and C

OTL TYPE

DATE

REF. CAP. VALUE 10 MFD.

X CHANNEL CAP. VALUE 01 MFD.

BREAKS PER HALF CYCLE 6

RF AMPS. 4

ENTRANCE SLIT 50 MICRONS

EXIT SLIT 25 MICRONS

TEMPERATURE

CNCTRATN PPM										AL	CV	DIVSR
400B	.000	.000	.000	.000	.000	.000	.000	.000	.000	6.052	10.00	1.436
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.689		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.290		
300B	.000	.000	.000	.000	.000	.000	.000	.000	.000	5.398	10.00	1.458
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.243		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.104		
200B	.000	.000	.000	.000	.000	.000	.000	.000	.000	3.972	10.00	1.345
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.159		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.067		
100B	.000	.000	.000	.000	.000	.000	.000	.000	.000	2.390	10.00	1.450
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.177		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.080		
50B	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.385	10.00	1.299
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.027		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.013		
20B	.000	.000	.000	.000	.000	.000	.000	.000	.000	.750	10.00	1.199
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.048		

Table A-7

7808/GB/BA Standards B and C, Normalized Output Data. (Sheet 2 of 3)

7808 GB/BA Standard B and C

SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.021		
10B	.000	.000	.000	.000	.000	.000	.000	.000	.000	.553	10.00	1.242
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.013		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.005		
5B	.000	.000	.000	.000	.000	.000	.000	.000	.000	.408	10.00	1.465
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.016		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.007		
1B	.000	.000	.000	.000	.000	.000	.000	.000	.000	.288	10.00	1.236
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.005		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.002		
0B	.000	.000	.000	.000	.000	.000	.000	.000	.000	.250	10.00	1.273
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.029		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.013		
400C	.000	.000	.000	.000	.000	.000	.000	.000	.000	6.149	10.00	1.325
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.403		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.183		
300C	.000	.000	.000	.000	.000	.000	.000	.000	.000	5.565	10.00	1.293
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.439		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.207		
200C	.000	.000	.000	.000	.000	.000	.000	.000	.000	4.296	10.00	1.458
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.360		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.157		
100C	.000	.000	.000	.000	.000	.000	.000	.000	.000	2.489	10.00	1.386
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.275		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.115		
50C	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.479	10.00	1.373
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.124		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.055		
20C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.695	10.00	1.180
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.052		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.023		

Table A-7

7808 GB/BA Standards B and C, Normalized Output Data (Sheet 3 of 3)

7808 GB/ BA Standard B and C

10C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.529	10.00	1.407
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.052		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.021		
5C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.402	10.00	1.211
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.036		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.015		
1C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.285	10.00	1.261
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.015		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.006		
0C	.000	.000	.000	.000	.000	.000	.000	.000	.000	.253	10.00	1.261
	.000	.000	.000	.000	.000	.000	.000	.000	.000	.019		
SPREAD	.000	.000	.000	.000	.000	.000	.000	.000	.000	.008		

Table A-8

7808 GB/BA Standards B and C Input Data, Concentration versus Clock Readings
(Sheet 1 of 2)

Input Data 7808 GB/BA Standards B and C

		AL	CV
1	400B	9.7	33.4
		9.1	32.7
		11.4	30.7
1	300B	11.8	33.0
		12.5	31.3
		12.7	30.4
1	200B	18.6	32.0
		18.0	32.2
		18.8	32.0
1	100B	28.2	33.3
		28.1	33.4
		29.6	30.5
1	50B	39.8	31.7
		39.4	32.6
		39.4	32.7
1	20B	52.6	30.8
		51.3	31.0
		51.5	34.3
1	10B	57.9	31.0
		57.6	32.1
		58.1	33.6
1	5B	63.7	32.7
		63.7	32.4
		64.5	30.3
1	1B	71.2	32.3
		70.8	32.9
		70.8	32.9
1	0B	75.3	32.1
		72.9	32.7
		73.1	33.1
1	400C	8.9	33.1
		10.2	30.3
		10.1	32.3
1	300C	12.8	32.2
		11.2	33.4
		11.2	32.8
1	200C	16.3	33.6
		18.0	31.7
		17.7	30.4
1	100C	26.6	33.5

Table A-8

7808 GB/BA Standards B and C Input Data, Concentration versus Clock Readings
(Sheet 2 of 2)

Input Data 7808 GB/BA Standards B and C

		28.1	32.9
		28.8	31.4
1	50C	37.6	32.1
		37.8	33.4
		39.3	31.6
1	20C	53.9	32.5
		52.4	32.8
		53.7	31.4
1	10C	58.8	33.7
		59.8	32.1
		57.8	31.1
1	5C	65.0	32.5
		63.2	31.7
		64.6	34.1
1	1C	70.7	32.1
		71.8	31.4
		70.9	33.3
1	0C	74.1	30.8
		72.6	32.9
		73.8	33.3

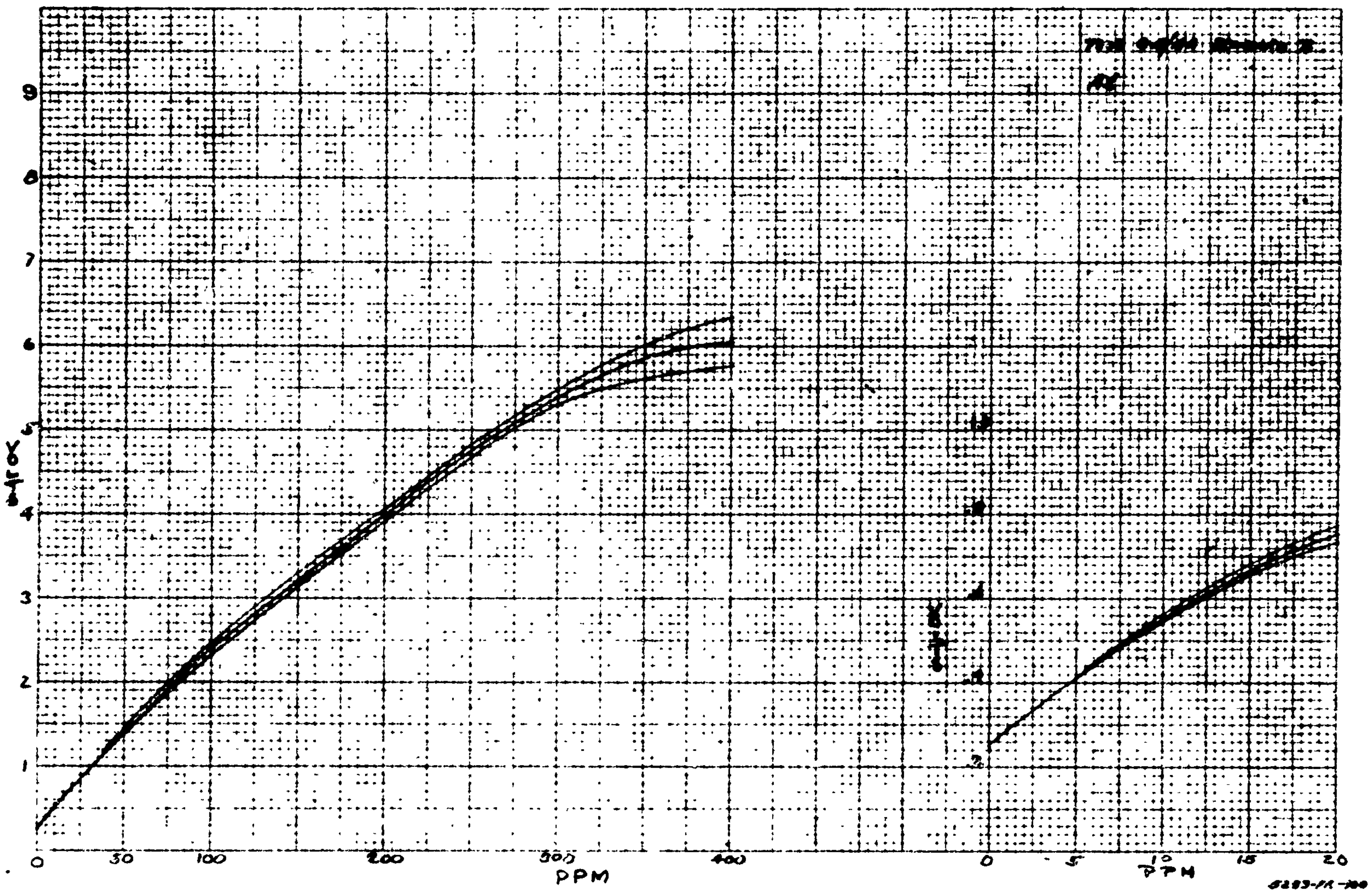


Figure A-28. Oil Type 7808 GB/BA Standard B, Aluminum

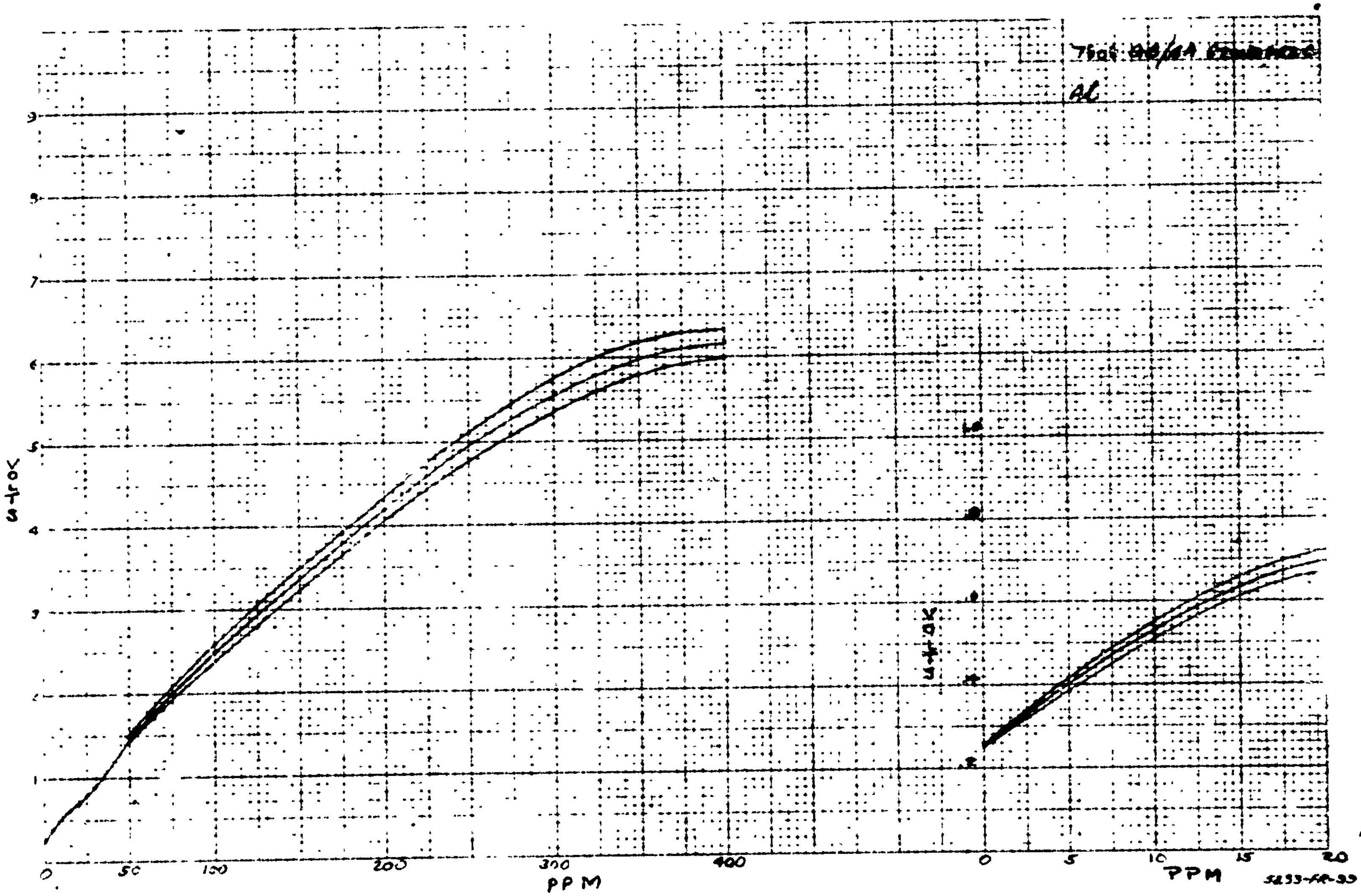


Figure A-29. 7808 GB/BA Standard C, Aluminum

APPENDIX B

ELECTROMAGNETIC INTERFERENCE
TEST REPORT
ON
BAIRD-ATOMIC OIL ANALYZER

ELECTROMAGNETIC INTERFERENCE

TEST REPORT

ON

BAIRD ATOMIC OIL ANALYZER

NOVEMBER 24, 1964

TEST REPORT NO. 248

TEST PERFORMED FOR: BAIRD ATOMIC, INC.
95 SECOND AVENUE
WALTHAM, MASS.

TEST PERFORMED BY: INTERFERENCE CONTROL
SANDERS ASSOCIATES, INC.
95 CANAL STREET
NASHUA, N. H.

PURPOSE

An evaluation to determine the interference level of the oil analyzer and suppress the level below MIL-I-26600 specification limit.

PROCEDURE

Conducted and radiated measurements were performed in accordance with the procedure outlined in MIL-I-26600.

TEST RESULTS

Broadband conducted measurements were performed on the unit as received. The levels, shown on Graph 1, varied from 108db uv/mc to 155db uv/mc : which is 5db to 70db above the specification limit. There was a 10db to 20db decrease when the gaps were altered as shown on Graph 2. The unit was still 65db above the specification limit at 4Mc. The analyzer was enclosed in a galvanized container and interference filters were installed on the input power leads. The level dropped below the specification limit except at 0.15Mc where it was 8db above the specification. Graph 3 shows this level.

Broadband radiated interference measurements were conducted on the oil analyzer as received. The interference level, shown on Graphs 4 and 5, varied from 165db uv/mc at .15Mc to 52db uv/mc at 10KMC, which is 30db to 80db above the specification limit. A copper screen was placed over the unit and grounded to the base (ground plane). This screen improved the level at the low end only as shown on Graphs 6 and 7. The coaxial loop was installed inside the container to determine its effect. No change was observed as shown on Graph 8. An aluminum shield was then placed over the coaxial line loop but no decrease in level was noted (Graph 9). A galvanized enclosure was placed over the copper enclosure. No basic improvement was observed except for a slight variation at the low frequency end.

Probing indicated that the leakage radiated from the prime power leads and from the base of the shield. Line filters were installed on the prime power leads. This decreased the level across the whole frequency range. The unit was still 0db to 20db above the specification limit above 30Mc as shown on Graphs 11 and 12.

SUPPRESSION

The oil analyzer was enclosed by a copper screen furnished by Baird Atomic. A galvanized container also furnished by Baird Atomic was placed over the copper screen. A better seal at the base of the container was necessary to decrease the interference level. The power leads were filtered with a Sprague JN17-989A filter to stop power line radiation.

CONCLUSIONS

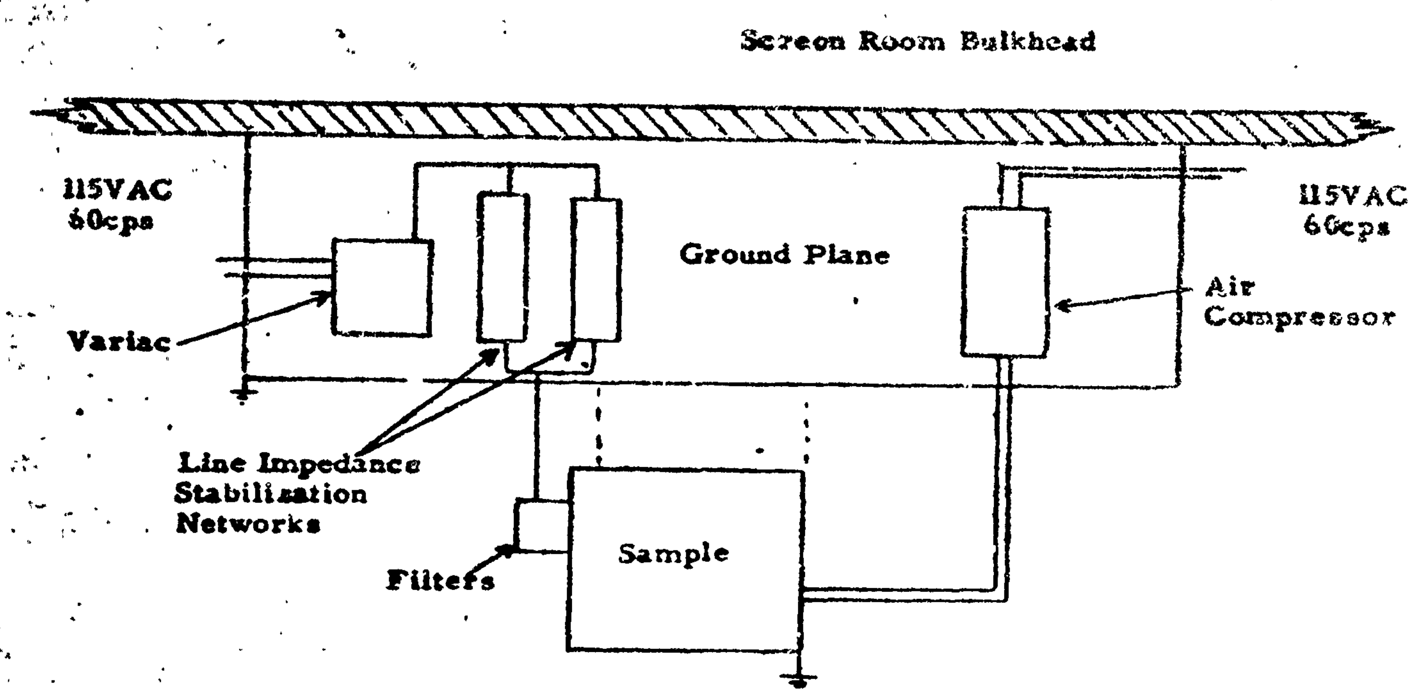
Broadband conducted interference measurements were conducted on the oil analyzer as received. The levels varied from 108db uv/mc to 155db uv/mc (5db to 70db above the specification limit. Except for one point, the level dropped below the specification when the analyser was enclosed in a galvanized container and suppression filters were placed on the input power leads. This point occurred at 0.15Mc where it was 8db above the specification limit.

Broadband radiated interference measurements were conducted on the oil analyzer as received. The levels varied from 165db uv/mc at 15Mc to 52db uv/mc at 10KMC (30db to 80db above the specification limit). A 30db to 50db improvement was observed at the low frequency end when a copper screen and a galvanised screen was placed over the oil analyzer. Probing indicated that the leakage radiated from the prime power leads and from the base of the shield. Line filters were installed and the radiation remeasured. The level was within specification up to 30Mc and was out of specification by 0db to 20db above 30Mc.

It was felt that tightening the base of the enclosure and the opening for the air will decrease the radiation. Filtering the power leads with a Sprague JN17-989A filter will further decrease the interference level.

R. Rancourt

R. Rancourt
Test Engineer


Screen Room Bulkhead
115VAC
60cps
Ground Plane
115VAC
60cps
Air
Compressor
Variac
Line Impedance
Stabilization
Networks
Sample
Filters

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ______

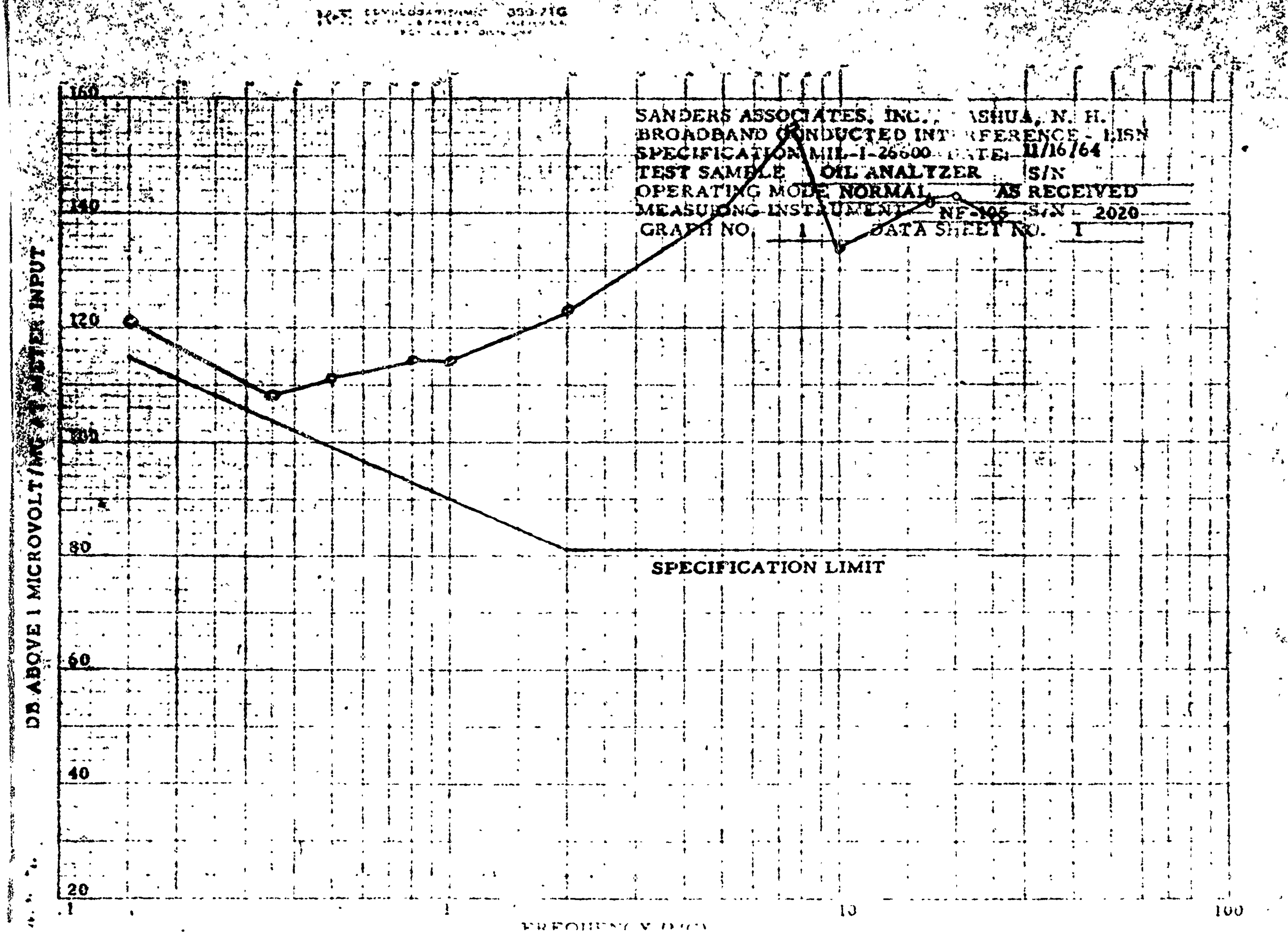
TEST SAMPLE:
MODEL OR TYPE [illegible]
SERIAL ______
TEST INFO:
DATA SHEET NO 1 - [illegible]
DATE [illegible] 64
CONTRACT NO ______

MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO:
NO [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READINGS DB/MC LINE NO 1	LINE NO 2	LINE NO 3	LINE NO 4	LINE NO 5	LINE NO 6	SPEC LIMIT	AMBIENT	REMARKS
[illegible]	121								115 VAC [illegible]
[illegible]	106								
[illegible]	[illegible]								NORMAL GAP
[illegible]	114								SPACING
1.	117								
[illegible]	123								SAMPLE AS
5.	[illegible]								RECEIVED AND
[illegible]	[illegible]								SET UP BY
10.	[illegible]								BAIRD PERSONNEL
[illegible]	[illegible]								
[illegible]	[illegible]								
[illegible]	13[illegible]								

ICF-5
3/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY ______


SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND CONDUCTED INTERFERENCE - LISN
SPECIFICATION MIL-I-26600 DATE 11/16/64
TEST SAMPLE OIL ANALYZER S/N
OPERATING MODE NORMAL AS RECEIVED
MEASURING INSTRUMENT NF-105 S/N 2020
GRAPH NO. 1 DATA SHEET NO. 1
SPECIFICATION LIMIT
DB ABOVE 1 MICROVOLT/MC AT METER INPUT
160
140
120
100
80
60
40
20
.1
1
10
100

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ______

TEST SAMPLE:
MODEL OR TYPE ______
SERIAL ______

TEST INFO:
DATA SHEET NO. 1A [illegible]
DATE [illegible]
CONTRACT NO. ______

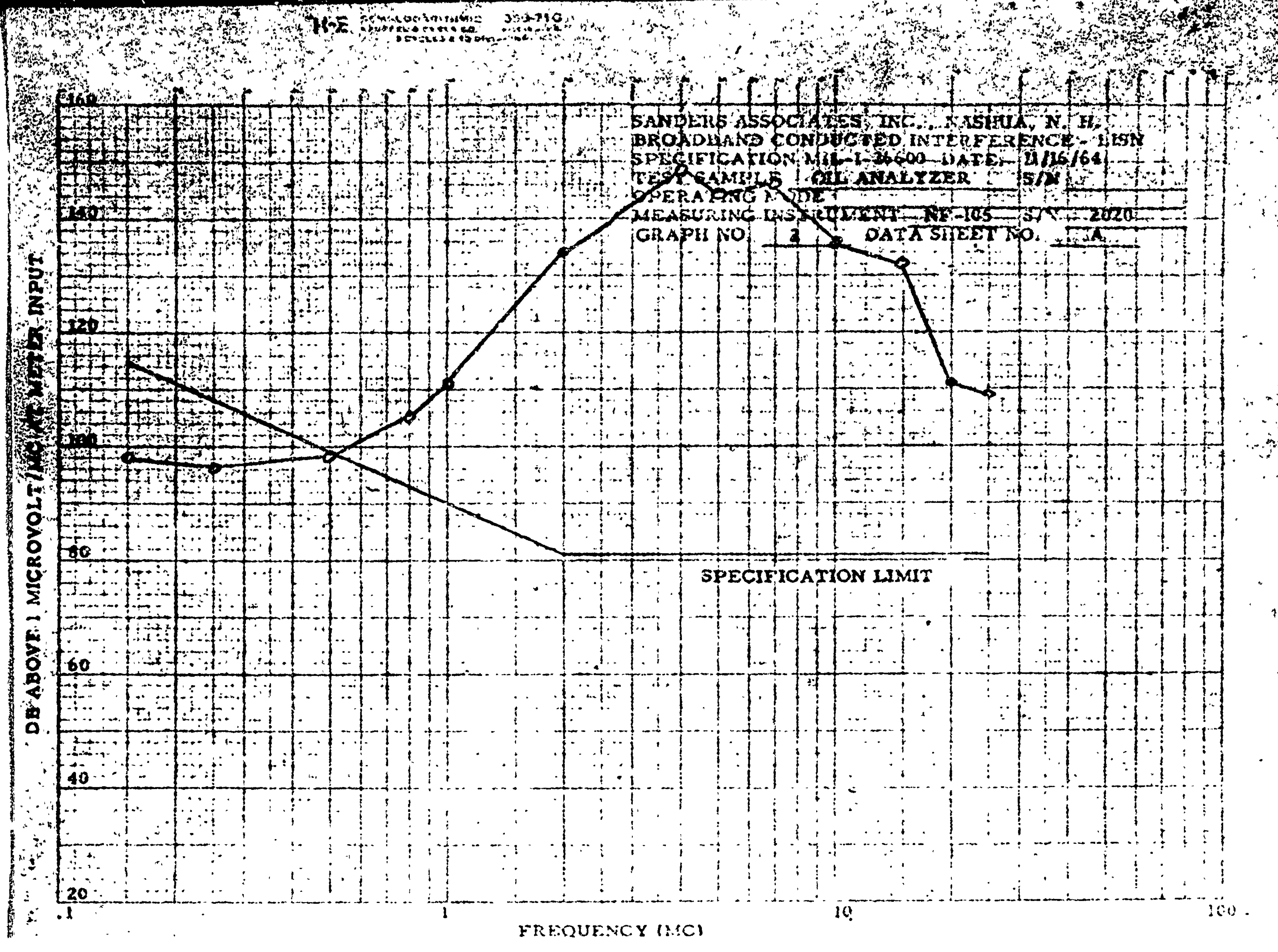
MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP ______

SPECIFICATION INFO:
NO. [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READINGS						SPEC. LIMIT	AMBIENT	REMARKS
	LINE NO 1	LINE NO 2	LINE NO 3	LINE NO 4	LINE NO 5	LINE NO 6			
[illegible]	[illegible]								115VAC LINE
[illegible]	[illegible]								
[illegible]	[illegible]								Gap Spacing
[illegible]	[illegible]								ALTERED
[illegible]	111								AND SAFETY
[illegible]	[illegible]								GAPS ARCING
[illegible]	[illegible]								
[illegible]	[illegible]								
[illegible]	[illegible]								
10.	126								
[illegible]	[illegible]								
[illegible]	[illegible]								
[illegible]	[illegible]								

ICF 5
5/63

MEASUREMENT PERFORMED BY ______
APPROVED BY ______


SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND CONDUCTED INTERFERENCE - LISN
SPECIFICATION MIL-I-26600 DATE 11/16/64
TEST SAMPLE OIL ANALYZER S/N
OPERATING MODE
MEASURING INSTRUMENT NF-105 S/N 2020
GRAPH NO. 2 DATA SHEET NO. 1A
SPECIFICATION LIMIT
DB ABOVE 1 MICROVOLT/MC AT METER INPUT
FREQUENCY (MC)
160
140
120
100
80
60
40
20
.1
1
10
100

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO.

TEST SAMPLE:
MODEL OR TYPE Board Ass
SERIAL

TEST INFO:
DATA SHEET NO. 2
DATE 11-18-64
CONTRACT NO.

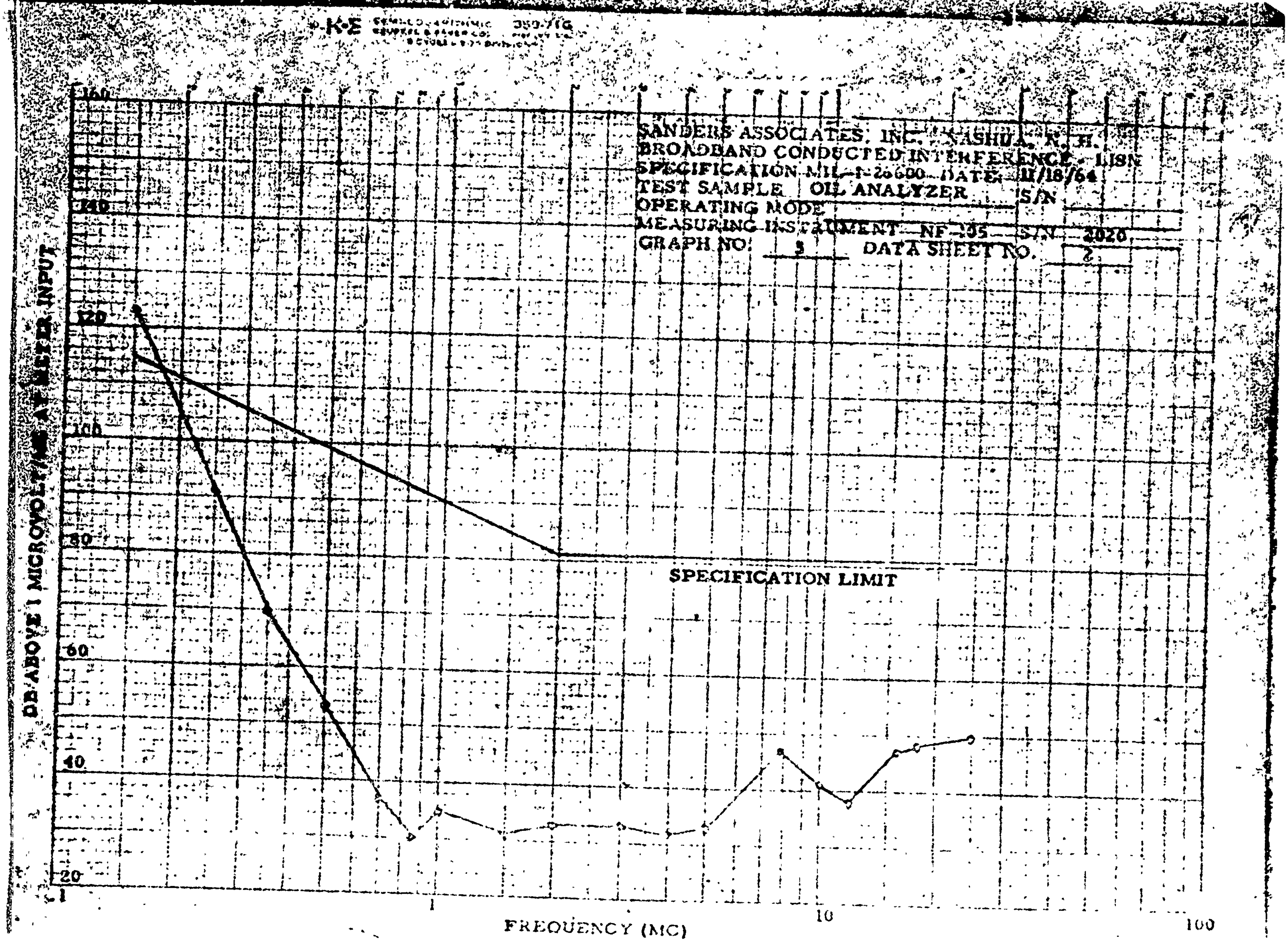
MEASURING INSTRUMENT:
MODEL NF 105 EMPIRE
SERIAL 2030
PICKUP LSN

SPECIFICATION INFO:
NO. Mil-I-26600
TEST PERFORMED RB Conducted

FREQ.	dBm (METER READINGS) LINE NO 1	LINE NO 2	LINE NO 3	LINE NO 4	LINE NO 5	LINE NO 6	SPEC LIMIT	AMBIENT	REMARKS
MC									
.150	123								
.250	91								Enclosure
.350	70								and INTERFE[illegible]
.500	53								filter installed
.700	27								
.850	30								Enclosure [illegible]
1.0	25								
1.5	31								
2.0	33								
3.0	33								
4.0	32								
5.0	33								
7.5	47								
10.0	41								
12.0	38								
16.0	47								
18	48								
25	50								

ICF-5
5/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY



K-E 359-71G
SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND CONDUCTED INTERFERENCE - LISN
SPECIFICATION MIL-I-26600 DATE 11/18/64
TEST SAMPLE OIL ANALYZER S/N
OPERATING MODE
MEASURING INSTRUMENT NF-105 S/N 2020
GRAPH NO. 3 DATA SHEET NO. 2
SPECIFICATION LIMIT
160
140
120
100
80
60
40
20
1
10
100
FREQUENCY (MC)

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ______

TEST SAMPLE: [illegible]
MODEL OR TYPE [illegible]
SERIAL
TEST INFO:
DATA SHEET NO 3
DATE [illegible]
CONTRACT NO.

MEASURING INSTRUMENT: [illegible]
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO:
NO. [illegible]
TEST PERFORMED [illegible]

FREQ	METER READING CARR.	METER READING P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
		[illegible]	[illegible]	[illegible]	DB µV/M			
.150		126	17.5	[illegible]	165.5			Spark gaps normal
[illegible]		120	4.		164			spacing
.40		124	[illegible]		159.5			
420		129	[illegible]		161			
[illegible]		121	[illegible]		153.5			Unit as
[illegible]		119	13		152			received
1.[illegible]		124	[illegible]		150			
1.[illegible]		120	8		148			
2.0		[illegible]	[illegible]		144.5			
[illegible]		120	[illegible]		142.5			
[illegible]		[illegible]	[illegible]		140.5			
[illegible]		[illegible]			134			
[illegible]		134	-1.5		152.5			
[illegible]		115	-1.		134			
[illegible]		112			130			
[illegible]		111	[illegible]		128.5			
[illegible]		152	-4.		148			
23		122	-4.7		152.3			
25		150	-5		145			
[illegible]		118	8.5		126			
[illegible]		124	8.6		132.6			
[illegible]		114	8.8		122.8			
[illegible]		121	9		130			
135		123	9.5		132.5			
[illegible]		114	9.9		123.9			
250		114	10.1		124.1			
[illegible]		112	10.4		122.4			
[illegible]		104	10.9		114.9			

ICF-6
5/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO.______

TEST SAMPLE
MODEL OR TYPE [illegible]
SERIAL ______

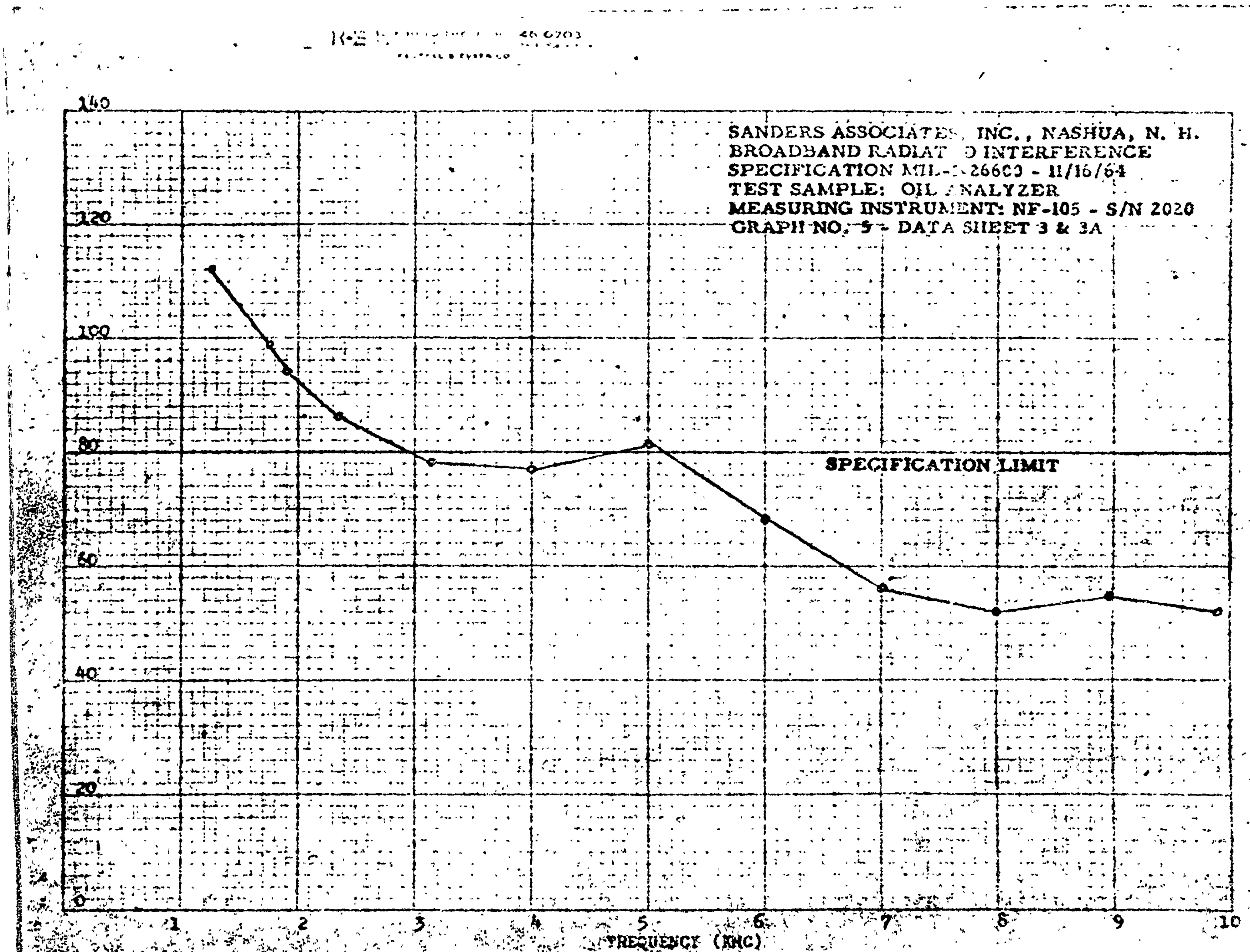
TEST INFO.
DATA SHEET NO. -3A RUN #1
DATE [illegible]
CONTRACT NO. ______

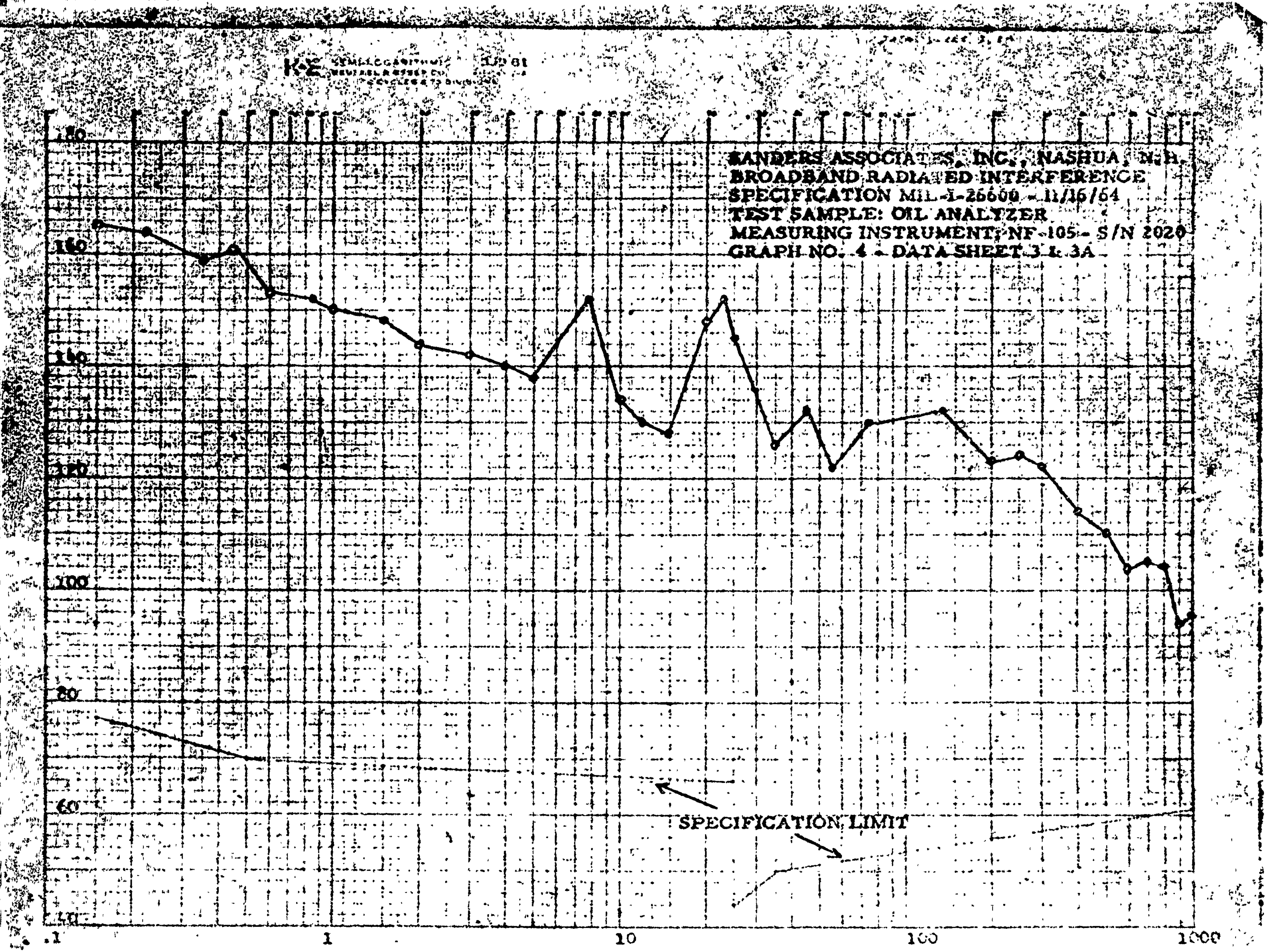
MEASURING INSTRUMENT
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]

SPECIFICATION INFO.
NO. [illegible]
TEST PERFORMED [illegible]

FREQ	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
		DB	DB		DB UV/M			
[illegible]		99	11.1		110.1			
[illegible]		93	11.5		104.5			
[illegible]		94	11.7		105.7			Unit as
[illegible]		92	12		104			received
[illegible]		82	12.4		94.4			
[illegible]		83	12.8		95.8			
KMC								
				cable loss /				
1.25		85	22.6	1.24/+4.1	112.9			
1.75		75	22.8	1.50/+1	99.4			
2.20		70	22.8	1.60/ ·	94.4			
2.75		65	21.6	1.74/-2	86.34			
3.15		55	22.3	2.24/[illegible]	77.9			
4.0		52	22.5	2.70/ [illegible]	77			12' RG 9U CABLE
5.0		57	20.7	3.00/ [illegible]	81.7			FROM ANT TO FIM
6		45	21.4	3.20/-1	68.6			
7.0		32	21.6	3.50/-1.8	55.9			
8.0		30	20.8	3.8/-2.4	52.2			
8.9		31	20.9	4.2/-.5	55.6			
7.7		26	20.7	4.5/+.9	52.1			

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY ______


SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIAT D INTERFERENCE
SPECIFICATION MIL-I-26600 - 11/16/64
TEST SAMPLE: OIL ANALYZER
MEASURING INSTRUMENT: NF-105 - S/N 2020
GRAPH NO. 5 - DATA SHEET 3 & 3A
SPECIFICATION LIMIT
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY (MHC)


SANDERS ASSOCIATES, INC., NASHUA, N.H.
BROADBAND RADIATED INTERFERENCE
SPECIFICATION MIL-I-26600 - 11/16/64
TEST SAMPLE: OIL ANALYZER
MEASURING INSTRUMENT: NF-105 - S/N 2020
GRAPH NO. 4 - DATA SHEET 3 & 3A
SPECIFICATION LIMIT
180
160
140
120
100
80
60
40
.1
1
10
100
1000

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ______

TEST SAMPLE:
MODEL OR TYPE ______
SERIAL ______

TEST INFO:
DATA SHEET NO [illegible]
DATE [illegible]
CONTRACT NO ______

MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]

SPECIFICATION INFO:
NO. [illegible]
TEST PERFORMED [illegible]

FREQ	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR. FACTOR	CORRECTED READING	SPEC. LIMIT	AMBIENT	REMARKS
[illegible]		DBµV	DB		DBµV/M			
		56	17.5	20	93.5			
210		57	14		91			[illegible]
350		47	15.5		82.5			[illegible]
[illegible]		[illegible]	12		86			[illegible]
[illegible]		48	12.5		80.5			[illegible]
[illegible]		44	13.		77			[illegible]
[illegible]		48	6		74			[illegible]
[illegible]		35	[illegible]		63			
1.0		39	9.5		68.5			
[illegible]		54	2.5		76.5			
[illegible]		[illegible]	3.5		75.5			[illegible]
[illegible]		[illegible]	4.		80			[illegible] shielded
7.8		85	-1.5		103.5			[illegible] (RF)
[illegible]		92	-1		91			[illegible]
12		[illegible]	0		93			[illegible]
15.		114	-4		130			
21		117	-4	↓	133			
[illegible]		114	-5		129			(X) no filter [illegible]
[illegible]		[illegible]	8.5		118.5			power [illegible]
45.		[illegible]	8.6		119.6			
62.		120	8.8		128.8			
70		125	9		134			[illegible]
130.		120	9.5		129.5			[illegible]
210		103	9.9		112.9			[illegible]
350.		107	10.2		117.2			and [illegible]
[illegible]		103	10.5		113.5			leads
500.		96	11.1		107.1			
600		93	11.5		104.5			
800		83	12		95			
[illegible]		79	12.4		91			
[illegible]		[illegible]	12.8		[illegible]			
								[illegible]

ICF-6
5/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION · REPORT NO. ______

TEST SAMPLE:
MODEL OR TYPE [illegible]
SERIAL ______

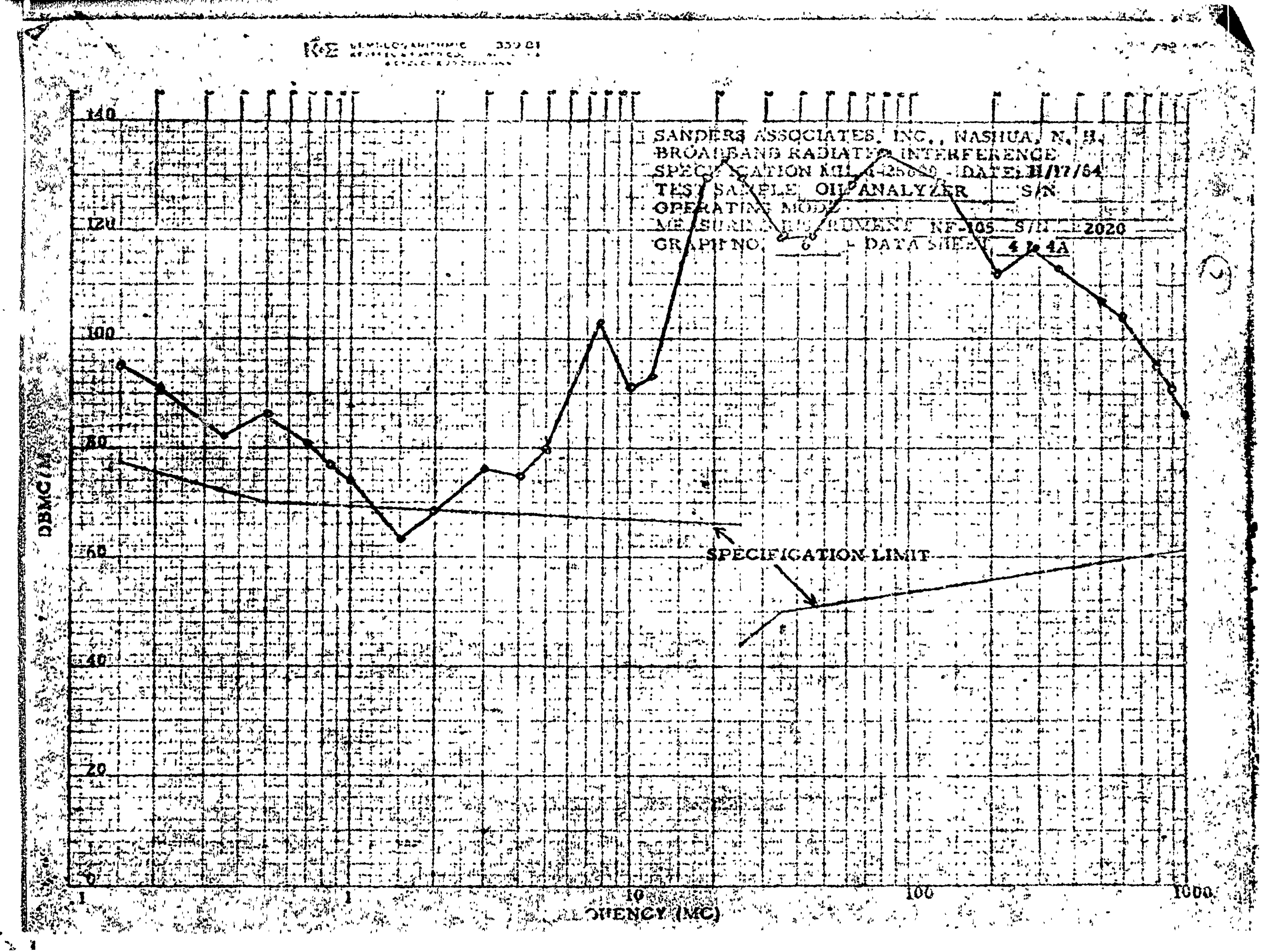
TEST INFO:
DATA SHEET NO [illegible]
DATE [illegible]
CONTRACT NO ______

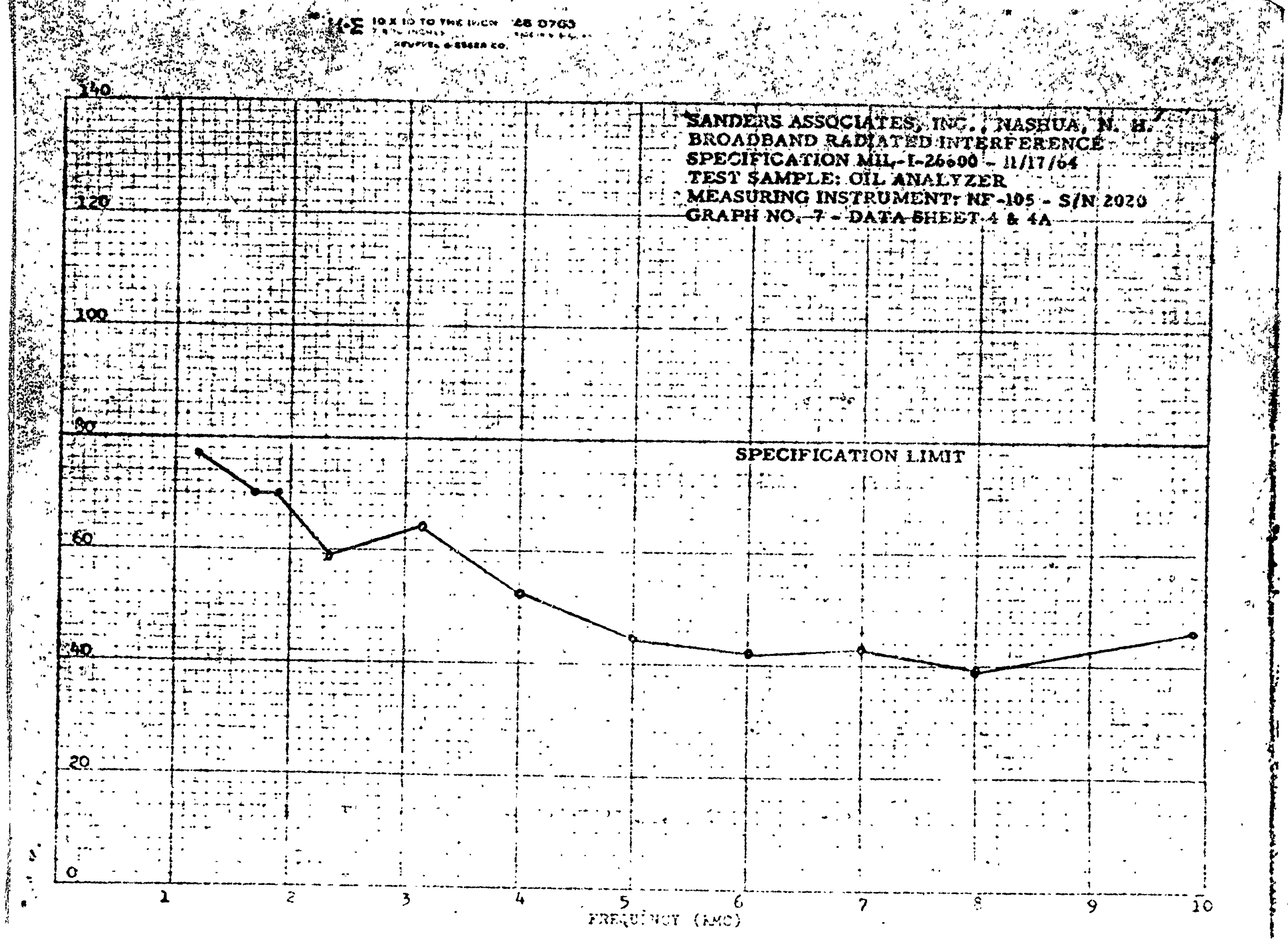
MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL ______
PICKUP [illegible]

SPECIFICATION INFO:
NO [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
KHZ		DBM	DB	[illegible]	DBMC/M			
[illegible]		50	22.6	1.24/+4.1	77.85			
[illegible]		45	22.8	1.5/+1	70.3			
[illegible]		46	22.8	1.6/0	70.4			
[illegible]		38	21.6	1.74/-2	59.34			
[illegible]		41	22.3	2.24/-1.8	64.54			
[illegible]		27	22.5	2.5/0	52			
5.0		20	20.7	3.0/+1	44.7			
[illegible]		18	21.4	3.20/-1	42.6			
7.0		17	21.6	3.50/-1.2	42.9			
8.0		17	20.8	3.8/-2.4	39.2			
9.8		20	20.7	4.5/+.9	46.1			

MEASUREMENT PERFORMED BY [signature]
APPROVED BY ______


SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
DATE: 11/17/64
OIL ANALYZER
S/N
OPERATING MODE
RF-105
2020
GRAPH NO.
6
DATA SHEET
4 & 4A
SPECIFICATION LIMIT
DBMC/M
140
120
100
80
60
40
20
0
1
10
100
1000


10 X 10 TO THE INCH 46 0703
KEUFFEL & ESSER CO.
SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
SPECIFICATION MIL-I-26600 - 11/17/64
TEST SAMPLE: OIL ANALYZER
MEASURING INSTRUMENT: NF-105 - S/N 2020
GRAPH NO. 7 - DATA SHEET 4 & 4A
SPECIFICATION LIMIT
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
FREQUENCY (MC)

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION · REPORT NO. ______

TEST SAMPLE:
MODEL OR TYPE ______
SERIAL ______

TEST INFO:
DATA SHEET NO [illegible]
DATE [illegible]
CONTRACT NO. ______

MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]

SPECIFICATION INFO:
NO [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
[illegible]		DBµV	DB		DBµV/M			
[illegible]		[illegible]	17.5	20	15.5			
210		57	14		91			[illegible]
350		47	15.5		82.5			[illegible]
[illegible]		[illegible]	12		86			[illegible]
700		[illegible]	12.5		81.5			[illegible]
[illegible]		44	[illegible]		77			[illegible]
[illegible]		[illegible]	[illegible]		74			
[illegible]		[illegible]	[illegible]		63			
[illegible]		[illegible]	9.5		68.5			
[illegible]		[illegible]	2.5		76.5			
[illegible]		[illegible]	3.5		75.5			[illegible]
[illegible]		[illegible]	4		78			[illegible]
9.8		85	-1.5		133.5			[illegible] (RF)
[illegible]		92	-1		91			[illegible]
12		[illegible]	0		93			[illegible] for DC gnd.
[illegible]		114	-4		130			
[illegible]		117	-4	V	133			
[illegible]		[illegible]	-5		127			(X) no filter on
[illegible]		[illegible]	8.5		118.5			power leads
45		[illegible]	8.6		119.6			
[illegible]		[illegible]	8.8		128.8			
80.		125	9		134			[illegible]
130.		[illegible]	9.5		129.5			[illegible]
210		103	9.9		112.9			[illegible]
[illegible]		107	10.2		117.2			and hot power
[illegible]		103	10.5		113.5			leads
[illegible]		96	11.1		107.1			
[illegible]		93	11.5		104.5			
[illegible]		83	12		95			
[illegible]		79	12.4		91			
[illegible]		74	12.8		86.8			
								[illegible]

ICF-6
5/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY ______

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO.

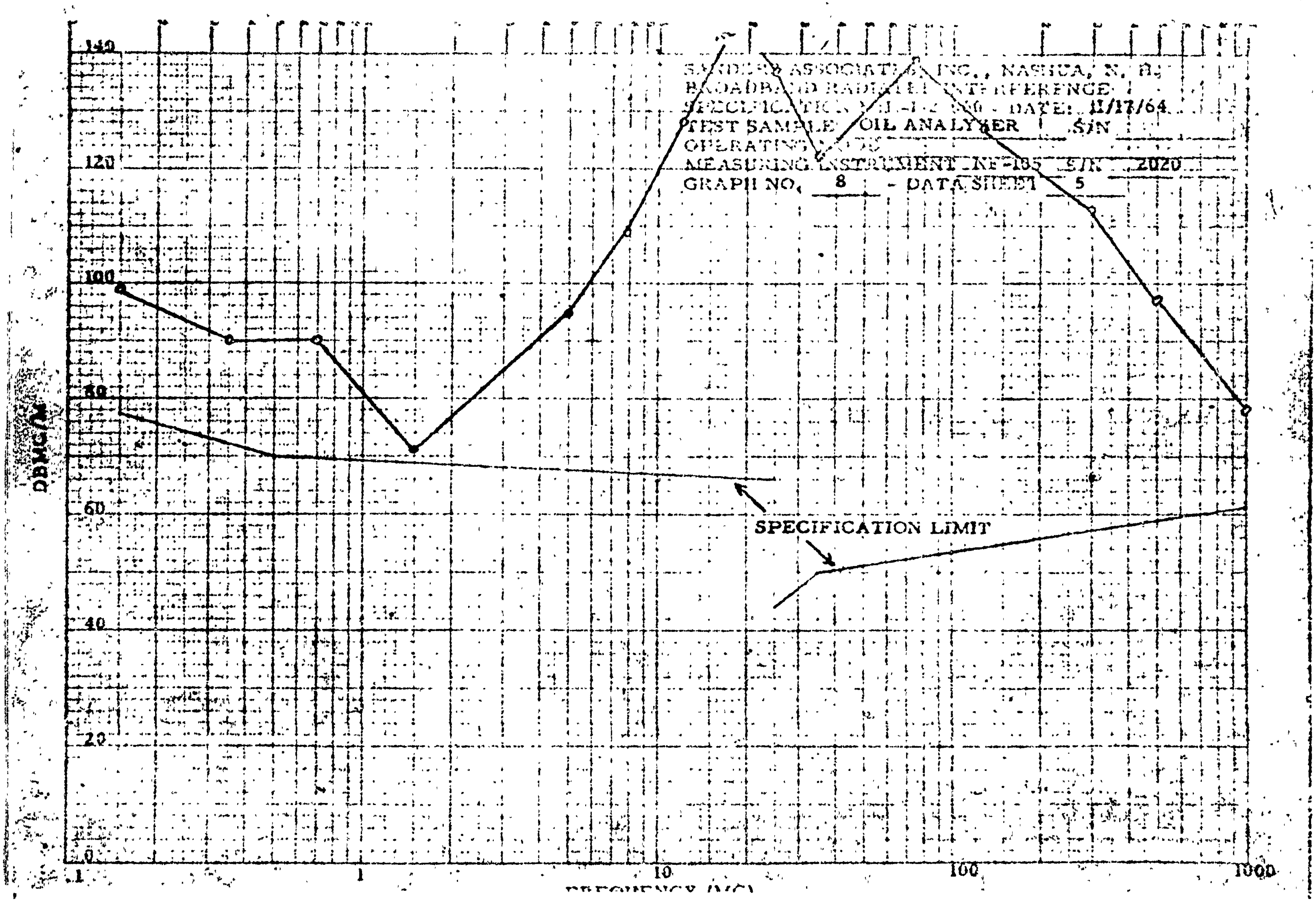
TEST SAMPLE:
MODEL OR TYPE
SERIAL
TEST INFO:
DATA SHEET NO 5 Run # 3
DATE 11-17-64
CONTRACT NO

MEASURING INSTRUMENT
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO
NO [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
KC		DBµV	DB	DB	DBµV/M			
150		60	14.5	20	94.5			[illegible]
300		55	15.5		90.5			[illegible]
600		57	13.5		90.5			[illegible]
1.5		43	8		71			
3.0		71	4.		95			[illegible]
7.8		91	-1.5		109.5			
12.		108	0		128			[illegible]
20.		136	-4		152			[illegible]
25.		122	-5	↓	137			
								[illegible]
								[illegible]
35.		114	8.5		122.5			[illegible]
75.		130	9.		139			[illegible]
125.		118	9.5		127.5			
300.		103	10.4		113.4			
500.		86	11.1		97.1			
1000.		66	12.8		78.8			

MEASUREMENT PERFORMED BY [signature]
APPROVED BY

KT-4
3/63



SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
DATE: 11/17/64
TEST SAMPLE OIL ANALYSER S/N
OPERATING
MEASURING INSTRUMENT NF-105 S/N 2020
GRAPH NO. 8 - DATA SHEET 5
SPECIFICATION LIMIT
DBMC/M
140
120
100
80
60
40
20
0
.1
1
10
100
1000

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION · REPORT NO. ____

TEST SAMPLE:
MODEL OR TYPE ____
SERIAL ____

TEST INFO:
DATA SHEET NO. 6 – [illegible] Roll #1
DATE 11-19-64
CONTRACT NO. ____

MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]

SPECIFICATION INFO:
NO [illegible]
TEST PERFORMED [illegible]

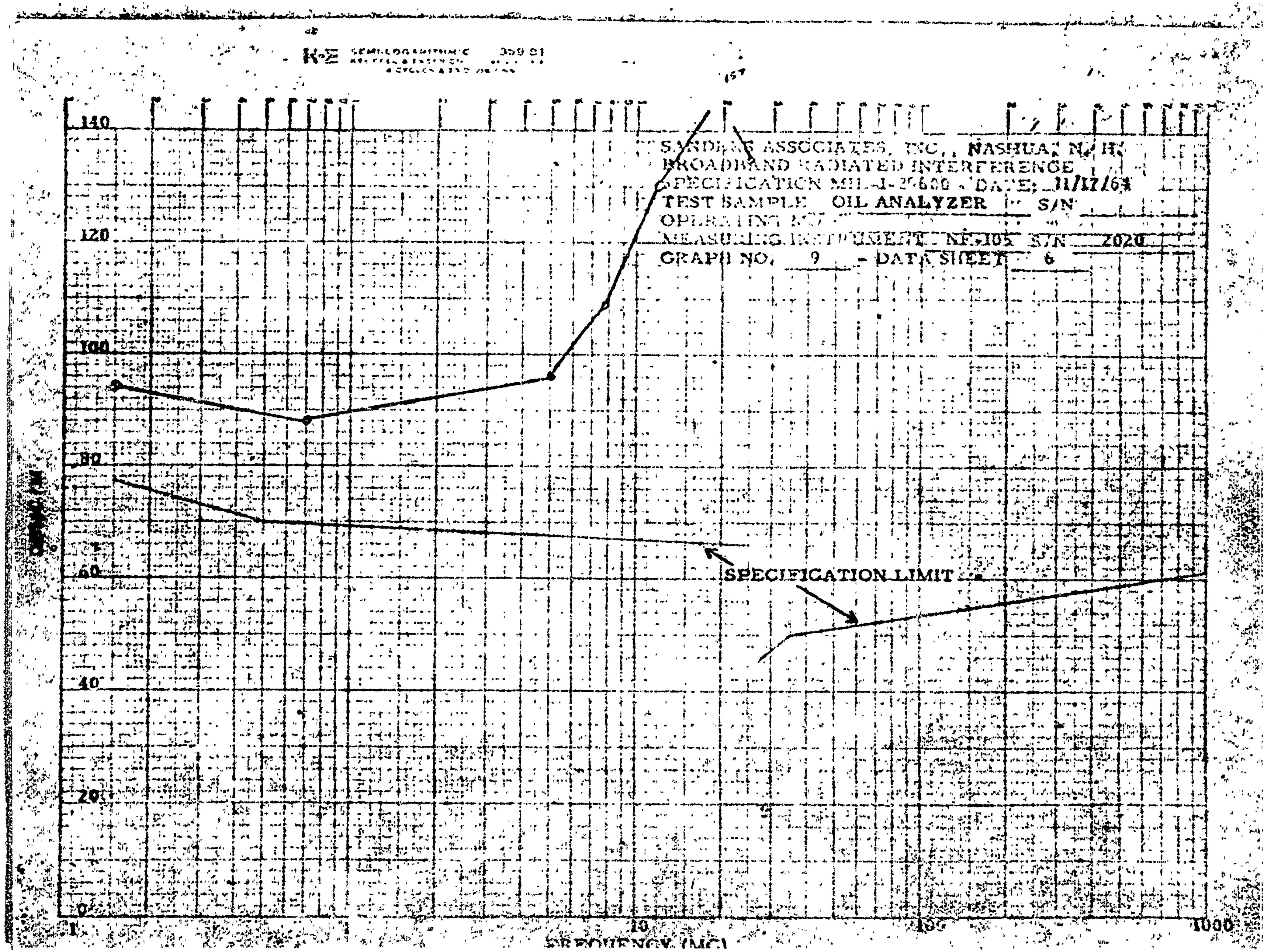
FREQ	METER READING CARR	METER READING P.	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
Mc		DB[illegible]	DB	DB	DB[illegible]/M			
.150		[illegible]	14.5	20	74			
.700		56	12.5	20	88.5			
5.0		72	4	20	96			
7.8		71	-1.5	20	101.5			[illegible]
								[illegible]
12.		110	0	20	130			[illegible] 5
20.		137	-4	20	153			[illegible]
								[illegible]
25.		120	-5	20	135			[illegible]
								[illegible]

(X) [illegible]

[illegible signature]

IGF-6
5/63

MEASUREMENT PERFORMED BY ____



SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
SPECIFICATION MIL-I-26600 DATE: 11/17/63
TEST SAMPLE OIL ANALYZER S/N
MEASURING INSTRUMENT NF-105 S/N 2020
GRAPH NO. 9 - DATA SHEET 6
SPECIFICATION LIMIT
140
120
100
80
60
40
20
0
1
10
100
1000
FREQUENCY (MC)

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION · REPORT NO. ______

TEST SAMPLE: [illegible]
MODEL OR TYPE [illegible]
SERIAL ______
TEST INFO: [illegible]
DATA SHEET NO [illegible]
DATE [illegible]
CONTRACT NO ______

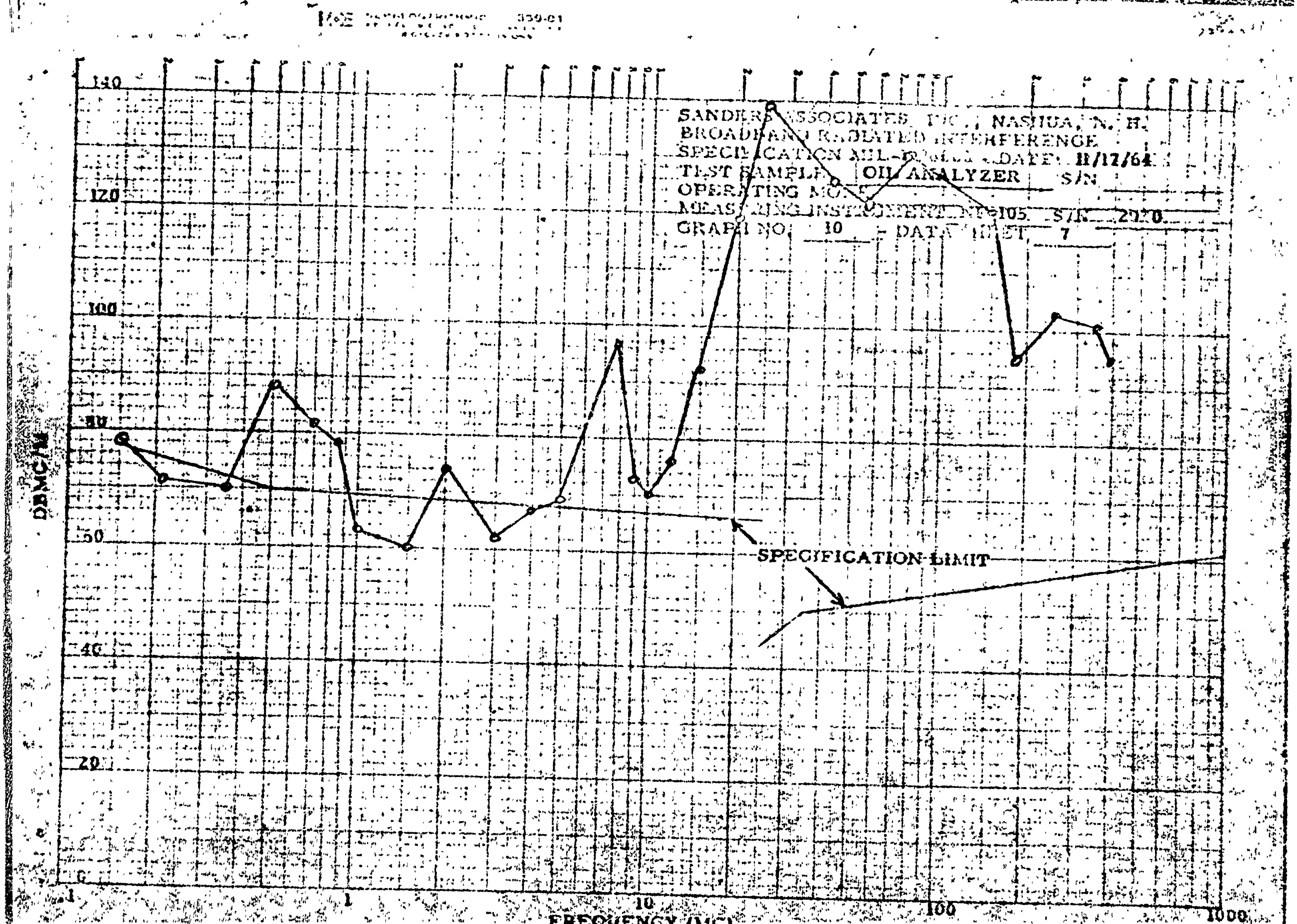
MEASURING INSTRUMENT: [illegible]
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO
NO. [illegible]
TEST PERFORMED [illegible]

FREQ.	METER READING CARR	METER READING P	ANTENNA FACTOR	CORR. FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS.
KC		DBIC	DB	DB	DB/M			
150		39	19.5	20	78.5			[illegible]
210		37	14		71			[illegible]
350		35	15.5		70.5			
500		56	12		88			[illegible]
700		50	12.5		82			[illegible]
850		45	13		78			
1.0		37	6		63			[illegible]
1.5		32	8		60			[illegible]
2.0		35	9.5		74.5			
3.0		40	2.5		62.5			4" x 3" [illegible]
4.0		44	3.5		69.5			[illegible]
5.0		53	-4		69			[illegible]
7.8		78	-1		97			[illegible]
9		54	-1		73			
10		51	-1		70			
12		56	0		76			[illegible]
15		76	-3.5		92.5			[illegible]
20		103	-4		119.5			[illegible]
25		124	-5		139			[illegible]
42		118	8.6		126.6			(X) [illegible]
60		114	8.8		122.8			[illegible]
75		122	9		131			[illegible]
115		112	9.4		121.4			[illegible]
[illegible]		86	9.8		95.8			
250		93	10.2		103.2			
300		91	10.6		101.6			
390		85	10.7		95.7			

[illegible signature]

ICE-4
5/63

MEASUREMENT PERFORMED BY [illegible]
APPROVED BY



SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
SPECIFICATION MIL- DATE: 11/17/64
TEST SAMPLE OIL ANALYZER S/N
OPERATING MODE
MEASURING INSTRUMENT NF105 S/N 2020
GRAPH NO. 10 DATA SHEET 7
SPECIFICATION LIMIT
DBMC/M
140
120
100
80
60
40
20
0
.1
1
10
100
1000

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ______

TEST SAMPLE:
MODEL OR TYPE [illegible]
SERIAL ______
TEST INFO:
DATA SHEET NO. 8
DATE 11-18-6[illegible]
CONTRACT NO. ______

MEASURING INSTRUMENT:
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO:
NO [illegible]
TEST PERFORMED [illegible]

FREQ	METER READING CARR	P	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
KC		dbmc	db	db	dbμv			
150		41	19.5	20	[illegible]			
[illegible]		35	14		[illegible]			
250		33	15.5		68.5			
300		31	12		63			
400		33	12.5		65.5			
800		32	13		65			
1.0		32	6		58			
1.5		31	8		[illegible]			
2.0		32	9.5		61.5			
3.5		33	2.5		55.5			
4.0		31	3.5		54.5			
5.0		33	4		57			
7.5		33	-1.5		51.5			
10		30	-1		49			
12		30	0		50			
15		33	-3.5		49.5			
20		42	-4.7		57.3			
25		38	-5		53			
35		41	8.5		49.5			
43		60	8.6		68.6			
60		49	8.8		57.8			
75		57	9		66			
95		63	9.2		72.2			
135		56	9.8		65.8			
270		53	10.2		63.2			
350		46	10.5		56.5			
400		45	10.5		55.5			
500		46	11.1		57.1			
600		53	11.5		64.5			
850		54	12.2		66.2			
900		40	12.7		52.7			

REMARKS:

Copper screen in closure and [illegible] ground plane [illegible] in place [illegible] ground strips attached to ground plane

[illegible] filter installed

PROBING INDICATED LEAKAGE WAS AT THE BASE OF [illegible] WHERE MATING SURFACES WERE NOT TIGHT. ALSO ANY EXISTING OPENING FOR AIR PUMP OR ACCESSORY WOULD HAVE TO BE SEALED (GE)

[illegible signature]

IC-4 5/63

MEASUREMENT PERFORMED BY ______
APPROVED BY ______

SANDERS ASSOCIATES, INC., NASHUA, N.H.

INTERFERENCE CONTROL ENGINEERING EVALUATION - REPORT NO. ____

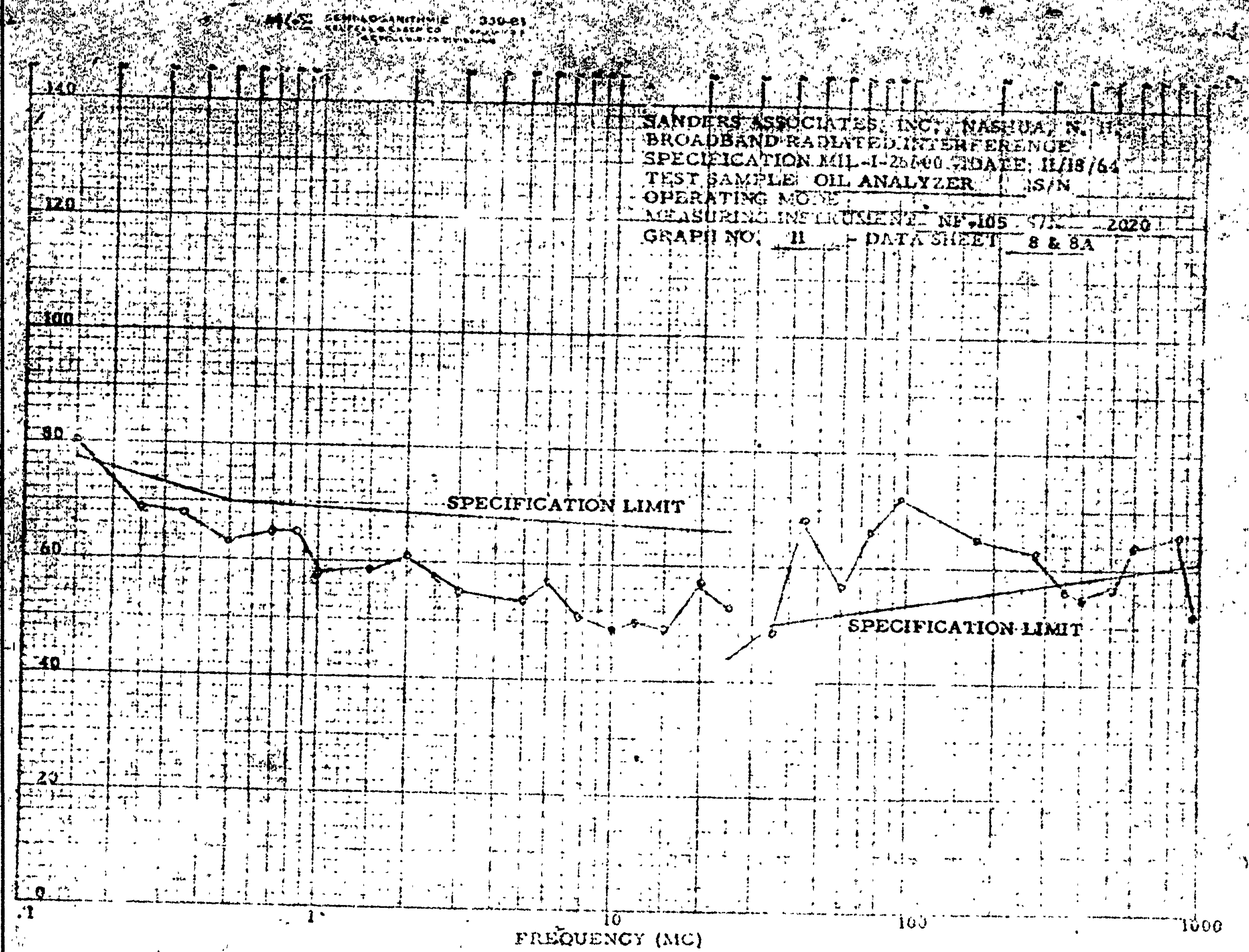
TEST SAMPLE:
MODEL OR TYPE [illegible]
SERIAL
TEST INFO
DATA SHEET NO 8-A
DATE 11-28-67
CONTRACT NO

MEASURING INSTRUMENT
MODEL [illegible]
SERIAL [illegible]
PICKUP [illegible]
SPECIFICATION INFO:
NO MIL-I-26600
TEST PERFORMED [illegible]

FREQ.	METER READING CARR	METER READING F	ANTENNA FACTOR	CORR FACTOR	CORRECTED READING	SPEC LIMIT	AMBIENT	REMARKS
KMC		DBUC	DB	DB	DB [illegible]	DBUC/M		
1.3		36	22.6	1.38/4.1	63.94	80		
1.70		31	22.8	1.5/+1	56.3			[illegible] Enclosure
1.85		30	22.8	1.6/0	54.4			in place
2.35		16	21.6	1.71/2	37.31			interference filter
3.5		15.5	22.3	2.24/-18	38.2			installed [illegible]
4.0		15	22.5	2.5/0	40			[illegible]
								[illegible]
5.0		21	20.7	2.0/+1	44.7			Single ground
6.0		20	21.4	3.2/-1	43.6			to ground plane
7.0		20	21.6	3.7/-1.2	44			
8.0		20	20.8	3.8/-2.4	42.2			
8.9		22	20.9	4.2/-5	46.5			
9.8		21	20.7	4.5/+.9	47.1			

ICT-6
6/63

MEASUREMENT PERFORMED BY [signature]
APPROVED BY


SANDERS ASSOCIATES, INC., NASHUA, N. H.
BROADBAND RADIATED INTERFERENCE
SPECIFICATION MIL-I-26600 DATE: 11/18/64
TEST SAMPLE OIL ANALYZER S/N
OPERATING MODE
MEASURING INSTRUMENT NF-105 2020
GRAPH NO. 11 DATA SHEET 8 & 8A
SPECIFICATION LIMIT
SPECIFICATION LIMIT
140
120
100
80
60
40
20
0
.1
1
10
100
1000
FREQUENCY (MC)