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NIST Technical Note 1424

NIST Measurement Assurance Program for Resistance

Paul A. Boynton, June E. Sims, and Ronald F. Dziuba

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[2] Some elements at Boulder, CO.

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Abstract - The National Institute of Standards and Technology (NIST) offers resistance Measurement Assurance Program (MAP) transfers at the 1 Ω and 10 kΩ levels, to provide a method of assessing and maintaining the quality of a customer's measurement process. This document describes the basic concepts of a resistance MAP, and the procedures for participating in the program. A discussion of the data analysis follows, with an explanation of the uncertainty of the estimate of the transfer. Also included is a sample MAP scenario, with data sheets, analysis results, and a final test report.

1. INTRODUCTION

1.1 What is a MAP?

The Measurement Assurance Program (MAP) services offered by NIST provide a tool for achieving quality assurance of the customer's measurement process. The MAP is a method of assessing the uncertainty of the measurement process, and provides NIST-traceable assigned values to the customer's standards. This procedure, completed with internal statistical process control techniques, gives the customer a technique for monitoring the quality of its measurement process.

1.2 Why a MAP?

Many laboratories may find it more advantageous to participate in a MAP rather than use the NIST calibration service. The calibration service, in which the customer laboratory sends its standards to NIST for calibration, assigns the values of the customer's standards relative to NIST's standards, and their uncertainties, thus indicating the quality of the NIST measurement process, and the short-term performance of those standards. The NIST MAP service samples the output of the customer's measurement process rather than checking the standards alone. This provides a picture of the quality of the customer's measurement process as well, and thus is a more effective method of traceability. As a result, problems with the customer's measurement system that would not necessarily be revealed by the regular calibration service would possibly be uncovered. A MAP indicates such deviations from the measurement's assumed quality, thus providing information that can help improve the precision and uncertainty of the customer's measurement process.

It is true that MAPs can be more expensive in the short term; still, they can save money in the long term. Often customers discover, that after participating in the program for a few years, the results allow them to increase the interval between MAPs. For example, some resistance MAP customers find that after a few years of annual transfers, they can reduce their participation to a biennial transfer.

1.3 How do MAPs work?

Each specific measurement situation requires its own procedures [1]. Generally, a set of transport standards is measured at NIST and then sent to the customer, usually via air freight, for measurement by the customer's system. After a minimum number of measurements have been taken (enough to assess whether the process is under control), the transport standards are returned to NIST for further measurements. The NIST data and the customer data are then analyzed, and a report is issued from NIST to the customer. This report states the offset of the customer's measurement process from the NIST standards, and the total uncertainty of the customer's measurement process. This uncertainty includes errors resulting from both random and systematic effects.

The transport standards are usually measured by the customer using their normal calibration conditions, as if they were part of the normal workload of the laboratory. This allows for a realistic assessment of the quality of the customer's measurement process. Many situations call for the use of a design scheme. In all cases, the customer's measurement process must be in statistical control while the transport standards are being measured. Thus, check standards or statistical tests need to be used on a regular basis in the laboratory.

1.4 Who should participate?

1.4.1 Types of labs. Standards laboratories that provide calibrations of electrical standards with an uncertainty within one order of magnitude of those available by NIST calibration services should consider participating in a MAP. As a rule, those laboratories that do not aspire to this level of uncertainty would find that the regular NIST calibration service should suffice. However, NIST MAP services used on a once-only basis can be used by laboratories to evaluate new calibration systems.

1.4.2 Customer requirements. The customer who is interested in participating in a NIST MAP should have the following:

1) an extensive comprehension of the particular measurement process in use;

2) an ongoing measurement control program, such as making repeated measurements on in-house check standards so that the random error of the measurement system can be estimated and ensure that the measurement process is in control;

3) some understanding of the basic concepts of statistical analysis or access to a statistician (NIST staff members are available to explain the detailed analysis of a MAP report); and

4) a desire to respond creatively to the results of the MAP.

NIST insists that these conditions exist before participating to avoid wasting time and resources both by the customer and NIST. If the customer needs the analysis that a MAP provides, these conditions should already exist.

2. DESCRIPTION OF SERVICES

2.1 Resistance MAP services

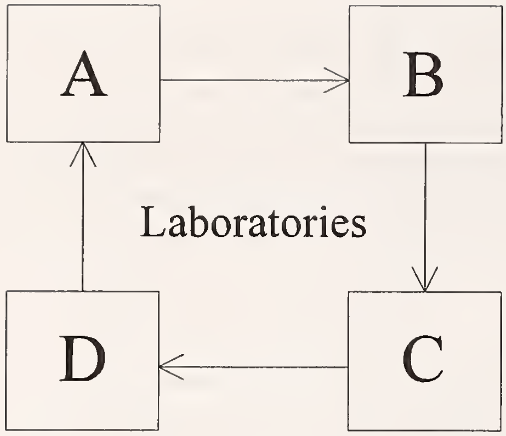
2.1.1 Present services. NIST offers MAPs at 1 Ω and 10 kΩ since they represent the two primary levels at which most customers maintain their unit of resistance. In the past, MAPs at other resistance levels have been offered, but have not been frequently requested by customers. In the future, a high-resistance MAP will be offered to help address the special problems at levels above 1 MΩ.

Transfers at both levels take a minimum of 13 weeks. Data are taken at NIST on the transfer standards for a minimum of four weeks. During the next four weeks the customer receives and measures the standards. Then for four additional weeks NIST measures the same transport standards. An additional week is necessary to process the data and to generate a report. Extra time may be required during any part of the MAP if unusual circumstances or problems arise.

Unlike many other types of MAPs, a design is not required. Normal laboratory measurement procedures can be used. The substitution methods used in resistance calibrations do not lend themselves well to calibration designs. However, errors caused by leakage currents, and lead and contact resistances are reduced by using substitution balancing techniques [2].

2.1.2 Group MAPs. Some laboratories engage in a regional group MAP, usually involving two to six companies, where they compare their standards in a round-robin design. One company serves as a pivot lab, and performs a MAP transfer with NIST, to link the data to the U.S. ohm. One such scheme is shown in Figure 1. Each lab begins by measuring a set of transport standards against their working standards. They then send the set to the next lab in the sequence, and receive another set of transport standards from another lab to calibrate. Eventually they work around the design until the lab receives its own transport standards back, and measures them to achieve closure. This provides traceability to NIST with no interdependence on the other labs.

If funds are available, the group can purchase a set of transport standards (possibly on the used equipment market) and rotate the package to each lab in a similar sequence. The pivot lab would begin and end the entire process with a set of measurements to provide closure. This scheme allows companies to reduce costs by sharing expenses and reducing the amount of effort required by NIST. Companies presently involved in regional group MAPS have found an additional benefit: they have discovered that this program provides a forum for the sharing of experience and information, which aids everyone involved.



Transfer standards sequence	Pivot Laboratory
a b c d a	A
b c d a b	B
c d a b c	C
d a b c d	D

Figure 1. Typical group MAP scheme.

2.1.3 Transport standards. To serve as transfer standards, resistors require the following properties:

1) low temperature coefficient of resistance (TCR) at the temperature of use;

2) long-term stability of resistance; and

3) rugged construction to handle traveling conditions.

The NIST 1 Ω package consists of four double-walled manganin Thomas-type resistors [3],[4]. Manganin is an alloy of approximately 84 percent copper, 12 percent manganese, and 4 percent nickel, and exhibits a small TCR at 25.0 °C and very good stability in resistance over time [3],[5]. The transport standards display TCRs within $((0 \pm 3) \times 10^{-6})$/K and drift rates within $((0 \pm 0.1) \times 10^{-6})$/year. All four of the resistors should be measured in an oil bath maintained at a nominal temperature of 25.0 °C. This type of resistor has a pressure effect; therefore, the customer is asked to record the barometric pressure at the time of measurement, as well as the depth of the oil to the surface of the amalgamated current terminals of the resistor.

The 10 kΩ package consists typically of four nickel-chromium alloy resistors [6], two to be measured in oil at 25.0 °C, and two to be measured in air at 23.0 °C. This alloy consists of approximately 75 percent nickel, 20 percent chromium, 2.5 percent copper, and 2.5 percent aluminum [7],[8]. Like manganin, it has a small TCR at the temperature of use, and proves to be stable in resistance over time. These transport standards have drift rates within $((0 \pm 0.2) \times 10^{-6})$/year, and TCRs within $((0 \pm 1) \times 10^{-6})$/K. The oil-type resistors (measured at 25.0 °C) are mounted in cylindrical housings, with good thermal conductivity between the resistance element and the outside metal case to minimize load effects and temperature errors. The air-types (measured at 23.0 °C) are mounted inside rectangular enclosures which are insulated to reduce the effects of room temperature fluctuations. These standards have thermometer wells and temperature sensors in close thermal contact with the resistance elements to monitor their temperature. The air-types display slight pressure coefficients.

2.1.4 Limitations. As stated above, the transfer standards exhibit some effects resulting from the transportation to and from the customer laboratory (see Table 1). This is especially true with the Thomas-type resistors. Analysis of MAP data over a 3-year period shows that there can be a slight shift in the mean value of a transfer standard. The 10 kΩ level MAP packages reflect a slightly smaller shift, especially for the air type standards, possibly a result of their more sturdy mounting.

The results in Table 1 were derived by fitting a line to the data that were taken before the standards were shipped, and fitting a line to the data that were taken after the standards were returned to NIST. To determine the shift in the mean of each standard, the differences between the predicted values for 15 days after the transfer were averaged for each resistor. The estimated standard deviation is a pooled standard deviation of the standard deviation of each resistor for each transfer.

Table 1. Effects on NIST MAP transfer standards resulting from transportation between NIST and customer laboratories

NIST MAP transfer standards	shift in mean (x 10^{-6})	estimated standard deviation (x 10^{-6})
1 Ω total	0.028	0.059
10 kΩ total	0.021	0.014
oil type	0.024	0.014
air type	0.018	0.013

The measurement results on each resistor are dependent on temperature. Since the temperature scale is not transferred during the MAP, it is assumed that the customer's temperature scale has been implemented according to the ITS-90. The recorded temperatures of the 1 Ω transport standards and the 10 kΩ transport standards are expected to be known in terms of the ITS-90 to within 0.005 °C and 0.05 °C, respectively. The temperatures of the air-type 10 kΩ standards are measured using temperature sensors positioned in their thermometer wells. The internal temperature sensors of these resistors are not used, since they have significant load coefficients.

Customers utilize one of several systems for the measurement of resistance, such as current comparators or one of a variety of resistance-ratio bridges. Some use direct comparison methods or substitution methods, others use calibration designs. This can make it more difficult to identify problem areas, since each customer has a unique operating procedure.

2.2 NIST resistance standards and measurements

NIST maintains the U.S. representation of the ohm, which has been based on the quantum Hall effect since January 1, 1990 [9]. A reference group of five 1 Ω Thomas-type resistors is maintained as a working standards group for calibration purposes. The mean of the group is predicted as a function of time from a linear least-squares analysis based on prior measurements against the quantized Hall resistance. The group is calibrated periodically against the U.S. representation of the ohm, and the results are compared to the predicted value to ensure the efficacy of the model used in the prediction and the accuracy of the measurement system. This is described in detail in [2]. Working standards are calibrated against this 1 Ω group using special ratio techniques. The 10 kΩ working standards are calibrated by periodically scaling up from this reference group using Hamon devices or cryogenic current comparators as ratio standards [2].

The 1 Ω transport standards are measured using an automated direct current comparator (DCC) potentiometer [10]. The 10 kΩ transport standards are measured using an automated guarded resistance bridge system [11]. NIST procedures follow recognized precision dc measurement practices, including current reversal techniques (to eliminate the effects of constant or linearly varying thermal emfs), substitution techniques (to reduce errors from leakage currents and lead and contact resistances), careful selection of dummy resistors, measurements under minimum power dissipation, and the use of check standards and statistical analyses to monitor the operation of the measurement system [2]. The statistical tests include comparing the ranges of the readings of each measurement run to a control value, comparing the measured values to the predicted values of each resistor under test (including the check standard), and monitoring the bridge zero.

2.3 MAP transfer procedures

2.3.1 Setting up a MAP transfer. A MAP transfer begins when the customer contacts NIST to participate in the program (see Fig. 2). At that time, the customer and the NIST Calbration Administrator make shipping, receiving, and billing arrangements, and NIST staff members are available to address technical questions. For first-time MAP customers, the technical staff member discusses the customer's measurement process and statistical control procedures.

Next, NIST staff set up special working files. Historical files are kept for each resistance working standard, including the MAP transport standards. From these files NIST staff create working files for each transport standard involved in the MAP. Each working file contains a header and the results of the last 12 measurements made at NIST. The data taken at the customer's laboratory are added to these files.

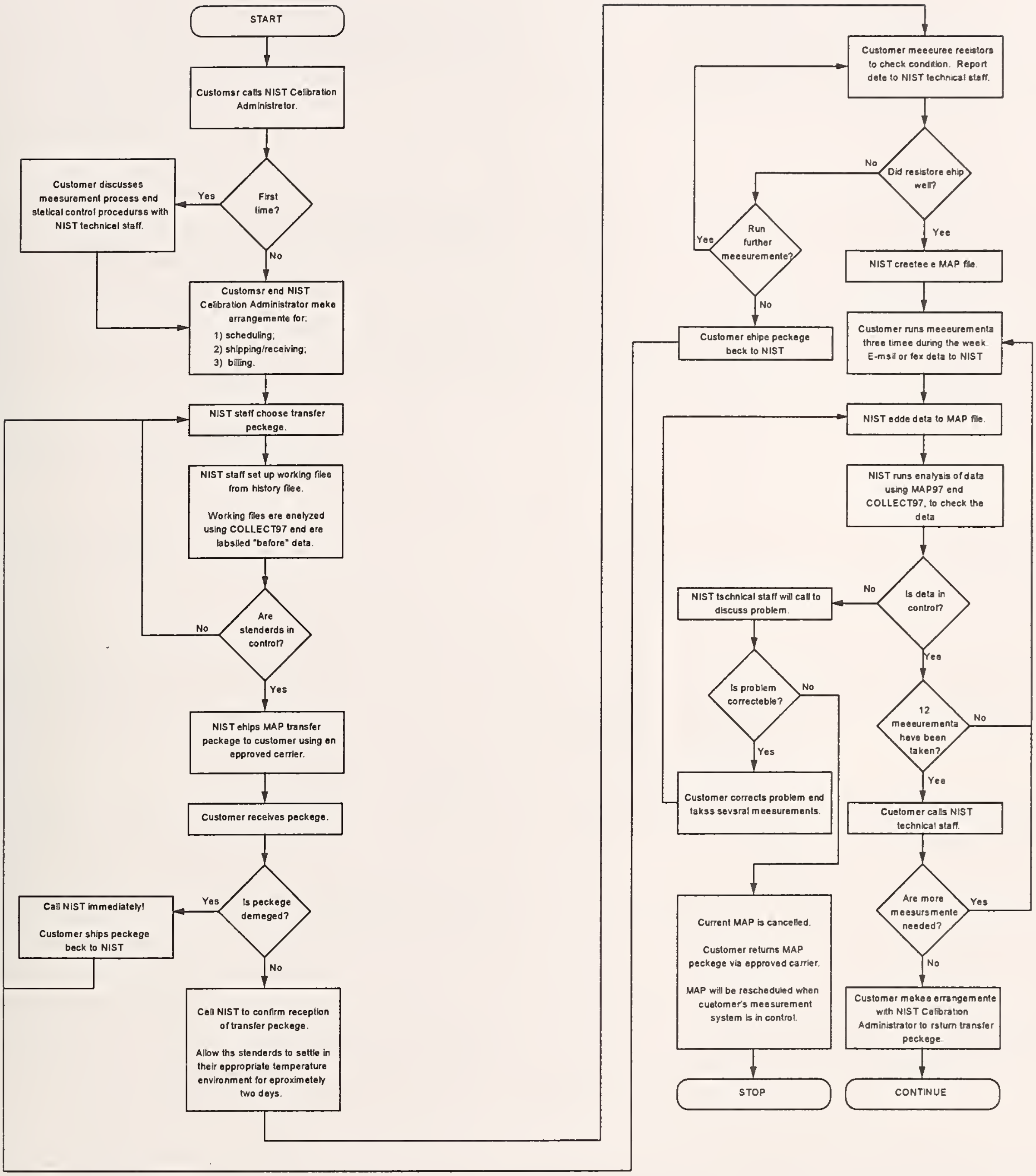


Figure 2. Flow-chart of resistance MAP procedures.

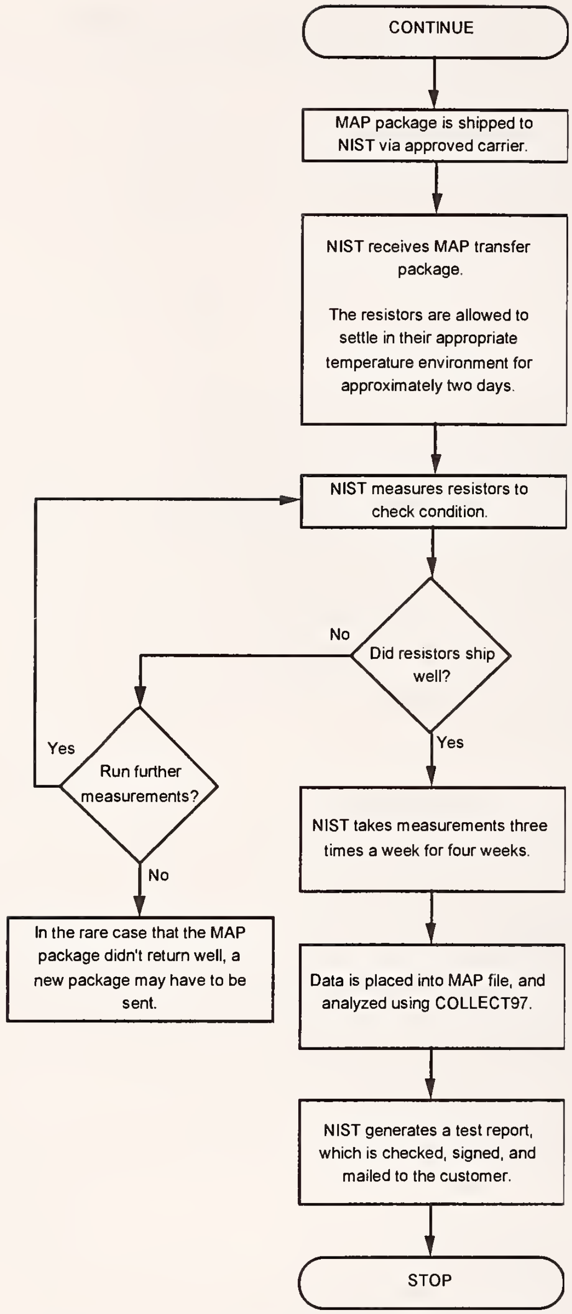


Figure 2 (continued). Flow-chart of resistance MAP procedures.

NIST staff check the transport standards by running the working files through a NIST program called COLLECT97, which provides an analysis of all the transport standards. This program performs a least-squared analysis of the data and determines the residual standard deviation. The program fits and plots the data versus time to ensure that the standards and the measurement system are in control before shipping. The program output is printed out and labeled "before" data, and the slope and intercept of the fit of each resistor are noted for later reference.

Then the NIST Calibration Coordinator ships the MAP package to the customer. These transport standards are rugged and transportable, and they are well characterized for effects of temperature, pressure, and drift. They are packed and shipped, usually via air freight, to the customer in special shipping containers. Oil-type resistors are placed in plastic bags prior to shipping, and the air-type resistors have their lids attached and closed. The shipment includes a folder packed in the transport box. The folder contains an introduction sheet, data sheets, return shipping labels, and a packing list (see Appendix I.1).

2.3.2 Measuring the resistors and sending data to NIST. The transport standards should be treated as part of the typical customer workload; the MAP package should be measured in the same manner as any other resistor that the customer receives for calibration. Thus the MAP data sheets ask only for the final value assigned to the transport standard along with the appropriate environmental conditions (temperature and pressure) for the particular measurement run. The customer laboratory has the choice to correct the data for a transport standard to nominal temperature (23.00 °C or 25.000 °C) and standard atmosphere (101.325 kPa) or have NIST make the corrections. Occasionally, the customer will be requested to run a balanced design for one set of measurements in order to access within-run precision and identify any measurement problems.

The customer performs measurements as outlined on the introduction sheet. The customer will make approximately 12 measurements, unless unusual circumstances warrant something different. No deviations from the instructions should be taken without first consulting the appropriate NIST staff.

The customer records the measurement results on the data sheets, as well as environmental conditions, date and time of measurement, and the operator performing the measurement. The customer returns the data to NIST at the end of each week, either by e-mail or fax. This allows NIST staff to follow the progress of the measurements while the MAP package is at the customer's site.

NIST staff create a customer MAP file (see Fig. 3) and give it a filename based on the customer laboratory, with an extension indicating the value of the MAP (e.g., 0T for 1 Ω Thomas types, 4S for 10 kΩ specials). This file includes the customer laboratory (e.g., LAB XXX), the resistance value of the MAP (e.g., 1T), the intercept year for the drift (e.g., DFYR 1997), and the depth of the oil (e.g., OIL 110) in mm on the first line. The second line labeled TR includes: the serial number of the transport standard (e.g., 1002), the temperature coefficients (alpha in10^{-6}/K and beta in $10^{-6}/K^2$), drift data (intercept value in 10^{-6} from nominal and the slope in 10^{-6}/year), and the pressure coefficient of the standard in 10^{-9}/hPa. The following lines labeled TL (only three of twelve lines indicated) include the customer laboratory data: the measurement date, correction of the standard from nominal in 10^{-6}, the barometric pressure in hPa, and the temperature of the standard in °C.

As data is received from the customer, it is placed in the MAP file. The MAPS97 software program corrects the data in the MAP file to standard temperature and pressure, and stores the results in a file called ANALYSIS.MAP. The corrected data is then included in the working files (weighted "0") and run by the COLLECT97 program (see Appendix I.2). Thus, the data can be checked to see if all is running smoothly. If the COLLECT97 results of the "during" data shows anything unusual, the NIST staff will notify the customer.

```
LAB LAB 1T DFYR 1997 OIL 110
TR 1002  2.2448 -0.5225 -0.8508 -0.0825 0.81
TL 02/24/1997 -1.173 1006.18 24.997 Z
TL 02/26/1997 -1.172 1010.92 24.997 Z
.
.
TL 03/21/1997 -1.153  992.20 24.997 Z
END
TR 1005  2.1458 -0.5231 -0.1952 -0.0972 0.90
TL 02/24/1997 -0.528 1006.18 24.997 Z
TL 02/26/1997 -0.529 1010.92 24.997 Z
.
.
TL 03/21/1997 -0.519  989220 24.997 Z
END
PAGE
TR 1014  1.6648 -0.4380  1.5006 -0.4592 2.94
TL 02/24/1997  0.939 1006.18 24.997 Z
TL 02/26/1997  0.942 1010.92 24.997 Z
.
.
TL 03/22/1997  0.915  992.20 24.997 Z
END
TR 1016  2.1738 -0.5260 -2.1422 -0.5033 3.09
TL 02/24/1997 -2.648 1006.18 24.997 Z
TL 02/26/1997 -2.632 1010.92 24.997 Z
.
.
TL 03/21/1997 -2.648  992.20 24.997 Z
END
STOP STOP
```

Figure 3. Sample customer MAP file "LAB.0T".

2.3.3 Returning the MAP package. After the last customer measurements arrive at NIST, the technical staff notifies the Calibration Coordinator, who in turn notifies the customer, so that the return shipping of the transport standards can be arranged. The customer returns the transport standards in their original shipping container, using the shipping labels included with the MAP packet. The resistors must be packed properly to minimize any effects as a result of shipping.

It is essential that the return of the standards be arranged through NIST. The Calibration Coordinator can assure that the shipping company understands the precautions and procedures necessary to lessen any transportation effects (such as not letting the standards sit out on a hot airport tarmac). Failure to make arrangements through NIST can jeopardize the results of the MAP transfer.

2.3.4 NIST follow-up measurements. As the NIST technical staff take the first follow-up measurements, they add the data to the transport standards working files. Running the COLLECT97 program determines if the resistors shifted during transit. If all looks well, the NIST staff takes 12 measurements over a period of four weeks, after which all measurements for the MAP are completed. All of the follow-up data are placed in the working files (see Appendix I.2).

2.3.5 Generating the report of the MAP. After all of the data are taken, the working files contain:

1) NIST "before" data (labeled "WEIGHT 1");
2) Customer "during" data (labeled "LWEIGHT 0 LAB"); and
3) NIST "after" data (labeled "WEIGHT 1").

The COLLECT97 program analyzes the working files one last time, generating the updated slopes and intercepts for the NIST measurements, slope and intercepts for the customer measurements, and the random and systematic errors of the MAP (see Appendix I.2).

Using the data generated by the COLLECT97 program, and information from the test folder, the NIST technical staff generate a test report for the customer laboratory (see Appendix I.2 and Appendix I.3).

3. DATA ANALYSIS

3.1 Estimate of the difference between the customer's unit of resistance and the U.S. ohm representation

Standard resistors usually display a linear drift over a short time period. Therefore, using the least-squares method [12], a straight line is fitted to the corrections from nominal of the "before" and "after" measurements taken by NIST on the transport standards, after being corrected for temperature and pressure. The slopes and intercepts of the fitted lines are used to predict the values of the transport standards on the dates of their measurements by the customer. Straight lines are also fitted to the data taken by the customer. The estimate of the difference between the unit of resistance as maintained by the customer laboratory and the U. S. ohm representation as maintained by NIST is determined by subtracting each NIST predicted value from each customer predicted value for each transfer standard for each date upon which the customer's measurements were made. Thus, for each resistor an average difference, ΔR, can be determined. The average over all resistors, ΔR_{mean}, represents the estimate of the difference between the units.

If this estimate is greater in magnitude than the combined standard uncertainty of the particular measurement, then NIST recommends adjusting the assigned mean value of the customer's reference standards such that

$$OHM_{LAB} - OHM = 0 \tag{1}$$

where OHM_{LAB} is the unit of resistance at the particular level (either 1 Ω or 10 kΩ), and OHM is the U.S. ohm representation. The combined standard uncertainty is determined by dividing the expanded uncertainty by two ($U/2$).

3.2 Uncertainty of the estimate of the difference

The uncertainty of the estimate of the difference consists of the combination of the Type A and Type B uncertainties resulting from errors in the measurement process [13], where Type A uncertainties are those that are evaluated by statistical methods based on observed data, and Type B uncertainties are those that are not. The expanded, or overall uncertainty can be expressed by the following equation:

$$U = 2 \{ s_{LAB}^2 + s_{NIST}^2 + t'^2 s_{transfer}^2 + \Sigma u_B^2 \}^{1/2} . \qquad (2)$$

The standard deviation of the customer data (s_{LAB}) estimates the effect of random error resulting from the customer laboratory measurements, and is determined by the following equation:

$$s_{LAB}^2 = \left(\frac{1}{MN}\right)^2 \sum_{j=1}^{M} \sum_{i=1}^{N} s_{ij_{LAB}}^2 , \qquad (3)$$

where M is the number of standards in the transfer package, N is the number of measurements at the customer laboratory for each transfer standard, and where $s_{ij_{LAB}}$ is the estimated standard deviation of the customer's predicted value of the j^{th} resistor for the i^{th} measurement at the customer laboratory. Since $s_{ij_{LAB}}$ is an estimate of the standard deviation of a predicted value for an actual measurement at the customer laboratory, it is calculated from the customer's data using the following equation [14]:

$$s_{ij_{LAB}}^2 = s_{j_{LAB}}^2 \left(\frac{1}{N} + \frac{(x_{ij_{LAB}} - \bar{x}_{j_{LAB}})^2}{\sum_{i=1}^{N} (x_{ij_{LAB}} - \bar{x}_{j_{LAB}})^2} \right) , \qquad (4)$$

where $s_{j_{LAB}}$ is the estimated residual standard deviation determined from the linear regression of the customer's data on the j^{th} resistor, $x_{ij_{LAB}}$ is the i^{th} measurement value of the j^{th} resistor, and $\bar{x}_{j_{LAB}}$ is the mean value of all the customer laboratory measurements on the j^{th} resistor.

The standard deviation of the NIST predicted data (s_{NIST}) estimates the effect of random error resulting from the NIST measurements, and is expressed as

$$s_{NIST}^2 = \left(\frac{1}{MN}\right)^2 \sum_{j=1}^{M} \sum_{i=1}^{N} s_{ij_{NIST}}^2 , \qquad (5)$$

where $s_{ij_{NIST}}$ is the estimated standard deviation of the NIST predicted value of the j^{th} resistor for the i^{th} measurement while at the customer laboratory. The values of $s_{ij_{NIST}}$ are calculated from NIST data using the following equation, which is similar to eq (4):

$$s^2_{ij_{NIST}} = s^2_{j_{NIST}} \left(\frac{1}{N} + \frac{(x_{ij_{NIST}} - \bar{x}_{j_{NIST}})^2}{\sum_{i=1}^{N} (x_{ij_{NIST}} - \bar{x}_{j_{NIST}})^2} \right) , \tag{6}$$

where $s_{j_{NIST}}$ is the estimated residual standard deviation determined from the linear regression of the "before" and "after" NIST data on the j^{th} resistor, $x_{ij_{NIST}}$ is the i^{th} measurement value of the j^{th} resistor, and $\bar{x}_{j_{NIST}}$ is the mean value of all the NIST measurements on the j^{th} resistor. Although the values of $s_{ij_{NIST}}$ are determined for actual measurement dates at the customer laboratory and not for measurement dates at NIST, the measurement dates used in the calculations are inside the range of NIST measurement dates and using the form of eq (4) is applicable.

The standard deviation of the ΔR measurements serves as an estimate of the variability of the transfer standards ($s_{transfer}$). The value of $s_{transfer}$ can be calculated by the equation:

$$s^2_{transfer} = \frac{1}{M(M-1)} \sum_{j=1}^{M} (\Delta R_j - \overline{\Delta R})^2 , \tag{7}$$

where

$$\Delta R_j = \frac{1}{N} \sum_{i=1}^{N} (R_{ij(pred)_{LAB}} - R_{ij(pred)_{NIST}}) \tag{8}$$

and represents the mean difference of the j^{th} resistor for the i^{th} measurement, $R_{ij(pred)}$ is the NIST predicted value of the j^{th} resistor for the i^{th} measurement at the customer laboratory, and

$$\overline{\Delta R} = \frac{1}{M} \sum_{j=1}^{M} \Delta R_j . \tag{9}$$

Notice that any shifts in mean or variability resulting from transportation effects are reflected in the above analysis.

To provide coverage for $s_{transfer}$, which has a low degree of freedom, it is multiplied by t', which is defined as

$$t' = \frac{t_{.975}}{2} \tag{10}$$

where $t_{.975}$ is a percent point of the Student t distribution. The value of $t_{.975}$ depends on the number of transfer standards (M), and can be obtained from Table 2. This value is divided by two to simplify the expression of eq (2).

Table 2. Percent point of the Student t distribution for various values of M.

Number of Transfer Standards M	Degrees of Freedom	Percent Point $t_{.975}$
2	1	12.71
3	2	4.30
4	3	3.18

The quantity Σu_B^2 in eq (2) is due to Type B uncertainties resulting from maintaining the working standards in terms of the quantum Hall effect, determining the environmental conditions (temperature and pressure), lead and contact resistances, leakage resistances, loading effects, and predicting the values for the NIST resistors while at the laboratory. Other possible Type B uncertainties in the measurement process are believed to be negligible. For a detailed analysis of Type B uncertainties, see [2]. They are 0.021×10^{-6} for the 1 Ω level and 0.037×10^{-6} for the 10 kΩ level.

The three Type A components and the Type B components are combined in quadrature (root-sum-square) according to the guidelines recommended by the International Bureau of Weights and Measure [15]. The uncertainty is multiplied by a coverage factor $k = 2$ as recommended in [13].

4. ACKNOWLEDGMENTS

The authors wish to express their gratitude to the Calibration Coordinator, Denise Prather, for her hard work and cooperation in keeping the logistics of the resistance MAPs flowing smoothly. We also like to thank Ted Moore for his invaluable service of setting up the computer files, entering the customer laboratory data, and running the computer programs. In addition, we thank Jack Neal (now retired) who for many years did the 10 kΩ calibrations.

APPENDIX I: Typical MAP

The following pages contain the introduction, data sheets, analysis, and final report of a typical resistance MAP. The information follows the outline below.

I.1 **MAP Packet:** contains procedures for both types of resistance MAPs, data sheets (including a front data sheet), and packing and return shipping labels.

I.2 **Analysis of data:** contains the working files of the transport standards, and sample input files and output of the software programs, to reflect the analysis of the MAP process.

I.3 **Results of MAP:** contains a sample report of test and its associated appendices.

I.1 MAP Packet

Introduction: The MAP packet is placed in a folder, shipped with the transport standards, and contains the following:

I.1.1 **Introduction to Resistance MAPs:** explains the suggested measurement procedure for both the 1 Ω and the 10 kΩ MAPs.

I.1.2 **Front data sheet:** gives data on the transport standards, and asks for information on the customer's reference standards.

I.1.3 **Data sheet:** one data sheet for each measurement run of transport standards; asks for the measurement results, the environmental conditions during the measurement, the date and time of measurement, and the name of the operator.

I.1.4 **Shipping order and labels:** shipping order and labels to place on the transport standards case for return shipping.

Examples of each are contained in the following pages.

RESISTANCE MAP - 1 Ω

Suggested Measurement Schedule:

1) Place resistors in oil bath @ 25 °C as soon as possible after arrival.

2) Measure resistors after ≈ 2 days in oil bath and report measurements to NIST. Report the data to the Technical Contact for resistance MAPs (301-975-4221). These are preliminary measurements to check the conditions of the resistors.

3) Measure each resistor three times a week from the 2nd through the 5th week for a total of 12 measurements for each resistor. After each week during this time period, send the data to NIST for analysis. Fax data to:

   National Institute of Standards and Technology
   Electricity Division
   Attn: Calibration Coordinator, Metrology B146
   Gaithersburg, MD 20899
   FAX: 1-301-926-3972

4) If no complications arise, this completes the measurements by the customer laboratory. The resistors are then packaged in their original container and returned to NIST. Contact the Calibration Coordinator (301-975-4221) for shipping instructions.

5) If the resistors have not settled after the first week, additional measurements may be necessary. You will be notified by NIST if this is the situation.

6) If problems arise with the resistors or time schedule, please notify the Technical Contact for resistance MAPs.

RESISTANCE MAP - 10 kΩ

Suggested Measurement Schedule:

1) Place resistors in their respective temperature environments (air temperature ≈ 23 °C, oil bath temperature ≈ 25 °C) as soon as possible after their arrival.

2) Measure resistors after ≈ 2 days in oil bath and report measurements to NIST. Report the data to the Technical Contact for resistance MAPs (301-975-4221). These are preliminary measurements to check the conditions of the resistors.

3) Measure each resistor three times a week from the 2nd through the 5th week for a total of 12 measurements for each resistor. After each week during this time period, send the data to NIST for analysis. Fax data to:

   National Institute of Standards and Technology
   Electricity Division
   Attn: Calibration Coordinator, Metrology B146
   Gaithersburg, MD 20899
   FAX: 1-301-926-3972

4) If no complications arise, this completes the measurements by the client laboratory. The resistors are then packaged in their original container and returned to NIST. Contact the Calibration Coordinator (301-975-4221) for shipping instructions.

5) If the resistors have not settled after the first week, additional measurements may be necessary. You will be notified by NIST if this is the situation.

6) If problems arise with the resistors or time schedule, please notify the Technical Contact for resistance MAPs.

FRONT DATA SHEET
FILL OUT THIS SHEET AND RETURN WITH FIRST RUN

ADDRESS

XYZ Resistance Laboratory — Name: P. P. Ems

Ohm City, MD 20899 — Phone #: 1-999-123-4567

SERIAL NUMBER	CORRECTION (ppm)	NOM. TEMP. (°C)	ALPHA (ppm/°C)	BETA (ppm/°C^2)	PRESSURE COEFF. (ppb/hPa)
X0001	1.29	25.00	-1.26	-0.508	2.0
X0002	-0.35	25.00	4.81	-0.525	1.9
X0003	-2.45	25.00	-2.01	-0.512	3.7
X0004	6.01	25.00	3.65	-0.530	2.1
X0005	-0.87	25.00	2.54	-0.519	2.8
X0006	4.22	25.00	-1.22	-0.532	1.6
1002		25.00	2.2448	-0.5225	0.61
1005		25.00	2.1458	-0.5231	0.68
1014		25.00	1.6648	-0.4380	2.21
1016		25.00	2.1738	-0.5260	2.32

INFORMATION NEEDED ON THIS SHEET

1. Corrections to the laboratory standards in ppm.
2. Nominal temperature of laboratory standards in degrees Celsius.
3. Temperature coefficients to the laboratory standards in ppm/°C and ppm/°C^2.
4. Pressure coefficients to the laboratory standards in ppb/hPa; if known.

Data Sheet No. 1

Laboratory: XYZ   Date: 2/24/1997   Time: 9:35 am

I. Assignment of corrections to the NIST transport standards by the Laboratory (LAB).

Serial Number	Correction (ppm)	Temperature (°C)	Barometric Pressure (hPa)	Depth of Oil to Mercury Wetted Surface of Resistor in mm
1002	-1.173	24.997	1006.2	110.0
1005	-0.528	24.997	1006.2	110.0
1014	0.939	24.997	1006.2	110.0
1016	-2.648	24.997	1006.2	110.0

Error Evaluation (if known)

Average Left-Right Error of Days Measurement NA

Standard Deviation of an Individual Measurement NA

Degrees of Freedom Associated with Std. Dev. Above: NA

II. The above corrections are based on intercomparison with the following laboratory standards.

Serial Number	Correction (ppm)	Temperature (°C)	Barometric Pressure (hPa)	Depth of Oil to Mercury Wetted Surface of Resistor in mm
X0001	1.29	24.997	1006.2	110.0
X0002	-0.36	24.997	1006.2	110.0
X0003	-2.44	24.997	1006.2	110.0
X0004	6.00	24.997	1006.2	110.0
X0005	-0.88	24.997	1006.2	110.0
X0006	4.22	24.997	1006.2	110.0

In the above assignment of laboratory standard corrections:

1. Were temperature corrections applied? Yes___ No ✔
   If Yes, to what temperature? ________

2. Were barometric pressure corrections applied? Yes___ No ✔
   If Yes, to what pressure? ________

3. Were corrections for depth of the oil to the mercury wetted surfaces applied?
   Yes ___ No ✔

This form will be made out on a typewriter. Care should be taken to make the last copy legible. The last copy may be retained for your files. The first five copies should be left attached to the stub.

1

FORM **NIST-386**
(REV. 11- 88)

SHIPPING ORDER

U.S. DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

1. FOR FURTHER INFORMATION CALL - TELEPHONE NUMBER	2. DIVISION	3. COST CENTER NUMBER AND REQUISITION NUMBER	4. DATE
Calibration Administrator (301) 975-4221	811	8111234 811-9999	2/19/97

5. SHIP FROM	6. SHIP TO
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY **RT. 270 & QUINCE ORCHARD ROAD** **GAITHERSBURG, MD. 20899**	XYZ Resistance Laboratory 51130 Thomas Drive Ohm City, MD 20899 Attn: P.P. Ems

7. DESCRIPTION *(Include NIST property and manufacturer's serial number when pertinent and itemize all separate parts or attachments)*

HAZARDOUS MATERIAL ☐ YES ☒ NO

4 - One-Ohm Resistors, Serial Nos. 1002, 1005, 1014, 1016

(If necessary, continue on plain paper with 4 carbon copies) 8. ESTIMATED VALUE $ 20,000.00

9. SUGGESTED METHOD OF SHIPMENT	10.
Messenger Service	☐ PREPAID ☐ COLLECT

11 PURPOSE *(E.G., RETURN OF TEST MATERIAL, LOAN, REPAIRS, ETC.)*	12. AUTHORIZED
Participation in the Resistance Measurement Assurance Program	Group Leader, 811 *(Signature and Title)*

13. NUMBER PIECES	14. GROSS WEIGHT	15. ESTIMATED SHIPPING COST	16. B/L NUMBER	17. SHIPPED VIA	18. DATE
1					

19. REMARKS	20. RECEIVED BY
Please keep in controlled environment between 18 & 28°C	

USCOMM-DC 89-6029

U.S DEPARTMENT OF COMMERCE
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
BLDG 220 **ROOM** B146
GAITHERSBURG, MD 20899-0001
OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE $300
811

XYZ Resistance Laboratory
51130 Thomas Drive
Ohm City, MD 20899

Attn: P.P. Ems

I.2 Analysis of MAP data

I.2.1 Introduction. This section discusses the working files and the input and output files of the software analysis at different points in the MAP process, showing a step-by-step analysis of the data. The outline below describes the sequence of data and analysis.

1. **"Before" data:**

   a. **Historical files:** Data files are kept on all of NIST's working standards, including the transport standards. To begin a MAP, working files containing the most recent 12 data points are created from these historical files.

   b. **COLLECT97:** Before NIST ships the transport standards to the customer, a least-squared analysis is performed on the data for the transport standards, using the COLLECT97 program, to check the performance of the package. The output is labeled "before" data, and the slope and intercept for each resistor are noted for future use in the MAP file.

2. **"During" data:**

   a. **MAP file:** When the customer begins sending data on the transport standards back to NIST, the data are placed in a special MAP file, which also contains the following information on each standard: serial number, slope and intercept based on the "before" data, temperature coefficients (α and β), pressure coefficient, and nominal temperature. In addition, the file contains the customer name in abbreviated form, and the depth of the resistors below the oil in the customer's oil bath.

   b. **MAPS97:** The MAPS97 program takes the newly created MAP file, and corrects the customer data for temperature and pressure, and stores all the data in a file called MAPS97.OUT. A listing of a sample MAPS97.OUT file is shown in Appendix I.2.2.

   c. **ANALYSIS.MAP:** This file is also an output of the MAPS97 program. It contains only the measurement dates and the corresponding "corrected" customer data that are to be entered in the working files.

   d. **Working files:** The data from ANALYSIS.MAP are added to the working files. A listing of sample working files, containing the output data from ANALYSIS.MAP, are shown in Appendix I.2.3. The customer data are labeled "LWEIGHT 0 LAB", while the NIST data are labeled "WEIGHT 1."

   e. **COLLECT97:** A least-squares analysis is performed on the customer data and the NIST data using the COLLECT97 program. This program fits the NIST data, then fits the customer data, and then finally determines the uncertainty of the measurement process. These data are labeled "during" data.

standards. This allows NIST staff to monitor the MAP in progress, and to identify and possibly correct any errors.

3. **<u>"After" data:</u>**

   a. **Working files:** After the transport standards have returned from the customer, initial measurements are made and stored in the working file, and labeled "WEIGHT 1."

   b. **COLLECT97:** COLLECT97 is run on the working files to determine if any shift has occurred upon returning. These data are labeled "after" data.

   For a period of about 4 weeks, NIST staff continues to take data, storing the results in the transport standard working files.

4. **<u>"Final" data:</u>**

   a. **Working files:** NIST staff take measurements on the transport standards and enters the data in the working files until 12 or more measurements have been taken since the return of the MAP package (see Appendix I.2.3).

   b. **COLLECT97:** The final least-squares analysis on all the customer data and on all the NIST data is performed using COLLECT97. A listing of a completed COLLECT97 output is shown in Appendix I.2.4. The output of this program includes all the information needed to generate a test report for the customer laboratory: the customer laboratory's corrected data, the difference data between the customer laboratory and NIST, the Type A and Type B uncertainties, and the expanded uncertainty.

      Note that the generalized equation for the standard deviation of a predicted value (STDPV) listed in the COLLECT97 output is given in matrix notation and is equivalent to the form of eqs (4) and (6) in the text. In the matrix equation, A and B correspond to the variances of the slope and intercept, respectively, and C is the covariance element, or off-diagonal term, of the variance-covariance matrix. The time variable, T, in the equation corresponds to the x-variable in the text equations. For a more detailed explanation on the equivalency of these equations refer to pages 82-83 in [14] or a similar text book on regression analysis.

I.2.2 Sample "MAPS97.OUT"

```
                                                Date 28 April, 1997     Time 14:47:22

                               Alpha     Beta     R1997.0     Slope      PC      Nominal Temp     Depth Oil

***** S/N 1002                2.2448   -0.5225   -0.8847   -0.4345    0.8100      25.000          110.00

                                LAB      NIST      LAB               Delta   Temp              Press
      Date          LAB        Corr      Pred     -Pred     Temp     Temp    Corr      B/P     Corr
 1   2 24 1997   -1.1730   -1.1681   -0.9502   -0.2179  24.997  -0.003 -0.0067  1006.2  0.0018
 2   2 26 1997   -1.1720   -1.1709   -0.9526   -0.2184  24.997  -0.003 -0.0067  1010.9  0.0057
 3   2 28 1997   -1.1580   -1.1393   -0.9549   -0.1843  24.997  -0.003 -0.0067   989.1  -.0120
 4   3  3 1997   -1.1650   -1.1567   -0.9585   -0.1982  24.997  -0.003 -0.0067  1002.0  -.0016
 5   3  5 1997   -1.1630   -1.1546   -0.9609   -0.1937  24.997  -0.003 -0.0067  1001.9  -.0017
 6   3  7 1997   -1.1570   -1.1408   -0.9633   -0.1775  24.997  -0.003 -0.0067   992.2  -.0095
 7   3 10 1997   -1.1650   -1.1551   -0.9668   -0.1883  24.997  -0.003 -0.0067  1000.0  -.0032
 8   3 12 1997   -1.1780   -1.1757   -0.9692   -0.2065  24.998  -0.002 -0.0045  1006.6  0.0022
 9   3 14 1997   -1.1530   -1.1347   -0.9716   -0.1631  24.997  -0.003 -0.0067   989.7  -.0116
10   3 17 1997   -1.1540   -1.1354   -0.9752   -0.1603  24.997  -0.003 -0.0067   989.3  -.0118
11   3 19 1997   -1.1640   -1.1601   -0.9776   -0.1825  24.997  -0.003 -0.0067  1007.4  0.0028
12   3 21 1997   -1.1530   -1.1368   -0.9799   -0.1568  24.997  -0.003 -0.0067   992.2  -.0095

                    Sigma    0.0147              0.0209   0.000                      8.0
                     Mean   -1.1523             -0.1873  24.997                    999.0
               Sigma Mean    0.0042              0.0060   0.000                      2.3

***** Delta R Mean of 1 Resistor(s) =   -0.1873   S/N= 1002

                               Alpha     Beta     R1997.0     Slope      PC      Nominal Temp     Depth Oil

***** S/N 1005                2.1458   -0.5231   -0.2755   -0.3104    0.9000      25.000          110.00

                                LAB      NIST      LAB               Delta   Temp              Press
      Date          LAB        Corr      Pred     -Pred     Temp     Temp    Corr      B/P     Corr
 1   2 24 1997   -0.5280   -0.5236   -0.3223   -0.2013  24.997  -0.003 -0.0064  1006.2  0.0020
 2   2 26 1997   -0.5290   -0.5289   -0.3240   -0.2049  24.997  -0.003 -0.0064  1010.9  0.0063
 3   2 28 1997   -0.5140   -0.4942   -0.3257   -0.1686  24.997  -0.003 -0.0064   989.1  -.0133
 4   3  3 1997   -0.5240   -0.5158   -0.3282   -0.1876  24.997  -0.003 -0.0064  1002.0  -.0018
 5   3  5 1997   -0.5250   -0.5167   -0.3299   -0.1868  24.997  -0.003 -0.0064  1001.9  -.0019
 6   3  7 1997   -0.5150   -0.4980   -0.3316   -0.1664  24.997  -0.003 -0.0064   992.2  -.0105
 7   3 10 1997   -0.5240   -0.5141   -0.3342   -0.1799  24.997  -0.003 -0.0064  1000.0  -.0035
 8   3 12 1997   -0.5280   -0.5262   -0.3359   -0.1903  24.998  -0.002 -0.0043  1006.6  0.0024
 9   3 14 1997   -0.5170   -0.4977   -0.3376   -0.1601  24.997  -0.003 -0.0064   989.7  -.0128
10   3 17 1997   -0.5190   -0.4994   -0.3401   -0.1593  24.997  -0.003 -0.0064   989.3  -.0132
11   3 19 1997   -0.5280   -0.5247   -0.3418   -0.1829  24.997  -0.003 -0.0064  1007.4  0.0031
12   3 21 1997   -0.5190   -0.5020   -0.3435   -0.1585  24.997  -0.003 -0.0064   992.2  -.0105

                    Sigma    0.0128              0.0162   0.000                      8.0
                     Mean   -0.5118             -0.1789  24.997                    999.0
               Sigma Mean    0.0037              0.0047   0.000                      2.3

***** Delta R Mean of 2 Resistor(s) =   -0.1831   S/N= 1002  1005
```

	Alpha	Beta	R1997.0	Slope	PC	Nominal Temp	Depth Oil
***** S/N 1014	1.6648	-0.4380	1.2275	-0.4692	2.9400	25.000	110.00

	Date	LAB	LAB Corr	NIST Pred	LAB -Pred	Temp	Delta Temp	Temp Corr	B/P	Press Corr
1	2 24 1997	0.9390	0.9374	1.1568	-0.2194	24.997	-0.003	-0.0050	1006.2	0.0066
2	2 26 1997	0.9420	0.9264	1.1542	-0.2278	24.997	-0.003	-0.0050	1010.9	0.0206
3	2 28 1997	0.9210	0.9695	1.1517	-0.1821	24.997	-0.003	-0.0050	989.1	-.0435
4	3 3 1997	0.9370	0.9478	1.1478	-0.2000	24.997	-0.003	-0.0050	1002.0	-.0058
5	3 5 1997	0.9350	0.9461	1.1452	-0.1991	24.997	-0.003	-0.0050	1001.9	-.0061
6	3 7 1997	0.9280	0.9675	1.1427	-0.1752	24.997	-0.003	-0.0050	992.2	-.0345
7	3 10 1997	0.9320	0.9484	1.1388	-0.1904	24.997	-0.003	-0.0050	1000.0	-.0114
8	3 12 1997	0.9390	0.9343	1.1362	-0.2019	24.998	-0.002	-0.0033	1006.6	0.0080
9	3 14 1997	0.9250	0.9720	1.1337	-0.1617	24.997	-0.003	-0.0050	989.7	-.0420
10	3 17 1997	0.9220	0.9700	1.1298	-0.1598	24.997	-0.003	-0.0050	989.3	-.0430
11	3 19 1997	0.9440	0.9388	1.1272	-0.1885	24.997	-0.003	-0.0050	1007.4	0.0102
12	3 21 1997	0.9150	0.9545	1.1247	-0.1702	24.997	-0.003	-0.0050	992.2	-.0345
		Sigma	0.0156		0.0213	0.000			8.0	
		Mean	0.9511		-0.1897	24.997			999.0	
		Sigma Mean	0.0045		0.0062	0.000			2.3	

***** Delta R Mean of 3 Resistor(s) = -0.1853 S/N= 1002 1005 1014

	Alpha	Beta	R1997.0	Slope	PC	Nominal Temp	Depth Oil
***** S/N 1016	2.1738	-0.5260	-2.3803	-0.3431	3.0900	25.000	110.00

	Date	LAB	LAB Corr	NIST Pred	LAB -Pred	Temp	Delta Temp	Temp Corr	B/P	Press Corr
1	2 24 1997	-2.6480	-2.6485	-2.4320	-0.2165	24.997	-0.003	-0.0065	1006.2	0.0070
2	2 26 1997	-2.6320	-2.6471	-2.4339	-0.2132	24.997	-0.003	-0.0065	1010.9	0.0216
3	2 28 1997	-2.6500	-2.5977	-2.4358	-0.1619	24.997	-0.003	-0.0065	989.1	-.0458
4	3 3 1997	-2.6380	-2.6254	-2.4386	-0.1868	24.997	-0.003	-0.0065	1002.0	-.0061
5	3 5 1997	-2.6400	-2.6271	-2.4405	-0.1866	24.997	-0.003	-0.0065	1001.9	-.0064
6	3 7 1997	-2.6460	-2.6033	-2.4423	-0.1609	24.997	-0.003	-0.0065	992.2	-.0362
7	3 10 1997	-2.6440	-2.6254	-2.4452	-0.1803	24.997	-0.003	-0.0065	1000.0	-.0120
8	3 12 1997	-2.6310	-2.6350	-2.4470	-0.1880	24.998	-0.002	-0.0043	1006.6	0.0084
9	3 14 1997	-2.6470	-2.5964	-2.4489	-0.1475	24.997	-0.003	-0.0065	989.7	-.0441
10	3 17 1997	-2.6510	-2.5993	-2.4517	-0.1476	24.997	-0.003	-0.0065	989.3	-.0452
11	3 19 1997	-2.6300	-2.6342	-2.4536	-0.1806	24.997	-0.003	-0.0065	1007.4	0.0107
12	3 21 1997	-2.6480	-2.6053	-2.4555	-0.1498	24.997	-0.003	-0.0065	992.2	-.0362
		Sigma	0.0192		0.0237	0.000			8.0	
		Mean	-2.6204		-0.1766	24.997			999.0	
		Sigma Mean	0.0055		0.0068	0.000			2.3	

***** Delta R Mean of 4 Resistor(s) = -0.1831 S/N= 1002 1005 1014 1016
***** Delta R Sigma Mean= 0.0032

I.2.3 Sample "Final" Data

Working Files

```
File: M1002M.OT

HEADER ANALYSIS OF NIST 1 Ω RESISTOR 1002
INTERCEPT 1997
UNITS PPM
SCALE 1.0
ITEM 1002
DATA
01/20/1997  -0.9288
01/22/1997  -0.9333
01/24/1997  -0.9274
01/27/1997  -0.9268
01/29/1997  -0.9163
01/31/1997  -0.9215
02/03/1997  -0.9212
02/05/1997  -0.9164
02/07/1997  -0.9183
02/10/1997  -0.9100
02/12/1997  -0.9100
02/14/1997  -0.9150
LWEIGHT 0 LAB
02/24/1997  -1.1681
02/26/1997  -1.1709
02/28/1997  -1.1393
03/03/1997  -1.1567
03/05/1997  -1.1546
03/07/1997  -1.1408
03/10/1997  -1.1551
03/12/1997  -1.1757
03/14/1997  -1.1347
03/17/1997  -1.1354
03/19/1997  -1.1601
03/21/1997  -1.1368
WEIGHT 1
03/31/1997  -1.0131
04/02/1997  -1.0116
04/04/1997  -1.0106
04/07/1997  -1.0090
04/09/1997  -1.0118
04/11/1997  -1.0108
04/14/1997  -1.0028
04/16/1997  -1.0081
04/18/1997  -1.0101
04/21/1997  -1.0058
04/23/1997  -1.0105
04/25/1997  -1.0127
END
```

```
File: M1005M.OT

HEADER ANALYSIS OF NIST 1 Ω RESISTOR 1005
INTERCEPT 1997
UNITS PPM
SCALE 1.0
ITEM 1005
DATA
01/20/1997  -0.3077
01/22/1997  -0.3056
01/24/1997  -0.3088
01/27/1997  -0.3113
01/29/1997  -0.2931
01/31/1997  -0.3011
02/03/1997  -0.2970
02/05/1997  -0.2957
02/07/1997  -0.2992
02/10/1997  -0.2929
02/12/1997  -0.3020
02/14/1997  -0.2980
LWEIGHT 0 LAB
02/24/1997  -0.5236
02/26/1997  -0.5289
02/28/1997  -0.4942
03/03/1997  -0.5158
03/05/1997  -0.5167
03/07/1997  -0.4980
03/10/1997  -0.5141
03/12/1997  -0.5262
03/14/1997  -0.4977
03/17/1997  -0.4994
03/19/1997  -0.5247
03/21/1997  -0.5020
WEIGHT 1
03/31/1997  -0.3688
04/02/1997  -0.3625
04/04/1997  -0.3652
04/07/1997  -0.3693
04/09/1997  -0.3644
04/11/1997  -0.3624
04/14/1997  -0.3633
04/16/1997  -0.3647
04/18/1997  -0.3641
04/21/1997  -0.3622
04/23/1997  -0.3663
04/25/1997  -0.3633
END
```

```
HEADER ANALYSIS OF NIST 1 Ω RESISTOR 1014
INTERCEPT 1997
UNITS PPM
SCALE 1.0
ITEM 1014
DATA
01/20/1997  1.1906
01/22/1997  1.1866
01/24/1997  1.1907
01/27/1997  1.1835
01/29/1997  1.1874
01/31/1997  1.1877
02/03/1997  1.1927
02/05/1997  1.1861
02/07/1997  1.1892
02/10/1997  1.1879
02/12/1997  1.1901
02/14/1997  1.1871
LWEIGHT 0 LAB
02/24/1997  0.9374
02/26/1997  0.9264
02/28/1997  0.9695
03/03/1997  0.9478
03/05/1997  0.9461
03/07/1997  0.9675
03/10/1997  0.9484
03/12/1997  0.9343
03/14/1997  0.9720
03/17/1997  0.9700
03/19/1997  0.9388
03/21/1997  0.9545
WEIGHT 1
03/31/1997  1.0963
04/02/1997  1.0889
04/04/1997  1.0897
04/07/1997  1.0900
04/09/1997  1.0909
04/11/1997  1.0935
04/14/1997  1.0917
04/16/1997  1.0930
04/18/1997  1.0958
04/21/1997  1.0950
04/23/1997  1.0980
04/25/1997  1.0957
END
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HEADER ANALYSIS OF NIST 1 Ω RESISTOR 1016
INTERCEPT 1997
UNITS PPM
SCALE 1.0
ITEM 1016
DATA
01/20/1997  -2.4108
01/22/1997  -2.4131
01/24/1997  -2.4132
01/27/1997  -2.4056
01/29/1997  -2.3992
01/31/1997  -2.4058
02/03/1997  -2.4094
02/05/1997  -2.4131
02/07/1997  -2.4105
02/10/1997  -2.4101
02/12/1997  -2.4069
02/14/1997  -2.4111
LWEIGHT 0 LAB
02/24/1997  -2.6485
02/26/1997  -2.6471
02/28/1997  -2.5977
03/03/1997  -2.6254
03/05/1997  -2.6271
03/07/1997  -2.6033
03/10/1997  -2.6254
03/12/1997  -2.6350
03/14/1997  -2.5964
03/17/1997  -2.5993
03/19/1997  -2.6342
03/21/1997  -2.6053
WEIGHT 1
03/31/1997  -2.4738
04/02/1997  -2.4787
04/04/1997  -2.4804
04/07/1997  -2.4792
04/09/1997  -2.4846
04/11/1997  -2.4801
04/14/1997  -2.4776
04/16/1997  -2.4786
04/18/1997  -2.4804
04/21/1997  -2.4808
04/23/1997  -2.4739
04/25/1997  -2.4736
END
```

1.2.4 Sample "COLLECT97"

Analysis of 1002 1005 1014 1016

	Mo	Da	Yr	Time	1002	SDPV	Residual	Wt	Mo	Da	Yr	Time	1005	SDPV	Residual	Wt
1	1	20	1997	0.055	-0.9288	0.0050	-0.0203	1	1	20	1997	0.055	-0.3077	0.0036	-0.0152	1
2	1	22	1997	0.060	-0.9333	0.0048	-0.0224	1	1	22	1997	0.060	-0.3056	0.0035	-0.0114	1
3	1	24	1997	0.066	-0.9274	0.0047	-0.0141	1	1	24	1997	0.066	-0.3088	0.0034	-0.0129	1
4	1	27	1997	0.074	-0.9268	0.0045	-0.0099	1	1	27	1997	0.074	-0.3113	0.0032	-0.0129	1
5	1	29	1997	0.079	-0.9163	0.0044	0.0029	1	1	29	1997	0.079	-0.2931	0.0032	0.0070	1
6	1	31	1997	0.085	-0.9215	0.0043	0.0001	1	1	31	1997	0.085	-0.3011	0.0031	0.0007	1
7	2	3	1997	0.093	-0.9212	0.0041	0.0040	1	2	3	1997	0.093	-0.2970	0.0029	0.0074	1
8	2	5	1997	0.099	-0.9164	0.0040	0.0112	1	2	5	1997	0.099	-0.2957	0.0029	0.0104	1
9	2	7	1997	0.104	-0.9183	0.0039	0.0117	1	2	7	1997	0.104	-0.2992	0.0028	0.0086	1
10	2	10	1997	0.112	-0.9100	0.0037	0.0235	1	2	10	1997	0.112	-0.2929	0.0027	0.0174	1
11	2	12	1997	0.118	-0.9100	0.0036	0.0259	1	2	12	1997	0.118	-0.3020	0.0026	0.0100	1
12	2	14	1997	0.123	-0.9150	0.0035	0.0233	1	2	14	1997	0.123	-0.2980	0.0025	0.0157	1
13	2	24	1997	0.151	-1.1681	0.0032	-0.2179	0	2	24	1997	0.151	-0.5236	0.0023	-0.2014	0
14	2	26	1997	0.156	-1.1709	0.0031	-0.2183	0	2	26	1997	0.156	-0.5289	0.0022	-0.2050	0
15	2	28	1997	0.162	-1.1393	0.0031	-0.1843	0	2	28	1997	0.162	-0.4942	0.0022	-0.1686	0
16	3	3	1997	0.170	-1.1567	0.0030	-0.1982	0	3	3	1997	0.170	-0.5158	0.0022	-0.1876	0
17	3	5	1997	0.175	-1.1546	0.0030	-0.1937	0	3	5	1997	0.175	-0.5167	0.0022	-0.1868	0
18	3	7	1997	0.181	-1.1408	0.0030	-0.1775	0	3	7	1997	0.181	-0.4980	0.0022	-0.1664	0
19	3	10	1997	0.189	-1.1551	0.0030	-0.1882	0	3	10	1997	0.189	-0.5141	0.0022	-0.1800	0
20	3	12	1997	0.195	-1.1757	0.0030	-0.2065	0	3	12	1997	0.195	-0.5262	0.0022	-0.1904	0
21	3	14	1997	0.200	-1.1347	0.0030	-0.1631	0	3	14	1997	0.200	-0.4977	0.0022	-0.1602	0
22	3	17	1997	0.208	-1.1354	0.0031	-0.1602	0	3	17	1997	0.208	-0.4994	0.0022	-0.1593	0
23	3	19	1997	0.214	-1.1601	0.0031	-0.1825	0	3	19	1997	0.214	-0.5247	0.0022	-0.1829	0
24	3	21	1997	0.219	-1.1368	0.0032	-0.1568	0	3	21	1997	0.219	-0.5020	0.0023	-0.1585	0
25	3	31	1997	0.247	-1.0131	0.0035	-0.0212	1	3	31	1997	0.247	-0.3688	0.0025	-0.0168	1
26	4	2	1997	0.252	-1.0116	0.0036	-0.0174	1	4	2	1997	0.252	-0.3625	0.0026	-0.0088	1
27	4	4	1997	0.258	-1.0106	0.0037	-0.0140	1	4	4	1997	0.258	-0.3652	0.0027	-0.0098	1
28	4	7	1997	0.266	-1.0090	0.0039	-0.0088	1	4	7	1997	0.266	-0.3693	0.0028	-0.0113	1
29	4	9	1997	0.271	-1.0118	0.0040	-0.0092	1	4	9	1997	0.271	-0.3644	0.0029	-0.0047	1
30	4	11	1997	0.277	-1.0108	0.0041	-0.0058	1	4	11	1997	0.277	-0.3624	0.0029	-0.0010	1
31	4	14	1997	0.285	-1.0028	0.0043	0.0057	1	4	14	1997	0.285	-0.3633	0.0031	0.0006	1
32	4	16	1997	0.290	-1.0081	0.0044	0.0028	1	4	16	1997	0.290	-0.3647	0.0032	0.0009	1
33	4	18	1997	0.296	-1.0101	0.0045	0.0032	1	4	18	1997	0.296	-0.3641	0.0032	0.0032	1
34	4	21	1997	0.304	-1.0058	0.0047	0.0111	1	4	21	1997	0.304	-0.3622	0.0034	0.0077	1
35	4	23	1997	0.310	-1.0105	0.0048	0.0087	1	4	23	1997	0.310	-0.3663	0.0035	0.0053	1
36	4	25	1997	0.315	-1.0127	0.0050	0.0089	1	4	25	1997	0.315	-0.3633	0.0036	0.0100	1

	1002	1005
Meas Wt=1	24.0000	24.0000
Mean	-0.9651	-0.3329
Range	0.1031	0.0764
S.D. Ind	0.0460	0.0328
S.D. Mean	0.0094	0.0067
Minimum	-1.0131	-0.3693
Maximum	-0.9100	-0.2929

Time in years from 1997.0; resistor corrections, SDPV's, and residuals in ppm.
*** NOTE: Zero weighted observations not included in the Mean etc.
Residual is the deviation from the fitted straight line
SDPV=SQRT(B+(2*C*T)+(A*(T**2)))

	Mo	Da	Yr	Time	1014	SDPV	Residual	Wt	Mo	Da	Yr	Time	1016	SDPV	Residual	Wt
1	1	20	1997	0.055	1.1906	0.0041	-0.0112	1	1	20	1997	0.055	-2.4108	0.0031	-0.0117	1
2	1	22	1997	0.060	1.1866	0.0040	-0.0126	1	1	22	1997	0.060	-2.4131	0.0030	-0.0121	1
3	1	24	1997	0.066	1.1907	0.0039	-0.0060	1	1	24	1997	0.066	-2.4132	0.0030	-0.0103	1
4	1	27	1997	0.074	1.1835	0.0038	-0.0093	1	1	27	1997	0.074	-2.4056	0.0028	0.0001	1
5	1	29	1997	0.079	1.1874	0.0037	-0.0028	1	1	29	1997	0.079	-2.3992	0.0028	0.0084	1
6	1	31	1997	0.085	1.1877	0.0036	0.0000	1	1	31	1997	0.085	-2.4058	0.0027	0.0037	1
7	2	3	1997	0.093	1.1927	0.0034	0.0089	1	2	3	1997	0.093	-2.4094	0.0026	0.0029	1
8	2	5	1997	0.099	1.1861	0.0033	0.0049	1	2	5	1997	0.099	-2.4131	0.0025	0.0011	1
9	2	7	1997	0.104	1.1892	0.0032	0.0105	1	2	7	1997	0.104	-2.4105	0.0024	0.0055	1
10	2	10	1997	0.112	1.1879	0.0031	0.0131	1	2	10	1997	0.112	-2.4101	0.0023	0.0088	1
11	2	12	1997	0.118	1.1901	0.0030	0.0179	1	2	12	1997	0.118	-2.4069	0.0023	0.0138	1
12	2	14	1997	0.123	1.1871	0.0030	0.0174	1	2	14	1997	0.123	-2.4111	0.0022	0.0115	1
13	2	24	1997	0.151	0.9374	0.0026	-0.2194	0	2	24	1997	0.151	-2.6485	0.0020	-0.2165	0
14	2	26	1997	0.156	0.9264	0.0026	-0.2279	0	2	26	1997	0.156	-2.6471	0.0020	-0.2132	0
15	2	28	1997	0.162	0.9695	0.0026	-0.1822	0	2	28	1997	0.162	-2.5977	0.0019	-0.1619	0
16	3	3	1997	0.170	0.9478	0.0025	-0.2000	0	3	3	1997	0.170	-2.6254	0.0019	-0.1868	0
17	3	5	1997	0.175	0.9461	0.0025	-0.1992	0	3	5	1997	0.175	-2.6271	0.0019	-0.1866	0
18	3	7	1997	0.181	0.9675	0.0025	-0.1752	0	3	7	1997	0.181	-2.6033	0.0019	-0.1609	0
19	3	10	1997	0.189	0.9484	0.0025	-0.1904	0	3	10	1997	0.189	-2.6254	0.0019	-0.1802	0
20	3	12	1997	0.195	0.9343	0.0025	-0.2020	0	3	12	1997	0.195	-2.6350	0.0019	-0.1879	0
21	3	14	1997	0.200	0.9720	0.0025	-0.1617	0	3	14	1997	0.200	-2.5964	0.0019	-0.1475	0
22	3	17	1997	0.208	0.9700	0.0026	-0.1598	0	3	17	1997	0.208	-2.5993	0.0019	-0.1475	0
23	3	19	1997	0.214	0.9388	0.0026	-0.1885	0	3	19	1997	0.214	-2.6342	0.0020	-0.1806	0
24	3	21	1997	0.219	0.9545	0.0026	-0.1702	0	3	21	1997	0.219	-2.6053	0.0020	-0.1498	0
25	3	31	1997	0.247	1.0963	0.0030	-0.0155	1	3	31	1997	0.247	-2.4738	0.0022	-0.0089	1
26	4	2	1997	0.252	1.0889	0.0030	-0.0204	1	4	2	1997	0.252	-2.4787	0.0023	-0.0119	1
27	4	4	1997	0.258	1.0897	0.0031	-0.0170	1	4	4	1997	0.258	-2.4804	0.0023	-0.0117	1
28	4	7	1997	0.266	1.0900	0.0032	-0.0128	1	4	7	1997	0.266	-2.4792	0.0024	-0.0077	1
29	4	9	1997	0.271	1.0909	0.0033	-0.0094	1	4	9	1997	0.271	-2.4846	0.0025	-0.0112	1
30	4	11	1997	0.277	1.0935	0.0034	-0.0042	1	4	11	1997	0.277	-2.4801	0.0026	-0.0048	1
31	4	14	1997	0.285	1.0917	0.0036	-0.0021	1	4	14	1997	0.285	-2.4776	0.0027	0.0005	1
32	4	16	1997	0.290	1.0930	0.0037	0.0017	1	4	16	1997	0.290	-2.4786	0.0028	0.0014	1
33	4	18	1997	0.296	1.0958	0.0038	0.0071	1	4	18	1997	0.296	-2.4804	0.0028	0.0014	1
34	4	21	1997	0.304	1.0950	0.0039	0.0102	1	4	21	1997	0.304	-2.4808	0.0030	0.0039	1
35	4	23	1997	0.310	1.0980	0.0040	0.0157	1	4	23	1997	0.310	-2.4739	0.0030	0.0126	1
36	4	25	1997	0.315	1.0957	0.0041	0.0160	1	4	25	1997	0.315	-2.4736	0.0031	0.0148	1

	1014	1016
Meas Wt=1	24.0000	24.0000
Mean	1.1408	-2.4438
Range	0.1038	0.0854
S.D. Ind	0.0486	0.0356
S.D. Mean	0.0099	0.0073
Minimum	1.0889	-2.4846
Maximum	1.1927	-2.3992

Time in years from 1997.0; resistor corrections, SDPV's, and residuals in ppm.
*** NOTE: Zero weighted observations not included in the Mean etc.
Residual is the deviation from the fitted straight line
SDPV=SQRT(B+(2*C*T)+(A*(T**2)))

Note: Resistor corrections, SDPV's, and residuals are in ppm.

*** 12 Observations with zero weight ***

	Mo	Da	Yr	1002	*SDPV*	Residual	1005	*SDPV*	Residual	1014	*SDPV*	Residual	1016	*SDPV*	Residual
1	2	24	1997	-1.1681	***0.0032***	-0.2179	-0.5236	***0.0023***	-0.2014	0.9374	***0.0026***	-0.2194	-2.6485	***0.0020***	-0.2165
2	2	26	1997	-1.1709	***0.0031***	-0.2183	-0.5289	***0.0022***	-0.2050	0.9264	***0.0026***	-0.2279	-2.6471	***0.0020***	-0.2132
3	2	28	1997	-1.1393	***0.0031***	-0.1843	-0.4942	***0.0022***	-0.1686	0.9695	***0.0026***	-0.1822	-2.5977	***0.0019***	-0.1619
4	3	3	1997	-1.1567	***0.0030***	-0.1982	-0.5158	***0.0022***	-0.1876	0.9478	***0.0025***	-0.2000	-2.6254	***0.0019***	-0.1868
5	3	5	1997	-1.1546	***0.0030***	-0.1937	-0.5167	***0.0022***	-0.1868	0.9461	***0.0025***	-0.1992	-2.6271	***0.0019***	-0.1866
6	3	7	1997	-1.1408	***0.0030***	-0.1775	-0.4980	***0.0022***	-0.1664	0.9675	***0.0025***	-0.1752	-2.6033	***0.0019***	-0.1609
7	3	10	1997	-1.1551	***0.0030***	-0.1882	-0.5141	***0.0022***	-0.1800	0.9484	***0.0025***	-0.1904	-2.6254	***0.0019***	-0.1802
8	3	12	1997	-1.1757	***0.0030***	-0.2065	-0.5262	***0.0022***	-0.1904	0.9343	***0.0025***	-0.2020	-2.6350	***0.0019***	-0.1879
9	3	14	1997	-1.1347	***0.0030***	-0.1631	-0.4977	***0.0022***	-0.1602	0.9720	***0.0025***	-0.1617	-2.5964	***0.0019***	-0.1475
10	3	17	1997	-1.1354	***0.0031***	-0.1602	-0.4994	***0.0022***	-0.1593	0.9700	***0.0026***	-0.1598	-2.5993	***0.0019***	-0.1475
11	3	19	1997	-1.1601	***0.0031***	-0.1825	-0.5247	***0.0022***	-0.1829	0.9388	***0.0026***	-0.1885	-2.6342	***0.0020***	-0.1806
12	3	21	1997	-1.1368	***0.0032***	-0.1568	-0.5020	***0.0023***	-0.1585	0.9545	***0.0026***	-0.1702	-2.6053	***0.0020***	-0.1498
			Mean	-1.1524	0.0031	-0.1873	-0.5118	0.0022	-0.1789	0.9511	0.0026	-0.1897	-2.6204	0.0019	-0.1766
			Range	0.0410	0.0002	0.0615	0.0347	0.0001	0.0465	0.0456	0.0001	0.0680	0.0521	0.0001	0.0690
			S.D. Ind	0.0147	0.0001	0.0209	0.0128	0.0000	0.0162	0.0156	0.0001	0.0213	0.0192	0.0000	0.0237
			S.D. Mean	0.0042	0.0000	0.0060	0.0037	0.0000	0.0047	0.0045	0.0000	0.0062	0.0055	0.0000	0.0068
			Minimum	-1.1757	0.0030	-0.2183	-0.5289	0.0022	-0.2050	0.9264	0.0025	-0.2279	-2.6485	0.0019	-0.2165
			Maximum	-1.1347	0.0032	-0.1568	-0.4942	0.0023	-0.1585	0.9720	0.0026	-0.1598	-2.5964	0.0020	-0.1475

Residual Mean of	1002	1005	1014	1016
	-0.187	-0.179	-0.190	-0.177

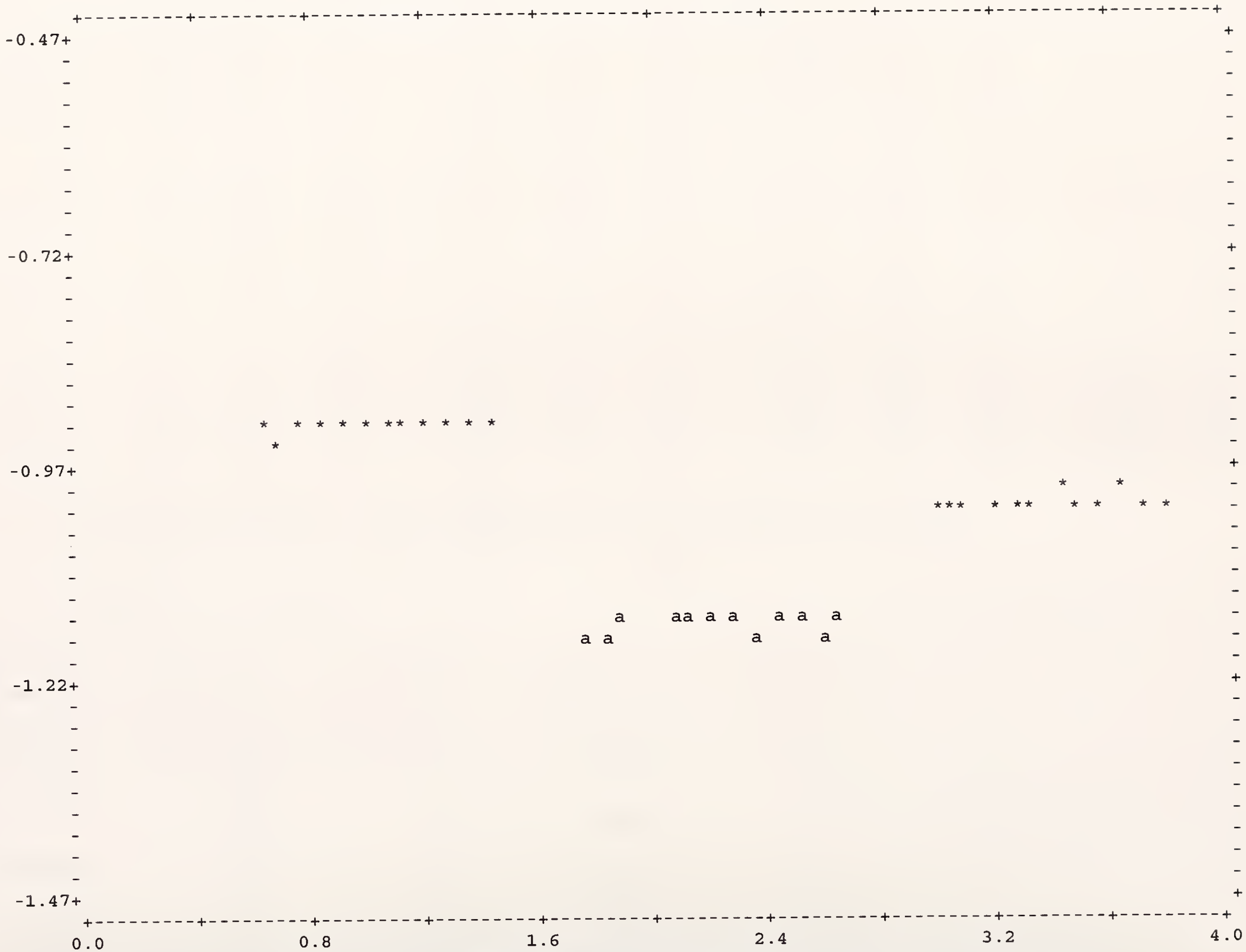
Mean= -0.183 SDM= 0.003

	1002	1005	1014	1016
Slope	-0.4345	-0.3104	-0.4692	-0.3431
1997.0 Intercept	-0.8847	-0.2755	1.2275	-2.3803
S.D. Slope	0.0305	0.0218	0.0254	0.0192
S.D. Intercept	0.0064	0.0046	0.0053	0.0040
Residual S.D.	0.0147	0.0105	0.0123	0.0092
Mean	-0.9651	-0.3329	1.1408	-2.4438
V(Slope) * A=	0.9272463D-03	0.4772556D-03	0.6464309D-03	0.3678258D-03
*				
V(Intercept)* B=	0.4068237D-04	0.2093930D-04	0.2836177D-04	0.1613814D-04
*				
Covariance * C=	-0.1714770D-03	-0.8825959D-04	-0.1195454D-03	-0.6802259D-04

Slope units are ppm/year
Intercept, S.D., and Mean are in ppm

A and B are the variance terms corresponding to Slope & Intercept, respectively
C is the covariance or the off diagonal term of the Variance-Covariance Matrix

Observations of item 1002 in ppm

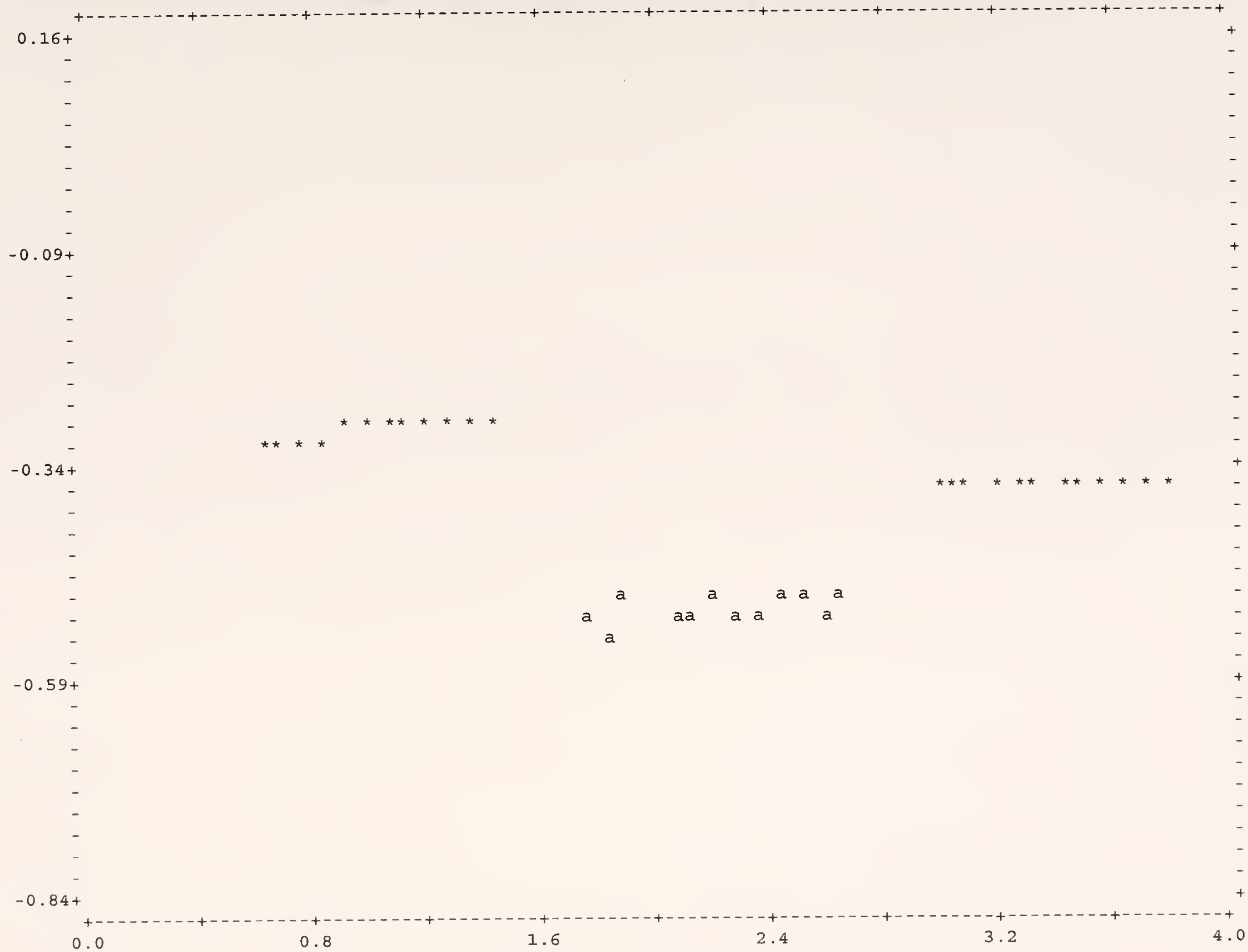


Time in months - starting 1/01/1997

Observation SCALE = 1.0 ppm

36 Points plotted
12 were weighted zero

Observations of item 1005 in ppm



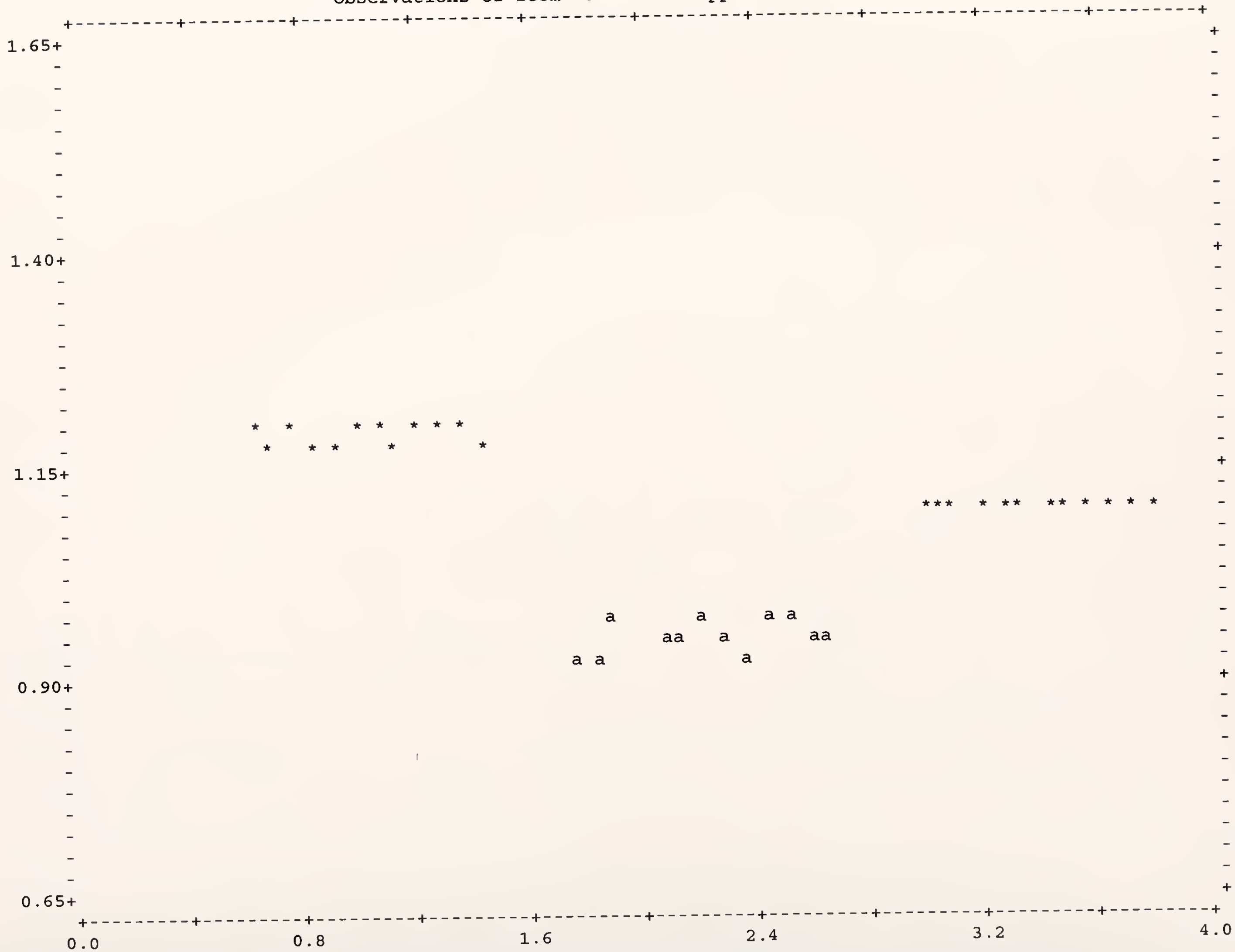
Time in months - starting 1/01/1997

Observation SCALE = 1.0 ppm

36 Points plotted
12 were weighted zero

Analysis of 1002 1005 1014 1016

Observations of item 1014 in ppm

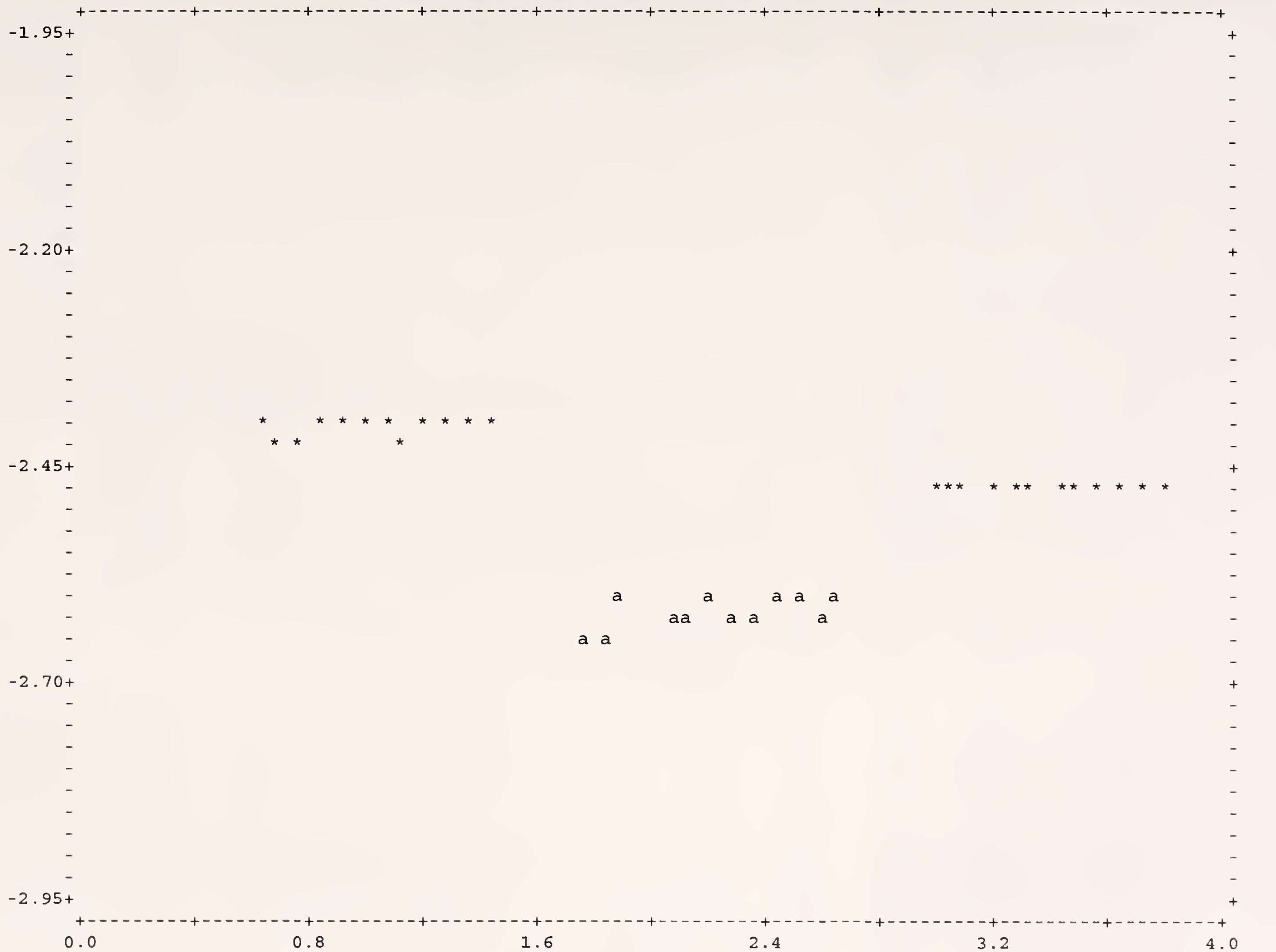


Time in months - starting 1/01/1997

Observation SCALE = 1.0 ppm

36 Points plotted
12 were weighted zero

Observations of item 1016 in ppm



Time in months - starting 1/01/1997

Observation SCALE = 1.0 ppm

36 Points plotted
12 were weighted zero

Analysis of 1002 1005 1014 1016

Note: Resistor corrections, SDPV's, and residuals in ppm.

	Mo	Da	Yr	Time	1002	*SDPV*	Residual	Wt	Mo	Da	Yr	Time	1005	*SDPV*	Residual	Wt
1	2	24	1997	0.151	-1.1681	***0.0075***	-0.0066	1	2	24	1997	0.151	-0.5236	***0.0069***	-0.0067	1
2	2	26	1997	0.156	-1.1709	***0.0067***	-0.0108	1	2	26	1997	0.156	-0.5289	***0.0062***	-0.0129	1
3	2	28	1997	0.162	-1.1393	***0.0059***	0.0193	1	2	28	1997	0.162	-0.4942	***0.0054***	0.0210	1
4	3	3	1997	0.170	-1.1567	***0.0049***	-0.0003	1	3	3	1997	0.170	-0.5158	***0.0045***	-0.0018	1
5	3	5	1997	0.175	-1.1546	***0.0044***	0.0003	1	3	5	1997	0.175	-0.5167	***0.0041***	-0.0035	1
6	3	7	1997	0.181	-1.1408	***0.0041***	0.0127	1	3	7	1997	0.181	-0.4980	***0.0038***	0.0144	1
7	3	10	1997	0.189	-1.1551	***0.0041***	-0.0039	1	3	10	1997	0.189	-0.5141	***0.0038***	-0.0029	1
8	3	12	1997	0.195	-1.1757	***0.0044***	-0.0259	1	3	12	1997	0.195	-0.5262	***0.0041***	-0.0158	1
9	3	14	1997	0.200	-1.1347	***0.0049***	0.0136	1	3	14	1997	0.200	-0.4977	***0.0045***	0.0118	1
10	3	17	1997	0.208	-1.1354	***0.0059***	0.0107	1	3	17	1997	0.208	-0.4994	***0.0054***	0.0089	1
11	3	19	1997	0.214	-1.1601	***0.0067***	-0.0155	1	3	19	1997	0.214	-0.5247	***0.0062***	-0.0172	1
12	3	21	1997	0.219	-1.1368	***0.0075***	0.0064	1	3	21	1997	0.219	-0.5020	***0.0069***	0.0047	1
				Meas Wt=1	12.0000								12.0000			
				Mean	-1.1524								-0.5118			
				Range	0.0410								0.0347			
				S.D. Ind	0.0147								0.0128			
				S.D. Mean	0.0042								0.0037			
				Minimum	-1.1757								-0.5289			
				Maximum	-1.1347								-0.4942			

Time in years from 1997.0

*** NOTE: Zero weighted observations not included in the Mean etc.

Residual is the deviation from the fitted straight line

SDPV=SQRT(B+(2*C*T)+(A*(T**2)))

Analysis of 1002 1005 1014 1016

Note: Resistor corrections, SDPV's, and residuals in ppm.

	Mo	Da	Yr	Time	1014	*SDPV*	Residual	Wt	Mo	Da	Yr	Time	1016	*SDPV*	Residual	Wt
1	2	24	1997	0.151	0.9374	*0.0084*	-0.0070	1	2	24	1997	0.151	-2.6485	*0.0097*	-0.0157	1
2	2	26	1997	0.156	0.9264	*0.0075*	-0.0190	1	2	26	1997	0.156	-2.6471	*0.0087*	-0.0163	1
3	2	28	1997	0.162	0.9695	*0.0066*	0.0230	1	2	28	1997	0.162	-2.5977	*0.0077*	0.0311	1
4	3	3	1997	0.170	0.9478	*0.0055*	-0.0003	1	3	3	1997	0.170	-2.6254	*0.0064*	0.0004	1
5	3	5	1997	0.175	0.9461	*0.0049*	-0.0031	1	3	5	1997	0.175	-2.6271	*0.0057*	-0.0032	1
6	3	7	1997	0.181	0.9675	*0.0046*	0.0172	1	3	7	1997	0.181	-2.6033	*0.0053*	0.0186	1
7	3	10	1997	0.189	0.9484	*0.0046*	-0.0035	1	3	10	1997	0.189	-2.6254	*0.0053*	-0.0065	1
8	3	12	1997	0.195	0.9343	*0.0049*	-0.0186	1	3	12	1997	0.195	-2.6350	*0.0057*	-0.0181	1
9	3	14	1997	0.200	0.9720	*0.0055*	0.0180	1	3	14	1997	0.200	-2.5964	*0.0064*	0.0185	1
10	3	17	1997	0.208	0.9700	*0.0066*	0.0144	1	3	17	1997	0.208	-2.5993	*0.0077*	0.0127	1
11	3	19	1997	0.214	0.9388	*0.0075*	-0.0179	1	3	19	1997	0.214	-2.6342	*0.0087*	-0.0242	1
12	3	21	1997	0.219	0.9545	*0.0084*	-0.0033	1	3	21	1997	0.219	-2.6053	*0.0097*	0.0027	1

	1014	1016
Meas Wt=1	12.0000	12.0000
Mean	0.9511	-2.6204
Range	0.0456	0.0521
S.D. Ind	0.0156	0.0192
S.D. Mean	0.0045	0.0055
Minimum	0.9264	-2.6485
Maximum	0.9720	-2.5964

Time in years from 1997.0

*** NOTE: Zero weighted observations not included in the Mean etc.

Residual is the deviation from the fitted straight line

SDPV=SQRT(B+(2*C*T)+(A*(T**2)))

	1002	1005	1014	1016
Slope	0.2682	0.1485	0.1958	0.3619
1997.0 Intercept	-1.2019	-0.5392	0.9149	-2.6873
S.D. Slope	0.1845	0.1704	0.2070	0.2396
S.D. Intercept	0.0344	0.0317	0.0385	0.0446
Residual S.D.	0.0140	0.0129	0.0157	0.0182
Mean	-1.1524	-0.5118	0.9511	-2.6204
V(Slope) * A=	0.3403295D-01	0.2905185D-01	0.4285013D-01	0.5738497D-01
V(Intercept)* B=	0.1180243D-02	0.1007501D-02	0.1486018D-02	0.1990078D-02
Covariance * C=	-0.6293765D-02	-0.5372602D-02	-0.7924338D-02	-0.1061229D-01

Slope units are ppm/year
Intercept, S.D.,and Mean are in ppm

A and B are the variance terms corresponding to Slope & Intercept, respectively
C is the covariance or the off diagonal term of the Variance-Covariance Matrix

Analysis of 1002 1005 1014 1016
Note: Resistor corrections and differences are in ppm.

	1002			1005			1014			1016		
	PVLAB	PVNIST	DR	PVLAB	PVNIST	DR	PVLAB	PVNIST	DR	PVLAB	PVNIST	DR
1	-1.1615	-0.9502	-0.2113	-0.5169	-0.3222	-0.1946	0.9444	1.1568	-0.2125	-2.6328	-2.4320	-0.2008
2	-1.1601	-0.9526	-0.2075	-0.5160	-0.3239	-0.1921	0.9454	1.1543	-0.2088	-2.6308	-2.4339	-0.1969
3	-1.1586	-0.9550	-0.2036	-0.5152	-0.3256	-0.1896	0.9465	1.1517	-0.2052	-2.6288	-2.4358	-0.1930
4	-1.1564	-0.9585	-0.1979	-0.5140	-0.3282	-0.1858	0.9481	1.1478	-0.1997	-2.6258	-2.4386	-0.1872
5	-1.1549	-0.9609	-0.1940	-0.5132	-0.3299	-0.1833	0.9492	1.1453	-0.1961	-2.6239	-2.4405	-0.1834
6	-1.1535	-0.9633	-0.1902	-0.5124	-0.3316	-0.1808	0.9503	1.1427	-0.1924	-2.6219	-2.4424	-0.1795
7	-1.1512	-0.9669	-0.1844	-0.5112	-0.3341	-0.1770	0.9519	1.1388	-0.1870	-2.6189	-2.4452	-0.1737
8	-1.1498	-0.9692	-0.1805	-0.5104	-0.3358	-0.1745	0.9529	1.1363	-0.1833	-2.6169	-2.4471	-0.1699
9	-1.1483	-0.9716	-0.1767	-0.5095	-0.3375	-0.1720	0.9540	1.1337	-0.1797	-2.6149	-2.4489	-0.1660
10	-1.1461	-0.9752	-0.1709	-0.5083	-0.3401	-0.1682	0.9556	1.1298	-0.1742	-2.6120	-2.4518	-0.1602
11	-1.1446	-0.9776	-0.1671	-0.5075	-0.3418	-0.1657	0.9567	1.1273	-0.1706	-2.6100	-2.4536	-0.1563
12	-1.1432	-0.9800	-0.1632	-0.5067	-0.3435	-0.1632	0.9578	1.1247	-0.1669	-2.6080	-2.4555	-0.1525
Mean	-1.1524	-0.9651	-0.1873	-0.5118	-0.3329	-0.1789	0.9511	1.1408	-0.1897	-2.6204	-2.4438	-0.1766
SD			0.0161			0.0105			0.0152			0.0161
SDM			0.0046			0.0030			0.0044			0.0047

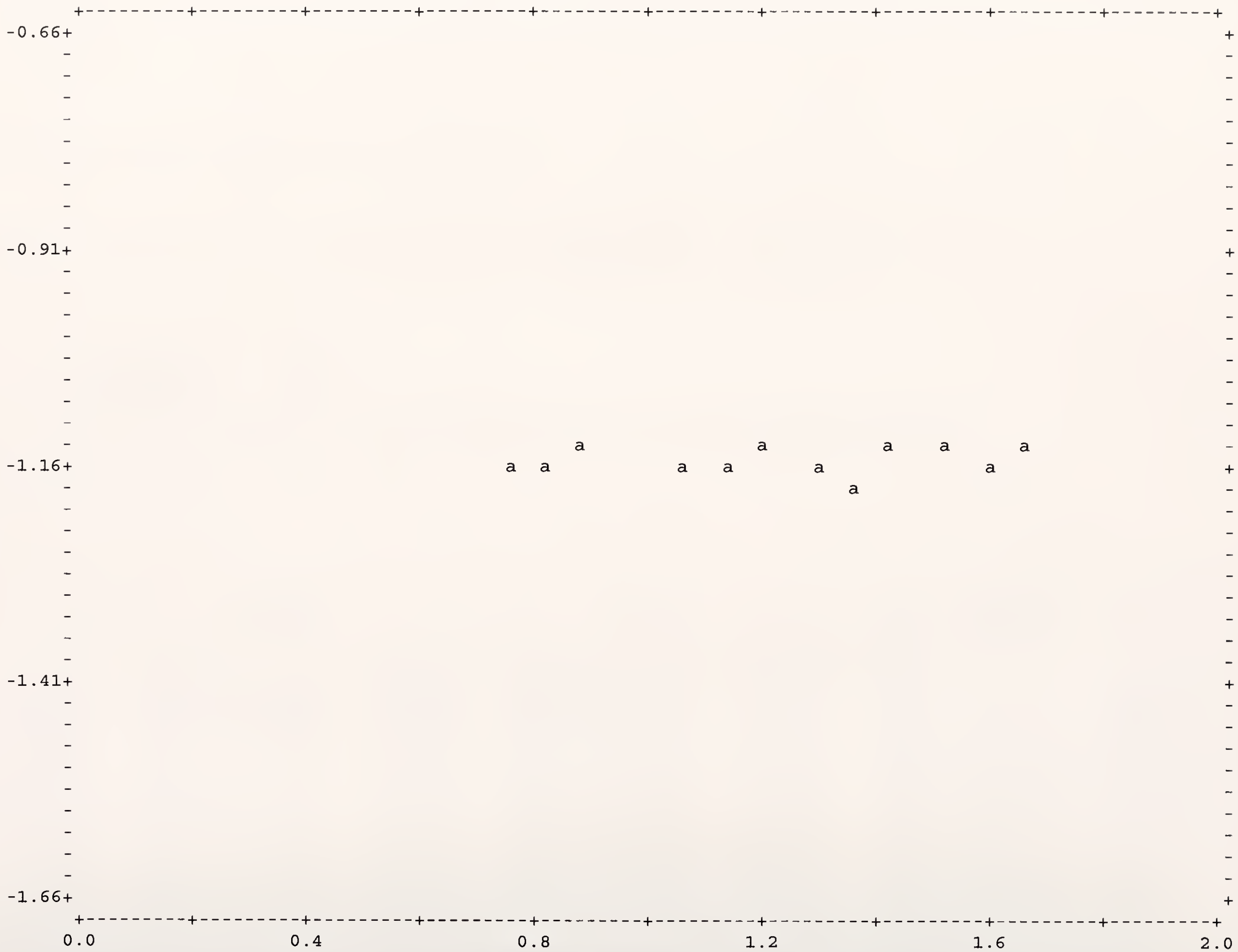
Delta R Mean = -0.1831 ppm

(Sigma)Sq(R)LAB X 10exp-16	0.00816	(a)
(Sigma)Sq(R)NIST X 10exp-16	0.00128	(b)
(Sigma)SqTRAN X 10exp-16	0.1004	
(T975/2)Sq	2.5281	
X 10exp-16	0.2538	(c)
(Sigma)SqTYPEB-0T X 10exp-16	4.4100	(d)

1 ohm Thomas uncertainty U = 2 x SgRt(a + b + c + d) = 0.0432 ppm

***NOTE: Updated information for MAPS program Year=1997

Observations of item 1002 in ppm

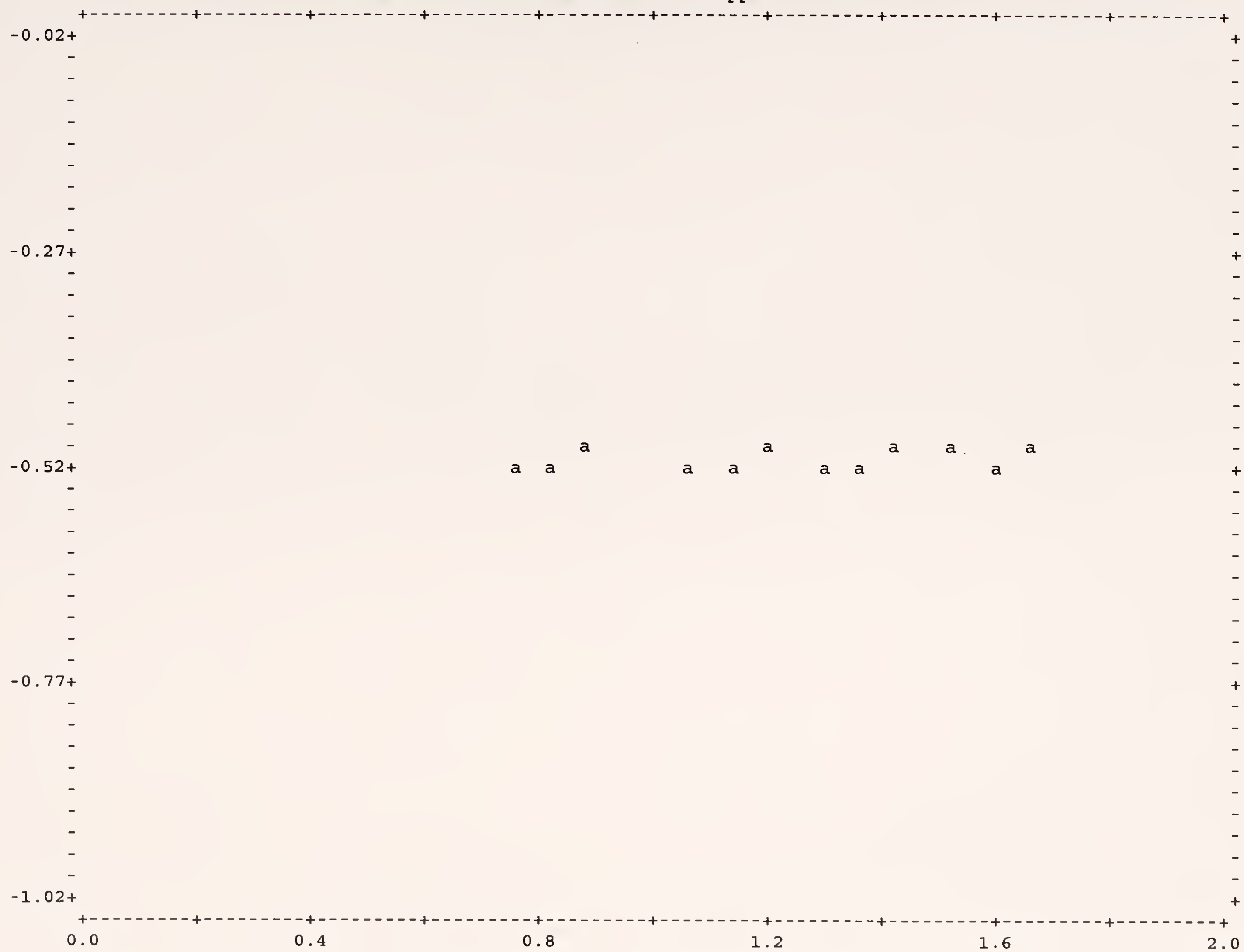


Time in months - starting 2/01/1997

Observation SCALE = 1.0 ppm

12 Points plotted

Observations of item 1005 in ppm

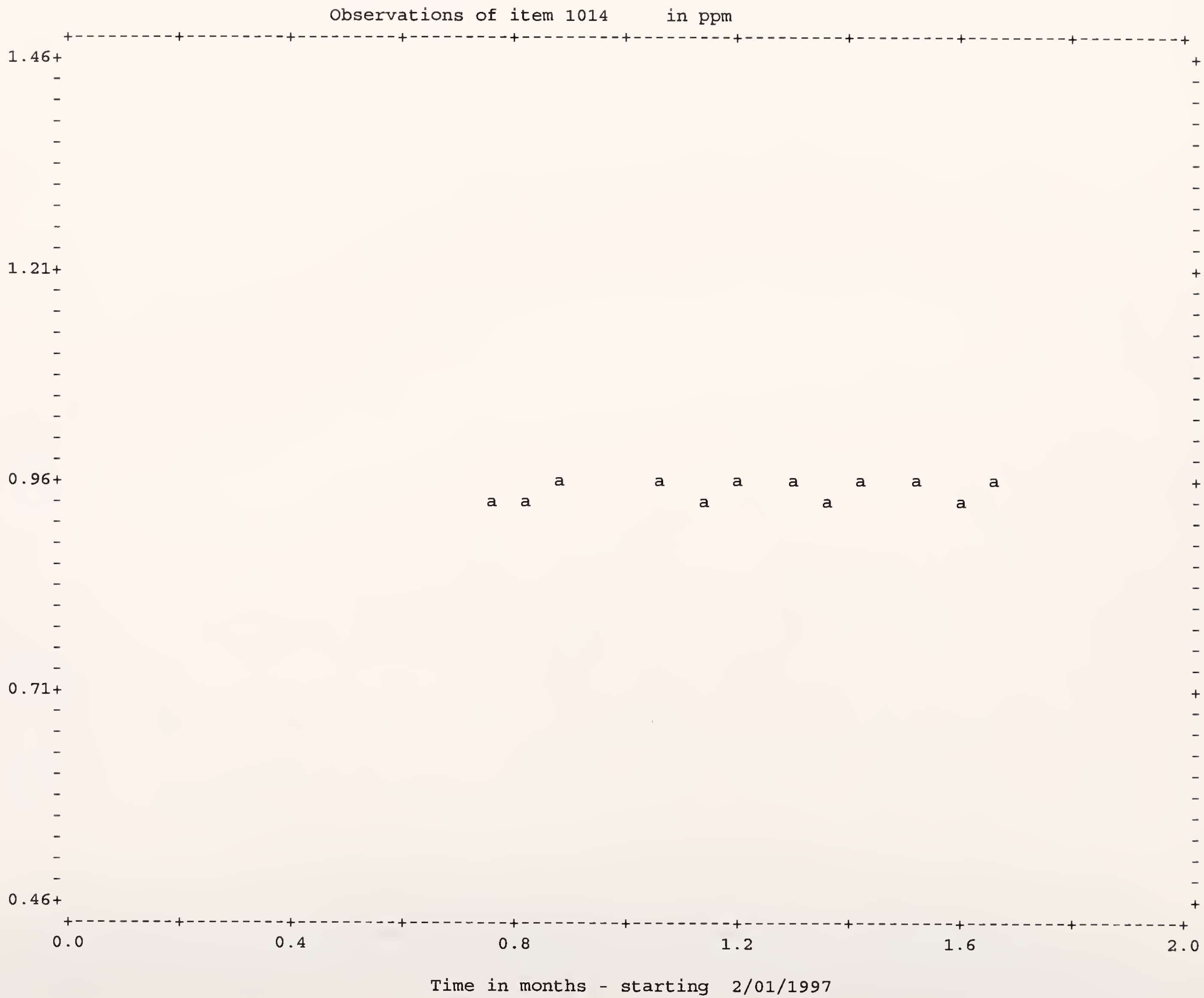


Time in months - starting 2/01/1997

Observation SCALE = 1.0 ppm

12 Points plotted

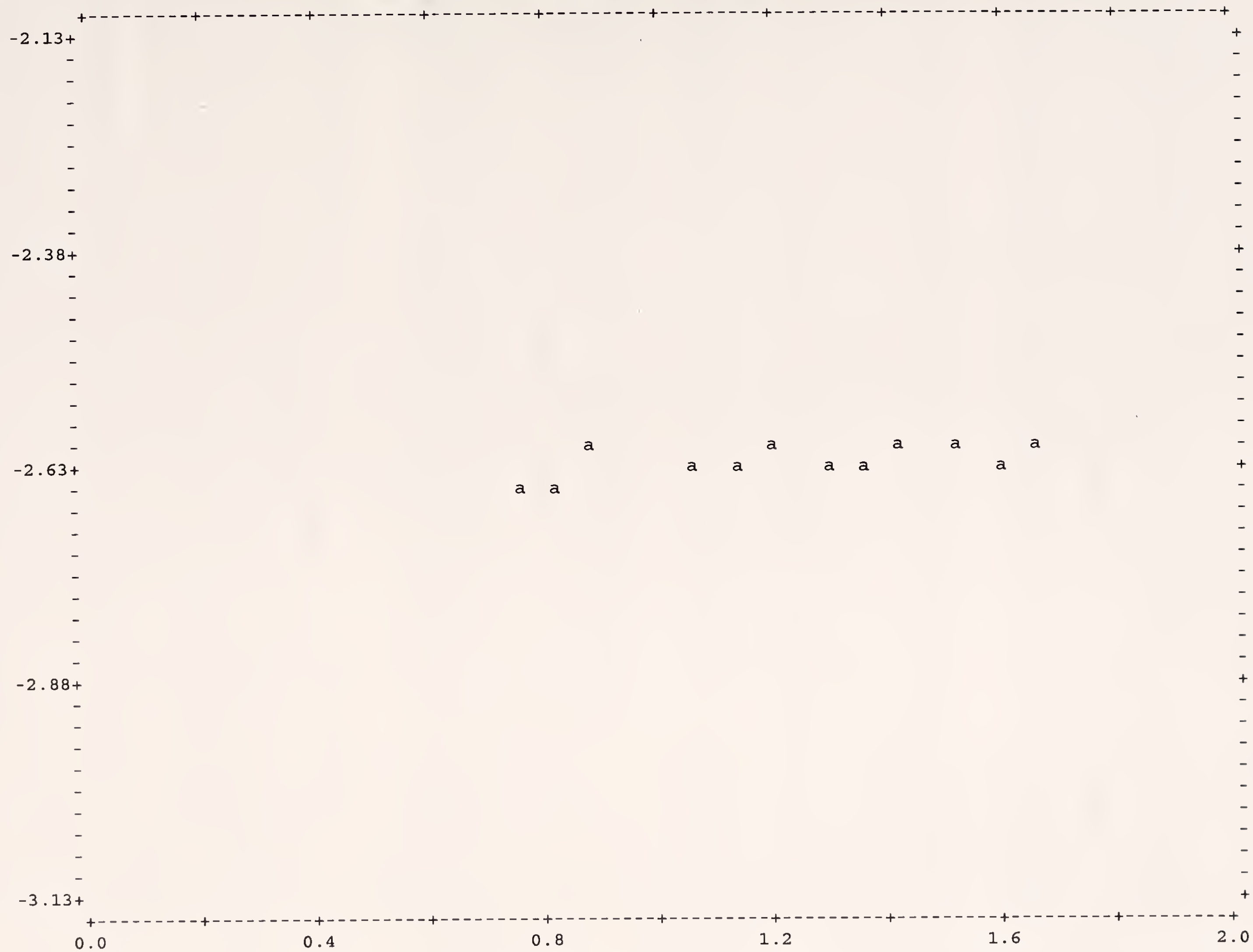
Analysis of 1002 1005 1014 1016



Observation SCALE = 1.0 ppm

12 Points plotted

Observations of item 1016 in ppm



Time in months - starting 2/01/1997

Observation SCALE = 1.0 ppm

12 Points plotted

I.3 Results of MAP

I.3.1 **Introduction.** The following pages contains the test report for a typical 1 Ω resistance MAP. The 10 kΩ report is similar. The report contains the following:

I.3.2 **Report of Test,** reports the difference between the unit of resistance as maintained by the customer, and the U. S. legal ohm, as maintained by NIST, and states the total uncertainty;

I.3.3 **Appendix A,** which explains the derivation of the uncertainty;

I.3.4 **Appendix B,** which summarizes the results between NIST and the customer; calculates the uncertainty, and

I.3.5 **Appendix C,** which contains information on the customer's reference standards based on the results of the MAP.

The data for calculating the uncertainty in Appendix B are obtained from the output of the COLLECT97 program. As an example, the **a**, **b**, **c**, and **d** quantities indicated on page 39 (page 12 of the COLLECT97 output) correspond to the terms in eq (2) in the text or to the identical equation in the Report of Test. They are calculated in the following manner, using 12 as the number of measurements (N), and 4 as the number of transfer standards (M):

a) This quantity (s_{LAB}^2) is calculated using eq (3). The $s_{ij_{LAB}}$ values are found on pages 36 and 37 (pages 9 and 10 of the COLLECT97 output) under the "SDPV" headings for the four MAP transfer standards. For this example "**a**" is equal to 0.816 x 10^{-18}.

b) This quantity (s_{NIST}^2) is calculated using eq (5). The $s_{ij_{NIST}}$ values are found on page 30 (page 3 of the COLLECT97 output) under the "SDPV" headings for the four MAP transfer standards. For this example, "**b**" is equal to 0.128 x 10^{-18}.

c) This quantity $(t'^2 s_{transfer}^2)$ is obtained using eqs (7), (8), (9), and (10). The percent point of the Student t distribution in eq (10) is found in Table 2 and, for this example, is equal to 3.18. The $\Delta R's$ and $\overline{\Delta R}$ are calculated using eqs (8) and (9) with the data found on page 30 (page 3 of the COLLECT97 output). As listed on page 30, the $\Delta R's$ for the four transfer standards are -0.187 ppm, -0.179 ppm, -0.190 ppm, and -0.177 ppm, respectively; the value of $\overline{\Delta R}$ is -0.183 ppm. The result of eq (7) then becomes 0.100 x 10^{-4}. Squaring eq (10) and multiplying it with eq (7) results in a value for "**c**" equal to 0.254 x 10^{-16}.

d) This quantity $(\sum u_B^2)$ is the Type B variance of the measurement process and is equal to $(0.021 \times 10^{-6})^2$ for the 1 Ω level (see [2] for a detailed analysis).

REPORT OF TEST

RESISTANCE MEASUREMENT ASSURANCE PROGRAM
AT THE 1 Ω LEVEL

XYZ Resistance Laboratory
Ohm City, MD 20899

The difference between the unit of resistance at the 1 Ω level maintained by the above laboratory (LAB) and the U.S. legal ohm, as maintained by the National Institute of Standards and Technology (NIST) in terms of the quantum Hall effect, was determined during the period between February 24, 1997 and March 21, 1997, and found to be:

$$OHM_{LAB} - OHM = (\ 0.183 \pm 0.043\ )\ \text{ppm}$$

The above value is based upon the test procedure described in Appendix A and the data summarized in Appendix B of this report. The expanded uncertainty of this difference given above is equal to

$$2\ \{\ s_{LAB}^2 + s_{NIST}^2 + t'^2 s_{transfer}^2 + \Sigma u_B^2\ \}^{1/2}\ ,$$

where s_{LAB} and s_{NIST} are the estimated Type A standard uncertainties based on the standard deviation of the measurements at the customer laboratory and NIST, respectively, $t's_{transfer}$ is the estimate of the variability of the transfer standards, and $u_B(i)$ is the estimated Type B standard uncertainty for each known component of uncertainty arising from a systematic effect (see Appendix A). The coverage factor 2 used by NIST is consistent with international practice.

If the measured difference between the unit of resistance as disseminated by the above laboratory and the U.S. legal ohm is greater in magnitude than the combined standard uncertainty (0.022 ppm), it is recommended that the assigned mean value of the laboratory's reference resistors be adjusted so that $OHM_{LAB} - OHM = 0$. Appendix C has been included in this report to facilitate recommended adjustments.

Measurements performed by:

(Technical Staff)
Electricity Division

For the Director,

(Group Leader), Group Leader
Electricity Division

Test Report No.: 811/012345-97
Reference: ABC-123
Date: April 1, 1997
Telephone Contact: 301-975-4221

Appendix A

Before and after the client laboratory measurements were taken on the transport resistors, determinations were made of the corrections to nominal of the transport resistors at NIST in terms of the U.S. legal ohm. Since resistors of this type usually exhibit a linear change in resistance with time, a straight line was fitted to the corrections to nominal determined at NIST for each resistor using the method of least squares, after adjustment to nominal temperature and barometric pressure. The resultant straight line was also fitted to the laboratory-assigned corrections to nominal for each of the transport resistors. The estimate of the difference, ΔR, in ppm, between the assignment of the resistance value of a transport resistor by the client laboratory and NIST was determined by subtracting the NIST predicted value from each laboratory predicted value for the same date.

The uncertainty of the estimate of the difference consists of the combination of the Type A and Type B uncertainties resulting from random and systematic errors of the measurement process, where Type A uncertainties are those that can be evaluated by statistical methods based on observed data, and Type B uncertainties are those that cannot. The expanded, or overall uncertainty can be expressed by the following equation:

$$U = 2 \left\{ s_{LAB}^2 + s_{NIST}^2 + t'^2 s_{transfer}^2 + \Sigma u_B^2(i) \right\}^{1/2} .$$

The standard deviation of the customer's data (s_{LAB}) estimates the effect of random error resulting from the customer's laboratory measurements, and is determined by the following equation:

$$s_{LAB}^2 = \left(\frac{1}{MN} \right)^2 \sum_{j=1}^{M} \sum_{i=1}^{N} s_{LAB_{ij}}^2 ,$$

where M is the number of standards in the transfer package, N is the number of measurements at the customer's laboratory for each transfer standard, and where $s_{LAB_{ij}}$ is the estimated standard deviation of the customer's predicted value of the j^{th} resistor for the i^{th} measurement at the customer's laboratory.

The standard deviation of the NIST predicted data (s_{NIST}) estimates the effect of random error resulting from the NIST measurements, and is expressed as

$$s_{NIST}^2 = \left(\frac{1}{MN} \right)^2 \sum_{j=1}^{M} \sum_{i=1}^{N} s_{NIST_{ij}}^2 ,$$

where $s_{NIST_{ij}}$ is the estimated standard deviation of the NIST predicted value of the j^{th} resistor for the i^{th} measurement at the customer's laboratory.

Test Report No.: 811/012345-97

The standard deviation of the ΔR measurements serves as an estimate of the variability of the transfer standards ($s_{transfer}$). The value of $s_{transfer}$ can be calculated from the equation:

$$s^2_{transfer} = \frac{1}{M(M-1)} \sum_{j=1}^{M} (\Delta R_j - \overline{\Delta R})^2 ,$$

where

$$\Delta R_j = \frac{1}{N} \sum_{i=1}^{N} (R_{ij} - R_{ij(pred)}) ,$$

and represents the mean difference of the j^{th} resistor for the i^{th} measurement, $R_{ij(pred)}$ is the NIST predicted value for j^{th} resistor for the i^{th} measurement at the customer's laboratory, and

$$\overline{\Delta R} = \frac{1}{M} \sum_{j=1}^{M} \Delta R_j .$$

Notice that any shifts in the mean or variability resulting from transportation effects are reflected in the above analysis.

To provide coverage for $s_{transfer}$, which has a low degree of freedom, it is multiplied by t', which is defined as

$$t' = \frac{t_{.975}}{2} ,$$

where $t_{.975}$ is a percent point of the Student t distribution. The value of $t_{.975}$ depends on the number of transfer standards (M), and can be obtained from Table 1. This value is divided by 2 because in the expanded uncertainty equation (U) it is effectively multiplied by the coverage factor 2.

Table 1. Percent point of the Student t distribution for various values of M

Number of Transfer Standards M	Degrees of Freedom	Percent Point $t_{.975}$
2	1	12.71
3	2	4.30
4	3	3.18

Test Report No.: 811/012345-97

The Type B uncertainties ($u_B(i)$) result from: a) maintaining the working standards in terms of the quantum Hall effect; b) determining the environmental conditions (temperature and pressure), lead and contact resistances, leakage resistances, loading effects; and, c) predicting the values for the NIST resistors while at the laboratory. Other possible Type B uncertainties in the measurement process are believed to be negligible. For a detailed analysis of Type B uncertainties, refer to "NIST Measurement Service for DC Standard Resistors," by R. F. Dziuba, P. A. Boynton, R. E. Elmquist, D. G. Jarrett, T. P. Moore, and J. D. Neal, NIST Technical Note 1298 (USGPO, Washington, DC, November 1992). The standard Type B uncertainties are 0.021 ppm for the 1 Ω level and 0.037 ppm for the 10 kΩ level.

The Type A components and the Type B components are combined in quadrature (root-sum-square) according to the guidelines recommended by the International Bureau of Weights and Measures in order to obtain the combined standard uncertainty. This combined standard uncertainty is multiplied by a coverage factor k = 2 to obtain the expanded or overall uncertainty (U) as recommended in "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results," by B. N. Taylor and C. E. Kuyatt, NIST Technical Note 1297 (USGPO, Washington, DC, 1992).

If the measured difference between the unit of resistance as disseminated by the customer laboratory and the U.S. legal unit of resistance is greater in magnitude than the characteristic standard deviation of a measurement of this type ($U/2$), it is recommended that the assigned mean value of the laboratory's reference resistors be adjusted so that OHM_{LAB} - OHM = 0.

Appendix B

Summary of results between NIST and LAB

Table 2. Summary of corrections to NIST transport standards.

Corrections in parts per million to nominal value are given for the NIST transport standards at a standard temperature of 25.00 °C and a standard pressure of 1013.25 hPa, which also includes a correction for the depth of oil to the mercury wetted surface of the resistor.

The results of this test were determined from data supplied by LAB taken from February 24, 1997 to March 21, 1997.

DATE	RUN	S/N 1002	S/N 1005	S/N 1014	S/N 1016
02/24/97	1	-1.168	-0.524	0.937	-2.648
02/26/97	2	-1.171	-0.529	0.926	-2.647
02/28/97	3	-1.139	-0.494	0.970	-2.598
03/03/97	4	-1.157	-0.516	0.948	-2.625
03/05/97	5	-1.155	-0.517	0.946	-2.627
03/07/97	6	-1.141	-0.498	0.968	-2.603
03/10/97	7	-1.155	-0.514	0.948	-2.625
03/12/97	8	-1.176	-0.526	0.934	-2.635
03/14/97	9	-1.135	-0.498	0.972	-2.596
03/17/97	10	-1.135	-0.499	0.970	-2.599
03/19/97	11	-1.160	-0.525	0.939	-2.634
03/21/97	12	-1.137	-0.502	0.954	-2.605
	mean	-1.152	-0.512	0.951	-2.620
	σ_{mean}	0.004	0.004	0.004	0.006

Appendix B
(Continued)

Table 3. Summary of differences between LAB and NIST.

Values for ΔR are given, in parts per million.

$$\Delta R = Corr_{LAB} - Corr_{NIST}$$

DATE	RUN	S/N 1002	S/N 1005	S/N 1014	S/N 1016
02/24/97	1	-0.211	-0.195	-0.212	-0.201
02/26/97	2	-0.208	-0.192	-0.209	-0.197
02/28/97	3	-0.204	-0.190	-0.205	-0.193
03/03/97	4	-0.198	-0.186	-0.200	-0.187
03/05/97	5	-0.194	-0.183	-0.196	-0.183
03/07/97	6	-0.190	-0.181	-0.192	-0.180
03/10/97	7	-0.184	-0.177	-0.187	-0.174
03/12/97	8	-0.180	-0.174	-0.183	-0.170
03/14/97	9	-0.177	-0.172	-0.180	-0.166
03/17/97	10	-0.171	-0.168	-0.174	-0.160
03/19/97	11	-0.167	-0.166	-0.171	-0.156
03/21/97	12	-0.163	-0.163	-0.167	-0.152
	mean	-0.187	-0.179	-0.190	-0.177
	σ_{mean}	0.005	0.003	0.004	0.005

$$\Delta R \text{ Mean} = -0.183 \pm U$$

Summary of uncertainty determination:

Number of Runs = 12

Total Degrees of Freedom = 11

$$U = 2 \times \{ 0.0082 \times 10^{-4} + 0.0013 \times 10^{-4} + 0.2538 \times 10^{-4} + 4.4100 \times 10^{-4} \}^{1/2}$$

$$U = \pm 0.043 \text{ ppm}$$

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Appendix C

Recommended adjustment to LAB reference resistors

Laboratory: XYZ Resistance Company Laboratory Standards: 6

$Corr_{LAB} - Corr_{NIST} = -0.183$

The table below contains information about your reference standards. Laboratory assigned corrections are the corrections used in determining the results of this experiment. The NIST assigned correction to each standard is the calculated mean of all values assigned to the standards in the experiment adjusted to the Δ R mean value found in Appendix B.

If the measured difference between the unit of resistance as disseminated by the above laboratory and the U.S. legal unit of resistance is greater in magnitude than the combined standard uncertainty (0.021 ppm), it is recommended that the assigned mean value of the laboratory's reference resistors be adjusted so that $\Omega_{LAB} - \Omega = 0$.

Table 4. Recommend adjustment to LAB reference resistors.

SERIAL NUMBER	LAB ASSIGNED CORRECTION (ppm)	NIST ASSIGNED CORRECTION (ppm)	TEMPERATURE (°C)
X0001	+1.29	+1.47	25.00
X0002	-0.35	-0.17	25.00
X0003	-2.45	-2.27	25.00
X0004	+6.01	+6.19	25.00
X0005	-0.87	-0.69	25.00
X0006	+4.22	+4.40	25.00
Mean	+1.31	+1.49	

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