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QUALITY ASSURANCE PROGRAM FOR THE NBS C, K, and Q LASER CALIBRATION SYSTEMS

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Prepared for :

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, Secretary
Luther H. Hodges, Jr., Under Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, Director

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Abstract

This report is a detailed procedure of how to set up and operate a Measurement Assurance Program (MAP) for a laser power and energy calibration facility. Items such as traceability, methods of self-checking measurement consistency, computer documentation and statistical analysis are discussed.

Key words: Calorimetry; laser beamsplitter system; laser calibration system; laser measurements; laser power calibration.

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I. INTRODUCTION

This report contains information pertaining to several quality assurance programs used by NBS to provide statistical control of the NBS C, K and Q Laser Calibrating Systems. Duplicates of these systems were delivered previously to the Aerospace Guidance and Metrology Center (AGMC) by the Optical Electronic Metrology Group at the National Bureau of Standards in Boulder, Colorado.

Information, previously supplied by NBS, dealt on an individual basis with the use, calibration and maintenance of the C- and K-Series calorimeters. In contrast, this report emphasizes the use of the two-calorimeter/beamsplitter configuration with a system's approach for producing precisely known laser beams for calibrating purposes.

The report is organized into eight sections, which are briefly described here. Section I discusses some of the purposes and needs of C, K and Q laser calibrating systems. Sections II, III, IV and V are concerned with the internal calibration and quality assurance performance of the systems themselves. Sections VI, VII and VIII are concerned with the calibration and statistical performance of transfer instruments assigned to C, K and Q systems.

One purpose of the C, K and Q calibrating systems is to provide accurately known laser beams for determining the calibration coefficients of a number of transfer standards at several power and energy levels at several discrete laser wavelengths.

A second purpose of the systems is to provide data for determining accuracy or uncertainty values for each and every calibrated beam run that is delivered by the three systems. The above two purposes are best served by using the two-calorimeter/beamsplitter configuration, rather than the direct substitution method. Some advantages of this configuration are:

A. To provide calibrated beams over a greater range,

B. Less stringent requirements on laser-power stability,

C. Beamsplitter runs allow self-consistency checks of the whole system. The beamsplitter ratio of a good quality beamsplitter remains very stable at a given wavelength, over a long period of time,

D. Both calorimeters can be treated equally as reference standards and provide a check against each other, and

E. Simplifies preparation of uncertainty statements by using statistics of the whole system rather than piece-meal statistics on individual components.

Proper use of the calibrating systems is important as the certified reports with calibration values and statements of total uncertainty are based on the integrity of the calibrating systems. A complete check of a system's uncertainty involves a set of 20 to 30 measurements that are too time-consuming to do more often than once or twice a year.

While the C, K and Q Series calorimeters have demonstrated good instrument stability and retain their electrical and laser calibration values for long periods of time, a need still exists for a quick, simple, day-to-day check and for a slightly more comprehensive monthly test to ensure system integrity. Some examples of what can happen are as follows: (1) Occasionally a calorimeter temperature-control amplifier malfunctions and needs to be replaced. (2) A calorimeter window may get slightly dirty due to the vacuum system or some other source and needs to be cleaned. (3) A fingerprint on the beamsplitter will give an inaccurate ratio and require cleaning. (4) Reversing the direction a laser beam passes through a sapphire beamsplitter may give a different beamsplitter ratio. (5) The calorimeter absorbing surface may be damaged by laser beams with excessive power density and change the calibration of the calorimeter.

Section II deals with electrical traceability to U.S. National Electrical and Time Standards. Since the laser calorimeter measurements are considered to be absolute, rather than relative measurements of energy, it is necessary to establish traceability to fundamental national standards. The electrical measurements concern standard cells, potentiometers, digital voltmeters, standard resistors and time-interval counters.

Section III contains several short- and long-term quality control plans varying from day-to-day operation to yearly calorimeter interchange evaluations. Some advantages of a NBS Measurements Assurance Program (MAP) with AGMC are discussed, which would result in a time-saving, independent appraisal of the AGMC system.

Section IV describes the Blue Book procedure used by NBS to evaluate the calibrated beam uncertainty at the 99% confidence interval for each system and laser wavelength. The Blue Book contains quantitative estimates of the error uncertainty for the electrical calibration coefficients, absorbing values, window transmission values, electrical traceability, inequivalence, D-factors (disagreement between calorimeters), amplifier gains and beamsplitter ratios.

Computer documentation of the calibrating system in Section V completes the system analysis from an internal viewpoint. Electrical calibration files for each calorimeter are kept on the computer in chronological order. Beamsplitter files are stored on the computer for each beamsplitter, and for each laser wavelength being provided by the system. Computer programs are available to quickly ascertain the status of a calorimeter or beamsplitter.

Using the C, K and Q systems for calibrating transfer standards is discussed in Section VI. Some desirable characteristics of a good transfer standard are presented. The chronology of both NBS conventional and MAP-type calibrations are described.

Some guidelines used by NBS concerning documentation and quality assurance of laser transfer standards is discussed in detail in Section VII. Measurements at only discrete power and energy levels is emphasized to more effectively utilize the efforts of a limited staff.

Section VIII describes the procedure used to produce regular calibration reports and MAP intercomparison reports. The total uncertainty of a report is the sum of the system uncertainty plus the imprecision of the measurements made on the transfer instrument.

II. UNITED STATES (U.S.) NATIONAL STANDARDS

A. Electrical Traceability

Calorimeters are the key elements of our calibrating systems. They have had a stable history, they allow reasonable error analysis, and their special design allows easy documentation of traceability to electrical standards. References 1, 2, and 3 report on earlier work, using calorimeters for the measurement of laser power and energy. The calorimeters provide the link for relating laser power or energy to electrical and time standards. Traceability to electrical standards is established by means of electrical calibration runs. The calorimeters and electrical calibrating power supplies are constructed so that two digital voltmeters, a standard resistor and a time-interval counter are required to make an electrical calibrating run. A special plug-in arrangement allows removal and individual calibration of every standard resistor, digital voltmeter, and time-interval counter that is used in the electrical calibration of the C, K and Q systems.

B. Standard Resistors

Documented traceability is easy to obtain for standard resistors. For instance, a certified NBS calibration is available by sending the resistors to NBS, Washington, D.C. However, standard resistors could be sent or obtained from any laboratory that has documented traceability to national standards. Some advantages of standard resistors are:

1. Stable to a few parts-per-million, depending on the ambient temperature,

2. Wide range of values available (0.001 to 10,000 Ω) in decade steps,

3. Do not require a constant-temperature oil bath when operated under ordinary room conditions, if 10 to 20 parts-per-million variation is tolerable,

4. Long life (many years),

5. Re-calibration is not difficult because resistors are small, rugged and easily shipped,

6. Re-calibration is only necessary every few years, depending on stability required, and

7. Very useful because of four-terminal design.

At present, NBS uses approximately 20 standard resistors in the C, K and Q traceability programs.

C. Standard Cell - Potentiometer Calibration Setup

Traceability of digital voltmeters to national electrical standards is provided by using a standard cell/potentiometer combination. Certified NBS calibrations, to provide documented traceability, are available for both standard cells and potentiometers by sending the items to NBS, Washington, D.C. Such items could be sent to any laboratory that has traceability to national standards. Some advantages of standard cells are:

1. They give an accurate voltage reference value to within ± 0.005 percent,

2. They give a voltage of convenient magnitude ($\sim$ 1.019 V),

3. Because of low temperature coefficient, they do not require a constant-temperature bath to maintain the output voltage to within 0.005 percent at normal laboratory temperatures,

4. The output voltage normally decreases only 20 to 40 μV per year,

5. Under normal temperature conditions (23° C), their practical life is 12 to 18 years, (if they are not abused),

6. They only require re-calibration every one to two years depending on required stability, and

7. Their re-calibration is easier because a cell is small and is easily shipped.

At present, NBS uses three standard cells in the C, K and Q traceability programs.

Some features of a good standard potentiometer, such as the one used by NBS are:

1. The instrument has a high degree of accuracy (0.001 percent),

2. The instrument is very stable because it is passive and is based on only the ratio of resistances,

3. The instrument has its own temperature-controlled environment to improve accuracy, and

4. Re-calibration is necessary only every few years, depending on the stability required.

At present, the Optical Electronic Metrology Group uses a highly accurate, calibrated potentiometer with a recently calibrated standard cell to perform a check on the accuracy of a high-quality digital voltmeter, designated as the Standard Digital Voltmeter (DVM) for our Group.

D. Digital Voltmeter Test System

The DVM test system checks the accuracy over a dynamic range (-10 V to +10 V) of the digital voltmeters used in the data acquisition systems, against the Standard DVM that was discussed above. See reference 10 for details. The triangular wave output voltage from a function generator is sampled, simultaneously by the Standard DVM and one or two digital voltmeters being tested. The digital voltage to the Standard DVM is converted to ASCII code and punched out on Paper Tape No. 1 with the test system's own tape punch. At the same time, the above voltage is sampled by the digital test meters, converted to ASCII code, and punched out on Paper Tape No. 2, with the data acquisiton tape punch. The voltage level from the generator is set to vary from 0 to ± 10 V, with a change rate of 0.002 Hz. The changing voltage goes through a complete cycle during a data acquisition period of eight or nine minutes. Paper Tapes No. 1 and 2 are then run on a computer program to calculate an overall systematic error for each test DVM. If the error is greater than the established specifications, the test meter is re-calibrated according to the manufacturer's instructions. NBS uses approximately ten digital voltmeters in the data acquisition systems.

E. Time-Interval Counters

The electrical calibration of calorimeters involves applying an accurately known amount of electrical power for a precise period of time to produce an amount of energy that can be accurately determined. Time-interval counters provide an accurate means of measuring the time periods since these counters are readily available with crystal oscillator stabilities of better than one part-per-million. Some methods using either standard frequencies or time signals from Radio Station WWV, are used to furnish a check of the accuracy of the time-interval counter and provide traceability to the National Standards of time. At present, NBS uses four time-interval counters for time period measurements.

III. QUALITY ASSURANCE FOR C, K AND Q LASER CALIBRATION SYSTEMS

A. First-Time Operation of a System

The procedure for the first-time use of a laser calibrating system involves an evaluation of electrical calibration coefficients for each calorimeter and amplifier scale being used. It is assumed at this point that the digital voltmeters, standard resistors and time-interval counters have all been calibrated with traceability to the national standards. Section II discusses in detail the traceability procedures used by the Optical Electronic Metrology Group at NBS, Boulder.

A first-time format for the electrical calibration of two C-Series calorimeters, C1 and C2, can be seen in Table I. One can determine the calibration coefficient for each scale by taking a simple average or by doing a least-squares routine, assuming that the best straight-line fit through a plot of the corrected rise values versus energy values goes through the origin. (See Appendix A for a discussion of computer program, /SL/.) The least-squares method has the advantage that the greater scatter of the lower-level readings does not unduly influence the calibration coefficient.

TABLE I.

Run No.	Calorimeter	Amplifier Scale
1	C1	1E5
2	C1	1E5
*	*	*
*	*	*
*	*	*
6	C1	1E5
7	C1	1E4
*	*	*
*	*	*
*	*	*
*	*	*
12	C1	1E4
13	C1	1E3
*	*	*
*	*	*
*	*	*
*	*	*
18	C1	1E3
19	C2	1E5
*	*	*
*	*	*
*	*	*
*	*	*
24	C2	1E5
25	C2	1E4
*	*	*
*	*	*
*	*	*
*	*	*
30	C2	1E4
31	C2	1E3
*	*	*
*	*	*
36	C2	1E3

In addition to providing the calibration coefficient, the program, /SL/, also provides the uncertainty of the calibration coefficient using t-statistics at the 99 percent confidence interval for a given data set. For instance, the C-Series calorimeters use chopped-stabilized amplifiers with gains (scales) of 1,000, 10,000 and 100,000 to cover the energy range of the calorimeters. For each calorimeter, a question arises whether to have individual calibration coefficients for each scale or to combine two or more scale values for a combined calibration coefficient. The goal is to make the confidence interval as small as practical, either by making more measurements or by combining or separating data according to scale.

A question arises as to how often the electrical calibration runs should be made and how often the calibration coefficient should be updated. Generally, beamsplitter ratio measurements are used as the control parameter to verify that the calibration system is operating correctly. When beamsplitter ratios do not fall within the normal range of scatter, a problem exists. One test that is usually made, is to make an electrical calibration run on each calorimeter and compare the electrical calibration coefficient values with previous data. If a trend or shift is suspected, several additional electrical runs should be made. Using the electrical coefficients in computer program, RUNSUM, (see Appendix E) is helpful in deciding whether a trend really exists. Plotting the coefficients with computer program /PL/, (see Appendix F) is also very helpful in determing whether a trend exists and when the trend or shift occurred. Some judgment must be exercised in determining what old data should be discarded, if a shift has taken place. The electrical calibration coefficient would be updated if it is decided that a shift has taken place.

A calibration system should be checked out at least one a year at some operating wavelength using Plan 1 and 2 which includes a set of electrical calibration runs. The electrical calibrations, beamsplitter values and D factors would be updated as a result of these measurements.

Each calorimeter uses an electrical heater made of manganin-wire for the electrical calibrations. The heater resistance can be considered to have the properties of a standard resistor because:

1. The electrical resistance of the manganin-wire is very stable at room temperatures due to its very low-temperature coefficient,

2. The calorimeter is temperature-controlled and the heater resistance operates in an environment of nearly a constant temperature, and

3. The heater was constructed as a four-terminal network to permit very accurate readings of voltage and current and the calculation of the effective heater resistance.

A plot of resistance versus time, (see /44CC/ in Appendix J, for example) for each calorimeter heater is a check of heater leakage to ground and of the DVM's used to measure the voltage and current. The percent difference of the worst case from the average value is used in the summary of errors pertaining to traceability. See Section IV for further details.

B. First-Time Operation of a System at a New Wavelength

The initial use of a new wavelength involves checking several parameters for wavelength dependence. This is accomplished by using either Quality Assurance Plan 1 or Plan 2 as described in Part D.

1. Calorimeter Absorption: Values of absorption have been determined by earlier measurements on the C, K and Q type calorimeter. Some of the results of these measurements are discussed in references 3, 4, 5, 6, and 7. For instance, the values of absorption for the C-Series calorimeters are independent of wavelength from 0.4 to 1.064 μm.

2. Beamsplitter Ratios: All the beamsplitter ratios used in the C, K and Q systems are wavelength-dependent. Beamsplitters are discussed in some detail in References 3, 4, 7, 8, and 9. Both of the following plans, 1 and 2, are designed to determine the correct beamsplitter ratio to use for each wavelength being provided.

3. Calorimeter Windows: All windows used in the C-Series system are wavelength-dependent. A choice is available between Plan 1 or 2, depending on whether window transmission measurements are to be made with the calibrating system or were made before, by independent means. Proceed to Part D.

C. Re-Evaluation of a System at an Old Wavelength

Either Plan 1 or 2 can be used for a periodic or special re-evaluation of a system at a previously used wavelength depending on whether the window transmission measurements were made independently or not.

D. Quality Assurance Plans 1 and 2

EL runs are defined as electrical calibration runs, where electrical energy is furnished to the calorimeter for determining the electrical calibration coefficient.

BS runs are defined as beamsplitter runs, where laser energy is furnished to both calorimeters via the beamsplitter to measure the beamsplitter ratio. Plans 1 and 2 assume that the electrical calibration measurements, as described in Section III.A. were completed sometime in the past and that the electrical calibration runs shown in Plan 1 and 2 are only to confirm the status quo. If the electrical measurements were recently completed, then the EL runs in Plan 1 and 2 could be deleted. Figure 1 in Appendix B shows the experimental arrangement for the beamsplitter and the low and high level calorimeter positions. The number of beamsplitter runs with C1 in the low level position and C2 in the high level position equals the number of beamsplitter runs with C2 in the low level position and C1 in the high level position.

Plan 1

Plan 1, the preferred plan, is either for those calorimeters that do not use windows at all, or those calorimeters that use windows, but where the window transmission values were measured independently. For instance, the window transmission measurements for six NBS, C-Series windows, were made by the the Optical Physics Division, NBS/Washington, D.C., from 400 to 1100 nm in 20 nm steps. Linear interpolation of these data provides the values of transmission for the laser wavelengths of interest. Plan 1 for a two-calorimeter/beamsplitter system is illustrated in Table II.

Plan 2

Plan 2 is for those calorimeters that use windows and where the window transmission values are to be measured at this time with the calibrating system. The plan is for a two-calorimeter/beamsplitter system. Each calorimeter has two windows assigned to it. The on-window is presently mounted in the calorimeter and the off-window is presently not mounted in the calorimeter and is the window being measured in the high-level beam. Calorimeter C1 has on-window 1A, and off-window 1B. Calorimeter C2 has on-window 2A, and off-window 2B. Plan 2 is shown in Table III.

Result

The main purpose of Plan 1 and 2 is to evaluate the correct beamsplitter ratio to use when producing an accurately known laser beam for calibration work. An average can be taken of all the beamsplitter ratios when calorimeter C1 is low, and calorimeter C2 is high. Another average can be taken of all the beamsplitter ratios when C2 is low and C1 is high. A derivation in Appendix B shows that the geometric mean of the two averages gives the correct beamsplitter ratio to use in future calculations.

Another purpose of Plan 1 or 2 is that if we have determined the correct values for electrical calibration, absorption, window transmission, etc., for both calorimeters, then the derivation in Appendix B will also give the best estimate of the disagreement between the two calorimeters. Since there is no reason to believe that one calorimeter is more accurate than another, the calorimeters are treated on an equal basis. A correction factor or D-factor for each calorimeter is determined by dividing the percent disagreement in half and adding this correction to the low-reading calorimeter and subtracting this correction from the high-reading calorimeter. When the beamsplitter data of Plan 1 or 2 is used with computer program, /ST2/, the program will calculate the absolute beamsplitter ratio and D-factor for each calorimeter as well as the 99 percent confidence intervals for the beam-splitter ratio and D-factors. See Appendix C for computer program /ST2C/.

E. Day-to-Day Check

The NBS C, K and Q calibrating systems are mainly used to calibrate transfer standards that are used in the NBS MAP Programs. Measurements are done periodically on the transfer instruments to accumulate a calibration history. Measurements are taken on transfer instruments before they are shipped to MAP customers and after the instruments are returned to

TABLE II

Plan 1

Run No.	Type of Run	Low Level Calorimeter	Low Level Scale	High Level Calorimeter	High Level Scale
1	EL	C1	low	--	--
2	EL	C1	medium	--	--
3	BS	C1	"	C2	high
4	BS	C1	"	C2	"
5	BS	C1	"	C2	"
6	EL	--	--	C2	"
7	EL	C2	low	--	--
8	EL	C2	medium	--	--
9	BS	C2	"	C1	high
10	BS	C2	"	C1	"
11	BS	C2	"	C1	"
12	EL	--	--	C1	"
13	EL	C1	low	--	--
14	EL	C1	medium	--	--
15	BS	C1	"	C2	high
16	BS	C1	"	C2	"
17	BS	C1	"	C2	"
18	EL	--	--	C2	"
19	EL	C2	low	--	--
20	EL	C2	medium	--	--
21	BS	C2	"	C1	high
22	BS	C2	"	C1	"
23	BS	C2	"	C1	"
24	EL	--	--	C1	"

TABLE III

Plan 2

Run No.	Type of Run	Low Level Calorimeter	Low Level Scale	High Level Calorimeter	High Level Scale	Off-Window In Beam
1	EL	C1	low	--	--	--
2	EL	C1	medium	--	--	--
3	BS	C1	"	C2	high	none
4	BS	C1	"	C2	"	1B
5	BS	C1	"	C2	"	none
6	BS	C1	"	C2	"	1B
7	BS	C1	"	C2	"	none
8	BS	C1	"	C2	"	1B
9	EL	--	--	C2	"	--
10	EL	C2	low	--	--	--
11	EL	C2	medium	--	--	--
12	BS	C2	"	C1	high	none
13	BS	C2	"	C1	"	2B
14	BS	C2	"	C1	"	none
15	BS	C2	"	C1	"	2B
16	BS	C2	"	C1	"	none
17	BS	C2	"	C1	"	2B
18	EL	--	--	C1	"	--
19	EL	C1	low	--	--	--
20	EL	C1	medium	--	--	--
21	BS	C1	"	C2	high	none
22	BS	C1	"	C2	"	1B
23	BS	C1	"	C2	"	none
24	BS	C1	"	C2	"	1B
25	BS	C1	"	C2	"	none
26	BS	C1	"	C2	"	1B
27	EL	--	--	C2	"	--
28	EL	C2	low	--	--	--
29	EL	C2	medium	--	--	--
30	BS	C2	"	C1	high	none
31	BS	C2	medium	C1	high	2B
32	BS	C2	"	C1	"	none
33	BS	C2	"	C1	"	2B
34	BS	C2	"	C1	"	none
35	BS	C2	"	C1	"	2B
36	EL	--	--	C1	"	--

ensure a stable instrument during the MAP intercomparison. A plot of calibration values versus chronological order for each transfer instrument provides a quick check of instrument stability and the calibration system validity. For instance, if the calibration values for several instruments all changed in the same direction at the same time, one should suspect trouble.

Day-to-day checks are easier to accomplish if all calibration runs are stored in chronological order in the computer file assigned to that instrument. Data is coded for different scales and wavelength for a particular instrument so the values can be separated for analysis. Several computer programs such as /S6/, /RU/, /PL/, /ASTM/ and /D2/, as shown in the Appendices D through H, are available for separating, plotting and statistically analyzing the calibration factors for trends, shifts and excessive scatter.

F. Monthly or Special Check

Each month a beamsplitter run at each wavelength being maintained provides further proof that the system is performing properly. The ratio of an uncoated beamsplitter can provide a very stable parameter for control purposes. If anything happens to the beamsplitter. or electronics for either calorimeter, it is very likely to cause a change in the beamsplitter ratio. A beamsplitter run can be made anytime a special check of the system is desired. The results of the beamsplitter runs are appended in chronological order to the end of the computer file assigned to that beamsplitter. Computer Program, /S7B/, as shown in Appendix I, can be used to copy the old beamsplitter values to a single-column file so that the programs discussed above could be used to detect trends, shifts and excessive scatter. See Part A., First-Time Operation of a System, for a discussion of trends and shifts in beamsplitter and electrical calibration values.

G. Annual Check

At this point, we assume that a sufficient number of calorimeter interchanges have previously been done, as described in Section III.C., to establish the system capability at each wavelength that calibration service is being offered. Once established, a yearly interchange according to Part C would be made at each of the wavelengths to verify the D-factor and beamsplitter ratio and re-evaluate the calibrated beam uncertainty. Electrical calibration runs would be made at the same time to verify the electrical calibration coefficient for each calorimeter.

H. NBS/AGMC MAP

A high precision MAP between NBS and AGMC would include a plan where the National Bureau of Standards would send several transfer standards to Aerospace Guidance and Metrology Center (AGMC) on a semi-annual basis for a MAP intercomparison. Some advantages of such a program would be:

1. To provide an independent check of the three AGMC systems,

2. To provide AGMC with written documentation of the status of their measurement systems,

3. To detect and provide help in solving any measurement problems that may occur or exist, and

4. A time-saver for AGMC, by eliminating the need for so many yearly checks as discussed in Section G.

One possible yearly plan could be that the following number of intercomparisons would be accomplished at AGMC utilizing NBS transfer standards:

2-C-Series	1 μW, 0.6328 μm
2-C-Series	1 mW, 0.6328 μm
2-C-Series	50 mW, 0.6471 μm
2-C-Series	500 mW, 1.064 μm
2-Q-Series	1 to 5 J, 1.064 μm
2-K-Series	50 W, 10.6 μm

Some other wavelengths that are maintained on the C-Series, and would be available to AGMC in a MAP Program, are 0.4880, 0.5145, and 0.5309 μm, in the 50 to 500 mW power level range.

IV. BLUE BOOK

A Blue Book is a designated loose-leaf notebook which contains a detailed account of all the parameters needed by the computer to calculate the power and energy in the calibrated beam output of a system. These parameters include values of electrical calibration, absorption, window transmission and D-factors for each calorimeter. In addition, the Blue Book contains a detailed system analysis of errors in measuring the values of electrical calibration, absorption, window transmission, SI traceability, inequivalence, D-factor and beam-splitter ratio. A summary of the errors at the 99 percent confidence interval level can be stored and used by the computer to produce a statement of system uncertainty for each calibration run.

A Blue Book exists for each calibration system and consists of a set of tables (forms) for each laser wavelength being provided by the system. A complete set of forms is filled out each time Plan 1 or 2 in Section III-D, is completed, either for setting up a new wavelength or re-evaluating an old wavelength. For examples of these tables, see Figures 1 through 9.

TABLE A. ELECTRICAL CALIBRATIONS

Date ______________________________

Wavelength ______________________________

A summary of electrical calibration data from program /SLOPE/ for each series calorimeter and scale setting.

Calorimeter	Scale	Measurements	Electrical K	99% Confidence Interval in %	For Period From	To

Worst % Case on 1E3 Scale __________

Worst % Case on 1E4 Scale __________

Worst % Case on 1E5 Scale __________

FIGURE 1.

TABLE B. ABSORPTION

Date ____________________________

Wavelength ____________________________

A summary of errors associated with calorimeter absorption from previous absorption measurements on calorimeters _____, _____, and _____.

Calorimeter	Absorption	% Error
__________	__________	_______
__________	__________	________
__________	__________	________

FIGURE 2.

TABLE C. INEQUIVALENCE

Date ______________________________

Wavelength ______________________________

Summary of the inaccuracy of the inequivalence between laser and electrical energy measurements, from previous measurements.

See ______________________________.

Calorimeter	% Inaccuracy
____________	____________
____________	____________
____________	____________

FIGURE 3.

TABLE D. WINDOW TRANSMISSION

Date ____________________

Wavelength ____________________

The window transmission values at the 99% confidence interval level for the above wavelength, include the correction for the second transmitted beam.

Data Source ____________________

Data Source Date ____________________

Calorimeter	Window Presently On	Meas. Date	Main Transmission	Secondary Transmission	Total Transmission	99% Conf. Interval in %

Use Worst Case Value ________

FIGURE 4.

TABLE E. TRACEABILITY

Date ____________________________

Wavelength ____________________________

Summary of errors pertaining to the traceability of our electrical measurements to the United States (U.S.) National Standards. See Section II for further discussion.

Source of Error	Source of Information	% Inaccuracy
Time Interval Measurement	____________	________
Standard Resistor	Calibration Report	________
Standard Cell	Calibration Report	________
Potentiometer	Calibration Report	________
Standard DVM	____________	________
DVM #1	____________	________
DVM #2	____________	________
Calorimeter Resistance (Worst Case)	____________	________
____________	____________	________
____________	____________	________
	Total	________

FIGURE 5.

TABLE F. D-FACTOR

Date ____________________________

Wavelength ____________________________

Summary of the absolute laser energy standard corrections (D-factors) for each series calorimeter. See Section III for further discussion.

Calorimeter	Source	D-Factor	99% Conf. Interval
__________	_______	_________	________
__________	_______	_________	________
__________	_______	_________	________

Largest D-Factor greater than 1	________
D-Factor with largest (1-D) difference	________
Greatest Range	________
	________
Greatest Range in %	________
D-Factor with largest % inaccuracy	________

FIGURE 6.

TABLE G. SCALE ERRORS

Date ____________________________

Wavelength ____________________________

Additional errors due to using different scales on the calorimeter amplifiers from Table A.

Largest Inaccuracy on 1E4 Scale _______________

Largest Inaccuracy on 1E5 Scale _______________

FIGURE 7.

TABLE H. BEAMSPLITTER RATIO

Date ____________________________

Wavelength ____________________________

Use ____________________________ to obtain the absolute beamsplitter ratio and the associated 99% confidence interval in percent.

Absolute Beam Ratio	99% Confidence Interval	Estimated Polarization Error	Total % Error

FIGURE 8.

TABLE I. SUMMARY OF ERRORS

Date ______________________________

Wavelength ______________________________

Summary of Errors	Percent at the 99% Confidence Interval		
	1E3	1E4	1E5
Table A Electricals Worst Case for Scale	_____	_____	_____
Table B Absorption	_____	_____	_____
Table C Inequivalence	_____	_____	_____
Table D Window Transmission	_____	_____	_____
Table E Electrical Traceability	_____	_____	_____
Table F D-Factors Greatest Range in Percent	_____	_____	_____
Greatest Percent Inaccuracy	_____	_____	_____
Table G Amplifier Scale Error	_____	_____	_____
Table H Beamsplitter Error	_____	_____	_____
TOTAL PERCENT ERROR	_____	_____	_____

FIGURE 9.

V. COMPUTER DOCUMENTATION FOR THE C, K AND Q CALIBRATING SYSTEMS

A computer is required to calculate the corrected rise value which is directly proportional to the joule energy input to a calorimeter. Since the use of a computer is required for part of the calculation anyway, there is a strong incentive to expand the use of the computer for all the calculations.

A computer with an interactive terminal and permanent file storage can be very effective for storing calibration data and for providing immediate access by the computer for evaluating some of the Blue Book parameters. Separate permanent computer files should be created for the following categories.

A. Electrical Calibration Files

Electrical calibration runs for each calorimeter and, in some cases, for each scale. See Appendix J for samples of electrical calibration files.

B. Beamsplitter Files

Beamsplitter runs for each beamsplitter for each wavelength are maintained. See Appendix K for samples of beamsplitter calibration files. Table L.1, as shown in Appendix L, can be used to supply code numbers which describe the different calorimeter/beamsplitter configurations.

When an electrical or beamsplitter run is made, the calibration value and other pertinent information is appended to the end of the appropriate file. Code numbers are often used in individual files to identify and allow the separation of unique sets of data for plotting and statistical purposes. When a status report of a calorimeter or a beamsplitter at one of the laser wavelengths is desired, the computer can be used to query the file and print out information pertaining to data trends, shifts and scatter. For convenience, the deviation for each calibration value, in percent, from the average calibration value is usually plotted versus run number on an interactive terminal. Such a plot can then be used as a guide to determine whether the instrument is, or is not, in statistical control.

C. Blue Book Matrix Files

After assigning the Blue Book parameters, the values are stored in permanent matrix files which are then accessed by the computer for future calculations of power and energy in the calibrated beam. Blue Book values are kept in separate matrix files to allow for easier file updating. The size of the matrix varies with the calibrating system. A 4 x 6 matrix may be adequate for a two-calorimeter/beamsplitter system at one wavelength. On the other hand, a C-Series three-calorimeter/beamsplitter system at six different wavelengths may use a 4 x 20 matrix. Such a matrix is shown in Appendix M. In addition, a description of how the Blue Book parameters are represented by the matrix is shown in a run of computer program, /DOC/. A zero in the matrix means that this location is not being presently used.

As can be seen, the matrix contains values of electrical calibration, absorption, beamsplitter ratios, window transmission, delivered beam uncertainty and beamsplitter code numbers. There is less chance of error in the calculations if the parameter values are supplied by such a computer file rather than being supplied directly by an operator.

VI. USING THE C, K AND Q LASER CALIBRATING SYSTEMS

The first five sections of this report were involved in getting the calibration systems in order, so they could be used for calibrating Laser Power and Energy Transfer Standards. Some subjects to consider when using the above calibrating systems are:

A. Transfer Standards

Some desirable characteristics of a good transfer standard are:

1. Short-term stability should be good. The calibration constant should at least remain stable to a few tenths of a percent for a six to twelve month period.

2. The instrument should have a small temperature coefficient, relative to responsivity, at normal room temperatures.

3. The output responsivity should be as uniform as possible over the surface of the detector.

4. The detector response should be relatively insensitive to wavelength.

5. The detector response should be linear. At the very least, the response should be linear on each scale.

6. The effects of detector saturation are very small at the power density level of operation.

7. The detector response time is fast relative to the experiment time.

8. The instrument's response is relatively insensitive to environmental effects such as humidity, pressure, line voltage, temperature, etc.

9. A self-contained digital readout is desirable for ease in reading and for saving time in establishing calibration traceability.

10. The head and readout unit should be a convenient size for shipping.

11. The head and readout unit should be of rugged construction to prevent damage in shipping.

12. When possible, use commercially-made transfer standards which can be purchased and used by the general public.

B. Conventional Calibration

The following chronology of a regular NBS calibration is an example of how a standards laboratory such as AGMC may conduct a conventional calibration.

1. As pre-arranged, the customer sends their laboratory transfer standard to NBS. The instrument may include a head unit with attached readout meter, or with only the head unit, in which case NBS furnishes the readout meter.

2. Before making any calibration runs, the status of the calibrating system at the appropriate wavelength must be ascertained. If recent measurements on other transfer standards at this wavelength indicate statistical control, we would assume a ready system status. For an alternative check, a beamsplitter run could be used to confirm a ready status. For a new wavelength, see Section III.B.

3. Assuming a ready status, a set of at least five calibrated beam runs is made where a known power or energy beam is supplied to the transfer standard. The calibration factor is equal to the net meter reading of the test instrument divided by the calibrated beam power or energy.

4. Statistics at the 99 percent confidence interval level for the average of the calibration runs is then obtained and compared with the transfer standard meter specifications or with previous data. If needed, additional runs may be made to improve the precision of the measurements.

5. The transfer standard is sent back to the customer.

6. A signed calibration report is sent to the customer based on the NBS system beam uncertainty plus the 99 percent confidence interval level of the measurements taken in Step 3.

7. The customer uses the transfer standard as he sees fit. Since conventional calibrations do not involve any customer measurements, there is little opportunity for an intercomparison of measurements to detect trends, shifts, excessive scatter or other problems relating to the customer's measurements.

C. Measurement Assurance Program (MAP)

The following chronology of a typical NBS MAP Program is an example of how a standards laboratory such as AGMC may participate in a MAP Program with other standards laboratories.

1. Select state-of-the-art transfer instruments to be used as NBS transfer standards for the desired laser wavelengths and power or energy levels.

2. Using the appropriate NBS calibrating system, make at least ten runs at each wavelength and scale of interest, preferrably over a period of time (at least one month) to determine the average calibration coefficient.

3. Just before sending a NBS transfer standard to a MAP customer, make a calibration run, append the results to file, and use ASTM Control Chart Program /ASTM/ (see Appendix G) to verify that the transfer instrument is under statistical control.

4. Send transfer instrument to customer.

5. Customer then calibrates transfer instrument, using his own laboratory standards and techniques. NBS will respond to a customer's request for information pertaining to measurement format, precautions, etc.

6. Customer sends instrument back to NBS.

7. NBS makes another calibrating run on standard and appends these results to file.

8. NBS re-runs ASTM Control Chart Program to verify statistical control.

9. Customer sends company calibration data of individual runs to NBS.

10. NBS analyzes both customer and NBS data and, using program /D2/, produces a report of intercomparison with appropriate statistics and error statements.

11. NBS sends signed intercomparison report to customer.

12. If any problems exist and if the customer desires, NBS will provide consultation on measurement problems.

VII. COMPUTER DOCUMENTATION AND QUALITY ASSURANCE OF LASER POWER AND ENERGY TRANSFER STANDARDS

A computer with permanent file storage and an interactive terminal can provide a very useful tool for data management with computer assistance. When a calibrated beam run is made on a particular transfer standard, the calibration value and other pertinent information is appended to the end of the permanent computer file created for this particular instrument.

Some guidelines that have been used by NBS pertaining to laser transfer standards are:

A. Format

Arrange computer files so that the calibration data for each instrument, for each mode (power or energy), for each wavelength and for each meter scale can be identified, separated and treated statistically as an independent entity. This can be accomplished by having separate files for each instrument and when appropriate, separate files for power and energy measurement data for each instrument. Code numbers are used in the individual files to identify and separate sets of data according to wavelength and meter scale. A typical file is shown in Appendix D. Computer programs as described in Appendices D, E, F, G, H can be used to detect trends, shifts or excessive scatter for a specified set of data. Computer printouts in a neat, fixed and familiar format saves time in data analysis.

B. Discrete Power and Energy Levels

The power and energy levels used for calibration must be assessed by each individual laboratory, such as AGMC, according to their needs and capabilities.

For example, the calibration runs for the NBS calibration and MAP Programs are usually made at discrete power and energy levels. The safety laws defining the four laser classifications, provide logical, discrete levels of nominal power at 1 μW, 1 mW and 500 mW.

The high interest in Q-Switched energy measurements at 1.064 μm generates a need for calibration runs at the 0.1, 1 and 10 J level. Single-pulse measurements are usually made with the 0.1 J scale while multiple pulse runs require the higher scales.

A NBS MAP Program with AGMC could be tailored to match the needs of AGMC with the capability of NBS.

C. Separate Calibration Coefficients for Each Scale and Wavelength

To more effectively utilize a limited staff, NBS only makes measurements at discrete power and energy levels as needed. No attempt is made to combine scales or wavelengths or to study linearity effects on a particular scale or between scales. Generally, we prefer to use a separate calibration value for each scale and wavelength.

D. Direct Calibrations

When possible, we calibrate the transfer standards directly with C, K and Q systems. This eliminates at least one step of calibration and generally improves the precision of our measurements.

E. Using Mean or Average Calibration Coefficients

The simplest determination of the calibration coefficient for each scale is to take the mean or average of the individual calibration run values. A more complicated method is to use a least-squares fit of a straight line through a plot of meter readings versus energy or power levels, where the slope of the line equals the calibration coefficient. The least-squares method has the advantage that the greater scatter of the lower level readings will not unduly influence the calibration coefficient. However, this method has little advantage in calibrating our transfer standards where measurements on a particular scale are usually made at only one nominal power or energy level.

F. Two-Sided 99 Percent Confidence Interval

The NBS statistical analysis is based on the two-sided 99 percent confidence intervals of the average or least-squares calibration coefficient. The less conservative 95 percent interval would also be acceptable. Probably the most important thing is to state plainly what type of statistical analysis is being used. The equation for the 99 percent confidence interval, e, in percent for the calibration coefficient, K, is

$$e(\%) = \pm \frac{100 \times t \times s}{K \times \sqrt{n}}$$

where

n is the number of measurements,

K is the average calibration coefficient,

s is the standard deviation of n measurements, and

t is the t-value from the table for Percentiles of the t Distribution (see EXPERIMENTAL STATISTICS, NBS Handbook 91) for $t_{.975}$ for n-1 degrees of freedom.

It is desirable to make e as small as reasonable, either by making more measurements, n, or by combining data in such a way as to make $s/\sqrt{n}$ smaller. Of course, better instruments with better measuring techniques may give a smaller s in the first place. The above equation appears in computer program, /D2/, which is described in Appendix H. The above program will take any set of numbers (up to 150 values), calculate the mean, standard deviation and the 90, 95 and 99 percent confidence interval for the mean in percent.

G. Status Categories

The status of a transfer standard at any given wavelength and scale will fall into one of several categories.

1. Insufficient data status. Insufficient number of calibration runs at this wavelength and scale. Desirable to have at least ten runs for each data set.

2. Inactive status. Sufficient number of calibration runs, but last run was taken over one year ago. This category may include old instruments, or wavelengths, no longer being maintained for the NBS calibration program.

3. Active status. This category includes the instruments at discrete wavelengths presently being used and maintained for our active calibration program. Generally, the last calibration run was made in the last three months. Measurements may be made periodically to maintain an active status.

4. Ready status. An instrument that, in the last few days, received a calibrating run, whose calibration value falls within the control chart limits of that instrument is considered to be in a ready status for that wavelength and scale. The instrument is ready to participate in a MAP program.

5. Repair status. An instrument needs repairs and is currently not available for calibration service.

Considering the different wavelengths and meter scales, it is highly probable that each instrument will fall into several status categories at the same time.

VIII. CALIBRATION AND MAP REPORTS

Calibration reports are provided to the customer for regular calibrations and formal MAP intercomparisons.

A. Regular Calibration Reports

For a regular NBS calibration, the customer sends his own transfer standard to NBS for measurement. NBS makes a number of calibration runs, N, and determines the mean value of the calibration coefficient. In addition, the uncertainty, A, of the mean, for N measurements is calculated at the 99 percent confidence interval using t-statistics. The uncertainty, B, of the NBS calibration system at the 99 percent confidence interval was determined, previously, as discussed in Sections II and III. The total uncertainty, C, for this calibration is the sum of A and B. A typical calibration report will contain the nominal energy or power, the number of measurements, N, the average (mean) calibration coefficient, the uncertainty, A, of N measurements, the NBS system uncertainty, B, and the total uncertainty, C, at the 99 percent confidence level. For convenience, the uncertainties, A, B and C are given in percent.

B. MAP (Measurement Assurance Program) Reports

For a NBS MAP intercomparison, NBS sends a well-evaluated NBS transfer standard to the customer (MAP participant) where he makes a number of measurements, N, using his calibration system to determine the mean calibration coefficient. The customer then returns the transfer standard to NBS with his evaluation of the calibration coefficient. NBS makes another calibration run on the transfer standard, appends these results to the previous data, and then calculates the latest mean value of the calibration coefficient, using the total number of measurements. In addition, the uncertainty, D, of the mean is determined at the 99 percent confidence interval using t-statistics. The uncertainty, B, of the NBS calibration system at the 99 percent confidence interval was determined, previously, for each laser wavelength and scale as discussed in Sections II and III.

The total uncertainty, C, for this intercomparison is the sum of D and B. A typical MAP report will contain the designation of the NBS transfer standard, wavelength of intercomparison, nominal power or energy level, number of customer measurments, N, customer's reported value of calibration coefficient, NBS reported values of calibration coefficient, NBS total uncertainty, C, and percent difference between customer and NBS.

IX. REFERENCES

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X. APPENDICES

APPENDIX A

Computer Program /SL/ for Electrical Calibration Factor

Computer program /SL/ uses electrical calibration data to find the best straight-line fit through zero and a plot of corrected rise values versus corresponding energy values using a linear least-squares calculation. The program calculates the electrical calibration factor (reciprocal of slope of line), standard deviation of residuals and 99 percent confidence interval for the slope according to Experimental Statistics, by M.G. Natrella, NBS Handbook 91, Paragraph 5-4.2.1. To do a least-squares fit, the program requires two columns of input data, where the first column is corrected rise values in microvolts and the second column is the corresponding values for energy in joules. A print-out is shown for input data File /444/, a computer run of /SL/, using File /444/ and a listing of Program /SL/.

COPY /444/ TO TEL

198.743	0.967611
900.345	4.38715
884.802	4.30903
1001.61	4.87603
623.318	3.03365
308.361	1.50149
383.745	1.86801
418.135	2.03697
832.416	4.05753
68.7373	0.335819
450.298	2.19321
130.44	0.637567
436.327	2.12373
190.161	0.925799
575.605	2.80253
147.137	0.720035
402.746	1.96238
541.485	2.63676
534.266	2.60097
659.583	3.21219
568.536	2.76487
569.731	2.77135
616.301	3.00386
869.624	4.23512
617.519	3.00434
870.003	4.23512
617.9332	3.004265

```
-BA
BASIC-5.15  73-11-13
>LOAD /SL/

>RUN
THIS IS 940 SLOPE PROGRAM. USES AN INPUT 2 COLUMN
ELECTRICAL DATA FILE TO FIND SLOPE, B, OF LINE,
Y=BX, THRU ORIGIN, STD.  DEV. OF RESIDUALS, AND 99%
CONFIDENCE INTERVALS ON SLOPE ACCORDING TO
NATRELLA 5-4.2.1
TYPE IN 2 COLUMN ELECTRICAL FILE IN / /? /444/
NO. OF RUNS IN INPUT FILE =
 27
MICROVOLTS      JOULES        THIS K (JOULES/MILLIVOLT)
 198.743        .967611          4.868654
 900.345        4.38715          4.872743
 884.802        4.30903          4.87005
 1001.61        4.87603          4.868192
 623.318        3.03365          4.866938
 308.361        1.50149          4.86926
 383.745        1.86801          4.867842
 418.135        2.03697          4.871561
 832.416        4.05753          4.874402
 68.7373        .335819          4.885542
 450.298        2.19321          4.870575
 130.44         .637567          4.887818
 436.327        2.12373          4.86729
 190.161        .925799          4.868501
 575.605        2.80253          4.868842
 147.137        .720035          4.893637
 402.746        1.96238          4.8725
 541.485        2.63676          4.869498
 534.266        2.60097          4.868305
 659.583        3.21219          4.870032
 568.536        2.76487          4.86314
 569.731        2.77135          4.864313
 616.301        3.00386          4.874014
 869.624        4.23512          4.870059
 617.519        3.00434          4.865178
 870.003        4.23512          4.867937
 617.9332       3.004265         4.861796

 SLOPE, B =        205.3703
 ELECTRICAL K =    4.869254

 STANDARD DEVIATION OF SLOPE =  .2884916E-01
 STANDARD DEVIATION OF RESIDUAL (Y'S) =          .4311138
 DEGREES OF FREEDOM= 26
 T VALUE FOR ABOVE D.F.= 2.778818
 99% CONF. INT. FOR SLOPE=+ OR - .0801666

 99$ CONFIDENCE INTERVAL IN % = .3903513E-01

 RANGE FACTOR FOR ABOVE NO. OF MEASUREMENTS IS  3.828

 99% IMPRECISION IN JOULES IS  .0803574E-01

 >
```

COPY /SL/ TO TEL

```
10  PRINT"THIS IS 940 SLOPE PROGRAM. USES AN INPUT 2 COLUMN"
20 PRINT"ELECTRICAL DATA FILE TO FIND SLOPE, B, OF LINE,"
30 PRINT"Y=BX, THRU ORIGIN, STD.  DEV. OF RESIDUALS, AND 99%"
40 PRINT"CONFIDENCE INTERVALS ON SLOPE ACCORDING TO"
50 PRINT"NATRELLA 5-4.2.1"
60 DIM K(200),X(200),Y(200),Z(200)
70 PRINT"TYPE IN 2 COLUMN ELECTRICAL FILE IN / /";
80 INPUTA$
90 OPENA$,INPUT
100 FORI=1TO200
110 INPUT FILE Y(I),X(I)
120 IFEOF(9)=1THEN180
140 N=I
150 NEXTI
160 PRINT"OVER 200 POINTS"
170 STOP
180 PRINT"NO. OF RUNS IN INPUT FILE =",N
190 IFN<>0THEN220
200 PRINT"NO DATA IN FILE ",A$
210 STOP
220 A=0
221 PRINT"MICROVOLTS     JOULES       THIS K (JOULES/MILLIVOLT)"
222 FOR I=1TON
223 PRINTY(I),X(I),1000*X(I)/Y(I)
224 NEXTI
225 PRINT
230 E=0
240 C=0
250 FORI=1TON
260 A=A+X(I)*Y(I)
270 E=E+X(I)*X(I)
280 C=C+Y(I)*Y(I)
290 NEXTI
300 B=A/E
310 PRINT"SLOPE, B =",B
320 B1=1000/B
330 PRINT"ELECTRICAL K =" ,B1
335 PRINT
340 IFN<>1THEN410
350 PRINT"ZERO DEGREES OF FREEDOM"
360 STOP
410 W=(C-(A*A/E))/(N-1)
420 D=W/E
430 S=SQR(D)
432 PRINT"STANDARD DEVIATION OF SLOPE =",S
434 W1=SQR(W)
436 PRINT"STANDARD DEVIATION OF RESIDUAL (Y'S) =",W1
440V=N-1
450IFV<>1THEN480
460T=63.657
470GOTO660
480IFV<>2THEN510
490T=9.925
500GOTO660
510IFV<>3THEN540
520T=5.841
530GOTO660
540IFV<>4THEN570
550T=4.604
560GOTO660
570IFV<>5THEN600
580T=4.032
```

```
590GOTO660
600G1=4.91699
610G2=8.83602
620G3=12.1466
630G4=12.0578
640G=2.575914
650T=G+G1/V+G2/V↑2+G3/V↑3+G4/V↑4
660PRINT" DEGREES OF FREEDOM=" V
670PRINT" T VALUE FOR ABOVE D.F.=" T
680PRINT"99% CONF. INT. FOR SLOPE=+ OR -"T*S
690PRINT
700PRINT"99$ CONFIDENCE INTERVAL IN % ="(100*T*S)/B
710PRINT
720K(2)=242.3
730K(3)=29.055
740K(4)=14.527
750K(5)=10.26
760K(6)=8.301
770K(7)=7.187
780K(8)=6.468
790K(9)=5.966
800K(10)=5.594
810K(11)=5.308
820K(12)=5.079
830K(13)=4.893
840K(14)=4.737
850K(15)=4.605
860K(16)=4.492
870K(17)=4.393
880K(18)=4.307
890K(19)=4.23
900K(20)=4.161
910K(21)=4.1
920K(22)=4.044
930K(23)=3.993
940K(24)=3.947
950K(25)=3.904
960K(26)=3.865
970K(27)=3.828
980K(30)=3.733
990K(35)=3.611
1000K(40)=3.518
1010K(45)=3.444
1020K(50)=3.385
1030K(55)=3.335
1040K(60)=3.293
1050K(65)=3.257
1060K(70)=3.225
1070K(75)=3.197
1080K(80)=3.173
1090K(85)=3.15
1100K(90)=3.13
1110K(95)=3.112
1120K(100)=3.096
1130K(150)=2.983
1140K(200)=2.921
1150IFN>27THEN1180
1160Q=K(N)
1170GOTO1670
1180IFN>32THEN1210
1190Q=K(30)
```

```
1200GOTO1670
1210IFN>37THEN1240
1220Q=K(35)
1230GOTO1670
1240IFN>42THEN1270
1250Q=K(40)
1260GOTO1670
1270IFN>47THEN1300
1280Q=K(45)
1290GOTO1670
1300IFN>52THEN1330
1310Q=K(50)
1320GOTO1670
1330IFN>57THEN1360
1340Q=K(55)
1350GOTO1670
1360IFN>62THEN1390
1370Q=K(60)
1380GOTO1670
1390IFN>67THEN1420
1400Q=K(65)
1410GOTO1670
1420IFN>72THEN1450
1430Q=K(70)
1440GOTO1670
1450IFN>77THEN1480
1460Q=K(75)
1470GOTO1670
1480IFN>82THEN1510
1490Q=K(80)
1500GOTO1670
1510IFN>87THEN1540
1520Q=K(85)
1530GOTO1670
1540IFN>92THEN1570
1550Q=K(90)
1560GOTO1670
1570IFN>97THEN1600
1580Q=K(95)
1590GOTO1670
1600IFN>120THEN1630
1610Q=K(100)
1620GOTO1670
1630IFN>170THEN1660
1640Q=K(150)
1650GOTO1670
1660Q=K(200)
1670GOTO1680
1680PRINT"RANGE FACTOR FOR ABOVE NO. OF MEASUREMENTS IS "Q
1690PRINT
1692P=SQR(W)*Q/B
1694PRINT"99% IMPRECISION IN JOULES IS "P
1700STOP
```

APPENDIX B

Beamsplitter Ratio and D-Factor Derivation

A two-calorimeter beamsplitter configuration is shown in Fig. 1. In Experiment 1, Calorimeter 1 is in the low-level position and Calorimeter 2 is in the high-level position. In Experiment 2, the calorimeters are interchanged with Calorimeter 2 in the low-level position and Calorimeter 1 in the high-level position.

We assume for each beamsplitter run that the system is linear and stable over the energy range of the experiment. Let

$$R12 = \frac{U2}{U1} \quad , \tag{1}$$

and

$$R21 = \frac{U1'}{U2'} \quad , \tag{2}$$

where

R12 -- beamsplitter ratio for Experiment 1.
R21 -- beamsplitter ratio for Experiment 2.
U1 -- energy to low-level calorimeter for Experiment 1.
U2 -- energy to high-level calorimeter for Experiment 1.
U2' -- energy to low-level calorimeter for Experiment 2.
U1' -- energy to high-level calorimeter for Experiment 2.

Say we assume a small error, α, between the two calorimeters, where α may be plus or minus. We also assume the two calorimeters perform equally well, and we will split the error, α, equally between them. For very small α, let the correction for Calorimeter 1 be $1 + \alpha$, and the correction for Calorimeter 2 be $1 - \alpha$ where we assume that for a very small α

$$1 + \alpha \simeq \frac{1}{1 - \alpha} \quad . \tag{3}$$

If we define the absolute beamsplitter ratio as B9, Eq. (1) then becomes

$$B9 = \frac{(1 - \alpha)U2}{(1 + \alpha)U1} \, , \tag{4}$$

and Eq. (2) becomes

$$B9 = \frac{(1 + \alpha)U1'}{(1 - \alpha)U2'} \quad . \tag{5}$$

We have two unknowns, B9 and α.

If we eliminate α by multiplying Eq. (4) by Eq. (5), the absolute beamsplitter ratio, B9, becomes

$$B9^2 = \frac{U2(1 - \alpha)U1'(1 + \alpha)}{U1(1 + \alpha)U2'(1 - \alpha)} , \tag{6}$$

$$B9 = \sqrt{\frac{U2\ U1'}{U1\ U2'}} \quad . \tag{7}$$

As can be seen, we can find the ratio, B9, without evaluating the error α. To find α, we eliminate B9 by setting Eq. (4) equal to Eq. (5) to obtain

$$\frac{U2(1 - \alpha)}{U1(1 + \alpha)} = \frac{U1'(1 + \alpha)}{U2'(1 - \alpha)} . \tag{8}$$

Substituting Eq. (3) in Eq. (8), we get

$$\frac{U2}{U1(1 + \alpha)^2} = \frac{U1'(1 + \alpha)^2}{U2'} , \tag{9}$$

$$(1 + \alpha)^2 = \sqrt{\frac{U2\ U2'}{U1\ U1'}} \quad . \tag{10}$$

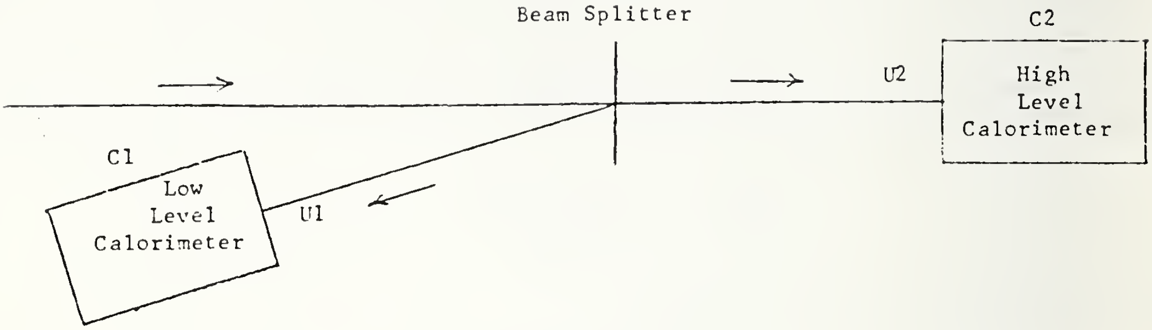
Expanding $(1 + \alpha)^2$ we obtain

$$(1 + \alpha)^2 = 1 + 2\alpha + \alpha^2 \tag{11}$$

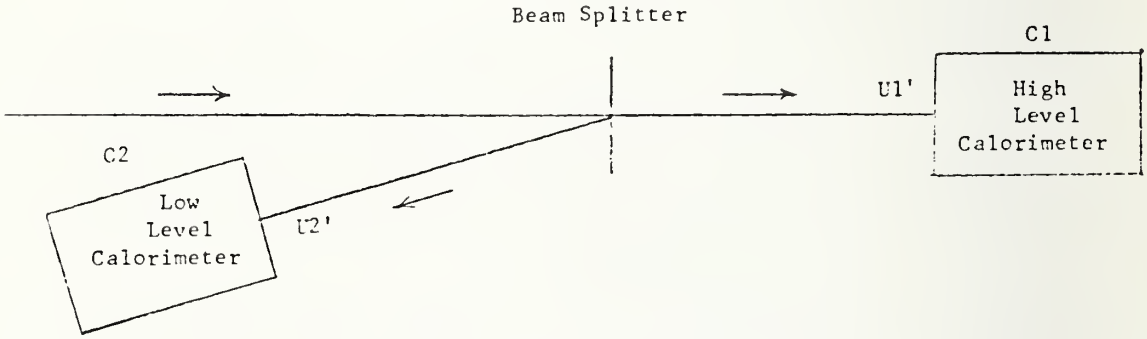
For small α, we neglect α^2 and Eq. (10) becomes

$$\alpha = \frac{1}{2} \left(\sqrt{\frac{U2\ U2'}{U1'\ U1}} - 1 \right) \quad . \tag{12}$$

As can be seen, α may be either plus or minus. In Program /ST2C/ we define $D = \alpha$.



Experiment No. 1



Experiment No. 2

Figure 1.

APPENDIX C

Computer Program, /ST2C/ for Beamsplitter Ratio

Appendix C includes a listing of Program /ST2C/ and the print-out of a computer run of /ST2C/ using input data files, /C/ and /D/. A listing of similar programs for a three-calorimeter intercomparison is also shown for Program /ST12/.

```
-COPY /C/ TO TEL

11.45573
11.44578
11.45999
11.45646

-COPY /D/ TO TEL

11.44814
11.44431
11.45393
11.45447

-BA
BASIC-5.15  73-11-13
>LOAD /ST2C/

>RUN
THIS IS 940 PROGRAM /ST2C/ DESIGNED TO FIND THE
ABSOLUTE BEAM SPLITTER RATIO AND D FACTOR FOR EACH
CALORIMETER WITH THE 99% CONFIDENCE INTERVAL, USING
2 C SERIES CALORIMETERS IN A REGULAR BEAM
SPLITTER SETUP.  BEFORE RUNNING THE PROGRAM, PUT IN
SCRATCH FILE /C/, A SINGLE COLUMN OF BEAM SPLITTER
RATIOS FOR C41 LOW LEVEL AND C46 HIGH LEVEL
POSITION. PUT IN FILE /D/, A SINGLE COLUMN
OF RATIOS FOR C46 LOW AND C41 HIGH.
THE NO. OF VALUES IN EACH FILE SHOULD EXCEED 4
AND THE RATIO OF /C/ PTS. TO /D/ PTS. SHOULD
LIE BETWEEN .8 AND 1.2
IF BEAM SPLITTER VALUES IN FILES /C/ AND /D/ ARE
IN ORDER, TYPE 1. OTHERWISE TYPE 0.? 1
NO. IN /C/ =              4
NO. IN /D/ =    4

DEGREES OF FREEDOM =             6
99% T VALUE FOR ABOVE DEG. OF FREEDOM =        3.728768
ESTIMATE OF SIGMA =              .4817674E-03

ABSOLUTE BEAM SPLITTER RATIO =                 11.45235
99% OF THE TIME, THE BEAM SPLITTER RATIOS WILL BE
WITHIN A + OR - PERCENTAGE RANGE OF            .0635123

D FACTOR FOR C41 CALORIMETER  =                1.000093
D FACTOR FOR C46 CALORIMETER  =                .9999066

TREATED EQUALLY, 99% OF THE TIME, THE D FACTORS WILL LIE
WITHIN A + OR - PERCENTAGE RANGE OF            .3175615E-01

TYPE IN WAVELENGTH? .5309
DATE IS     79/01/05 16:47:36

BEAM SPLITTER RATIOS IN FILE /C/
LOW LEVEL CAL. HIGH LEVEL CAL. BEAM SPLIT. RATIOS RUN NO.
C41         C46  11.45573       1
C41         C46  11.44578       2
C41         C46  11.45999       3
C41         C46  11.45646       4
```

```
BEAM SPLITTER RATIOS IN FILE /D/
LOW LEVEL CAL. HIGH LEVEL CAL. BEAM SPLIT. RATIOS RUN NO.
C46          C41   11.44814        1
C46          C41   11.44431        2
C46          C41   11.45393        3
C46          C41   11.45447        4
```

```
COPY /ST2C/ TO TEL

10 PRINT"THIS IS 940 PROGRAM /ST2C/ DESIGNED TO FIND THE"
20 PRINT"ABSOLUTE BEAM SPLITTER RATIO AND D FACTOR FOR EACH"
30 PRINT"CALORIMETER WITH THE 99% CONFIDENCE INTERVAL, USING"
40 PRINT"2 C SERIES CALORIMETERS IN A REGULAR BEAM"
50 PRINT"SPLITTER SETUP.  BEFORE RUNNING THE PROGRAM, PUT IN"
60 PRINT"SCRATCH FILE /C/, A SINGLE COLUMN OF BEAM SPLITTER"
70 PRINT"RATIOS FOR C41 LOW LEVEL AND C46 HIGH LEVEL"
80 PRINT"POSITION. PUT IN FILE /D/, A SINGLE COLUMN"
90 PRINT"OF RATIOS FOR C46 LOW AND C41 HIGH."
100 PRINT"THE NO. OF VALUES IN EACH FILE SHOULD EXCEED 4"
105 PRINT"AND THE RATIO OF /C/ PTS. TO /D/ PTS. SHOULD"
107 PRINT"LIE BETWEEN .8 AND 1.2"
110 PRINT"IF BEAM SPLITTER VALUES IN FILES /C/ AND /D/ ARE"
120 PRINT"IN ORDER, TYPE 1. OTHERWISE TYPE 0.";
130 INPUTA3
140 IFA3=1THEN160
150 STOP
160 OPEN/C/,INPUT
170 DIMW(100),X(100),Y(100),Z(100)
180 FORI=1TO100
190 INPUT FILEY(I)
200 IFEOF(9)=1THEN230
210 N1=I
220 NEXTI
225 GOTO310
230 PRINT"NO. IN /C/ =",N1
232 IFN1>3THEN240
236 PRINT"LESS THAN 5 VALUES IN /C/"
238 STOP
240 CLOSE
250 OPEN/D/,INPUT
260 FOR I=1TO100
270 INPUTFILEZ(I)
280 IFEOF(9)=1THEN330
290 N2=I
300 NEXTI
310 PRINT"OVER 100 POINTS IN /C/ OR /D/"
320 STOP
330 PRINT"NO. IN /D/ =",N2
332 IFN2>3THEN340
336 PRINT"LESS THAN 5 VALUES IN /D/"
338 STOP
340 S1=0
341 N9=N1/N2
342 IFN9>1.2THEN345
343 IFN9<.8THEN345
344 GOTO350
345 PRINT"NO. OF PTS. RATIO OUT OF RANGE"
346 STOP
350 FORI=1TON1
360 X(I)=LOG(Y(I))
370 S1=S1+X(I)
380 NEXTI
```

```
390 S2=0
400 FORI=1TON2
410 W(I)=LOG(Z(I))
420 S2=S2+W(I)
430 NEXTI
440 N3=N1+N2
450 N4=N1-N2
460 S3=S1+S2
470 S4=S1-S2
480 D3=(N3)↑2-(N4)↑2
490 B1=(N3*S3-N4*S4)/D3
500 D1=(N3*S4-N4*S3)/D3
510 S=0
520 FORI=1TON1
530 S=S+(B1+D1-X(I))↑2
540 NEXTI
550 FORI=1TON2
560 S=S+(B1-D1-W(I))↑2
570 NEXTI
580 S8=S/(N3-2)
590 B=EXP(B1)
600 D=EXP(D1/2)
610 B2=(S8*N3*(2*N1)↑2)/(D3)↑2
620 D2=(S8*N3*(2*N2)↑2)/(D3)↑2
630 V=N3-2
640 T=V/(-0.71557217916l+0.387490270184*V)+6.0E-4
650 B4=T*SQR(B2)*100
660 D4=(T*SQR(D2)*100)/2
670 S7=SQR(S8)
700 PRINT
710 PRINT"DEGREES OF FREEDOM =",V
720 PRINT"99% T VALUE FOR ABOVE DEG. OF FREEDOM =",T
730 PRINT"ESTIMATE OF SIGMA =",S7
740 PRINT
750 PRINT"ABSOLUTE BEAM SPLITTER RATIO =",B
760 A$="99% OF THE TIME, THE BEAM SPLITTER RATIOS WILL BE"
770 B$="WITHIN A + OR - PERCENTAGE RANGE OF "
780 C$="D FACTOR FOR C41 CALORIMETER  ="
790 D$="D FACTOR FOR C46 CALORIMETER  ="
800 E$="TREATED EQUALLY, 99% OF THE TIME, THE D FACTORS WILL LIE"
810 PRINTA$
820 PRINTB$,B4
830 PRINT
840 PRINTC$,D
850 PRINTD$,1/D
860 PRINT
870 PRINTE$
880 PRINTB$,D4
890 PRINT
900 PRINT"TYPE IN WAVELENGTH";
910 INPUTW8
920 F$="DATE IS"
930 G$=DAT(X)
940 PRINTF$,G$
950 H$="LOW LEVEL CAL. HIGH LEVEL CAL. BEAM SPLIT. RATIOS RUN NO."
960 I$="BEAM SPLITTER RATIOS IN FILE /C/"
970 J$="BEAM SPLITTER RATIOS IN FILE /D/"
980 K$="C41          C46"
990 L$="C46          C41"
1000 PRINT
1010 PRINTI$
1020 PRINTH$
```

```
1030 FORI=1TON1
1040 PRINTK$,Y(I),I
1050 NEXTI
1060 PRINT
1070 PRINTJ$
1080 PRINTH$
1090 FORI=1TON2
1100 PRINTL$,Z(I),I
1110 NEXTI
1200 END
```

COPY /ST12/ TO TEL

```
10 PRINT"THIS IS 940 PROGRAM STAT12 FOR C SERIES CALORIMETERS"
20 PRINT"THIS PROGRAM IS DESIGNED ONLY FOR 12 BEAM SPLITTER"
30 PRINT"RUNS OF 2 EACH FOR THE 6 POSSIBLE CONFIGURATIONS"
40 PRINT"OF 3 C SERIES CALORIMETERS TAKEN 2 AT A TIME"
50 PRINT" IN A BEAM SPLITTER SETUP"
55 GOTO120
60 PRINT"FOR INSTRUCTIONS FOR INPUT VALUES, TYPE 1. ELSE 0";
70 INPUTA1
80 IFA1=1THEN100
90 GOTO300
100 PRINT"TYPE BEAM SPLITTER VALUES IN A SINGLE COLUMN"
110 PRINT"TO SCRATCH DATA FILE /B/, USING THE FOLLOWING ORDER"
115 GOTO252
120 P$="SET LOW LEVEL CALORIMETER HIGH LEVEL CALOR. BEAM SPLITTER R."
140 I$="1ST          C444                  C413 "
150 J$="1ST          C414                  C443 "
160 K$="1ST          C464                  C413 "
170 L$="1ST          C414                  C463 "
180 M$="1ST          C464                  C443 "
190 N$="1ST          C444                  C463 "
200 O$="2ND          C444                  C413 "
210 R$="2ND          C414                  C443 "
220 S$="2ND          C464                  C413 "
230 T$="2ND          C414                  C464 "
240 U$="2ND          C464                  C443 "
250 V$="2ND          C444                  C463 "
251 GOTO60
252 PRINT
255 PRINTP$
260 PRINTI$
262 PRINTJ$
264 PRINTK$
266 PRINTL$
270 PRINTM$
272 PRINTN$
274 PRINTO$
276 PRINTR$
278 PRINTS$
280 PRINTT$
282 PRINTU$
290 PRINTV$
295 PRINT
300 PRINT"IF BEAM SPLITTER VALUES IN FILE /B/ ARE IN "
305 PRINT"ORDER, TYPE 1. ELSE 0";
310 INPUTA3
320 IFA3=1THEN340
330 STOP
340 OPEN/B/,INPUT
350 DIMV(15),W(12)
360 FORI=1TO15
370 INPUTFILEV(I)
380 IFEOF(9)=1THEN410
390 N1=I
400 NEXTI
410 IFN1=12THEN440
420 PRINT"NO. OF VALUES DOESN'T = 12"
430 STOP
440 FORI=1TO12
```

```
450 W(I)=LOG(V(I))
460 NEXTI
470 T=0
480 FORI=1TO12
490 T=T+W(I)
500 NEXTI
510 Z=T/12
520 B=EXP(Z)
530 X=(W(1)+W(7)-W(2)-W(8)-W(5)-W(11)+W(6)+W(12))/12
540 Y=(W(3)+W(9)-W(4)-W(10)+W(5)+W(11)-W(6)-W(12))/12
550 Y2=EXP(X)
560 Y3=EXP(Y)
570 Y1=1/(Y2*Y3)
580 S=0
590 FORI=1TO12
600 W(I)=-1*W(I)
610 NEXTI
620 S=S+(W(1)+2*X+Y+Z)↑2+(W(7)+2*X+Y+Z)↑2
630 S=S+(W(2)-2*X-Y+Z)↑2+(W(8)-2*X-Y+Z)↑2
640 S=S+(W(3)+X+2*Y+Z)↑2+(W(9)+X+2*Y+Z)↑2
650 S=S+(W(4)-X-2*Y+Z)↑2+(W(10)-X-2*Y+Z)↑2
660 S=S+(W(5)-X+Y+Z)↑2+(W(11)-X+Y+Z)↑2
670 S=S+(W(6)+X-Y+Z)↑2+(W(12)+X-Y+Z)↑2
680 S1=SQR(S)/3
690 E9=100*3.25*S1/SQR(12)
700 E1=100*3.25*S1/SQR(18)
705 PRINT
710 A$="ABSOLUTE BEAM SPLITTER RATIO ="
720 PRINTA$,B
730 B$="D FACTOR FOR C41 CALORIMETER ="
740 C$="D FACTOR FOR C44 CALORIMETER ="
750 D$="D FACTOR FOR C46 CALORIMETER ="
760 E$="99% OF THE TIME, THE BEAM SPLITTER RATIOS WILL BE"
770 F$="WITHIN A + OR - PERCENTAGE RANGE OF "
780 PRINTE$
790 PRINTF$,E9
800 PRINT
810 PRINTB$,Y1
820 PRINTC$,Y2
830 PRINTD$,Y3
840 PRINT
850 G$="TREATED EQUALLY, 99% OF THE TIME, THE D FACTORS WILL LIE"
860 PRINTG$
870 PRINTF$,E1
880 PRINT"TYPE IN WAVELENGTH";
890 INPUTW8
900 W$=DAT(X)
910 PRINT"DATE IS ",W$
912 PRINT
916 PRINTP$
920 PRINTI$,V(1)
930 PRINTJ$,V(2)
940 PRINTK$,V(3)
950 PRINTL$,V(4)
960 PRINTM$,V(5)
970 PRINTN$,V(6)
980 PRINTO$,V(7)
990 PRINTR$,V(8)
1000 PRINTS$,V(9)
1010 PRINTT$,V(10)
1020 PRINTU$,V(11)
1030 PRINTV$,V(12)
9999 PRINT"DONE"
10000 END
```

APPENDIX D

Computer Program /S6/ Used to Separate Calibration Values According to Wavelength and/or Scale

Appendix D gives an example of how Program /S6/ can be used to separate and print out the Code 9 values from a typical power meter file to single column, File /A/. A listing of /S6/ is also included.

COPY /15/ TO TEL

9.61527E-Ø1	78Ø1274	Ø.96825E-Ø3	.6328	3464	9
9.6Ø122E-Ø1	78Ø1275	Ø.969Ø4E-Ø3	.6328	3464	9
9.6Ø756E-Ø1	78Ø1311	1.Ø2274E-Ø3	.6328	3464	9
9.64984E-Ø1	78Ø2Ø12	1.Ø2965E-Ø3	.6328	3464	9
9.6678ØE-Ø1	78Ø2Ø22	1.Ø2753E-Ø3	.6328	3464	9
9.61246E-Ø1	78Ø2Ø33	Ø.9831ØE-Ø3	.6328	3464	9
9.63326E-Ø1	78Ø2Ø61	1.1Ø347E-Ø3	.6328	3464	9
9.62951E-Ø1	78Ø2Ø92	Ø.97222E-Ø3	.6328	3464	9
9.52Ø48E-Ø1	78Ø2172	1.Ø9669E-Ø6	.6328	3465	3
9.5687ØE-Ø1	78Ø2173	1.Ø6399E-Ø6	.6328	3465	3
9.55321E-Ø1	78Ø2212	1.Ø5Ø54E-Ø6	.6328	3465	3
9.54587E-Ø1	78Ø2242	1.13Ø33E-Ø6	.6328	3465	3
9.48927E-Ø1	78Ø2271	1.14445E-Ø6	.6328	3465	3
9.54925E-Ø1	78Ø3Ø11	1.Ø8595E-Ø6	.6328	3465	3
9.6Ø8Ø9E-Ø1	78Ø3Ø23	Ø.88ØØ9E-Ø3	.6328	3464	9
9.63434E-Ø1	78Ø5Ø41	Ø.82995E-Ø3	.6328	3464	9
9.49678E-Ø1	78Ø5Ø42	1.36646E-Ø6	.6328	3465	3
9.51282E-Ø1	78Ø6Ø21	1.Ø7224E-Ø6	.6328	3465	3
9.59383E-Ø1	78Ø6Ø22	Ø.99335E-Ø3	.6328	3464	9
9.61943E-Ø1	78Ø6Ø23	Ø.95848E-Ø3	.6328	3464	9
9.62947E-Ø1	78Ø6261	Ø.9959ØE-Ø3	.6328	3464	9
9.48Ø9ØE-Ø1	78Ø6264	1.2657ØE-Ø6	.6328	3465	3
9.62273E-Ø1	78Ø7Ø61	Ø.91824E-Ø3	.6328	3464	9
9.52719E-Ø1	78Ø7Ø62	1.28443E-Ø6	.6328	3465	3
9.6Ø248E-Ø1	78Ø9141	Ø.95642E-Ø3	.6328	3464	9
9.5Ø383E-Ø1	78Ø9142	1.12828E-Ø6	.6328	3465	3

-

```
BA
BASIC-5.15  73-11-13
>LOAD /S6/

>RUN
USE TO COPY 1ST COLUMN DATA FROM A 6 COL. POWER OR ENERGY
FILE SPECIFIED ACCORDING TO WAVELENGTH AND SCALE
TO SCRATCH DATA FILE /A/
TYPE IN 6 COLUMN INPUT FILE IN / /? /15/
NO. OF VALUES IN FILE =    26
TYPE 30 FOR ALL WAVELENGTHS; 1 FOR 1.06; 2 FOR .6471;
3 FOR .6328; 4 FOR .5145; 5 FOR .4880; 6 FOR .5309? 3
TYPE 30 FOR ALL CODE NOS. EXCEPT 99; 1 FOR CODE 1;
2 FOR CODE 2, ETC.?? 9
NO. OF SELECTED POINTS =  15
TO PRINT SELECTED POINTS TO TELETYPE, TYPE 1. ELSE 0? 1
 .961527
 .960122
 .960756
 .964984
 .96678
 .961246
 .963326
 .962951
 .960809
 .963434
 .959383
 .961943
 .962947
 .962273
 .960248
TO PRINT SELECTED POINTS TO FILE /A/, TYPE 1. ELSE 0? 1
NO. OF VALUES IN /A/=
 15
END

>QUIT

-
```

COPY /S6/ TO TEL

```
120 REM THIS IS PROGRAM STRIP6
130 PRINT "USE TO COPY 1ST COLUMN DATA FROM A 6 COL. POWER OR ENERGY"
140 PRINT "FILE SPECIFIED ACCORDING TO WAVELENGTH AND SCALE"
150 PRINT "TO SCRATCH DATA FILE /A/"
160 DIM A(100),Y(100),D(100),F(100)
170 DIM B(100),C(100),E(100)
180 PRINT "TYPE IN 6 COLUMN INPUT FILE IN / /";
190 INPUT Q$
200 GO TO 470
210 PRINT "TYPE 30 FOR ALL WAVELENGTHS; 1 FOR 1.06; 2 FOR .6471;"
220 PRINT "3 FOR .6328; 4 FOR .5145; 5 FOR .4880; 6 FOR .5309";
230 INPUT W9
240 PRINT "TYPE 30 FOR ALL CODE NOS. EXCEPT 99; 1 FOR CODE 1;"
250 PRINT "2 FOR CODE 2, ETC.?";
260 INPUT C9
270 IF W9<>30 THEN 290
280 GO TO 460
290 IF W9<>1 THEN 320
300 W9=1.06
310 GO TO 460
320 IF W9<>2 THEN 350
330 W9=0.6471
340 GO TO 460
350 IF W9<>3 THEN 380
360 W9=0.6328
370 GO TO 460
380 IF W9<>4 THEN 410
390 W9=0.5145
400 GO TO 460
410 IF W9<>5 THEN 432
420 W9=0.488
430 GO TO 460
432 IFW9<>6THEN440
434 W9=0.5309
436 GOTO460
440 PRINT "NO SUCH WAVELENGTH. TRY AGAIN"
450 GO TO 210
460 GO TO 650
470 OPEN Q$,INPUT
480 A$="CALIBRATION     RUN NO.  POW. OR ENER. WAVE. CAL. SCALE"
500FORI=1TO100
510 INPUTFILEA(I),B(I),C(I),D(I),E(I),F(I)
520IFEOF(9)=1THEN570
530 N=I
540 NEXT I
550 PRINT "OVER 100 POINTS"
560 STOP
570 PRINT "NO. OF VALUES IN FILE =",N
580:#.#####!!!! ######## #.#####!!!! ##.#### #### ##
620 N1=0
640 GO TO 210
650 FOR I=1 TO N
```

```
660 IF F(I)=99 THEN 730
670 IF W9=30 THEN 690
680 IF D(I)<>W9 THEN 730
690 IF C9=30 THEN 710
700 IF F(I)<>C9 THEN 730
710 N1=N1+1
720 Y(N1)=A(I)
730 NEXT I
740 PRINT "NO. OF SELECTED POINTS = "N1
741 PRINT"TO PRINT SELECTED POINTS TO TELETYPE, TYPE 1. ELSE 0";
742INPUTQ
743 IFQ=1THEN745
744 GOTO750
745 FORI=1TON1
746 PRINTY(I)
747 NEXTI
750PRINT"TO PRINT SELECTED POINTS TO FILE /A/, TYPE 1. ELSE 0";
755INPUT P
760 IF P=1 THEN 780
770 GO TO 850
780 OPEN/A/,OUTPUT
810 FOR I=1 TO N1
820 PRINTFILEY(I)
830 NEXT I
840 PRINT "NO. OF VALUES IN /A/= ",N1
850 PRINT "END"
860 END
```

APPENDIX E

Computer Program, /RU/, a RUNSUM Program to Detect Trends in Statistical Data

Program /RU/ is a RUNSUM program to detect trends in statistical data. The difference (residual) between each data point and the mean is compared with the standard deviation starting with the first point. As the program progresses point-by-point, a running total, RUNSUM, is kept according to the following rules.

1. A residual less than 1σ, add 0.
2. A " " " 2σ, " 1.
3. A " " " 3σ, " 2.
4. A " " " 4σ, " 3.
5. A " " " 5σ, " 4.
6. A " greater " 5σ, " 5.
7. When a residual changes sign, RUNSUM is set to 0, before proceeding to Steps 1 through 6.

When the RUNSUM value equals 5 or greater, a trend is indicated. A listing of /RU/ is shown in Appendix E, as well as a printout of a typical computer run on Program /RU/.

```
QUIT

-COPY /RU/ TO TEL

120 REM THIS IS PROGRAM RUNSUM
130 PRINT "A RUNSUM TEST PROGRAM TO DETECT TRENDS IN A SINGLE"
140 PRINT "COLUMN DATA FILE /A/"
145 OPEN/A/,INPUT
150 N=0
180 DIM S(200),T(200),Z(200)
190 FOR I=1 TO200
200 INPUT FILE Z(I)
210 IFEOF(9)=1THEN270
230 N=I
240 NEXT I
250 PRINT "OVER 200 POINTS"
260 STOP
270 FOR I=1 TO N
280 IF I=1 THEN 310
290 S(I)=S(I-1)+Z(I)
300 GO TO 320
310 S(I)=Z(I)
320 NEXT I
330 J=S(N)/N
340 FOR I=1 TO N
350 IF I=1 THEN 380
360 T(I)=T(I-1)+(Z(I)-J)↑2
370 GO TO 390
380 T(I)=(Z(I)-J)↑2
390 NEXT I
400 V3=SQR(T(N)/(N-1))
410 F$="AVERAGE:"
420 GOTO1110
430 PRINTF$,J
440 G$="STANDARD DEVIATION:"
450 PRINTG$,V3
460 H$="PERCENT STANDARD DEVIATION:"
470 PRINTH$,100*V3/J
480 V5=V3
490 K1=J
500 P=0
510 R=0
520:###  #.#####!!!! #.#####!!!!   ##       ##        $$$$
530 E$="  I      Z(I)       RESIDUAL   >SIGMA   RUNSUM   TREND"
540 PRINT
550 PRINT E$
560 FOR I=1 TO N
570 D=Z(I)-K1
580 IF Z(I)>K1 THEN 640
590 IF P=-1 THEN 620
```

```
600 R=0
610 P=-1
620 Q=K1-Z(I)
630 GO TO 680
640 IF P=1 THEN 670
650 R=0
660 P=1
670 Q=Z(I)-K1
680 IF Q>V5 THEN 710
690 G=0
700 GO TO 930
710 IF Q>2*V5 THEN 750
720 G=1
730 R=R+1
740 GO TO 930
750 IF Q>3*V5 THEN 790
760 G=2
770 R=R+2
780 GO TO 930
790 IF Q>4*V5 THEN 830
800 G=3
810 R=R+3
820 GO TO 930
830 IF Q>5*V5 THEN 870
840 G=4
850 R=R+4
860 GO TO 930
870 IF Q>6*V5 THEN 910
880 G=5
890 R=R+5
900 GO TO 930
910 G=6
920 R=R+6
930 IF R>4 THEN 970
940 T$="NO"
960 GO TO 990
970 T$="YES"
990 PRINT USING 520,I,Z(I),D,G,R,T$
1030 NEXT I
1040 GOTO1360
1110 A$="THE DATE IS "
1120 C$="THIS IS FILE "
1130 PRINT "TYPE IN FILE REMARKS"
1140 INPUT D$
1150 B$=DAT(X)
1180 PRINT
1200 PRINTA$,B$
1210 PRINT
1220 GOTO430
1360 PRINT "END"
1370 END
```

```
BA
BASIC-5.15   73-11-13
>LOAD /RU/

>RUN
A RUNSUM TEST PROGRAM TO DETECT TRENDS IN A SINGLE
COLUMN DATA FILE /A/
TYPE IN FILE REMARKS
? SIL15 AT 1 MILLIWATT AT .6328

THE DATE IS     79/01/08 16:40:33

AVERAGE:            .9621819
STANDARD DEVIATION:                .1966743E-02
PERCENT STANDARD DEVIATION:        .2044045

  I     Z(I)        RESIDUAL     >SIGMA   RUNSUM   TREND
  1  9.61527E-01  -.06549E-02      0        0        NO
  2  9.60122E-01  -.20599E-02      1        1        NO
  3  9.60756E-01  -.14259E-02      0        1        NO
  4  9.64984E-01  2.80207E-03      1        1        NO
  5  9.66780E-01  4.59807E-03      2        3        NO
  6  9.61246E-01  -.09359E-02      0        0        NO
  7  9.63326E-01  1.14407E-03      0        0        NO
  8  9.62951E-01  0.76907E-03      0        0        NO
  9  9.60809E-01  -.13729E-02      0        0        NO
 10  9.63434E-01  1.25207E-03      0        0        NO
 11  9.59383E-01  -.27989E-02      1        1        NO
 12  9.61943E-01  -.23893E-03      0        1        NO
 13  9.62947E-01  0.76507E-03      0        0        NO
 14  9.62273E-01  0.91067E-04      0        0        NO
 15  9.60248E-01  -.19339E-02      0        0        NO
END

>
```

APPENDIX F

Computer Program, /PL/, a Plotting Routine for a Single Column of Data

Appendix F contains a listing and a sample run of Plot Program /PL/.

COPY /PL/ TO TEL

```
120 REM THIS IS PROGRAM PLOT
130 PRINT "A PLOT OF PERCENT DIFFERENCE FROM THE AVERAGE OF A SINGLE"
140 PRINT "COLUMN OF DATA IN FILE /A/ "
150 N9=200
160 DIM T(N9),W(N9),P(N9),Q(N9),R(N9)
170 PRINT "TITLE OF PLOT"
180 INPUT L$
190 OPEN/A/,INPUT
200 FOR I=1TO200
210 INPUT FILEP(I)
220 IF EOF(9)=1THEN270
230 N=I
240 NEXT I
250 PRINT "OVER 200 POINTS"
260 STOP
270 S=0
280 FOR I=1 TO N
290 S=S+P(I)
300 NEXT I
310 A1=S/N
320 FOR I=1 TO N
330 R(I)=100*(P(I)-A1)/A1
340 NEXT I
350 A$="NO. OF POINTS:"
360 PRINT A$,N
370 B$="AVERAGE:"
390 PRINTB$,A1
400 FOR I=1 TO N
410 IF I=1 THEN 440
420 W(I)=W(I-1)+R(I)↑2
430 GO TO 450
440 W(I)=R(I)↑2
450 NEXT I
460 IF N=1 THEN 2290
470 V=SQR(W(N)/(N-1))
480 C$="STANDARD DEVIATION:"
490 V9=V*A1/100
500 PRINTC$,V9
510 D$="1 SIGMA IN PERCENT ="
520 PRINTD$,V
530 E$="3 SIGMA IN PERCENT ="
540 PRINTE$,3*V
550 FOR K=1 TO N
560 IF K>1 THEN 590
570 C=R(K)
580 GO TO 620
590 IF R(K)>C THEN 610
600 GO TO 620
610 C=R(K)
```

```
620 NEXT K
630 F$="Y MAX. PERCENT ="
640 PRINTF$,C
650 FOR K=1 TO N
660 IF K>1 THEN 690
670 D=R(K)
680 GO TO 720
690 IF R(K)<D THEN 710
700 GO TO 720
710 D=R(K)
720 NEXT K
730 G$="Y MIN. PERCENT ="
740 PRINTG$,D
750 PRINT "FOR INSTRUCTIONS, TYPE 1. ELSE 0?";
760 INPUT M1
770 IF M1=0 THEN 860
780 PRINT "SCALE IS DIVIDED INTO 6 LARGE INTERVALS WHICH ARE"
790 PRINT "SCALED IN PERCENT.  AN INPUT OF 1, GIVES A SCALE FROM"
800 PRINT "-3 SIGMA TO +3 SIGMA IN PERCENT.  AN INPUT OF 2 GIVES"
810 PRINT "A SCALE OF -N TO +N.  AN INPUT OF 3 GIVES A SCALE"
820 PRINT "FROM -N TO +M PERCENT."
830 PRINT "USE 1 FOR A SCALE IN TERMS OF SIGMA PERCENT"
840 PRINT "USE 2 FOR A SCALE IN TERMS OF -N TO +N PERCENT"
850 PRINT "USE 3 FOR A SCALE FROM -P TO +Q PERCENT"
860 PRINT "TYPE 1, 2, OR 3?";
870 INPUT M2
880 IF M2=1 THEN 930
890 IF M2=2 THEN 980
900 IF M2=3 THEN 1080
910 PRINT "INVALID NO. TRY AGAIN"
920 GO TO 830
930 PRINT "TYPE 3 FOR 3 SIGMA.  TYPE 6 FOR 6 SIGMA?";
940 INPUT M3
950 Q1=M3*V
960 Q0=-Q1
970 GO TO 1020
980 PRINT "TYPE .3,.6,.9,1.2, ETC. OR A MULTIPLE OF .3?";
990 INPUT M4
1000 Q1=M4
1010 Q0=-M4
1020 F1=Q0+Q1/3
1030 F2=Q0+2*Q1/3
1040 F3=Q0+3*Q1/3
1050 F4=Q0+4*Q1/3
1060 F5=Q0+5*Q1/3
1070 GO TO 1120
1080 PRINT "TYPE IN Y MIN. WITH MINUS SIGN";
1090 INPUT Q0
1100 PRINT "TYPE IN Y MAX. ?";
1110 INPUT Q1
1120 Q2=1
1130 Q3=N
1140 Q4=1
1150 Q5=(Q1-Q0)/60
1160 Q6=0
1170 IF N>10THEN 1176
1172 E=2
1174 GOTO1190
1176 IF N>16THEN1182
1178 E=1
```

```
1180 GOTO1190
1182 E=0
1190 PRINT"FOR PLOT MOVE PAPER AND TYPE 1. ELSE 0";
1200 INPUT E9
1210 IF E9=0 THEN 2300
1230 L9=0
1250 FOR X=Q2 TO Q3 STEP Q4
1260 Y=R(X)
1270 IF E=0 THEN 1370
1280 IF E=1 THEN 1340
1300 PRINT
1340 PRINT
1370 IF Q6=0THEN1790
1380 IF Q6=20 THEN 1450
1400 PRINT X;
1430 GO TO 1490
1450 PRINT X;
1480 Q6=10
1490 Q7=Q0+2*Q5
1500 Z=Q7+0.5*Q5
1510 IF Z<Y THEN 1700
1520 Q6=Q6+1
1530 IF Z-Y>2*Q5 THEN 1660
1540 IF Z-Y>Q5 THEN 1610
1560 PRINT "  +"
1570 GO TO 2090
1610 PRINT " +"
1620 GO TO 2090
1660 PRINT "+"
1670 GO TO 2090
1700 Q7=Q7+3*Q5
1720 PRINT "   ";
1730 GO TO 1500
1760 Q6=Q6+1
1770 GO TO 2090
1790 PRINT "       ",L$
1792 T$=DAT(X)
1794 PRINT"DATE IS ",T$
1800 GO TO 1830
1830 H$="PERCENT STANDARD DEVIATION: "
1850 PRINTH$,V
1860 GO TO 1890
1880 IF L9=1 THEN 1910
1890 PRINTB$,A1
1900 GO TO 1930
1930 I$="                PERCENT DIFFERENCE FROM AVERAGE"
1950 PRINT I$
1960 GO TO 1980
1980:###.## ####.##   ####.##   ####.##   ####.##   ####.##   ####.##
2000 PRINT USING 1980,Q0,F1,F2,F3,F4,F5,Q1
2010 GO TO 2030
2030 J$=" I.........I.........I.........I.........I.........I.........I"
 2050 PRINT J$
2080 GO TO 1450
2090 NEXT X
2100 GOTO2300
2290 PRINT"ONLY O VALUE IN FILE /A/ "
2300 PRINT"END"
2310 END
```

```
 BA
BASIC-5.15  73-11-13
>LOAD /PL/

>RUN
A PLOT OF PERCENT DIFFERENCE FROM THE AVERAGE OF A SINGLE
COLUMN OF DATA IN FILE /A/
TITLE OF PLOT
? SIL15 AT 1 MILLIWATT AT .6328
NO. OF POINTS:  15
AVERAGE:            .9621819
STANDARD DEVIATION:             .1966743E-02
1 SIGMA IN PERCENT =            .2044045
3 SIGMA IN PERCENT =            .6132136
Y MAX. PERCENT =                .4778791
Y MIN. PERCENT =               -.2908944
FOR INSTRUCTIONS, TYPE 1. ELSE 0?? 1
SCALE IS DIVIDED INTO 6 LARGE INTERVALS WHICH ARE
SCALED IN PERCENT.  AN INPUT OF 1, GIVES A SCALE FROM
-3 SIGMA TO +3 SIGMA IN PERCENT.  AN INPUT OF 2 GIVES
A SCALE OF -N TO +N.  AN INPUT OF 3 GIVES A SCALE
FROM -N TO +M PERCENT.
USE 1 FOR A SCALE IN TERMS OF SIGMA PERCENT
USE 2 FOR A SCALE IN TERMS OF -N TO +N PERCENT
USE 3 FOR A SCALE FROM -P TO +Q PERCENT
TYPE 1, 2, OR 3?? 2
TYPE .3,.6,.9,1.2, ETC. OR A MULTIPLE OF .3?? .6
FOR PLOT MOVE PAPER AND TYPE 1. ELSE 0? 1
```

```
              SIL15 AT 1 MILLIWATT AT .6328
DATE IS       79/01/09 08:14:27
PERCENT STANDARD DEVIATION:     .2044045
AVERAGE:          .9621819
            PERCENT DIFFERENCE FROM AVERAGE
 -.60    -.40      -.20      0.00       .20       .40       .60
I.........I.........I.........I.........I.........I.........I
1                           +

2                   +

3                       +

4                                             +

5                                                      +

6                         +

7                                    +

8                                  +

9                       +

10                                     +

11               +

12                             +

13                                  +

14                              +

15                    +
END

>
```

APPENDIX G

Computer Program /ASTM/, an ASTM Program to Provide 2 Control Charts

Appendix G contains a listing and a sample run of Program /ASTM/.

COPY /ASTM/ TO TEL

```
10 PRINT"TYPE 1 TO SKIP DIRECTIONS. ELSE 0";
20 INPUT A9
30 IFA9=1THEN150
40 PRINT"THIS PROGRAM PROVIDES 2 CONTROL CHARTS; ONE FOR INDIVIDUALS, X";
50 PRINT"AND ONE FOR MOVING RANGE, R, OF TWO OBSERVATIONS. SEE ASTM"
60 PRINT"MANUAL ON QUALITY CONTROL OF MATERIALS, PAGE 105, FOR DETAILS."
70 PRINT"CONTROL CHART #1 DISPLAYS INDIVIDUAL RESIDUAL READINGS"
80 PRINT"IN PERCENT WITH CONTROL LIMITS VERSUS RUN NO. "
90 PRINT"CONTROL CHART #2 DISPLAYS MOVING RANGE VALUES WITH"
92 PRINT"CONTROL LIMITS VERSUS RUN NO."
100 PRINT"CONTROL LIMITS SHOULD BE BASED ON AT LEAST 15 INDIVIDUAL"
110 PRINT"MEASUREMENTS. THIS PROGRAM NEEDS AT LEAST 10 POINTS TO RUN."
120 PRINT"SINGLE COLUMN INPUT DATA MUST BE IN FILE /A/ BEFORE RUNNING."
150 N9=200
160 DIM P(N9),R(N9),G(N9)
170 PRINT " TITLE OF PLOT"
180 INPUT L$
190 OPEN/A/,INPUT
200 FOR I=1TO200
210 INPUT FILEP(I)
220 IF EOF(9)=1THEN270
230 N=I
240 NEXT I
250 PRINT "OVER 200 POINTS"
260 STOP
270 S=0
280 FOR I=1 TO N
290 S=S+P(I)
300 NEXT I
310 A1=S/N
320 FOR I=1 TO N
330 R(I)=100*(P(I)-A1)/A1
340 NEXT I
350 A$="NO. OF POINTS:"
360 PRINT A$,N
362 IFN>9THEN365
363 PRINT"PROGRAM NEEDS AT LEAST 10 POINTS TO RUN."
364 STOP
365 IFN>14 THEN370
366 PRINT"PROGRAM SHOULD HAVE AT LEAST 15 POINTS TO SET GOOD CONTROL LI
370 B$="AVERAGE:"
390 PRINTB$,A1
420 T=0
422 FORI=2TON
424 G(I)=ABS(P(I)-P(I-1))
426 T=T+G(I)
427 NEXTI
428 R=T/(N-1)
429 R5=100*R/A1
430 U=2.66*R
440 H=3.267*R
800 PRINT"TO PLOT #1, TYPE 1. TO PLOT #2, TYPE 2. ELSE 0";
810 INPUTA5
815 IFA5=0THEN2300
816 FOR I=1TO10
817 PRINT
```

```
818 NEXTI
820 IFA5=1THEN840
825 IFA5=2THEN850
830 PRINT"INVALID NO. TRY AGAIN."
835 GOTO800
840 M2=2
845 GOTO890
850 M2=3
860 GOTO890
890 IF M2=2 THEN 980
900 IF M2=3 THEN 1080
980 P1=100*U/A1
990 M4=3*P1/2
1000 Q1=M4
1005 Q9=Q1
1010 Q0=-M4
1020 F1=Q0+Q1/3
1030 F2=Q0+2*Q1/3
1040 F3=Q0+3*Q1/3
1050 F4=Q0+4*Q1/3
1060 F5=Q0+5*Q1/3
1070 GO TO 1120
1080 Q0=0
1100 Q1=3*H/2
1111 F1=100*Q1/6
1112 F2=100*Q1/3
1113 F3=100*Q1/2
1114 F4=200*Q1/3
1115 F5=500*Q1/6
1116 Q9=100*Q1
1120 IFA5=1THEN1123
1121 IFA5=2THEN1126
1122 STOP
1123 Q2=1
1124 C9=1
1125 GOTO1130
1126 Q2=2
1127 C9=2
1130 Q3=N
1140 Q4=1
1150 Q5=(Q1-Q0)/60
1160 Q6=0
1176 IF N>16THEN1182
1178 E=1
1180 GOTO1250
1182 E=0
1250 FOR X=Q2 TO Q3 STEP Q4
1252 IFA5<>1THEN1260
1254 Y=R(X)
1256 GOTO1270
1260 Y=G(X)
1270 IF E=0 THEN 1370
1280 IF E=1 THEN 1340
1300 PRINT
1340 PRINT
1370 IF Q6=0THEN1790
1380 IF Q6=20 THEN 1450
1450 PRINT " ";
1480 Q6=10
```

```
1490 Q7=Q0+2*Q5
1500 Z=Q7+0.5*Q5
1510 IF Z<Y THEN 1700
1520 Q6=Q6+1
1530 IF Z-Y>2*Q5 THEN 1645
1540 IF Z-Y>Q5 THEN 1595
1545 IFC9<6THEN1560
1550 PRINT "  !"
1555 GOTO2090
1560 PRINT "  +"
1570 GO TO 2090
1595 IFC9<6THEN1610
1600 PRINT " !"
1605 GOTO2090
1610 PRINT " +"
1620 GO TO 2090
1645 IFC9<6THEN1660
1650 PRINT"!"
1655 GOTO2090
1660 PRINT "+"
1670 GO TO 2090
1700 Q7=Q7+3*Q5
1720 PRINT "   ";
1730 GO TO 1500
1760 Q6=Q6+1
1770 GO TO 2090
1790 PRINT "      ",L$
1792 T$=DAT(X)
1794 PRINT"DATE IS ",T$
1800 GO TO 1830
1830 H$="AVERAGE RANGE IN PERCENT"
1850 PRINTH$,R5
1860 IFA5=2THEN1900
1890 PRINTB$,A1
1900 IFA5=1THEN1930
1910 IFA5=2THEN1940
1930 I$="                PERCENT DIFFERENCE FROM AVERAGE"
1935 GOTO1950
1940 I$="     MOVING RANGE, R"
1950 PRINT I$
1960 GO TO 1980
1980:###.## ####.##   ####.##   ####.##   ####.##   ####.##   ####.##
2000 PRINT USING 1980,Q0,F1,F2,F3,F4,F5,Q9
2010 GO TO 2030
2030 J$=" I.........I.........I.........I.........I.........I.........I"
2050 PRINT J$
2080 GO TO 1450
2090 C9=C9+1
2095 IFC9<6THEN2290
2200 IFA5<>1THEN2250
2205 IFC9=6THEN2215
2210 IFC9=7THEN2225
2212 IFC9=8THEN2280
2215 Y=-P1
2220 GOTO1270
```

```
2225 Y=PI
2235 GOTO1270
2250 IFC9=6THEN2260
2255 IFC9=7THEN2265
2257 IFC9=8THEN2280
2260 Y=0
2262 GOTO1270
2265 Y=H
2275 GOTO1270
2280 C9=1
2290  NEXTX
2292 FORI=1TO20
2293 PRINT
2294 NEXTI
2295 GOTO800
2300 PRINT"END"
2310 END
```

```
BA
BASIC-5.15  73-11-13
>LOAD /ASTM/

>RUN
TYPE 1 TO SKIP DIRECTIONS. ELSE Ø? Ø
THIS PROGRAM PROVIDES 2 CONTROL CHARTS; ONE FOR INDIVIDUALS, X,
AND ONE FOR MOVING RANGE, R, OF TWO OBSERVATIONS. SEE ASTM
MANUAL ON QUALITY CONTROL OF MATERIALS, PAGE 1Ø5, FOR DETAILS.
CONTROL CHART #1 DISPLAYS INDIVIDUAL RESIDUAL READINGS
IN PERCENT WITH CONTROL LIMITS VERSUS RUN NO.
CONTROL CHART #2 DISPLAYS MOVING RANGE VALUES WITH
CONTROL LIMITS VERSUS RUN NO.
CONTROL LIMITS SHOULD BE BASED ON AT LEAST 15 INDIVIDUAL
MEASUREMENTS. THIS PROGRAM NEEDS AT LEAST 1Ø POINTS TO RUN.
SINGLE COLUMN INPUT DATA MUST BE IN FILE /A/ BEFORE RUNNING.
TITLE OF PLOT
? SIL15 AT 1 MILLIWATT AT .6328
NO. OF POINTS:  15
AVERAGE:          .9621819
TO PLOT #1, TYPE 1. TO PLOT #2, TYPE 2. ELSE Ø? 1
```

SILI5 AT 1 MILLIWATT AT .6328

DATE IS 79/01/09 08:50:36

AVERAGE RANGE IN PERCENT .231119

AVERAGE: .9621819

PERCENT DIFFERENCE FROM AVERAGE

```
TO PLOT #1, TYPE 1. TO PLOT #2, TYPE 2. ELSE Ø? 2




               SIL15 AT 1 MILLIWATT AT .6328
DATE IS        79/Ø1/Ø9 Ø8:52:45
AVERAGE RANGE IN PERCENT       .231119
    MOVING RANGE, R
  Ø.ØØ      .18       .36       .54       .73       .91      1.Ø9
 I.........I.........I.........I.........I.........I.........I
         +

    +

                        +

           +

 !

                                         !

                               +

            +

   +

             +

               +

 !

                                         !

                       +

               +

        +

      +

            +

 !

                                         !
```

APPENDIX H

Computer Program, /D2/, a Statistical Program to Provide Average, Standard Deviation 90%, 95%, and 99% Confidence Interval Data

Appendix H contains a listing and a sample run of Program /D2/.

```
COPY /D2/ TO TEL

120 REM THIS IS PROGRAM DEV2
130 REM LAST REVISED ON JAN. 9, 1978
140 PRINT "A PROGRAM TO GIVE AVERAGE, STANDARD DEVIATION, 90%, 95% AND"
150 PRINT "99% CONFIDENCE INTERVALS FOR A SINGLE COLUMN OF DATA"
160 PRINT "IN FILE /A/"
170 DIM X(150),K(150),S(150),H(150)
175 DIMY(150)
180 OPEN/A/,INPUT
190 FORI=1TO150
200 INPUTFILEX(I)
210 IFEOF(9)=1THEN260
220 N1=I
230 NEXT I
240 PRINT "OVER 150 POINTS IN FILE /A/"
250 STOP
260 A$="NO. OF POINTS IN /A/ ="
261 PRINT"FOR STATISTICS ON RECIPROCALS, TYPE 1. ELSE 0";
262 INPUTA9
263 IFA9=1THEN265
264 GOTO280
265 PRINT"VALUES IN /X/   RECIPROCALS"
266 FOR I=1TON1
267 Y(I)=X(I)
268 X(I)=1/Y(I)
269 PRINT Y(I),X(I)
270 NEXTI
280 IF N1<>1 THEN 310
290 PRINT "ZERO DEGREES OF FREEDOM"
300 STOP
310 B$="FIRST VALUE IN FILE /A/ = "
330 C$="LAST VALUE IN FILE /A/ = "
350 FOR I=1 TO N1
360 IF I=1 THEN 390
370 S(I)=S(I-1)+X(I)
380 GO TO 400
390 S(I)=X(I)
400 NEXT I
410 J=S(N1)/N1
440 J0=J
450 D$="AVERAGE = "
470 FOR I=1 TO N1
480 IF I=1 THEN 510
490 H(I)=H(I-1)+(X(I)-J)↑2
500 GO TO 520
510 H(I)=(X(I)-J)↑2
520 NEXT I
530 R=SQR(H(N1)/(N1-1))
560 R0=R
570 E$="STANDARD DEVIATION = "
590 F$="PERCENT STANDARD DEVIATION = "
592 T$="PERCENT STANDARD ERROR = "
594 U$="EST. OF STD. ERROR = SQR ROOT (STD. DEV SQUARED/NO. OF MEAS.)"
596 V$="SEE NBS SPECIAL PUB. 300, VOL. 1, PAGE 71-1203"
```

```
600 P1=100*R/J
630 P0=P1
640 P9=SQR(P0↑2/N1)
660 V=N1-1
670 GOSUB 2070
700 S0=T0
710 GOSUB 2120
740 M0=T5
750 GOSUB 2170
780 L0=T9
790 F=100*R/(SQR(N1)*J)
800 N$="DEGREES OF FREEDOM = "
820 G$=".95% T VALUE   .975% T VALUE    .995% T VALUE"
860 C0=T0*F
900 H$="90 % OF THE TIME THE ABOVE AVERAGE WILL LIE"
910 I$="95 % OF THE TIME THE ABOVE AVERAGE WILL LIE"
920 J$="99 % OF THE TIME THE ABOVE AVERAGE WILL LIE"
930 K$="WITHIN A + OR - PERCENTAGE RANGE OF "
940 C5=T5*F
980 C9=T9*F
1620 Q$="DATE : "
1630 R$=DAT(X)
1640 PRINTQ$,R$
1650 PRINT "TYPE IN REMARKS FOR THIS RUN"
1660 INPUT S$
1730 PRINT
1740 FOR I=1 TO N1
1750 PRINTX(I)
1760 NEXT I
1770 PRINT
1780 PRINT A$,N1
1790 PRINTB$,X(1)
1800 PRINTC$,X(N1)
1810 PRINT
1820 PRINTD$,J0
1830 PRINTE$,R0
1840 PRINTF$,P0
1850 PRINT
1852PRINTU$
1854 PRINTV$
1856 PRINTT$,P9
1858 PRINT
1860 PRINTN$,V
1870 PRINTG$
1880 PRINTS0,M0,L0
1890 PRINT
1900 PRINTH$
1910 PRINTK$,C0
1920 PRINT
1930 PRINTI$
1940 PRINTK$,C5
1950 PRINT
1960 PRINTJ$
1970 PRINTK$,C9
1980 PRINT
2060 GO TO 2250
```

```
2070 IF V>4 THEN 2100
2080 T0=15.016+V*(-12.1829+V*(3.8945-0.4135*V))
2090 RETURN
2100 T0=V/(-0.559925368278+0.60784409253*V)+6.0E-4
2110 RETURN
2120 IF V>4 THEN 2150
2130 T5=34.958+V*(-31.3655+V*(10.208-1.0945*V))
2140 RETURN
2150 T5=V/(-0.6115993191+0.5101102332*V)+6.0E-4
2160 RETURN
2170 IF V>1 THEN 2200
2180 T9=63.657
2190 RETURN
2200 IF V>5 THEN 2230
2210 T9=35.362+V*(-20.6568+V*(4.6965-0.36367*V))
2220 RETURN
2230 T9=V/(-0.7155721779161+0.38749027018 4*V)+6.0E-4
2240 RETURN
2250 PRINT"DONE"
2260 END
```

```
-BA
BASIC-5.15  73-11-13
>LOAD /D2/

>RUN
A PROGRAM TO GIVE AVERAGE, STANDARD DEVIATION, 90%, 95% AND
99% CONFIDENCE INTERVALS FOR A SINGLE COLUMN OF DATA
IN FILE /A/
FOR STATISTICS ON RECIPROCALS, TYPE 1. ELSE 0? 0
DATE :           79/01/09 09:00:54
TYPE IN REMARKS FOR THIS RUN
? SIL15 AT 1 MILLIWATT AT .6328

 .961527
 .960122
 .960756
 .964984
 .96678
 .961246
 .963326
 .962951
 .960809
 .963434
 .959383
 .961943
 .962947
 .962273
 .960248

NO. OF POINTS IN /A/ =          15
FIRST VALUE IN FILE /A/ =       .961527
LAST VALUE IN FILE /A/ =        .960248

AVERAGE =         .9621819
STANDARD DEVIATION =            .1966743E-02
PERCENT STANDARD DEVIATION =    .2044045

EST. OF STD. ERROR = SQR ROOT (STD. DEV SQUARED/NO. OF MEAS.)
SEE NBS SPECIAL PUB. 300, VOL. 1, PAGE 71-1203
PERCENT STANDARD ERROR =        .5277702E-01

DEGREES OF FREEDOM =            14
.95% T VALUE    .975% T VALUE    .995% T VALUE
 1.76163         2.144569        2.973446

90 % OF THE TIME THE ABOVE AVERAGE WILL LIE
WITHIN A + OR - PERCENTAGE RANGE OF              .0929736

95 % OF THE TIME THE ABOVE AVERAGE WILL LIE
WITHIN A + OR - PERCENTAGE RANGE OF              .113184

99 % OF THE TIME THE ABOVE AVERAGE WILL LIE
WITHIN A + OR - PERCENTAGE RANGE OF              .1569296

DONE

>QUIT

-
```

APPENDIX I

Computer Program, /S7B/, Used to Separate Beamsplitter Ratios for Different Code Numbers

Appendix I contains a listing of Program, /S7B/, that is used to separate and print to Scratch File /A/ those beamsplitter ratios of interest.

COPY /S7B/ TO TEL

```
12Ø REM THIS IS PROGRAM STRIP7B
13Ø PRINT "USE TO COPY ALL BEAM SPLITTER RATIOS OR ACCORDING TO CODE"
14Ø PRINT "NO. FROM A 7 COLUMN BEAM SPLITTER CONTROL FILE FROM "
15Ø PRINT "SPECFIED FILE TO SCRATCH DATA FILE /A/"
16Ø N=15Ø
17Ø DIM A(N),B(N),C(N),D(N),E(N)
18Ø DIM F(N),G(N),Y(N)
19Ø N2=Ø
2ØØ PRINT "TYPE IN 7 COLUMN BEAM SPLITTER FILE IN //";
21Ø INPUT Q$
22Ø OPENQ$,INPUT
23Ø A$="TOTAL NO. OF POINTS IN FILE ="
24Ø B$="NO. OF POINTS IN FILE /A/ ="
25Ø FOR I=1TO15Ø
26Ø INPUT FILEA(I),B(I),C(I),D(I),E(I),F(I),G(I)
27Ø IF EOF(9)=1THEN32Ø
28Ø N=I
29Ø NEXT I
3ØØ PRINT "OVER 15Ø POINTS"
31Ø STOP
32Ø:##.##### ### ######## ##.#### #### #### ##.#####
36Ø PRINTA$,N
37Ø PRINT
38Ø N1=N
43Ø PRINT "TYPE CODE NUMBER.  OTHERWISE TYPE 999 FOR ALL CODE NOS.";
44Ø INPUT R9
48Ø FOR I=1 TO N1
49Ø IF R9=999 THEN 51Ø
5ØØ IF B(I)<>R9 THEN 54Ø
51Ø N2=N2+1
52Ø Y(N2)=A(I)
54Ø NEXT I
55Ø PRINT"NO. OF SELECTED POINTS ="N2
56Ø PRINT"TO PRINT SELECTED POINTS TO TELETYPE, TYPE 1. ELSE Ø";
57Ø INPUTQ
58Ø IFQ=1THEN6ØØ
59Ø GOTO63Ø
6ØØ FORI=1TON2
61Ø PRINTY(I)
62Ø NEXTI
63Ø PRINT"TO PRINT SELECTED POINTS TO FILE /A/, TYPE 1. ELSE Ø";
64Ø INPUTP
65Ø IFP=1THEN67Ø
66Ø GOTO999
67Ø OPEN/A/,OUTPUT
68Ø FORI=1TON2
69Ø PRINTFILEY(I)
7ØØ NEXTI
71Ø PRINTB$,N2
999 PRINT"END"
1ØØØ END

-
```

APPENDIX J

Two Typical Electrical Clibration Files, /444/ and /44CC/, as Stored on the Computer

Two typical electrical calibration files are shown in Appendix J. File /444/ is a two-column file, where the first column has corrected rise values and the second column has corresponding values of energy (joules). Such a file is kept for each calorimeter for each scale that is maintained.

The /44CC/ file is for all the electrical calibration runs for C44, regardless of scale. Going from left to right, the values are energy in joules, calibration coefficient in joules-per-millivolt, resistance of the calibrating heater, cooling constant, time of energy input, residual data fit in percent, and run number.

COPY /44CC/ TO TEL

6.0405	4.87637	100.8570	0.001119	272	1.11	6027073
6.0409	4.87570	100.8500	0.001117	272	0.68	6027073
0.9676	4.86866	100.8410	0.001108	208	0.66	6028073
8.5957	4.86600	100.8420	0.001112	112	0.20	6029073
4.3871	4.87273	100.8550	0.001112	240	0.83	7002073
9.8613	4.87193	100.8420	0.001106	288	0.39	7003073
4.3090	4.87005	100.8360	0.001110	88	0.78	7009073
0.0575	4.87187	100.8340	0.001045	12	2.53	7010073
0.0575	4.91141	100.8370	0.001081	12	2.44	7010073
0.0575	4.88487	100.8370	0.001084	12	2.47	7010073
0.0575	4.85522	100.8360	0.001120	12	2.25	7010073
0.0575	4.87067	100.8340	0.001149	12	3.04	7010073
0.0575	4.91235	100.8340	0.000905	12	1.90	7010073
0.0575	4.90996	100.8330	0.001061	12	2.57	7010073
4.8760	4.86819	100.8340	0.001099	92	0.92	7019073
3.0337	4.86694	100.8330	0.001099	72	0.44	8023073
1.5015	4.86926	100.8260	0.001104	92	0.31	9011073
0.3459	4.87471	100.8430	0.001087	204	1.21	11011073
1.8680	4.86784	100.8440	0.001101	204	0.31	11011073
6.9985	4.86004	100.8500	0.001112	248	0.28	11030073
8.0690	4.86678	100.8460	0.001134	268	0.28	12007073
2.0370	4.87156	100.8320	0.001139	36	0.34	1007074
4.0575	4.87440	100.8330	0.001104	140	1.70	1031074
7.6321	4.86027	100.8410	0.001111	148	0.21	1031074
0.3358	4.88554	100.8510	0.001131	148	0.94	2014074
2.1932	4.87057	100.8430	0.001115	268	0.31	2014074
0.6376	4.88782	100.8590	0.001096	228	0.32	3020074
2.1237	4.86730	100.8590	0.001118	152	0.36	3020074
0.9258	4.86850	100.8600	0.001090	172	0.34	4016074
0.6199	4.86592	100.8600	0.001160	148	1.60	4016074
0.7568	4.86813	100.8460	0.001103	76	1.06	5020074
2.8025	4.86884	100.8450	0.001117	176	0.27	5020074
20.8002	4.87040	100.7780	0.001172	40	0.51	6010074
22.8723	4.87002	100.7790	0.001182	44	0.44	6010074
0.2516	4.87167	100.7890	0.001141	84	1.47	6011074
0.2516	4.87797	100.7890	0.001102	84	0.70	6011074
0.7057	4.87454	100.7880	0.001112	208	1.03	6011074
0.7200	4.89363	100.7970	0.001118	164	0.35	7025074
1.9624	4.87250	100.8090	0.001139	164	0.34	7025074
2.6368	4.86950	100.8630	0.001122	220	0.30	8027074
2.6010	4.86831	100.8530	0.001127	32	0.30	8027074
24.3503	4.85846	100.8360	0.001132	300	0.26	9027074
3.2122	4.87003	100.8520	0.001130	300	0.64	11007074
31.6862	4.85689	100.8560	0.001150	250	0.43	11007074
2.7649	4.86313	100.8450	0.001150	300	0.41	1015075
21.6656	4.86227	100.8460	0.001177	180	0.20	1020075
21.6014	4.85870	100.8390	0.001128	180	0.26	1024075
2.7713	4.86432	100.8430	0.001116	300	0.33	1028075
0.1051	4.89826	100.7980	0.001228	300	1.18	8005075
23.1403	4.86321	100.8099	0.001149	220	0.35	8005075
25.1744	4.86693	100.7863	0.001181	20	0.41	8011075
0.2856	4.87751	100.7774	0.001123	2	2.00	8012075
0.3213	4.86739	100.8511	0.001116	300	0.00	1016076

3.0039	4.87401	100.8470	0.001171	300	0.00	1019076
4.2351	4.87006	100.8506	0.001160	40	0.00	1019076
23.2933	4.86271	100.8506	0.001179	220	0.00	1019076
0.3213	4.85913	100.8541	0.001108	300	0.01	7608131
3.0043	4.86517	100.8671	0.001123	300	0.00	7608132
4.2351	4.86794	100.8568	0.001129	40	0.00	7608133
23.2926	4.85935	100.8475	0.001138	220	0.01	7608134
0.3213	4.86283	100.8446	0.001066	300	0.01	7711081
3.0043	4.86180	100.8437	0.001083	300	0.01	7711082
21.1637	4.85518	100.8278	0.001097	200	0.01	7711083

COPY /444/ TO TEL

198.743	0.967611
900.345	4.38715
884.802	4.30903
1001.61	4.87603
623.318	3.03365
308.361	1.50149
383.745	1.86801
418.135	2.03697
832.416	4.05753
68.7373	0.335819
450.298	2.19321
130.44	0.637567
436.327	2.12373
190.161	0.925799
575.605	2.80253
147.137	0.720035
402.746	1.96238
541.485	2.63676
534.266	2.60097
659.583	3.21219
568.536	2.76487
569.731	2.77135
616.301	3.00386
869.624	4.23512
617.519	3.00434
870.003	4.23512
617.9332	3.004265

-

APPENDIX K

Computer File, /YT/, a Typical Beamsplitter File for a Given Laser Wavelength

A typical beamsplitter file, /YT/, is shown in Appendix K. From left to right, the columns are beamsplitter ratio, code number, run number, wavelength, low-level calorimeter, high-level calorimeter, and energy (joules) to high-level calorimeter. Such a file exists for each beamsplitter and for each wavelength being maintained. Also shown is a run of Program /S7B/, which can be used to separate and print first column beamsplitter ratio to Scratch File /A/. In addition, a plot of all the beamsplitter values is shown in a computer run of /PL/.

COPY /YT/ TO TEL

11.64580	12,	76030501	1.0600	3464	3413	12.84050
11.64710	12	76030502	1.0600	3464	3413	27.18790
11.64140	10	7603503	1.0600	3464	3413	21.86820
11.66460	10	7603504	1.0600	3464	3413	20.69950
11.64220	10	7603082	1.0600	3464	3413	15.86590
11.64660	10	7603083	1.0600	3464	3413	16.25350
11.65060	12	7603151	1.0600	3464	3413	21.21800
11.64770	12	7603152	1.0600	3464	3413	20.80770
11.64770	12	7604021	1.0600	3464	3413	10.90980
11.64920	12	7604022	1.0600	3464	3413	13.88940
11.66210	9	7604281	1.0600	3414	3463	13.21360
11.66290	9	7604282	1.0600	3414	3463	13.29790
11.66840	9	7604283	1.0600	3414	3463	13.47280
11.66470	9	7604284	1.0600	3414	3463	13.26110
11.64023	15	7608091	1.0600	3414	3443	18.35203
11.63604	15	7608093	1.0600	3414	3443	16.44810
11.66714	17	7608112	1.0600	3414	3463	15.52333
11.65580	17	7608114	1.0600	3414	3463	16.76773
11.67485	16	7608161	1.0600	3444	3413	13.77973
11.70825	16	7608163	1.0600	3444	3413	23.40371
11.68597	19	7608172	1.0600	3444	3463	18.85713
11.65184	19	7608174	1.0600	3444	3463	19.84209
11.66475	20	7608255	1.0600	3464	3443	19.04584
11.62801	20	7608257	1.0600	3464	3443	17.80859
11.64934	18	7608262	1.0600	3464	3413	17.44419
11.64213	18	7608264	1.0600	3464	3413	22.51588
11.66588	8	7609241	1.0600	3464	3413	15.12832
11.66757	8	7610073	1.0600	3464	3413	18.52174
11.67301	8	7610262	1.0600	3464	3413	16.24837
11.66211	8	7611221	1.0600	3464	3413	16.72545
11.66426	8	7612301	1.0600	3464	3413	12.33115
11.65047	8	7701262	1.0600	3464	3413	10.68418
11.61917	10	7703181	1.0600	3464	3413	20.07786
11.69477	9	7801091	1.0600	3414	3463	16.91940
11.69418	9	7802072	1.0600	3414	3463	22.47015
11.69004	9	7803131	1.0600	3414	3463	22.51866
11.66568	9	7804182	1.0600	3414	3463	7.43130
11.68531	9	7804183	1.0600	3414	3463	22.04359
11.68272	9	7805163	1.0600	3414	3463	15.53490
11.69516	9	7806052	1.0600	3414	3463	23.16932
11.69019	9	7810041	1.0600	3414	3463	21.93694

```
>RUN
USE TO COPY ALL BEAM SPLITTER RATIOS OR ACCORDING TO CODE
NO. FROM A 7 COLUMN BEAM SPLITTER CONTROL FILE FROM
SPECFIED FILE TO SCRATCH DATA FILE /A/
TYPE IN 7 COLUMN BEAM SPLITTER FILE IN //? /YT/
TOTAL NO. OF POINTS IN FILE =
 41

TYPE CODE NUMBER.  OTHERWISE TYPE 999 FOR ALL CODE NOS.? 999
NO. OF SELECTED POINTS =
 41
TO PRINT SELECTED POINTS TO TELETYPE, TYPE 1. ELSE Ø? 1
 11.6458
 11.6471
 11.6414
 11.6646
 11.6422
 11.6466
 11.65Ø6
 11.6477
 11.6477
 11.6492
 11.6621
 11.6629
 11.6684
 11.6647
 11.64Ø23
 11.636Ø4
 11.66714
 11.6558
 11.67485
 11.7Ø825
 11.68597
 11.65184
 11.66475
 11.628Ø1
 11.64934
 11.64213
 11.66588
 11.66757
 11.673Ø1
 11.66211
 11.66426
 11.65Ø47
 11.61917
 11.69477
 11.69418
 11.69ØØ4
 11.66568
 11.68531
 11.68272
 11.69516
 11.69Ø19
 TO PRINT SELECTED POINTS TO FILE /A/, TYPE 1. ELSE Ø? 1
 NO. OF POINTS IN FILE /A/ =
  41
 END

 >
```

```
QUIT

-BA
BASIC-5.15  73-11-13
>LOAD /PL/

>RUN
A PLOT OF PERCENT DIFFERENCE FROM THE AVERAGE OF A SINGLE
COLUMN OF DATA IN FILE /A/
TITLE OF PLOT
? S72 BEAM SPLITTER RATIOS AT 1.Ø64
NO. OF POINTS:  41
AVERAGE:         11.662Ø9
STANDARD DEVIATION:              .2ØØ7786E-Ø1
1 SIGMA IN PERCENT =             .1721635
3 SIGMA IN PERCENT =             .51649Ø4
Y MAX. PERCENT =                 .3957746
Y MIN. PERCENT =                -.368Ø676
FOR INSTRUCTIONS, TYPE 1. ELSE Ø?? 1
SCALE IS DIVIDED INTO 6 LARGE INTERVALS WHICH ARE
SCALED IN PERCENT.  AN INPUT OF 1, GIVES A SCALE FROM
-3 SIGMA TO +3 SIGMA IN PERCENT.  AN INPUT OF 2 GIVES
A SCALE OF -N TO +N.  AN INPUT OF 3 GIVES A SCALE
FROM -N TO +M PERCENT.
USE 1 FOR A SCALE IN TERMS OF SIGMA PERCENT
USE 2 FOR A SCALE IN TERMS OF -N TO +N PERCENT
USE 3 FOR A SCALE FROM -P TO +Q PERCENT
TYPE 1, 2, OR 3?? 2
TYPE .3,.6,.9,1.2, ETC. OR A MULTIPLE OF .3?? .45
FOR PLOT MOVE PAPER AND TYPE 1. ELSE Ø? 1
```

```
S72 BEAM SPLITTER RATIOS AT 1.064
DATE IS          79/01/09 09:15:16
PERCENT STANDARD DEVIATION:     .1721635
AVERAGE:         11.66209
             PERCENT DIFFERENCE FROM AVERAGE
  -.45    -.30      -.15      -.00       .15       .30       .45
 I.........I.........I.........I.........I.........I.........I
 1                     +
 2                     +
 3                  +
 4                               +
 5                   +
 6                     +
 7                       +
 8                      +
 9                      +
 10                       +
 11                              +
 12                              +
 13                                  +
 14                               +
 15                  +
 16               +
 17                                 +
 18                          +
 19                                     +
 20                                                        +
 21                                            +
 22                        +
 23                                +
 24           +
 25                       +
 26                   +
 27                                +
 28                                 +
 29                                    +
 30                              +
 31                               +
 32                       +
 33     +
 34                                                 +
 35                                                +
 36                                              +
 37                                +
 38                                           +
 39                                          +
 40                                                 +
 41                                              +
 END

 >
```

APPENDIX L

Table L Defines Code Numbers for Different Beamsplitter Configurations

Table L.1, as shown in Appendix L, defines the code numbers used in the beamsplitter files to designate the various combinations of windows and calorimeters used by NBS in a three-calorimeter/beamsplitter configuration.

TABLE L.

Code No.	Low Level Calorimeter	Low Level Window	High Level Calorimeter	High Level Window
1	C44	BK7A-3	C46	FS-12
2	C46	FS-12	C44	BK7A-3
3	C41	FS-7	C44	FS-6
4	C44	FS-6	C41	FS-7
5	C41	FS-10	C44	BK7A-3
6	C44	BK7A-3	C41	FS-10
7	C41	FS-10	C46	FS-12
8	C46	FS-12	C41	FS-10
9	C41	FS-7	C46	FS-8
10	C46	FS-8	C41	FS-7
11	C46	FS-8	C44	FS-6
12	C44	FS-6	C46	FS-8

APPENDIX M

Computer File, /CMAT/, Contains All Required C-series Parameters

In Appendix M, a copy of File /CMAT/ is shown that contains all the parameters needed by the C-Series calibrating system to calculate the value of the calibrating beam. Also shown is a computer run and listing of Program /DOC/, which documents the values found in /CMAT/.

COPY /CMAT/ TO TEL

1Ø	41	44	46
12	Ø.9999	1	1
11	4.24443	4.86211	4.94741
3	4.25255	4.86926	4.94878
4	4.25675	4.87ØØØ	4.95214
9	1.ØØØ47	Ø.999886	Ø.999649
11.6587	Ø.9321	Ø.9331	Ø.93Ø1
11.545	Ø.93Ø5	Ø.9314	Ø.9294
11.5288	Ø.93Ø4	Ø.9312	Ø.9293
11.427Ø	Ø.9285	Ø.9291	Ø.9281
11.4372	Ø.9291	Ø.9296	Ø.9286
1.Ø6	1.23	1.29	1.42
.6471	.9Ø	.96	1.Ø9
.6328	.9Ø	.96	1.Ø9
.5145	.94	.97	1.17
.488Ø	.92	.95	1.15
4	1.27	Ø	Ø
Ø	Ø	Ø	Ø
.53Ø9	.93	.96	1.16
11.45235	Ø.9293	Ø.9299	Ø.9287

-

```
>RUN
 THIS 940 PROGRAM /DOC/ IS USED TO DEFINE AND DOCUMENT
 THE ELEMENTS IN /CMAT/ MATRIX.


 10             41             44             46
 12             .9999          1              1
 11             4.24443        4.86211        4.94741
 3              4.25255        4.86926        4.94878
 4              4.25675        4.87           4.95214
 9              1.00047        .999886        .999649
 11.6587        .9321          .9331          .9301
 11.545         .9305          .9314          .9294
 11.5288        .9304          .9312          .9293
 11.427         .9285          .9291          .9281
 11.4372        .9291          .9296          .9286
 1.06           1.23           1.29           1.42
 .6471          .9             .96            1.09
 .6328          .9             .96            1.09
 .5145          .94            .97            1.17
 .488           .92            .95            1.15
 4              1.27           0              0
 0              0              0              0
 .5309          .93            .96            1.16
 11.45235       .9293          .9299          .9287
ELECTRICAL CALIBRATION CONSTANTS, K, IN JOULES PER MILLIVOLT
SEE LATEST BLUE BOOK TABLE A.1.1
CALORIMETER     SCALE          ELECTRICAL K
C41             1 E3            4.24443
C41             1 E4            4.25255
C41             1 E5            4.25675

C44             1 E3            4.86211
C44             1 E4            4.86926
C44             1 E5            4.87

C46             1 E3            4.94741
C46             1 E4            4.94878
C46             1 E5            4.95214



 CALORIMETER    ABSORPTION     D FACTOR
 C41             .9999          1.00047
 C44             1              .999886
 C46             1              .999649


 GEOMETRIC MEAN BEAM SPLITTER RATIOS
 WAVELENGTH     BEAM SPLITTER RATIO
  1.06           11.6587
  .6471          11.545
  .6328          11.5288
  .5309          11.45235
  .5145          11.4372
  .488           11.427
```

WINDOW TRANSMISSION VALUES

WAVELENGTH	1.06	
CALORIMETER	WINDOW	TOTAL TRANSMISSION
C41	FS7	.9321
C44	FS6	.9331
C46	FS8	.9301

WAVELENGTH	.6471	
CALORIMETER	WINDOW	TOTAL TRANSMISSION
C41	FS7	.9305
C44	FS6	.9314
C46	FS8	.9294

WAVELENGTH	.6328	
CALORIMETER	WINDOW.	TOTAL TRANSMISSION
C41	FS7	.9304
C44	FS6	.9312
C46	FS8	.9293

WAVELENGTH	.5309	
CALORIMETER	WINDOW	TOTAL TRANSMISSION
C41	FS7	.9293
C44	FS6	.9299
C46	FS8	.9287

WAVELENGTH	.5145	
CALORIMETER	WINDOW	TOTAL TRANSMISSION
C41	FS7	.9291
C44	FS6	.9296
C46	FS8	.9286

WAVELENGTH	.488	
CALORIMETER	WINDOW	TOTAL TRANSMISSION
C41	FS7	.9285
C44	FS6	.9291
C46	FS8	.9281

DELIVERED BEAM UNCERTAINITY VALUES
AT THE 99% CONFIDENCE INTERVAL

WAVELENGTH	1 E3	1 E4	1 E5
1.06	1.23	1.29	1.42
.6471	.9	.96	1.09
.6328	.9	.96	1.09
.5309	.93	.96	1.16
.5145	.94	.97	1.17
.488	.92	.95	1.15

DELIVERED BEAM UNCERTAINITY AT THE 99% CONFIDENCE LEVEL
AT THE 1 MICROWATT LEVEL IS 1.27

TABLE A - BEAM SPLITTER CODE NUMBERS

CODE NO.	LOW LEVEL CALORIMETER	LOW LEVEL WINDOW	HIGH LEVEL CALORIMETER	HIGH LEVEL WINDOW
3	C41	FS7	C44	FS6
12	C44	FS6	C46	FS8
10	C46	FS8	C41	FS7
11	C46	FS8	C44	FS6
4	C44	FS6	C41	FS7
9	C41	FS7	C46	FS8

COPY /DOC/ TO TEL

```
10 PRINT" THIS 940 PROGRAM /DOC/ IS USED TO DEFINE AND DOCUMENT"
20 PRINT" THE ELEMENTS IN /CMAT/ MATRIX."
25 PRINT
26 PRINT
27 PRINT
30 DIMB(20,4)
40 OPEN/CMAT/, INPUT
50 FORI=1TO20
60 FOR J=1TO4
70 INPUT FILE B(I,J)
80 NEXTJ
90 NEXTI
95 MAT PRINT B
100 A$(1)="C41"
110 A$(2)="C44"
120 A$(3)="C46"
130 B$(1)="1E3"
140 B$(2)="1E4"
150 B$(3)="1E5"
160 C$="CALORIMETER"
170 D$="SCALE"
172 E$="ELECTRICAL K"
174 F$="ABSORPTION"
176 G$="D FACTOR"
178 I$="WAVELENGTH"
180 J$="BEAM SPLITTER RATIO"
182 K$="WINDOW"
184 L$="TOTAL TRANSMISSION"
186 M$="FS7"
188 N$="FS6"
190 P$="FS8"
192 Z$(1)="FS7"
194 Z$(2)="FS6"
196 Z$(3)="FS8"
200 PRINT"ELECTRICAL CALIBRATION CONSTANTS, K, IN JOULES PER MILLIVOLT"
204 PRINT"SEE LATEST BLUE BOOK TABLE A.1.1"
```

```
210 PRINTC$,D$,E$
220 FORJ=1TO3
230 FORI=1TO3
235 K=I+2
240 L=J+1
250 PRINTA$(J),B$(I),B(K,L)
260 NEXTI
265 PRINT
270 NEXTJ
300 PRINT
310 PRINT
320 PRINT
330 PRINTC$,F$,G$
340 FORI=1TO3
345 J=I+1
350 PRINTA$(I),B(2,J),B(6,J)
360 NEXTI
370 PRINT
380 PRINT
390 PRINT
400 W(1)=B(12,1)
410 W(2)=B(13,1)
420 W(3)=B(14,1)
430 W(4)=B(19,1)
440 W(5)=B(15,1)
450 W(6)=B(16,1)
460 R(1)=B(7,1)
470 R(2)=B(8,1)
480 R(3)=B(9,1)
490 R(4)=B(20,1)
500 R(5)=B(11,1)
510 R(6)=B(10,1)
520 PRINT"GEOMETRIC MEAN BEAM SPLITTER RATIOS"
530 PRINTI$,J$
540 FORI=1TO6
550 PRINTW(I),R(I)
560 NEXTI
570 PRINT
580 PRINT
590 PRINT
600 PRINT"WINDOW TRANSMISSION VALUES"
610 FORJ=1TO6
620 PRINTI$,W(J)
630 PRINTC$,K$,L$
640 FORI=1TO3
645 L=I+1
650 IFJ<4THEN680
660 IFJ=4THEN730
670 IFJ>4THEN750
680 K=J+6
700 PRINTA$(I),Z$(I),B(K,L)
710 GOTO770
730 PRINTA$(I),Z$(I),B(20,L)
740 GOTO770
```

```
750 IFJ<>5THEN764
760 PRINTA$(I),Z$(I),B(11,L)
762 GOTO770
764 PRINTA$(I),Z$(I),B(10,L)
770 NEXTI
780 PRINT
790 NEXTJ
792 PRINT
794 PRINT
796 PRINT
800 PRINT"DELIVERED BEAM UNCERTAINITY VALUES"
805 PRINT"AT THE 99% CONFIDENCE INTERVAL"
810 PRINTI$,B$(1),B$(2),B$(3)
820 PRINTW(1),B(12,2),B(12,3),B(12,4)
830 PRINTW(2),B(13,2),B(13,3),B(13,4)
840 PRINTW(3),B(14,2),B(14,3),B(14,4)
850 PRINTW(4),B(19,2),B(19,3),B(19,4)
860 PRINTW(5),B(15,2),B(15,3),B(15,4)
870 PRINTW(6),B(16,2),B(16,3),B(16,4)
880 PRINT
890 PRINT
900 PRINT
910 PRINT"DELIVERED BEAM UNCERTAINITY AT THE 99% CONFIDENCE LEVEL"
920 PRINT"AT THE 1 MICROWATT LEVEL IS ",B(17,2)
930 PRINT
940 PRINT
950 PRINT
1000 PRINT"TABLE A - BEAM SPLITTER CODE NUMBERS"
1010 PRINT"CODE NO.                LOW LEVEL                 HIGH LEVEL"
1015 PRINT"            CALORIMETER        WINDOW    CALORIMETER   WINDOW"
1020 N9=1
1040 X$="C41"
1045 U$=M$
1048 V$=N$
1050 Y$="C44"
1060 GOTO1738
1070 X$="C44"
1075 U$=N$
1078 V$=P$
1080 Y$="C46"
1090 GOTO1738
1100 X$="C46"
1105U$=P$
1108 V$=M$
1110 Y$="C41"
1120 GOTO1738
1130 X$="C46"
1135 U$=P$
1138 V$=N$
1140 Y$="C44"
1150 GOTO1738
1160 X$="C44"
1165 U$=N$
1168 V$=M$
1170 Y$="C41"
```

```
1180 GOTO1738
1190 X$="C41"
1195 U$=M$
1198 V$=P$
1200 Y$="C46"
1210 GOTO1738
1738 IFX$="C41" THEN1750
1742 IFX$="C44" THEN1774
1746 IFX$="C46" THEN1798
1750 IFX$="C44" THEN1758
1754 IFY$="C46" THEN1766
1758 G5=B(4,1)
1762 GOTO1824
1766 G5=B(6,1)
1770 GOTO1824
1774 IFY$="C41" THEN1782
1778 IFY$="C46" THEN1790
1782 G5=B(5,1)
1786 GOTO1824
1790 G5=B(2,1)
1794 GOTO1824
1798 IFY$="C41" THEN1806
1802 IFY$="C44" THEN1814
1806 G5=B(1,1)
1810 GOTO1824
1814 G5=B(3,1)
1818 GOTO1824
1824 PRINTG5,X$,U$,Y$,V$
1830 N9=N9+1
1840 IFN9=2THEN1070
1850 IFN9=3THEN1100
1860 IFN9=4THEN1130
1870 IFN9=5THEN1160
1880 IFN9=6THEN1190
1890 IFN9>6THEN1900
1900 PRINT
1910 PRINT"THE MATRIX IS NEARLY FULL. ONLY LINE 18 IS OPEN"

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

This report is a detailed procedure of how to set up and operate a Measurement Assurance Program (MAP) for a laser power and energy calibration facility. Items such as traceability, methods of self-checking measurement consistency, computer documentation and statistical analysis are discussed.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*)

Calorimetry; laser beamsplitter system; laser calibration system; laser measurements; laser power calibration.

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