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DOCUMENTATION OF THE NBS C, K, AND Q LASER CALIBRATION SYSTEMS

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CONTENTS

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This report provides a complete guide for the documentation of the NBS laser power and energy calibration systems. The report also describes a detailed procedure for operating the three (C, K, and Q) calibration systems under computer control.

Key words: computerized calibration system; computerized laser calibration; laser calibration documentation; laser calibration guide.

1. Introduction

The first purpose of this report is to document the NBS laser power and energy calibration systems. A considerable amount of the documentation is contained in articles published in archival journals. Reference to these previously published articles will be generous, but brief. For greater detail, the reader is encouraged to consult the original articles. That part of the documentation not previously published will be discussed in greater detail in this report.

The second purpose of this report is to serve as a guidebook for operating the NBS C, K, and Q calibration systems. The trend toward automation and the additional use of computers increases the need for more detailed operating instructions. For convenience, this report is divided into 13 sections for ease in locating specific information.**

Section 1 is a summary of this report with comments on using the documentation as a guidebook for operating the three calibration systems.

Section 2 includes a description of the NBS laser power and energy calibration service with a listing of the NBS-owned transfer instruments used in the laser NBS Measurement Assurance Program (MAP). The list includes the various combinations of instruments, wavelength, power, energy, and time scales. Shipping instructions for the MAP Transfer Standards are also included.

Section 3 discusses some of the design philosophy used in building the NBS laser calibration systems. Arguments are given as to why the isoperibol calorimeter was adapted as a key element in the three calibration systems as opposed to producing a standard laser source. The theory of isoperibol calorimetry is already well documented. Some advantages of using a two calorimeter-beamsplitter configuration for monitoring and extending the useful range of laser measurements are discussed with reference to several published articles for greater detail. A brief description is given of the microwatt calibration setup.

Section 4 contains a list of calorimeters in the C series calibration system with detailed information on the limits of energy, power, energy injection time, laser beam size, and beam density for each C series calorimeter. Other described items include safety equipment, transfer standards, and

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**Certain commercial equipment, instruments, or materials are identified in this paper in order to adequately specify the experimental procedure. Such identification does not imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

data acquisition gear. Some problems and precautions encountered in using the C series calibration system are enumerated. Sections 5 and 6 cover similar material for the K and Q calibration systems, respectively.

Section 7 describes the computer equipment and programs. The primary components of the computer system are listed with the main features of each unit. Several conventions were adapted in writing the software programs from scratch. Some conventions were arbitrarily adopted and some dictated by hardware and computer considerations. A method of backup procedure for the program and data disks is described. An important part of the programming concerns the use of control parameters which are discussed in detail. A program glossary includes the most widely-used programs at the present time.

Section 8 is intended to serve as a day-to-day guide for operating the C series calibration system. For convenience, the instructions were divided into three catagories: prerun, run, and shutdown routines. Instructions were numbered separately for clarity. Safety concerning possible eye damage is stressed.

Prerun routines specify equipment, instruments, scale settings, operating parameters, computer programs, alignment procedures, and other tasks that must be completed before doing a regular measurement run. All runs require completing the prerun computer and parameter routine. To automatically repeat several identical measurement runs during a normal day requires that all the computer operating parameters be set beforehand. The following schedule for a normal day of operation was used as a format for writing the control program, AMEM4.

8:00 a.m.	Complete two prerun routines to set up operating parameters for a measurement run. Turn on all equipment that needs at least 1 h warmup.
9:00 a.m.	If necessary, turn up laser power. Make a last minute check that everything is ready for the beginning run.
9:15 a.m.	Program, AMEM4, automatically starts first run.
10:15 a.m. to 4:15 p.m	Program, AMEM4, automatically begins subsequent runs every hour at 15 min past the hour.
4:30 to 4:45 p.m.	Shutdown routine to properly turn off and secure the system.

Regular run routines assume that the appropriate prerun routines have been completed. Runs can be started manually anytime by pressing START RUN, or automatically every hour as explained above. Due to cooling considerations, it is not desirable to run most high-power lasers continuously. Generally, between runs the laser power is manually reduced to a lower level. The laser is then adjusted to the higher power only during the measurement run. Such a run is considered a semiautomatic run since some operator attention is required during the run. For some types of runs the computer will require input data from the operator. Data from the calorimeters is read directly into the computer memory and stored on magnetic tape.

The shut down procedure is to protect the computer disks and to avoid any possible damage to the water-cooled lasers when the equipment is turned off.

Section 9 is a step-by-step guide for operating the K series calibration system. These operating instructions are divided into prerun, run and shutdown routines. The K series CO_2 laser is our most powerful laser and all laser routines include safety precautions. The system automatically turns on yellow and red warning lights when the laser is operating.

Prerun routines include instructions for turning on the laser gas bottles, laser cooling water, K system data acquisition rack, K calorimeters, constant current supplies, transfer instruments, etc. Details include checking beam alignment, beam size, shutter operation, and instrument and laser settings.

Regular run routines assume that the appropriate prerun routines have been completed. Since the K series laboratory and the 4051 computer are located in different parts of the building, it is not feasible to read data directly from the K calorimeters into the computer memory. As a substitute, the calorimeter data is recorded on magnetic tape during a measurement run and then hand carried to the computer. However, before computer processing can take place, the control parameters must be set by completing the prerun computer parameter routine. Program MAG1 inputs the magnetic tape data on queue and is the first program in a chain of programs used to process a typical K series measurement run.

The electrical shutdown routine describes the procedure for returning the K system to a secure status concerning cooling water, electrical calibration power supplies, data acquisition equipment, and the K calorimeters.

The laser shutdown routine describes a similar procedure for returning the K system to a secure status concerning gas bottles, cooling water, interlocking electrical circuits, beamsplitters, mirrors, calorimeters, and other equipment.

Section 10 is intended as a step-by-step guide for operating the Q series calibration system. The instructions are divided into three catagories: prerun, run, and shutdown. Because of the high peak power, the YAG Q-switched laser is considered our most dangerous laser concerning possible eye damage. For safety, all the laser routines emphasize the use of goggles, screens, limited access areas, beam blockers, safety chains, etc. Red and yellow warning lights are used to protect operators and other personnel.

Prerun routines specify equipment scales, instrument settings, computer programs, operating parameters, alignment procedures, and other tasks that must be completed before doing a regular measurement run. To automatically repeat several identical measurement runs during a normal day requires that all the computer operating parameters be set beforehand. Completely automatic runs only apply for Q series electrical calibration runs using the above schedule and prerun electrical routine. All runs require completing the prerun computer and parameter routine for the Q series. Beamsplitter and calibrated beam runs require completing the prerun beamsplitter or calibrated beam routine.

Regular run routine assumes that the appropriate prerun routines have been completed. Measurement runs can be started manually any time, or automatically started every hour by control program AMEM4. Electrical calibration runs will then run every hour, unattended. For beamsplitter and calibrated beam runs, program AMEM4 transfers control to the Q series room 3078 where the regular Q series beamsplitter or calibrated beam run routine provides a step-by-step guide to the operator for continuing the laser run.

The shutdown procedure includes computer shut down as well as securing the Q laser system.

An operating procedure is provided in section 11 for each transfer standard used in the NBS MAP program. A set of detailed instructions is included for each combination of power, energy, wavelength, CW, Q-switched, scale, etc. for each transfer instrument. The appropriate instructions are sent with the transfer standard at the time of the MAP intercomparison.

A discussion of systematic and random errors to provide the total uncertainty of a system is given in section 12. System errors include errors due to electrical calibration, absorption, equivalence, window transmission, traceability, D-factor, scale, and beamsplitter ratio. NBS uses the 99 percent confidence interval method in reporting measurement results in calibration and MAP reports.

Section 13 discusses quality control maintenance for the three calibration systems. The procedure is covered in detail in NBSIR 79-1619.

2. The NBS Laser Power and Energy Calibration Service

2.1 General Description

The Optical Electronic Metrology Group of the Electromagnetic Technology Division (724.02) offers a set of laser Measurement Assurance Programs (MAP) for the measurement of laser radiation. These measurement services are available for an annual cost as listed below. The basic philosophy and some details of the MAP concept are explained in references 1 and 2.

Some non-MAP calibration services are also available and, on request, specific information can be supplied regarding these services if none of the listed laser measurement assurance programs satisfy the needs of the customer. The laser MAP is designed to be a continuing program that is renewable for each participant on an annual basis. The direct costs for the services associated with the program are supported by the MAP participants. The minimum services to be provided to each laser MAP participant are as follows:

- An NBS-characterized transfer standard, evaluated for the specific wavelength and power range of laser radiation, will be forwarded to the participants twice per year. This transfer standard has been evaluated against the national standards maintained by NBS and its calibration constant is known within an uncertainty not substantially different from the uncertainty of the national standards. The calibration constant of the instrument will be unknown to the participant. The participants will be asked to calibrate the NBS transfer standard in accordance with their normal procedures, or in accordance with procedures sent with the instrument. The data will then be sent to NBS where an analysis will be performed. An NBS report will be forwarded to the participants and will contain a scale factor they may use in order to make their measurements consistent with the national standards. The report will also contain information on the precision of the intercomparison and this will document their measurement system relative to the national standards. Data from their internal quality assurance program, along with these NBS reports, will provide the basis for documenting the accuracy of their laser measurements.
- A limited amount of consultation from the NBS staff is available to assist in resolving problems associated with laser measurements. If necessary, one of the NBS staff can visit the participant's facility to assist with measurement problems. The participant would be expected to provide the cost for travel and lodging for this visit.

2.2 NBS Special Publication 250, 1980 Edition

Comments on laser power and energy measurements are on page 55-56 of the publication. Laser measurement programs currently available as described in the December 1980 appendix are as follows:

4.4 Laser Parameters

Direct inquiries to:
William E. Case
Electromagnetic Technology Division, 724.02
National Bureau of Standards
Boulder, Colorado 80303
Telephone: 303-497-3741

4.4A Special Calibration — At cost

4.4B Measurement Assurance Program for Laser Power or Energy

		$ per year
514.5 nm	10 mW - 600 mW	1610
632.8 nm	1 mW	1610
632.8 nm	(1 μW, 30 μW, 100 μW) (Cost is $1000 to participants of 1 mW, 632.8 nm, laser map where intercomparisons are performed together.)	
647.1 nm	10 mW - 200 mW	1610
1.06 μM	10 mW - 1 W	1610
1.06 μM	(Q-switched) 100 mJ - 10 J	2690
10.6 μM	5 - 50 W	2155

2.3 Power Meters Used in NBS MAP

The following list of NBS-owned power meters shows in detail the various combinations of power meters, power levels, and wavelengths that are presently used in the NBS laser power MAP.

Power Meter	Power Level	Wavelength (μm)
SIL 12.5	1 μW	0.6328
SIL 12.5	1 mW	0.6328
SIL 14	1 μW	0.6328
SIL 14	10 μW	0.6328
SIL 14	1 mW	0.6328
SIL 15	1 μW	0.6328
SIL 15	10 μW	0.6328
SIL 15	1 mW	0.6328
SIL 16	1 μW	0.6328
SIL 16	10 μW	0.6328
ECPRA4	1 mW	0.6328
ECPRA4	1 mW	1.0640
TC 15	100 mW	0.6471
TC 15	100 mW	1.0640
TC 15	1 W	1.0640
TC 24	100 mW	0.5145
TC 24	100 mW	0.6471
TC 24	100 mW	1.0640
TC 24	1 W	1.0640
TC 36	100 mW	0.4880
TC 36	100 mW	0.5145
TC 36	1 W	0.4880
TC 36	1 W	0.5145
TC 39	100 mW	0.5145
TC 39	100 mW	1.0640
TC 39	1 W	0.5145
TC 39	1 W	1.0640
TC 45	100 mW	0.5145
TC 45	100 mW	1.0640
TC 45	1 W	0.5145
TC 45	1 W	1.0640
A 1274	5 W	10.6000
A 1274	50 W	10.6000

2.4 Energy Meters Used in NBS MAP

The following list of NBS-owned energy meters shows in detail the various combinations of energy meters, continuous (C series) or Q-switched (Q series) energy modes, energy levels, integration time periods, and wavelengths that are presently used in the NBS laser energy MAP.

Energy Meter	Energy Mode	Energy Level J	Time s	Wavelength μm
TC 15	CW	1	10	1.0640
TC 15	CW	10	10	1.0640
TC 15	CW	1	100	1.0640
TC 15	CW	10	100	1.0640
TC 15	Q-swit	1	100	1.0640
TC 15	Q-swit	10	100	1.0640
TC 24	CW	0.1	10	0.5309
TC 24	CW	1	10	0.5309
TC 24	CW	0.1	20	0.5309
TC 24	CW	0.1	10	1.0640
TC 24	CW	1	10	1.0640
TC 24	CW	10	10	1.0640
TC 24	CW	10	40	1.0640
TC 24	Q-swit	0.1	10	1.0640
TC 24	Q-swit	1	10	1.0640
TC 24	Q-swit	10	10	1.0640
TC 24	Q-swit	10	40	1.0640
TC 39	CW	10	10	1.0640
TC 39	Q-swit	10	10	1.0640
TC 45	CW	0.1	10	1.0640
TC 45	CW	1	10	1.0640
TC 45	CW	10	10	1.0640
TC 45	CW	10	40	1.0640
TC 45	Q-swit	0.1	10	1.0640
TC 45	Q-swit	1	10	1.0640
TC 45	Q-swit	10	10	1.0640
TC 45	Q-swit	10	40	1.0640

2.5 Shipping Instructions for MAP Transfer Standards

1. When you receive our transfer standard please locate and read the enclosed operating instructions.

2. After completing measurements please send transfer standard back to NBS.
   A. Send by common carrier.
   B. Sender must prepay shipping charges.
   C. Ship to:
      U.S. Department of Commerce, NBS
      William E. Case
      Electromagnetic Technology Division, 724.02
      325 Broadway
      Boulder, CO 80303

3. Before shipping back to NBS, be sure that instrument is properly packed. Disconnect all the plug-in cables before shipping.

4. Please call William E. Case at NBS using phone number 303-497-3741 and advise when the instrument was shipped.

3. System Design Philosophy

3.1 Isoperibol Calorimetry

Generally, laser sources are not stable enough in power output to be used directly as a standard sources such as standard cells are used. Even the output of gas lasers, which are generally the most stable, varies with alignment, aging, gas mixture, pressure, temperature, and the surface condition of mirrors, prisms, etc.

In lieu of trying to use a laser as a standard source, other means were considered for providing a standard device for laser measurement. One possibility was to use an isoperibol calorimeter as a standard detector. The theory of isoperibol calorimetry is well documented. The abstract from reference 3 states the following:

> Laser power and energy measurements are commonly made in calorimeters operating in a constant temperature environment. Calorimeters of this type are analyzed in terms of the first law of thermodynamics and the boundary value problem describing heat flow in the calorimeter. This theory of the measurement suggests design features of the calorimeter, sources of error to be avoided in design and operation, and tests to demonstrate experimentally the adequacy of the design. The analysis shows how time-temperature data can be used to allow for the temperature gradient on the calorimeter and the heat exchange due to transients in the temperature.

The above publication includes a list of 13 references pertaining to isoperibol calorimetry.

A practical application of the theory of isoperibol laser calorimetry is demonstrated in reference 4. The abstract states:

> Principles and detailed procedures are described for measuring laser energy and power in terms of electrical energy based on voltage, resistance, and frequency standards. The construction of a small isoperibol calorimeter used for the measurements is described. The calorimeter will accomodate 0.01 to 20 J and 4 x 10^{-5} to 1 W cw and is limited to a maximum pulse intensity of 0.1 J/cm^2. The standard deviation of comparison measurements using two calorimeters and a beam splitter is 0.08 percent when the smaller energy input is not less than 0.3 J. The estimated limits of systematic error for one calorimeter are ±1.0 percent of the laser energy measured by the calorimeter.

Of prime importance is that the electrically calibrated calorimeter provides an accurate means of allowing laser measurements to be traceable to well established national electrical standards. Of equal importance is the ability to evaluate all of the significant errors with an uncertainty on the order of one percent.

Measurements using the theory of isoperibol calorimetry are only practical when using a special computer program to reduce the calorimeter data. Such a program, as described in reference 5 uses numerical integration and least squares fit routines of relevant portions of the calorimeter temperature-time curve to calculate a quantity defined as the corrected rise, which is directly proportional to energy.

3.2 Two Calorimeter-Beamsplitter Configuration

The usefulness of the direct-substitution method of calibration is somewhat limited because of the unstable power output of most lasers. The addition of an uncoated beamsplitter to the calibration system which allows the use of a monitor calorimeter during a measurement run greatly diminishes the adverse effects of this problem. References 6 and 7 discuss some of the measurement procedures and precautions when using beamsplitters. The advantages of using beamsplitters led to the development of the two calorimeter-beamsplitter configuration which is now used in the C, K, and Q calibration systems. Reference 8 covers in detail how to set up and operate a measurement assurance program for a laser power and energy calibration facility using the two calorimeter-beamsplitter configuration.

3.3 Calibration at the 1 μW Level

Reference 9 was used as the basis of our 1 μW calibration capability at 0.6328 μm, which is part of the C series system. The calibration routine uses a fused quartz beamsplitter to provide a 1 μW secondary transmitted beam by monitoring the main transmitted beam of 0.819 mW with the high-level calorimeter. The calculated ratio assumes a vertically polarized laser beam, and an angle of incidence where the reflection from a mirror in the M=2 beam coincides with the M=3 beam (see the above publication for nomenclature). Alignment details are given in section 8.

4. Description of the C Series Calibration System

4.1 Primary Equipment

The NBS C series calorimeters were primarily designed to accurately measure cw laser energy and power in the visible and near infrared spectrum. The three calorimeters are electrically calibrated to provide traceability to the national electrical standards. Each calorimeter has its own temperature controller to provide an isoperibol environment for the calorimeter absorber. Each calorimeter is provided with a special shielded cable and connector to provide the calorimeter thermopile output voltage to a Keithley model 140 amplifier. The system uses the two calorimeter-beamsplitter configuration to provide accurately known laser beams for the calibration of laser transfer standards. The principal items in the C system are:

1. Calorimeter C41 with temperature controller TC-5 [4].
   a. Maximum energy injection time--300 s
   b. Energy range--0.1 to 22 J
   c. Maximum energy density--0.1 J/cm^2
   d. Laser aperture--20 mm
   e. Wavelength range--0.488 to 1.064 μm
   f. Beamsplitter size--preferably 5 mm
2. Calorimeter C44 with temperature controller TC-5-4. This calorimeter is identical to C41 (see specification above).
3. Calorimeter C46 with temperature controller TC-5-11. This calorimeter is identical to C41 (see specifications above).
4. Keithley amplifier, model 140, NBS #139775, for low-level calorimeter.
5. Keithley amplifier, model 140, NBS #142403, for high-level calorimeter.
6. Spectra Physics HeNe laser, model 124A, NBS #142853.
7. Spectra Physics HeNe laser, model 125, NBS #136529.
8. Coherent argon laser, model CR-3, NBS #143869.

9. Coherent krypton laser, model CR500K, NBS #143638.
10. Holobeam YAG laser, model 250, NBS #138627.
11. Lens of 2 m focal length for reducing beam size.
12. Sapphire beamsplitter S-72.
    a. Diameter 25 mm
    b. Beam ratio 11.43 to 11.65 (variable depending on wavelength)
    c. Wedge angle 1°
13. Fused quartz beamsplitter BS-4.
    a. Diameter 50 mm
    b. Beam ratio 819 (for HeNe)
    c. Wedge angle 2°
14. Elgar 6000 ac line conditioner, NBS #136027, to eliminate adverse effects from 115 V supply line transients.
15. Five iron tables, three milling tables, several stands, magnetic chucks, etc. for mounting components in the beamsplitter configuration.
16. FJW Industries infrared viewer specially designed for viewing 1.064 μm radiation.
17. Kodak IR phosphor card for beam location and alignment of 1.064 μm beam.
18. BK7A glass filter.

4.2 Safety Equipment

1. Protective goggles specially designed to block 1.064 μm radiation when using the YAG laser.
2. Interlocked red and yellow warning lights that blink when semaphore beam blocker is removed allowing the laser beam to enter the measurement room.
3. Provide a separate laser room. (Lasers located in another room adjacent to calorimeter room.)
4. Provide beam blockers for capturing the various transmitted and reflected beams.
5. Provide a separate computer room, away from the laser radiation.

4.3 Transfer Standards

1. EG&G laser power meter, model 460-1, with silicon detector head 460-2 designated as SIL 12.5.
2. EG&G laser power meter, model 460-1, with silicon detector head 460-2 designated as SIL 14.
3. EG&G laser power meter, model 460-1, with silicon detector head 460-2 designated as SIL 15.
4. EG&G laser power meter, model 460-1, with silicon detector head 460-2 designated as SIL 16.
5. Calorimetrics twin calorimeter, model TC-1, serial #15, with meter, model MC2-P, NBS #145348.
6. Calorimetrics twin calorimeter, model TC-1, serial #24, with meter, model MC2-P, NBS #145926.
7. Calorimetrics twin calorimeter, model TC-1, serial #36, with meter, model MC2, NBS #146232.
8. Calorimetrics twin calorimeter, model TC-1, serial #39, with meter, model MC2-P, NBS #147103.
9. Calorimetrics twin calorimeter, model TC-1, serial #15, with meter, model MC3.
10. NBS pyroelectric laser power meter, model ECPRA4.

4.4 C series Rack

1. Main power switch applies 115 supply voltage to the rack.
2. Computer Measurements Company dual preset controller, model 913, gives the present point count and starts the energy injection routine on the count of 23.
3. HP scaler timer, model 5202L, NBS #135047, controls the electric gate that determines the time energy will be applied to the calorimeter.

4. Pulse driver circuit PD-3 opens and closes the relays for applying either electrical or laser energy to the calorimeter.
5. Time base generator TB-1, a quartz-controlled generator which supplies an accurately known frequency to the scaler timer.
6. Electrical calibrating circuit AU-3A provides a regulated dc voltage for the electrical calibration of a C series calorimeter. Provides terminals for connections to a C series calorimeter, a standard resistor, a mercury relay unit, and the IEEE 488 bus.
7. Panel TP-1 provides terminal connections for 3 different power levels when doing electrical calibration runs.
8. Panel PA-1 provides a switch for doing either an electrical or a laser run.

4.5 Problems and Precautions

4.5.1 Laser Beam Size

A common problem is that the diameter of the laser beam is nearly as large as the diameter of the aperture of the detector. Since our measurement criteria is to measure the total beam energy, it is desirable to reduce the laser beam diameter to, say, one half of the aperture diameter to be assured that we capture all of the beam. Regular eyeglass blanks with focal lengths of 1 or 2 m make excellent lenses for reducing the laser beam with only slow divergence after going through the focal point. The lens is inserted before the beamsplitter. A collimator can also be used for controlling the size of the beam. Generally, it is not desirable to focus the laser beam to a very small area. This will avoid damage to detectors due to a high energy density.

4.5.2 Laser Beam Purity

Most laser beams contain spurious radiation around the periphery of the beam. Usually, apertures with adjustable diameters are used to block out the undesirable radiation. However, if the edge of the aperture is too close to the main beam, diffraction will cause a scattering of the beam for a star effect and a loss of energy in the main beam. Usually one or two apertures are placed before the beamsplitter to clean up the edge of the beam. This is another reason for making the beam diameter one half the diameter of the detector aperture.

4.5.3 Cleanliness of Optical Components

Beamsplitters and windows should always be covered when not in use. Smoking should not be allowed in laser laboratories. The beamsplitter ratio is the ratio of the transmitted beam energy to the reflected beam energy from the front surface. A change in beam splitter ratio may mean an invisible film has formed on the beamsplitter surface giving a slightly higher ratio, perhaps 0.3 percent. Cleaning the beamsplitter with methyl alcohol may restore the old ratio. A change in the apparent beamsplitter ratio may also be due to a change in one of the calorimeters, either due to a dirty window, a shift in the electrical calibration factor, a change in amplifier gain, or some other reason.

4.5.4 Laser Beam Polarization

The two calorimeter-beamsplitter configuration was made long enough (6 to 7 m) to allow the incoming laser beam to miss the low-level calorimeter and still have a very small (1 to 2°) angle of incidence between the incoming beam and the projection of the beamsplitter normal. With such a small angle, the difference in beam ratio due to the different polarizations is negligible when using the sapphire beamsplitter S-72. However, in the microwatt setup which uses fused quartz beamsplitter BA-1, the angle of incidence is 8° and the beam ratio varies approximately 3.5 percent between the vertical and horizontal polarization. In this case, it is important to arbitrarily select and use the same polarization for all measurements. The laser used for the microwatt measurements has vertical polarization.

4.5.5 Wedged Optical Components

It is important that all beamsplitters, windows, etc. do not have parallel faces, but have wedged surfaces of 1 to 2°. Reflections from parallel surfaces can cause large errors due to wave interference.

4.5.6 Q-Switched Laser Pulses

Do not measure Q-switched pulses with a C series calorimeter. The surface of the absorber would be damaged by the high energy density.

5. Description of K Series Calibration System

5.1 Primary Equipment

The NBS K series calorimeters are primarily designed to accurately measure high power CO_2 laser radiation at a wavelength of 10.6 μm, at power levels up to 1000 W. The calorimeters are electrically calibrated to provide traceability to national electrical standards. Each calorimeter has its own temperature controller to provide an isoperibol environment for the calorimeter absorber. Each calorimeter has its own dedicated constant-current supply unit to provide an analog output voltage proportional to the energy input.

The system uses the two calorimeter-beamsplitter configuration to provide accurately known laser beams for the calibration of laser transfer standards. The principal items in the K system are:

1. Calorimeter K12 with temperature controller TC-5. This is a K1-type calorimeter. See figure 5.2-1 for a plot of energy versus power.
    a. Maximum energy injection time, 300 s
    b. Energy range: 300 to 3000 J
    c. Power range: 5 to 1000 W
    d. Laser aperture: 40 mm
    e. Beam size: preferably 20 mm
    f. Peak beam density: 1 J/cm^2
2. Calorimeter K13 with temperature controller TC5-12. This is a K1 type, identical to K12.
3. Calorimeter K22 with temperature controller TC-5. See figure 5.2-2 for a plot of energy versus power. The K2 series is a scaled down version of the K1 series to extend the range to lower power measurement.
    a. Maximum energy injection time: 300 s
    b. Energy range: 12 to 120 J
    c. Power range: 0.2 to 40 W
    d. Laser aperture: 40 mm
    e. Beam size: preferably 10 mm
    f. Peak beam density: 0.1 J/cm^2
4. CO_2 laser--Photon Sources, NBS #143530

   a. Continuous wave (cw)
   b. Maximum power available for calibration: 250 W
   c. Water cooled
5. Zinc selenide beamsplitter, ZS1SB
   a. Diameter: 50 mm (2 in)
   b. Beam ratio: ~4
   c. Wedge angle: 1°
6. Potassium chloride beamsplitter, KCL1SB
   a. Diameter: 50 mm (2 in)
   b. Beam ratio: ~27
   c. Wedge angle: 1°
   d. Provided with temperature-controlled environment
7. Three molybdenum mirrors for controlling direction and size of laser beam.
8. Electrically-controlled, water-cooled shutter for accurately controlling the laser beam injection time.
9. Small helium-neon laser with associated optics to provide a visible beam for accurately measuring the laser injection time.
10. Pulse generator (NBS #141789) to provide short, variable-width single pulses of laser energy for system alignment.
11. Heat-sensitive paper targets for alignment.
12. Elgar ac line conditioner (NBS #138018) to eliminate bad effects from 115 V supply line transients.
13. Cooling water manifold for filter manipulation.
14. Tables, stands, magnetic chucks, hardware, etc. for mounting components in the beamsplitter configuration.

5.2 Safety Equipment

1. Plastic goggles.
2. Operating booth with clear plastic panels.
3. Interlocked yellow and red warning lights at room entrance.
4. Baffles at room entrance to avoid direct beam contact.

5.3 Transfer Standards

1. Coherent transfer standard head, model 201, serial #1274.
2. Coherent transfer standard head, model 201, serial #1359.
3. Keithley amplifier, model 140, NBS #143272.
4. Integrating digital voltmeter, NBS-2. The head 1274 and DVM NBS-2 are used in our 10.6 μm MAP program as a shippable transfer standard.
5. Dymec integrating DVM, model 2401C, NBS #128773.

5.4 K Series Electrical Calibration Rack

1. Electronic Measurements Inc. SCR power supply, NBS #143937.
2. Standard resistor, NBS #144299.
3. Dummy load.
4. Switching circuits.

5.5 SI Rack

1. Dana DVM, NBS #144281. Reads voltage across standard resistor.
2. Fluke DVM, NBS #142442. Reads voltage across calorimeter heater.
3. Newport printer, NBS #143792.
4. Datos, NBS #144227.
5. Facit paper punch, NBS #144233.

5.6 Electrical Traceability Equipment

1. Standard cell 831388.
2. Standard cell 790068.
3. Standard cell 857557.
4. Guildline precision vernier potentiometer, model 9144, serial #22039, NBS #118323.
5. Cambridge instrument spot galvanometer.

5.7 K Data Acquisition Rack

A low- and a high-level analog voltage output is available to the K data acquisition rack from the two calorimeter-beamsplitter configuration.

1. Tektronix digital cartridge tape recorder, model 4923. Every 10 s, on command from the Datos, the recorder receives digital data from low-level DVM #1 and high-level DVM #2 and records the data on the cartridge tape.
2. ECCI preset controller gives the present point count, opens the shutter on count 32 and closes the shutter on the programmed preset count.
3. Newport DVM #1, NBS #141886, converts analog voltage from the low-level calorimeter to a digital output voltage.
4. Newport DVM #2, NBS #143949, converts analog voltage from the high-level calorimeter to a digital output voltage.
5. Datos, model 305, NBS #142904, interfaces the built-in clock, the two DVMs, the digital recorder, and the shutter control unit.
6. Pulse driver circuit PD-8 opens and closes the laser shutter on command from the preset controller.
7. HP time interval counter 5300A, NBS #143531, and HP 5304A, NBS #143532, accurately measures the open shutter time (laser injection time).
8. Sensor amplifier SC-3 amplifies the sensor head voltage to activate the time interval counter.
9. Sensor head. During the open shutter time the sensor head develops an output voltage due to the helium neon laser beam.

5.8 Problems and Precautions

The discussion of problems and precautions for the C series applies to the K series except for the following:

1. Glass lenses are not useful at 10.6 µm. Flat and convex molybdenum mirrors are used at 10.6 µm to reduce the beam diameter. Don't attempt to clean the molybdenum mirrors.
2. Don't attempt to clean the zinc selenide beamsplitter. A suitable method of cleaning is not known.
3. Don't attempt to clean the KCL beamsplitter which is kept in a slightly heated enclosure to avoid water absorption.

6. Description of the Q series Calibration System

6.1 Primary Equipment

The NBS Q series calorimeters were primarily designed to accurately measure YAG Q-swutched laser energy at a wavelength of 1.064 µm. The calorimeters are electrically calibrated to provide traceability to the national electrical standards. Each calorimeter has its own temperature controller to provide an isoperibol environment for the calorimeter absorber. Each calorimeter is provided with a special manufacturer supplied shielded cable and connector to provide the calorimeter thermopile output voltage to a Keithley model 140 amplifier.

The system uses the two calorimeter-beamsplitter configuration to provide accurately known laser beams for the calibration of laser transfer standards. The principal items in the Q system are:

1. Calorimeter Q1B with temperature controller TC-5 [10].
   a. Maximum energy injection time: 40 s
   b. Energy range: 0.4 to 15 J
   c. Maximum energy density per pulse: 3 J/cm^2
   d. Laser aperture: 32 mm x 32 mm
   e. Minimum pulse width: 20 ns documented, 0.2 ns probable.
   f. Wavelength range: 1.06 µm documented.
   g. Beam size: preferably 10 mm
2. Calorimeter Q1C with temperature controller TC-5-16. This calorimeter is identical to Q1B. See specifications above.
3. Keithley amplifier, model 140, NBS #142068, for low-level calorimeter.
4. Keithley amplifier, model 140, NBS #142404, for high-level calorimeter.
5. International Laser Systems, Inc. YAG laser, model LL-102, NBS #144773.
   a. Q-switched: 1.064 µm
   b. Maximum energy per pulse with amplifier: 0.170 J
   c. Maximum energy per pulse without amplifier: 0.070 J
6. Lens: 1 m focal length
7. Lens: 2 m focal length, for reducing beam size
8. Zinc selenide beamsplitter ZSQ
   a. Diameter: 50 mm
   b. Beam ratio: ~3.75
   c. Wedge angle: 1°
9. Schott Glass SFG beamsplitter SF-61
   a. Diameter: 25 mm
   b. Beam ratio: ~11
   c. Wedge angle: 1°
10. Elgar ac line conditioner, NBS #135426. To eliminate adverse effects due to 115 V supply line transients.
11. Three iron tables, magnetic chucks, hardware, etc. for mounting components in the beamsplitter configuration.
12. FJW Industries infrared viewer. Battery operated instrument specially designed for viewing 1.064 µm radiation.
13. Kodak IR phosphor card, for beam location and alignment.
14. Sensor amplifier SC-2 with sensor head. For counting the number of laser pulses during the energy injection time.

6.2 Safety Equipment

1. Protective goggles specially designed to block 1.064 μm radiation.
2. Baffles at room entrance to avoid direct beam contact when coming into the room.
3. Interlocked red and yellow warning lights that blink when laser power supply is on or laser shutter is open.
4. Beam blockers for capturing the various transmitted and reflected beams.
5. Safety chain to block the passageway while doing laser alignment and measurement.

6.3 Transfer Standards

1. Calorimetrics twin calorimeter, model TC1, serial #15, with meter, model MC2-P NBS #145348.
2. Calorimetrics twin calorimeter, model TC1, serial #24, with meter, model MC2-P NBS #145926.
3. Calorimetrics twin calorimeter, model TC1, serial #39, with meter, model MC3 NBS #147103.
4. Calorimetrics twin calorimeter, model TC1, serial #45 with meter, model MC3.

6.4 Q Series Rack

1. Computer Measurements Co., dual preset controller, model 913, gives the present point count and starts the energy injection routine on the count of 32.
2. Main power switch applies 115 supply voltage to the rack.
3. Start run panel: Press START RUN switch to begin a laser measurement.
4. HP scalar timer, model 5202L, NBS #137821, controls the electronic gate that determines the electrical energy injection time or the time period that the laser is allowed to fire.
5. Pulse driver circuit PD-2 opens and closes the relay for electrical calibration runs or the relay for laser calibration runs.
6. Q Datos coupler, model 305, NBS #143359, and Newport meters, NBS #142389 and NBS #143440, are used for setting the voltage across the standard resistor before making an electrical calibration run.
7. HP time interval counter, 5300A, NBS #143531, and HP 5304A, NBS #143532, accurately measures the energy injection time.
8. NBS clock unit CU-1 determines the pulse rate that the laser will fire during the energy injection time.
9. Kepco power supply, model JQE, NBS #141989, supplies electrical power to a Q calorimeter during an electrical calibration run.
10. Timebase generator TB-2 is a quartz controlled generator supplying an accurately known frequency to the HP scaler timer.
11. Electrical calibration circuit AU-4B provides terminals for connections to the Q series electrical calibration heaters, the standard resistor, the mercury relay unit, MR-1, the Kepco power supply, and the IEEE 488 bus.
12. Panel PA-3 provides a switch for doing either an electrical or a laser run.
13. Mercury relay unit MR-1 switches either electrical or laser energy to a calorimeter.
14. Leeds and Northrop 10 Ω standard resistor, serial #1192753, is used for determining the current through the electrical heater during an electrical calibration run.

6.5 Problems and Precautions

The discussion of problems and precautions for the C series apply to the Q series except for the following:

1. Don't attempt to clean the zinc selenide beamsplitter. A suitable method of cleaning is not known.
2. It is preferrable to use the SF-61 beamsplitter. SF-61 is glass and can be cleaned with methyl alcohol. The Q-switched pulses do not fluoresce on the incident surface of the SF-61 beamsplitter as they do on the surface of the zinc selenide beamsplitter.

7. Computer Programs and Equipment

7.1 Primary Equipment

1. Tektronix graphic computer, model 4051
   a. 32 K bytes of memory
   b. GPIB (IEEE standard 488-1975) bus
   c. Extended BASIC
   d. Magnetic cartidge tape drive
   e. ROM pack for file manager
   f. ROM pack for printer
   g. RS232 interface
2. Tektronix file manager, model 4907
   a. Dual 8-in floppy disc
   b. GPIB (IEEE 488-1975) bus
   c. Real time clock
3. Tektronix matrix printer model 4641
   a. Tractor-driven paper feed
   b. Separate ROM interface with 4051
4. Data acquisition rack
   a. Timing generator, HP model 59308A
   b. Scanner, HP model 3495A
   c. Digital voltmeter, HP model 3455A
5. ROM expander
   a. Accomodates up to 16 ROMs
   b. We presently use 5 ROMs

7.2 Programming Conventions

The following conventions were adapted, some arbitrary and some dictated by hardware and software considerations.

1. All programs are written in extended BASIC.
2. All programs are written from scratch especially for this application (no canned programs).
3. All programs are stored in files on 8-in floppy disks designated as program disks.
4. All data is stored in data files on 8-in floppy disks designated as data disks.
5. All measurement runs are made using program disk MAIN PROG and either data disk MAIN DATA or data disk MAINFDATA. MAIN DATA disk is used for NBS-owned instruments and MAINFDATA disk is used for non-NBS-owned instruments.
6. The MAIN PROG disk is only used in device 0.
7. MAIN DATA and MAINFDATA disks are only used in device 1 except during backup operations.
8. The MAIN REPORT disk is used for writing calibration reports and is used only in device 0.
9. The above disks have the following backups:
   a. MAIN PROG: BACKPROG1 and BACKPROG2

b. MAINDATA: BACKDATA1 and BACKDATA2

c. MAINFDATA: BACKFDATA

d. MAIN REPORT: BACKREPORT

10. The backup schedule is to use program DUPDISC to duplicate MAIN PROG disk on BACKPROG1 during one week and on BACKPROG2 during the next week. The process could continue each week for each main program and each main data disk.

11. Changes in program files are easily made by typing new line numbers or retyping old line numbers and saving the program.

12. In practice, data files can only be created, renamed, or changed by specific basic programs. Data files are categorized by the number of columns.

    a. Program DMAKE is used to create 1- to 9-column data files.

    b. Program DCOPY is used to save the data in a 1- to 9-column data file under a new name.

    c. Programs, EDIT1D, EDIT2D, . . . EDIT9D are used to replace, delete, insert, append, and sort data in existing 1- to 9-column data files.

13. The computer provides a hard copy printout for every measurement run which is then filed for a permanent record.

14. Pertinent calibration data for a measurement run is automatically appended by the computer to previous calibration data to provide a measurement history for each unique set of data.

15. In every BASIC program, line one contains the name of the program. Before saving a program LIST1 to determine the exact name to save.

16. Input data for every measurement run includes the voltage output from both the low- and high-level calorimeters, even though only one is being used. The low-level readings are always in the first column and the high-level readings are always in the second column.

17. Due to the large size of the programs and the 32 K byte limitation of the computer memory, the programs are usually divided into three parts. Those parameters that will be needed by parts 1, 2, and 3 are stored on a magnetic tape cartridge in the computer tape drive. When the first part is run, the computer reads in the parameter values, makes the necessary calculations needed for the second and third part, stores these results on the same magnetic tape, and loads and runs part two. Similarly, part two repeats the above procedure and loads and runs part three. The printer provides a hard copy record and the disk unit provides computer storage of pertinent data. The computer then returns control to part one for another measurement run at a later time.

18. Where possible, the computer programs use the menu concept to avoid input errors and to provide a list of options.

19. The computer only uses A$ through Z$ which limits the alphanumeric variables at any one time to 26. Several programs reuse the alphanumeric variables by redefining them as the program continues.

20. A date run number is used for each run with a year, month, day, and run of the day format. For instance, 8110162 would be used for the second run of the day on October 16, 1981. The date run number increases with time and is very useful for sort routines.

21. Use single letter variables for arrays only. For other variables, use a letter with a number.

7.3 Parameter Programs

The trend toward automation and the increasing role of the computer in the measurement process requires setting up beforehand a set of parameters to provide all the information needed by the computer to complete a measurement run. To accomodate all of the various combinations of power meters, power levels, energy meters, energy levels, integration time periods, wavelengths, and continuous or Q-switched energy for the three calibration systems requires a set of twenty-two parameters for each measurement run. A parameter notebook is maintained for each system for NBS-owned instruments and is divided into sections for electrical, beamsplitter, and calibrated beam runs. A fourth notebook, SXCQK, contains parameters for non-NBS-owned instruments. Entries are made with pencil so the parameters can easily be updated. At present, over 600 sets of parameters with over 13,000 entries have been entered in the 4 notebooks.

For each section of each notebook a separate computer program exists where the parameters are already stored or a space has been reserved for future use. All of the electrical and beamsplitter run parameters have been stored, but not all of the calibrated beam parameters. Before doing a measurement run, the parameters for the proper code number must be set in the appropriate computer program.

Program SOP permits the operator to select the correct parameters for the calibration system, type of run, code number, and date run number for the desired measurement run. SOP then selects either program SCEEE, SCBS, SCCP, SCCE, SKEE, SKBS, SKCP, SQEE, SQBS, SQCE, or SXCQK for the correct set of parameters and copies the values to the magnetic tape in the computer tape drive. Computer control is then transferred to program AMEM4 for C and Q series runs or to program MAG1 for K series runs. The control parameters are listed below.

- N9 Date/run number with YYMMDDR format as 8104121 for April 12, 1981 for the first run of the day.
- C4 Minute after the hour to start an automatic run. Computer will automatically do eight runs in a day.
- N0 or N1 Total number of data points needed. Program MAG1 uses N0; program AMEM4 uses N1.
- G1 Low-level amplifier gain setting. Use 1,000 for 1E3, 10,000 for 1E4, and 100,000 for 1E5. If low-level calorimeter is not being used set G1 = 0.
- G2 High-level amplifier gain setting. Use 1,000 for 1E3, 10,000 for 1E4, and 100,000 for 1E5. If high-level calorimeter is not being used, set G2 = 0.
- A$ Low-level calorimeter designation such as C414 which is calorimeter C41 with 1E4 amplifier gain.
- B$ High-level calorimeter designation such as C463 which is calorimeter C46 with 1E3 amplifier gain.
- Z4 Energy injection time in seconds. Time period when shutter or electronic window is open.
- A7 Mode number for type of run: 1 for electrical, 2 for BS, and 3 for calibrated beams.
- W8 Wavelength in μm, use 0.488, 0.5145, 0.5309, 0.6328, 0.6471, 1.06, or 10.6.
- R5 Value of standard resistor in Ω for electrical runs. May be used for other input for laser runs.
- P0 Number of blank lines to bring paper to starting point. Useful for automatic computer runs.
- G$ Disk file name for transfer device being calibrated; only used for calibrated beam runs.
- J5 Power/energy mode number. 0 for power runs, 1 for energy, -1 for special case.
- R8 Beginning data point for calibration run on transfer instrument; only used when transfer instrument is read with 488 bus.

R9 Ending data point for calibration run on transfer instrument; only used when transfer instrument is read with 488 bus.

F4 Factor to adjust calibration factor for powers of 10; allows adjustment to mV, mW, etc.

A4 Factor to adjust calibration factor to standard DVM readings. Adjust transfer meter readings to standard DVM reading.

B2 Beam splitter designation for C, K, or Q system. Each system has two beam splitters (see par. book).

K5 Control parameter for automatic calibration beam runs. K5=0 except when using 488 bus to read transfer instrument.

K7 Control parameter to designate the C, K, or Q series. 1 for C series, 2 for Q, 3 and above for K series.

S0 Transfer instrument code number for calibration beam runs. For example, for 31510, use 3 for C series, 15 for 1 J, 10 for 10 s.

7.4 C Series Programs

1. AMEM4: Control program to start a measurement run. Reads input data and records on magnetic tape. Automatically calls up program ACR1.
2. ACR1: Calculates corrected rise for low- or high-level calorimeter or both and records results on magnetic tape. For an electrical or beamsplitter run, program calls up AC2A. For a calibrated beam run, program calls up AC2B.
3. AC2A: For electrical runs, the program calculates the electrical calibration factor for the specified calorimeter and appends the factor and other pertinent data to the appropriate electrical calibration files on the data disk. For beamsplitter runs, the program calculates the beamsplitter ratio and appends the ratio and other pertinent data to the appropriate beamsplitter file on the data disk. The program provides a hard copy record from the printer and returns the computer to control program AMEM4.
4. AC2B: For calibrated beam runs, the program calculates the calibration factor of the transfer instrument and appends the factor and other pertinent data to the appropriate transfer file on the data disk. The program provides a hard copy record from the printer and returns the computer to control program AMEM4.

7.5 K Series Programs

1. MAG1: Control program to begin processing a K series run. Requires operator input and tape manipulation as instructed by the computer. Reads input data and records on magnetic tape. Automatically calls up program ACR1.
2. ACR1: Calculates corrected rise for low- or high-level calorimeter or both and records results on magnetic tape. For an electrical or beamsplitter run, program calls up AK2A. For a calibrated beam run, program calls up AK2B.
3. AK2A: For electrical runs, the program calculates the electrical calibration factor for the specified calorimeter and appends the factor and other pertinent data to the appropriate electrical calibration files on the data disk. For beamsplitter runs, the program calculates the beamsplitter ratio and appends the ratio and other pertinent data to the appropriate beamsplitter file on the data disk. The program provides a hard copy record from the printer and returns the computer to control program MAG1.
4. AK2B: For calibrated beam runs, the program calculates the calibration factor of the transfer instrument and appends the factor and other pertinent data to the appropriate transfer

file on the data disk. The program provides a hard copy record from the printer and returns to control program MAG1.

7.6 Q Series Programs

1. AMEM4: Control program to start a measurement run. Reads input data and records on magnetic tape. Automatically calls up program ACR1.
2. ACR1: Calculates corrected rise for low- and high-level calorimeter or both and records results on magnetic tape. For an electrical or beamsplitter run, program calls up AQ2A. For a calibrated beam run, program calls up AQ2B.
3. AQ2A: For electrical runs, the program calculates the electrical calibration factor for the specified calorimeter and appends the factor and other pertinent data to the appropriate electrical calibration files on the data disk. For beamsplitter runs, the program calculates the beamsplitter rtio and appends the ratio and other pertinent data to the appropriate beamsplitter file on the data disk. The program provides a hard copy record from the printer and returns the computer to control program AMEM4.
4. AQ2B: For calibrated beam runs, the program calculates the calibration factor of the transfer instrument and appends the factor and other pertinent data to the appropriate transfer file on the data disk. The program provides a hard copy record from the printer and returns the computer to control program AMEM4.

7.7 Program Glossary (includes only presently-used programs)

AC2A A C series program that automatically follows corrected rise program ACR1 for processing a C system electrical or beamsplitter run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA. Program transfers computer control to program AMEM4.

AC2B A C series program that automatically follows corrected rise program ACR1 for processing a C system calibrated laser beam run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA. Program transfers computer control to program AMEM4.

ACR1 A combined corrected rise program which uses a least squares exponential curve fit and a numerical integration routine to make the necessary corrected rise calculations for either of the C, K, and Q calibration systems. This program is automatically loaded by either program AMEM4 or MAG1. On completion, ACR1 loads either program AC2A, AC2B, AK2A, AK2B, AQ2A, or AQ2B.

AK2A A K series program that automatically follows corrected rise program ACR1 for processing a K system electrical or beamsplitter run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA. Program transfers computer control to program AMEM4.

AK2B A K series program that automatically follows corrected rise program ACR1 for processing a K system calibrated laser beam run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA.

AMEM4 The main control program for beginning a measurement run under computer control. Program will either begin a measurement run, automatically every hour or on a cue from the operator at any time. AMEM4 takes a set of data points every 4 s and stores the data on magnetic tape. The program then calls up corrected rise program, ACR1, to continue the measurement run. At the end of the computer run, program control is returned to AMEM4 for the next measurement run. Program AMEM4 reads voltages from the IEEE 488 bus and stores them on magnetic tape.

AQ2A A Q series program that automatically follows corrected rise program ACR1 for processing a Q system electrical or beamsplitter run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA. Program transfers computer control to program AMEM4.

AQ2B A Q series program that automatically follows corrected rise program AQR1 for processing a Q system calibrated laser beam run with a detailed hard copy record from the printer and a permanent computer record of this run by adding new data to previous calibration data on floppy disk MAINDATA.

BDATE The second part in program sequence BSCAN-BDATE-BPLOT, where BDATE processes run number data to give a more accurate time plot of beamsplitter ratio variation versus years, portions of years, months, etc. in program BPLOT. The improved plot allows for a more accurate detection of trends in the beamsplitter ratio.

BPLOT The third program in program sequence BSCAN-BDATE-BPLOT, where BPLOT produces a plot of percent variation of beamsplitter ratio from the average versus time in years, months, etc. on the computer screen. The plot gives a graphic view of the status of the calibration factor over the years as to stability, scatter, and possible trends. Pertinent portions of the above data can be output to the printer for a hard copy record to be used for confirming the status of the calibrating system at a certain wavelength.

BSCAN A program to scan beamsplitter ratio disk files to verify the status of each laser beamsplitter ratio used in the NBS calibration and MAP program. The BSCAN menu itemizes the various combinations of beamsplitters and wavelengths that are used in the three calibration systems. The program sequence is BSCAN-BDATE-BPLOT.

DAD2 A statistical program that reads single column data from disk file A and calculates the number of points, the average, the standard deviation, the percent standard deviation, the degrees of freedom, and the 90, 95, and 99 percent level of confidence in percent.

DARU Runs a statistical program to objectively detect trends in a single column of data found in disk file A at device 1 with calculated results displayed on the computer screen and sent to the printer for a hard copy record.

DAS6 A program to select data by wavelength and scale from a 6-column power or energy disk data file at device 1 and copy separated data to disk file A to be later used by programs DARU, DAPL, and DAD2.

DDUPL A program that greatly simplifies the saving of a 1- to 9-column disk data file at device 1 by copying to another disk file with a different name.

DUPDISC A program with a simple routine for safely backing up the main program and data disks used for the three calibration systems. Disk backup should be done weekly. On command, DUPDISC copies all the files on the disk at device 0 to the disk at device 1. Old disk files at disk 1 are deleted.

EDATE The second part in program sequence ESCAN-EDATE-EPLOT, where EDATE processes date run number data to give a more accurate time plot of energy meter calibration factor variation versus years, portions of years, months, etc. in program EPLOT. The improved plot allows for a more accurate detection of trends in the calibration factor. The program is for NBS-owned energy meters.

EDIT2T A program for editing a two-column data file on magnetic tape located in the computer tape drive. The program menu includes stop, replace, delete, insert, append, copy data to printer, save latest version on disk file, and print up-to-date listing on the screen.

EDIT6D A program for editing a 6-column power or energy transfer meter file on disk at device 1. The program menu includes stop, replace, delete, insert, append, copy data to printer, save latest version on disk file, print up-to-date listing on the screen, and sort on date run number.

EDIT7BD A program for editing a 7-column power or energy transfer meter file on disk at device 1. The program menu includes stop, replace, delete, insert, append, copy data to printer, save latest version on disk file, print up-to-date listing on the screen, and sort on date run number.

EDITTS A program to directly edit the control parameters on magnetic tape C, K, or Q without using the longer SOP program routine. The parameters can be recalled, changed, and restored on the magnetic control tape.

ELDATE The second part in program sequence ELSCAN-ELDATE-ELPLOT, where ELDATE processes run number data to give a more accurate time plot of electrical calibration factor versus years, portions of years, months, etc. in program ELPLOT. The improved plot allows for a more accurate detection of trends in the calibration factor. The program is for NBS-owned calorimeters.

ELPLOT The third program in program sequence ELSCAN-ELDATE-ELPLOT, where ELPLOT produces a plot of percent variation of electrical calibration factor from the average versus time in years, months, etc. on the computer screen. The plot gives a graphic view of the status of the electrical calibration factor over the years as to stability, scatter, and possible trends. Pertinent portions of the above data can be output to the printer for a hard copy record to be used for preparing MAP and calibration reports.

ELSCAN A program to scan electrical calibration factor disk files to verify the status of each calorimeter used in the NBS calibration and MAP program. The ELSCAN menu itemizes the various combinations of scales and calorimeters that are used in the three calibration systems. The program sequence is ELSCAN-ELDATE-ELPLOT.

EPLOT The third program in program sequence ESCAN-EDATE-EPLOT, where EPLOT produces a plot of percent variation of energy meter calibration factor from the average versus time in years, months, etc. on the computer screen. The plot gives a graphic view of the status of the calibration factor over the years as to stability, scatter, and possible trends. Pertinent portions of the above data can be output to the printer for a hard copy record to be used for preparing MAP and calibration reports.

ESCAN A program to scan NBS-owned energy meter files to verify the status of each calorimeter used in the NBS MAP program and to produce statistical information for preparing MAP reports. The ESCAN menu itemizes the various combinations of energy meters, amplifier gains (scales), beamsplitters, and laser wavelengths that are available. The program sequence is ESCAN-EDATE-EPLOT. Program ESCAN requires MAINDATA disk at device 1.

MAG1 The first program in a sequence of three to process a measurement run on the K-calibration system where the calorimeter data was previously recorded on a magnetic tape cartridge. The program requires operator input and manipulation of two magnetic tapes. The program then calls up corrected rise program ACR1 to continue the processing routine. At the end of the computer run, program control is returned to MAG1 for the next run. The program sequence is either MAG1-ACR1-AK24-MAG1 or MAG1-ACR1-AK2B-MAG1.

PDATE The second part in program sequence PSCAN-PDATE-PPLOT, where PDATE processes run number data to give a more accurate time plot of power meter factor versus years, portions of years, months, etc. in program PPLOT. The improved plot allows for a more accurate detection of trends in the calibration factor. The program is for NBS-owned power meters.

PPLOT The third program in program sequence PSCAN-PDATE-PPLOT, where PPLOT produces a plot of percent variation of power meter calibration factor from the average versus time in years, months, etc. on the computer screen. The plot gives a graphic view of the status of the power meter factor over the years as to stability, scatter, and possible trends. Pertinent portions of the above data can be output to the printer for a hard copy record to be used for preparing MAP and calibration reports.

PSCAN A program to scan NBS-owned power meter disk files to verify the status of each laser transfer power meter used in the NBS MAP program and to produce statistical information for preparing MAP reports. The PSCAN menu itemizes those combinations of power meters, amplifier gains (scales), beamsplitters, and laser wavelengths that are available. The program sequence is PSCAN-PDATE-PPLOT. Program PSCAN requires MAINDATA disk at device 1.

SCBS A C series program where control parameters are stored for C series beamsplitter runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, CPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape C. The program sequence is SOP-SCBS-AMEM4.

SCCE A C series program where control parameters are stored for C series calibrated energy beam runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, CPAR for NBS-owned transfer instruments. Program SOP uses this program to copy the chosen set of parameters to magnetic tape C. The program sequence is SOP-SCCE-AMEM4.

SCCP A C series program where control parameters are stored for C series calibrated power beam runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, CPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape C. The program sequence is SOP-SCCP-AMEM4. Program SCCP is for NBS-owned transfer instruments.

SCEL A C series program where control parameters are stored for C series electrical runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, KPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape C. The program sequence is SOP-SCEL-AMEM4.

SKCP A K series program where control parameters are stored for K series calibrated power beam runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, KPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape K. The program sequence is SOP-SKCP-AMEM4. Program SKCP is for NBS-owned transfer instruments.

SLOPE A program for calculating the electrical calibration factor from a paired data set using a least squares fit procedure as described in reference 11. The results are used in compiling the total system error.

SOP A program that permits the operator to select the correct control parameters for the calibration system, type of run, code number, and date run number for the desired measurement run. Program SOP then loads the correct parameter program and copies the control parameters to the magnetic control tape in the computer tape drive. Finally, computer control is transferred to either AMEM4 or MAG1.

SQBS A Q series program where control parameters are stored for Q series beamsplitter runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook QPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape Q. The program sequence is SOP-SQBS-AMEM4.

SQCE A Q series program where control parameters are stored for Q series calibrated energy beam runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, QPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape Q. The program sequence is SOP-SQCE-AMEM4.

SQEL A Q series program where control parameters are stored for Q series electrical runs. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook, QPAR. Program SOP uses this program to copy the chosen set of parameters to magnetic tape Q. The program sequence is SOP-SQEL-AMEM4.

SXCQK A combined program where control parameters are stored for measurement runs on non-NBS laser transfer standards for the C, K, and Q systems. Parameters are stored in basic data statements starting at line number equal to 100 times the code number shown in notebook SXCQK. Program SOP uses this program to copy the chosen set of parameters to magnetic tape C. The program sequence is either SOP-SXCQK-AMEM4 or SOP-SXCQK-MAG1.

XDATE The second part in program sequence XSCAN-XDATE-XPLOT, where XDATE processes date run number data to give a more accurate time plot of calibration factor variation versus years, portions of years, months, etc. in program, XPLOT. The improved plot allows for a more accurate detection of trends in the calibration factor. The program is for non-NBS-owned transfer instruments.

XPLOT The third program in program sequence XSCAN-XDATE-XPLOT, where XPLOT produces a plot of percent variation of calibration factor from the average versus time in years, months, etc. on the computer screen. The plot gives a graphic view of the status of the power meter factor over the years as to stability, scatter, and possible trends. Pertinent portions of the above data can be output to the printer for a hard copy record to be used for preparing MAP and calibration reports. XPLOT is only for non-NBS-owned instruments.

XSCAN A program to scan nonNBS-owned power meter disk files to verify the status of each laser transfer power meter used in the NBS MAP program and to produce statistical information for preparing MAP reports. The XSCAN menu itemizes those combinations of power meters, amplifier gains (scales), beamsplitters, and laser wavelengths that are available. The program sequence is XSCAN-XDATE-XPLOT. Program XSCAN requires MAINDATA disk at device 1.

8. Operating Procedure for the C Series Calibration System

8.1 Prerun Electrical Routine for the C Series

1. Turn on main power switch in C series rack.
2. Set switch on PA-1 panel to electrical.
3. Turn on power switch on calibrating unit AU-3A.
4. Locate notebook CPAR and determine the code number with the set of parameters for this particular type of electrical run.
5. Check and, if necessary, make connections or adjust instrument settings to agree with the above parameters.

   G1: Gain setting for low-level calorimeter. If not being used, G1 must equal 0.

   G2: Gain setting for high-level calorimeter. If not being used, G2 must equal 0.

   A$: Must be the correct designation for the low-level calorimeter, if it is the calorimeter being calibrated. For instance, A$ for calorimeter C41 on the IE5 scale would be designated C415.

   B$: Must be the correct designation for the high-level calorimeter, if it is the calorimeter being calibrated. For instance, B$ for calorimeter C46 on the IE3 scale would be designated C463.

   Z4: Set scaler-timer thumbnail switches to the value specified by Z4.

   R5: On back side of C series rack in unit AU-3A, plug in standard resistor with the value of resistance specified by R5.

   L5: On panel TP-1, connect wire lug to terminal specified by L5.
6. Remove the target cap from the calorimeter aperture for the calorimeter to be calibrated.
7. Turn on amplifier connected to the calorimeter being electrically calibrated.
8. Set switch SW-4 to the calorimeter being calibrated.
9. On AU-3A panel, insert twin banana plug into the manual position.
10. Reset scaler timer and press switch for a dry run test. A relay should operate and the scaler-timer should start counting. When the count equals the thumbnail switch setting the scaler-time should stop the count and operate the relay again.
11. Reset the time interval counter.

12. Press and hold the test switch on AU-3A for a few seconds and observe that the letter C appears on the time interval counter display. Release the switch and the count should appear on the display.
13. Complete the prerun computer and parameter routine for the C series at this time to allow at least 1-h warmup of the data acquisition equipment.

8.2 Prerun Beamsplitter or Calibrated Beam Routine for the C Series

1. Turn on main power switch in C series rack.
2. Set switch on PA-1 panel to laser.
3. Turn on amplifier connected to the high-level calorimeter.
4. For microwatt calibration runs uncover beamsplitter BS-4. For all other runs uncover beamsplitter S-72.
5. Turn on amplifier connected to the low-level calorimeter.
6. For all runs except microwatt runs place 2 m lens in spotting holder SH-1.
7. Turn on semaphore power supply. Do not raise semaphore at this time.
8. If this is a calibrated beam run, set the transfer instrument on the proper scale and locate at the desired high or low level position. Turn on power switch.
9. Eye safety must be considered first when using any laser. Under no circumstances should a person look directly into a laser beam or into a mirror that may reflect a laser beam. Looking directly into the smallest lasers can cause eye damage equivalent to a person's looking directly at the sun. The C series calibration system uses five different lasers to cover the range of powers and wavelengths needed for the NBS MAP program.

   Generally, goggles are not worn when the laser beam wavelength is in the visible range. The various transmitted and reflected beams are easily located and terminated in either the measuring instruments or absorbed with a number of beam blockers painted with an absorbing black paint. White 3x5 cards are commonly used for aligning and checking the quality of the beam, especially around the edges. For power levels of 200 or 300 mW and above, even the reflections from a white card are uncomfortable to view and a pair of goggles for another wavelength can sometimes be used to dim the beam for better viewing.

   Goggles must be worn when using lasers with invisible beams, such as the YAG laser at 1.064 μm. Since the beams cannot be seen, the eye could be injured by such a beam before you were even aware that a beam was present.
10. Laser menu.
    a. For 1 to 10 μW calibrated beam runs at 0.6328 μm, place 15 mW laser in four spotting holes in the laser room and turn on power switch. Go to step 11.
    b. For a 1 mW calibrated beam run or a beamsplitter run at 0.6328 μm, place the prism mounted on a magnetic stand in spotting holder and set BK7A glass filter approximately 3 in behind prism. Turn on 50 mW laser. If this is a beamsplitter run, remove variable light attenuator and go to step 16. For a calibrated beam run, place variable attenuator in laser beam just before the beam enters the hole in the wall. Proceed to step 11.
    c. For a beamsplitter or a calibrated beam run 0.4880 or 0.5145 μm, place chain hoist over center of argon laser. Raise laser platform to remove holding blocks. Lower laser platform into spotting holes in iron cylinders. Turn on cooling water valve marked "ARGON OUT." Next, turn on valve marked "ARGON IN." Let water run 10 min before

turning on argon laser. Turn on laser power switch on laser room wall. Turn on line switch on argon power supply. When delay light goes out, turn current adjust fully clockwise and press tube start switch. When the laser fires, turn current adjust dial for a laser current of 15 A. Go to step 11.

d. For a beamsplitter or a calibrated beam run at 0.5309 or 0.6471 μm, place chain hoist over the center of krypton laser. Raise laser platform to remove holding blocks. Lower laser platform into spotting holes in iron cylinders. Turn on cooling water valve marked "KRYPTON OUT." Next, turn on valve marked "KRYPTON IN." Let water run 10 min before turning on krypton laser. Turn on laser power switch on laser room wall. Turn on line switch on krypton power supply. When delay light goes out, turn current adjust fully clockwise and press tube start switch. When the laser fires, turn current adjust dial for a laser current of 20 A. Go to step 11.

e. For a beamsplitter or a calibrated laser beam run at 1.064 μm, open cooling water valve marked "YAG OUT." Next, turn on valve marked "YAG IN." Turn on laser power switch on laser room wall. Turn on (ON-OFF) switch on YAG laser control panel. Pump motor should now circulate cooling water through laser head. Run the pump at least 10 min before firing the laser. Remove or move other lasers that obstruct the laser beam path. When ready to fire the laser, put on 1.064 μm goggles and turn current adjust on control panel to 7. Press fire button. If laser fires, set current adjust for a laser current reading of 15 A. Use IR phosphor card to detect the presence of the laser beam. If laser does not fire, set current adjust to 0, then back to 7 and try again.

11. Raise semaphore and position laser and/or prism so laser beam strikes approximately in the center of the shutter. Adjust iris in front of shutter so the beam is centered in the iris. Adjust the iris diameter to cut out stray radiation but not so much as to clip the main beam to produce a star effect (diffraction) when the beam is viewed around the edges with a white card at the high level calorimeter site. If this is a microwatt calibration, proceed to step 12. Otherwise, move beamsplitter S-72 so beam goes through the center. Adjust high-level calorimeter so beam is centered on aperture target. Adjust beamsplitter S-72 to center the beam on the target of the low-level calorimeter. Move the hinge with the large aperture (3/4" diameter) in front of the calorimeter so the beam goes through the aperture. Use the hinge with the solid surface to block the laser beam. Remove calorimeter target. Momentarily let the laser beam go through to the calorimeter while observing that the two reflections from the calorimeter window are equally spaced about the main beam. If not, carefully adjust the calorimeter to move the beams into position. Repeat the above process for both calorimeters. Go to step 18.

12. For a microwatt calibration, place variable light attenuator about 30 mm in front of the laser. Locate transfer instrument and fasten detector head to the aluminum beam connected to the microwatt milling head. Do not lower head at this time. Connect cables to transfer instrument, set power to 1 or 10 μW scale for 0.6328 μm and turn on ac power. Move beam-splitter S-72 away from beamsplitter BS-4. Adjust BS-4 into beam path until laser beam goes through center of beamsplitter. Collimator attached to laser should be adjusted to give a beam diameter of 2 mm at beamsplitter BS-4. Remove barrier BA-1. Place white card about 8 in on laser side of beamsplitter and adjust card so three equally spaced reflections from the beamsplitter can be seen.

13. Place holder of second white card with 2 mm hole about 25 mm on other side of beamsplitter so that the small secondary beam (not the main beam) passes through the hole to the

reflecting mirror. Adjust mirror so reflection comes back on itself through the hole in the card, through the beamsplitter, and coincides with the faintest reflection of the three equally spaced reflections discussed above. This may require a small adjustment of the beamsplitter. Momentarily blocking the beam from the mirror with a cord will help verify that the two beams actually coincide. Lower detector into beam and adjust head so beam strikes the center of the aperture. Turn out lights and rotate head so reflection nearly reflects back on itself, but not exactly.

14. Raise arm and place the bottom part of the wooden box on the aluminum platform and lower detector head into the box slot. Adjust the milling head so the laser beam strikes the center of the detector aperture. The beam diameter should be 1 to 2 mm.
15. Carefully place the 100 mm tube in the tube clamp and wooden box and locate very close to the detector head so the tube blocks most of the outside light. Carefully place the upper part of the wooden box over the tube.
16. Unblock the laser beam to the high-level calorimeter and adjust the calorimeter platform so the laser beam is centered on the target of the high-level calorimeter. Check that the two reflections from the calorimeter window are equally spaced about the incoming beam. Block the high-level beam.
17. Turn on the desk lamp at the operating table. Turn out all the other lights in the measurement room. Switch transfer meter to the 10^{-5} scale for 2 μW or to the 10^{-6} scale for 1 μm measurements. Block the beam to the transfer meter and adjust the desk lamp rheostat for a zero meter reading. Unblock the laser beam to the transfer meter and adjust the variable light attenuator in the laser room for a 1 or 2 μW reading. Go to step 20.
18. If this is a beamsplitter run, go to step 23. If this is a calibrated energy beam run, go to the next step. For a calibrated power beam run, place transfer meter in the high or low location. If the transfer meter has an analog voltage output that is to be used for IEEE 488 bus input to the computer, connect transfer voltage cable to transfer meter output jack. If this is a microwatt run, go to step 20.
19. With transfer meter in position, set scales for the appropriate power range. Block the laser beam to the monitor calorimeter with the hinged beam blocker. Adjust the transfer meter stand so so the laser beam goes through the center of the meter aperture while at the same time insuring that any reflections from the instrument are equally spaced around the incoming beam. Use as a power meter to set the laser beam to the desired power level. Use the white card to insure that the laser beam is clean around the edges and that the beam size is small enough that there is little doubt that the transfer instrument is capturing all of the laser beam. If this is a calibrated energy run go to step 22.
20. If this is a calibrated power run where the computer is set to read the analog voltage output of the transfer meter, block the laser beam to the monitor calorimeter and set the laser power to the desired level. If not already completed, do prerun and parameter routine for C series and return to this step.
21. Press user-defined key TRANSFER VOLTAGE for scanner response and voltage readings on the digital voltmeter (DVM). Compare by eye the digital voltage readings of the transfer instrument with the system DVM. Block the laser to the transfer instrument and again compare readings. If these values agree within 0.1 or 0.2 percent, proceed to step 23. If disagreement is greater, then it is perhaps better to read and record the transfer voltage by hand and not use the system DVM for reading the transfer voltage. For a large disagreement (10 or 20 percent), check the transfer meter.

22. For a calibrated energy beam run using an appropriate transfer meter, set switches to the desired energy and time scales. See specific instructions for the instrument being used. Make an integrator run without laser input to check that instrument is operating properly.

23. Press user-defined key LOW LEVEL DVM for a scanner response with low-level DVM readings. Check the scale and the normal range of the low-level voltage readings. Press user-defined key HIGH LEVEL DVM for a scanner response with high-level DVM readings. Check the scale and the normal range of the high-level voltage readings. For a calorimeter to be in the ready condition, the normal voltage range for each amplifier scale is as follows:

Amplifier scale	Normal DVM voltage range
1E3	-0.02 to -0.08
1E4	-0.3 to -0.6
1E5	-9.0 to -6.0

24. Locate the notebook with the set of parameters used in the prerun computer routine and compare the parameter values with the actual instruments and settings in the C series room. In particular, check G1, G2, A$, B$, and Z4. If a calorimeter is not to be used, then the G1 or G2 parameter must be set to zero.

8.3 Prerun Computer and Parameter Routine for the C Series

1. Locate dual disk unit.
2. Locate device 1. Press power switch on.
3. Locate device 0. Press power switch on.
4. Update toy block day-month-year display above computer.
5. Turn on computer and type in the day-month-year hour-minute format. For example, for September 5, 1981, at 8:16 a.m., type CALL "SETTIM," "05-SEP-81 08:16." For today's date, use toy block display and for today's time, read 24-h clock on the right side of the computer. The clock light should go out on device 0.
6. Turn on main power switch in the data acquisition rack.
7. Determine the parameter code number for this type of run as follows:
   a. For runs on NBS-owned instruments, use notebook CPAR.
   b. For runs on non-NBS-owned instruments, use notebook SXCQK.
8. For runs not listed, enter a new set of parameters in the appropriate notebook in pencil.
9. Turn on computer and insert disk named MAINPROG in device 0.
10. Type CALL "MOUNT," 0, A$.
11. If the set of parameters is marked with a red check in the above notebook, proceed to the next step. If not, load the program listed at the top of the notebook page, for example, OLD "SCCP." Multiply code number XX by 100. List XX00, XX99 on the computer to check the status of the stored parameters for code number XX. For code number 18, a list 1800, 1899 prints those line numbers being used to store the code 18 parameters. Retype or type new line numbers to change or input new numbers. LIST 900, 999 for a sample format. When ready to store the correct numbers, LIST 1 for the correct name of the program. Type SAVE "XXXX" where XXXX is the name of the program.

12. Load and run program SOP. Type OLD "SOP." When loaded, type RUN. Follow the computer instructions. At the end of the run, program AMEM4 will be loaded and running (reading the clock).
13. Press user defined key, "LIST PARA" to list parameters on the screen. Check these values with the values in the notebook. For corrections, repeat steps 11 and 12, or use program EDITTS to make corrections on magnetic tape C.
14. Program AMEM4 will automatically start a measurement run at 15 min past the hour or at anytime the user-defined key START RUN is pressed.
15. Check the actual instruments and settings and, if necessary, switch settings to agree with the chosen set of parameters in the above notebook. In particular, check parameters G1, G2, A$, B$, and Z4. If either A$ and/or B$ disagree, it may be necessary to use a new code number.
16. If this is an electrical calibration, press user-defined key E1. Voltage reading E1 should be very nearly zero. Press user-defined key E2. If R5 ≈ 10 Ω, then E2 should approximately equal 0.33 V. If R5 ≈ 1000 Ω, then E2 should approximately equal 10 V.

8.4 Regular Electrical Run for the C Series

1. Complete prerun electrical and computer routines. Instruments should warm up at least 1 h before making measurements.
2. If program AMEM4 is not in control, type OLD "AMEM4." When loaded, type RUN. Check screen display for the correct parameters by pressing user-defined key LIST PARA. If not okay, either load and run program EDITTS or repeat prerun computer and parameter routine for the C series.
3. For an electrical run on a calorimeter in the low-level position, press user-defined key LOW LEVEL DVM. This voltage should show a normal negative value on the system DVM before starting a run. Normal values, according to scales, are as follows:

Amplifier scale	DVM voltage range
1E3	-0.02 to -0.08
1E4	-0.3 to -0.6
1E5	-9.0 to -6.0

4. For an electrical run on a calorimeter in the high-level position, press user-defined key, HIGH LEVEL DVM. This voltage should show a normal negative value on the system DVM before starting a run. Use the above values as a guide.
5. Press user-defined key E1. The system DVM voltage should read nearly zero.
6. Press user-defined key E2. The system DVM should read approximately 0.33 V for R5 = 10 Ω or 10 V for R5 = 1000 Ω.
7. On unit AU-3A place twin banana plug in RELAY position.
8. Program AMEM4 will automatically start a run every hour at 15 min past the hour or when the user-defined key START RUN is pressed.
9. At the beginning of a run, the computer will reset the preset controller and scaler-timer.
10. The preset controller will then start the run and display the latest count at 4 s intervals.

11. The computer screen will display the count, the low- and high-level calorimeter voltage readings, and the electrical calibration voltages, E1 and E2. E1 is the voltage across the calorimeter heater. E2 is the voltage across the standard resistor.
12. On count 23 the scaler-timer will switch electrical energy to the calorimeter being calibrated for the time interval set on the thumbnail switches.
13. The computer will continue taking data until a count of N1 points is reached. The computer then starts processing the data and making the necessary calculations to complete the run. A hard copy record of the run is provided by the printer and a permanent computer record is made by adding pertinent data for this run to previous calibration data stored on floppy disk MAINDATA.
14. At the end of the run control of the computer is returned to program AMEM4 which will continue subsequent, identical runs every hour without further operator attention until 4:30 p.m.
15. After the first run check the hard copy printout for any mistakes caused by incorrect parameters or any other reason. To correct parameter values, load and run program EDITTS.
16. To edit electrical calibration data on the disk file, load and run either EDIT7ED or EDIT2D program and follow program instructions.
17. To compare electrical runs with previous electrical runs, load and run program ELSCAN. A plot of percent variation of electrical calibration values from the average versus time in years will appear on the screen.
18. To continue with more identical runs, load and run program AMEM4.

8.5 Regular Beamsplitter or Calibrated Beam Run for the C Series

1. Complete prerun routines. Instruments should warm up at least 1 h before making measurements.
2. If program AMEM4 is not in control, load AMEM4 and type RUN. Check screen display for correct parameters by pressing user-defined key LISTPARA. If not okay, either load and run program EDITTS or repeat prerun computer and parameter routine for C series.
3. Press user-defined key LOW LEVEL DVM. This voltage should show a negative value on the system DVM before starting a run. For additional information, see prerun beamsplitter or calibrated beam for C series for the normal voltage range.
4. Press user-defined key HIGH LEVEL DVM. This voltage should also show a negative value on the system DVM before starting a run.
5. If a transfer instrument voltage is being read by the computer, press TRANSFER VOLTAGE for a system DVM reading. If this is a calibrated energy beam run, take and record a preintegrator run on the transfer instrument without laser input. Reset meter.
6. If this is a 1.064 μm laser run put on goggles.
7. When ready to start a measurement run be sure the shutter is closed and the beam blockers will not block the desired laser beam. Press user-defined key START RUN.
8. Computer will reset the preset controller and scaler-timer.
9. The computer will start the run and the preset controller will display the latest count every 4 s.
10. The computer screen should display the count, the low- and high-level DVM readings, and for most calibrated power beam runs the transfer voltage E5 will also appear.
11. If the semaphore is not already up, raise before a count of 15.
12. If this is a calibrated energy beam run, press START halfway between count 22 and 23.

13. On a count of 23, the scaler-timer should open the laser shutter. After the time period set by the thumbnail switches has elapsed, the scaler-timer should close the shutter. If this is a high-power YAG laser run, lower the semaphore and turn down the YAG laser.
14. The computer will continue taking measurements every 4 s until a count of N1 is reached. If this is a calibrated energy run, record gross meter reading when red light comes on. Reset meter and press start again. When the red light comes on again, record the postintegrator value. Average the preintegrator and postintegrator values and calculate the net integrator value. Computer will stop and wait for operator to type in the net integrator value.
15. The computer will continue processing the run and provide a hard copy record from the printer and a permanent computer record of this run by adding pertinent data for this run to previous calibration data, stored on floppy disk MAINDATA.
16. At the end of processing control of the computer will be returned to program AMEM4.
17. Check the hard copy printout for any mistakes caused by incorrect parameters or for any other reason.
18. To edit beamsplitter data on the disk file, load and run program EDIT7BD and follow program instructions.
19. To edit calibrated beam data on the disk file, load and run progrm EDIT6D and follow instructions.
20. To compare beamsplitter runs with previous beamsplitter runs, load and run program BSCAN. A plot of percent variation of beamsplitter ratio from the average versus time in years will appear on the screen.
21. To compare calibrated power beam runs with previous runs, load and run program PSCAN. A plot of percent variation of calibration factor from the average versus time in years will appear on the screen.
22. To compare calibrated energy beam runs with previous runs, load and run program ESCAN. A plot of percent variation of calibration factor from the average versus time in years will appear on the screen.
23. Programs PSCAN and ESCAN each provide hard copy printout with selected statistical information that is used for preparing MAP and calibration reports.
24. For repeated identical runs every hour, load and run AMEM4.

8.6 Shutdown Routine for the C Series

1. For water-cooled lasers, turn off everything except that part of the operation concerned with the water cooling. Allow cooling to continue for at least 10 min before turning off the water. Other lasers can immediately be turned off.
2. Turn off any transfer instruments being used. Replace aperture plugs.
3. Turn off main power switch in the C series rack.
4. Turn off amplifier for high-level calorimeter. Replace target in high-level calorimeter aperture.
5. Replace beamsplitter cover.
6. Turn off amplifier for low-level calorimeter. Replace target in low-level calorimeter aperture.
7. Turn off the semaphore power supply.
8. After 10 min turn off the laser cooling water. For the YAG laser, turn off the ON-OFF power switch. On the hose connections, turn off the valve marked IN first, then the valve marked OUT.

9. Turn off the laser power switch mounted on the wall.
10. Turn off main power switch in data acquisition rack.
11. Turn off printer switch.
12. Remove magnetic tape C from.
13. Turn off computer.
14. Remove all disks from device 1.
15. Remove all disks from device 0.
16. Turn off power switch on device 0.
17. Turn off power switch on device 1.

9. Operating Procedure for K Series Calibration System

9.1 Prerun Electrical Routine for the K Series System

1. Check to see if temperature controllers are working properly.
2. Turn on constant current generator for calorimeter being calibrated. Connect a BNC cable from the output jack to the input of one of the DVMs in the K data acquisition rack.
3. Turn on power terminal strip for K data acquisition rack.
4. Turn on data acquisition unit.
5. Turn on preset controller.
6. Turn on tape unit.
7. Turn on MAIN POWER SWITCH in electrical calibration rack.
8. Disconnect three-phase power cord to the K calibration power supply.
9. Connect the power cord of the time interval counter to the ac power terminal strip mounted inside the back of the cabinet of the K calibration cabinet.
10. Install a coaxial cable from the time interval counter INPUT A to the BNC connector marked TIMER on the current regulator panel.
11. Connect a BNC cable from the lower DVM input to the BNC adapter marked CURRENT.
12. Connect a BNC cable from the upper DVM input to the BNC adapter marked VOLTAGE.
13. Connect the four wire cable from the current regulator block marked WRBG to box BX-1. Connect white, red, black, and green wires in box BX-1 to the matching colors on the terminal block.
14. Be sure the following initial conditions are true concerning the K calibration power supply before continuing.
    a. The 110 V terminal strip inside of the cabinet is switched OFF.
    b. The main power supply, an SCR power supply is switched off.
    c. The main power supply current and voltage controls are set fully counterclockwise.
    d. The water supply valve is closed.
    e. The power switch on the timer panel is OFF.
    f. The power switch on the current regulator panel is OFF.
    g. The power switch on the time interval counter is OFF.
    h. The calorimeter IN-OUT switch is in the OUT position.
    i. The POWER-DUMMY switch is in the POWER position.
    j. The LOAD ADJUST control on the POWER side is turned fully clockwise. This is a ten-turn potentiometer.
    k. The LOAD ADJUST control on the DUMMY side is turned fully clockwise. This is a ten-turn potentiometer.

15. The main power supply requires clockwise phase rotation. Plug the four-prong phase indicator into the three-phase power receptacle. If the phase is clockwise go to the next step. Otherwise, try another three-phase power receptacle or use a four-wire extension cord which reverses the phase.

16. Plug the three-phase, four-wire plug into a three-phase power source receptacle with clockwise phase rotation.

17. Plug the three-wire cable of the terminal strip located inside the back of the power supply cabinet into a 115 V three-wire, single-phase power source receptacle.

18. Turn the POWER switch of the main power supply to the ON position. The power supply indicator light will show red.

19. Turn ON the 115 V terminal strap located inside of the cabinet. Close the cabinet door.

20. Open the valve of the water supply and adjust the water flow to energize the interlock flow switch. The main power supply will then be energized and the power supply fan will operate.

21. Turn the POWER switch on the timer panel to the ON position. The red light and the OFF and READY lights will be lighted.

22. Turn on the power to the time-interval counter and adjust the knob for more than a half turn. The counter should be set to display the time in milliseconds.

23. Set the power switch on the current regulator panel to the ON position. The clear pilot light will be lighted.

24. At this time it is necessary to determine how much energy, in joules, is to be applied to the heater of the calorimeter. Next, the level of the electrical power and the length of time the power is to be applied must be determined. The DUMMY load resistance in the power supply and the resistance of the calorimeter calibration heaters are both approximately 100 Ω. A sample calculation is given below.

    Calibration energy desired: 1500 J

    Calibration power chosen: 50 W

$$\text{Time} = \frac{\text{Energy}}{\text{Power}} \quad \frac{1500}{50} = 30 \text{ s}$$

$$(\text{current})^2 = \frac{\text{Power}}{\text{Resistance}} = \frac{50}{100} = 0.5 \text{ A}^2$$

Current = 0.707 A

Voltage E1 = current x calorimeter resistance

E1 = 0.707 x 100 = 70.7 V

For a 1 Ω sensing resistor,

Voltage E2 = current x sensing resistance

E2 = 0.707 x 1 =0.707 V.

25. Turn both the voltage and current controls of the main power supply clockwise until the current shown by the dc ammeter is near the desired value. The voltmeter on the main power supply will indicate 100 times the current value.

26. The voltmeter on the current regulator panel, above the LOAD ADJUST controls, will indicate zero. The reading of the voltmeter that is on the current regulator panel above the CALORIMETER switch will match the voltage reading of the main power supply. Since the LOAD ADJUST switch is in the POWER position, the current through the power load resistance is then adjusted with the POWER control knob by turning it counterclockwise until LOAD ADJUST voltmeter indicates 10 to 20 V. The current is now regulated for the POWER side.
27. Switch the LOAD ADJUST switch to the DUMMY position to allow the current to go through the DUMMY load resistance. The voltmeter on the LOAD ADJUST side will now indicate the same as the main power supply.
28. The CALORIMETER voltmeter on the right hand side of the rack will indicate zero. Adjust the current through the DUMMY load by adjusting the DUMMY control by turning it counterclockwise until the calorimeter voltmeter indicates 10 to 20 V. The current through the DUMMY load is now regulated.
29. Adjust the current through the DUMMY load to the value previously determined for the calibration by alternately adjusting the current of the main power supply and the DUMMY control, while keeping the reading of the voltmeter on the CALORIMETER side between 10 and 20 V.
30. Alternately, switch the LOAD ADJUST switch between the DUMMY and POWER loads while observing the current indication on the main power supply ammeter. The POWER control should be adjusted to make the two currents nearly equal. This is observed by the needle deflection of the ammeter on the main power supply. The currents should be nearly equal to reduce the change in current on the power supply to a minimum during the switching operation.
31. Position the LOAD ADJUST switch to the POWER side. The voltmeter above this switch should indicate 10 to 20 V. The voltmeter above the calorimeter should indicate the same as the voltmeter on the main power supply.
32. Change the CALORIMETER switch to the IN position. The amber light will now be lighted.
33. Set the thumbnail switches on the timer panel to the number of seconds, the electrical energy is to be applied to the calorimeter heater.
34. Reset the time interval counter.
35. In the electrical calibration rack set upper DVM sample rate to EXT.
36. Set function switch to VDC on either the 100 or 1000 V scale.
37. Set clock to 02.0 s.
38. Press printer clock STOP/RESET switch.
39. Depress printer POWER switch to turn instrument on.
40. Test paper tape printout by pressing printer clock START switch and run a few seconds. Press STOP/RESET switch. Press PAPER to run out a short length of paper and tear off. Printout should show nearly 0 V.
41. Press printer POWER to turn off unit.
42. Press NBS clock OFF switch.
43. Set NBS clock unit to 020 for a 2 s interval.
44. Set lower DVM rate control to EXT. Set scale to 1 or 10 V dc.
45. On paper punch, press POWER ON switch.
46. Press DC ON switch.
47. Press FEED HOLES switch to advance paper tape.
48. Press clock STOP/RESET switch.
49. Press NBS clock unit OFF switch.
50. Press DATA OUTPUT switch to the depressed position.

51. Press NBS clock ON switch.
52. Punch should punch at interval set (2 s) on NBS clock.
53. Press NBS clock OFF to stop.
54. Before testing both printer and punch, press printer clock STOP/RESET and NBS clock OFF.
55. Depress printer POWER switch to turn unit on.
56. Press printer clock ON to start both printer and punch. Observe that both printer and punch are operating normally.
57. Press printer clock STOP/RESET switch to stop printer.
58. Press NBS clock OFF to stop punch.
59. Press printer PAPER switch and tear off paper.
60. Press punch FEED HOLES and tear off paper tape.
61. A test run can be made using the 100 Ω resistor in box BX-1 as a substitute for a calorimeter electrical heater. The LOAD ADJUST switch should be in the POWER position. The CALORIMETER switch should be in the IN position. The OFF and GO lights should show red. If not, press RESET on the timer panel. Reset the time interval counter.
62. When ready, press printer clock ON to start both printer and punch.
63. Press START on timer panel. The upper DVM should read approximately 70 V and lower DVM should read approximately 0.7 V. The letter C should appear in the time interval display.
64. At the end of the time interval the timer panel will automatically switch off and the OFF and NO-GO lights will show red. The time interval counter should give the same time as shown on the thumbnail switches.
65. The voltage E1 should be printed on the paper tape from the printer.
66. Press FEED HOLES and tear off punched paper tape. Turn teletype switch to LOCAL and place punched tape in tape reader. Press reader switch to begin a printout of voltage E2 on the teletype. The first column is the voltage reading across the sensing resistor. The second column is the DVM scale setting.
67. Turn off printer by pressing POWER switch again to prevent accidental paper run out.
68. Turn off punch by pressing POWER ON switch to off position to prevent accidental tape punching.
69. In the data acquisition rack, adjust preset controller switch #1 setting to 32.
70. Set thumbnail switches to 010.000 s.
71. Press data acquisition OFF switch.
72. Insert magnetic tape cartridge I in tape slot in tape unit.
73. Reset controller for a zero count.
74. On the tape unit, press REVERSE switch. While pressing WRITE switch, press RUN switch. Red light above WRITE should come on.
75. Check tape unit by pressing the data acquisition ON switch. Tape I should move a portion of a turn every 8 or 9 counts.
76. Observe that one of the DVMs is reading the voltage output of the calorimeter being calibrated.
77. When satisfied that operation is normal press data acquisition OFF switch.
78. On the tape unit, press the STOP switch and then the REVERSE switch to ready the tape unit for an actual run.
79. Go to routine for regular electrical run for the K series.

9.2 Prerun Beamsplitter or Calibrated Beam Routine for K Series

1. Check to see if temperature controllers are working properly.
2. Turn on constant current generators for both calorimeters.
3. Turn on data acquisition rack.
4. Turn on tape unit.
5. Turn on 115 V strip for helium laser and pulse generator.
6. Turn on other instruments that are used in the measurements such as amplifiers, integrating voltmeters, chart recorders, etc.
7. DO NOT ADJUST REGULATOR VALVES TO 3 GAS CYLINDERS.
8. Slowly turn on main valves on the top of the three gas cylinders. The regulated pressure gauges should read 40 psi.
9. Slowly turn on the small black valves on the side of each gas cylinder.
10. Inside the laser, locate the small valve on the right, labeled the nitrogen valve. For low-power runs this valve is closed. For high-power runs this valve is open. For medium-power runs the valve is set so the ball is at 1.75. See table for range of power values.
11. The current setting on the laser control panel is set for different power levels. See table 1 for different settings for different power levels.
12. Turn on cooling water to laser. Use the valve on the filter side that has a tag labeled "use this side." The input and output pressures should read nearly the same. Using both filters or the other filter and noting the different pressures should help determine when a filter needs changing.
13. Slowly turn on cooling water to shutter and adjust for 30 psi.
14. Turn on the main power switches on wall located to the left of the large switch.

Table 1. Laser Power Setting

ZnSe Beamsplitter					
Maximum Gas Mix			N_2 off watts		
Current	Reflected Beam	Trans. Beam	Current	Reflected Beam	Trans. Beam
200	41.7	166.4	200	6.9	27.7
250	45.9	185.2	250	8.3	33.4
300	51.7	206.4	300	9.8	39.3
350	54.6	222.5	350	11.1	44.6
400	56.9	225.6	400	12.4	49.9
450	62.5	251.1	450	13.6	55.0
500	61.3	246.3	500	14.7	59.3
550	66.0	265.5	550	15.6	64.0
600	68.8	280.4	600	16.9	68.5

KCL Beamsplitter

Current	N_2 off watts Reflected Beam	Trans. Beam
200	1.39	37.9
250	1.77	48.21
300	1.82	49.58
350	2.06	55.93
400	2.35	63.48
450	2.54	68.63
500	2.72	74.02
550	2.93	79.14
600	3.37	90.88

15. In the K series room there are 2 laser setups, the TEA laser and the K series. When either laser is on, everyone in the room wears plastic goggles. The laser for 10.6 μm is a powerful laser and can burn a hole in a fire brick. The beam is invisible and the only way we can tell where the transmitted and reflected beams are is by using heat sensitive paper and observing the burn pattern. This is useful for aligning the measuring instruments but only gives a rough approximation of the size of the beam.
16. A control booth with plastic panels is very useful for safely observing the experiment. Goggles are also worn as an extra precaution.
17. There are two safety warning lights outside the door of the K series room. A yellow light means the laser power supply is on but there is no high voltage being applied to the laser. A red light means the laser high voltage is producing a laser beam. With a yellow light, enter with caution. With a red light, don't enter or enter only with goggles on.
18. As you enter the K series room there is a semiprotected area where you can pick up a set of goggles before entering the rest of the room.
19. Take covers off of beamsplitter, mirrors, etc.
20. Connect output (+) of pulse generator to laser cable. Set pulse width (s) to 1. Set pulse width vernier to 9:00. Plug pulse generator into 110 V strip. Adjust laser pulse energy with pulse width vernier. See complete instructions for pulse generator.
21. Insert key in controls switch and set to ARM.
22. Put on goggles.
23. Press MASTER START button.
24. Let run for 5 min to equalize the gas.
25. Set MODE switch to RESET.
26. Press H.V. ON switch.
27. Set mode switch to EXT.
28. On PD-8 set shutter switch to MANUAL and other shutter switch to MANUAL OPEN SHUTTER.
29. Press MAN. switch once on pulse generator and observe any burn pattern on calorimeter target. For a darker burn, press MAN. switch again. You can also set VERNIER to 10:00 or 11:00 and press MAN. switch again.
30. Move beam splitter and/or instruments for best alignment of burn spot for each calorimeter and transfer instrument being used.

31. When satisfied with the alignment set MODE switch to RESET.
32. Press MASTER STOP button.
33. Adjust preset controller #1 setting to open the shutter on a count of 32.
34. Set preset controller #2 dial to the count needed for the desired time interval while observing the maximum and minimum limits of power, energy, and injection times for all the calorimeters and power meters being used. Use table for laser power settings and table for total point count as a guide.
35. Check out the tape unit, the laser shutter, and the time interval counter by making a dry run (without laser) as follows:
    a. In the K data acquisition rack, set thumbnail switches to 10.000 s.
    b. Press data acquisition OFF switch.
    c. Insert magnetic tape cartridge I in tape slot in tape unit.
    d. Reset preset controller for a zero count.
    e. Set automatic timer switch to MANUAL.
    f. Reset time interval counter.
    g. Set shutter switch to MANUAL OPEN SHUTTER. A letter C should appear on time interval counter.
    h. In a few seconds set shutter switch to MANUAL CLOSE SHUTTER.
    i. The C should disappear and the few seconds of count should appear in the readout.
    j. Set automatic timer switch to AUTOMATIC TIMER position.
    k. Reset time interval counter.
    l. On the tape unit press REVERSE switch. While pressing WRITE switch, press RUN switch. Red light above WRITE should come on.
    m. Begin the dry run by pressing the data acquisition ON switch. Tape cartridge I should move a portion of a turn every 8 or 9 counts.
    n. On count 32, the laser shutter should open. The shutter should then close when the count equals the preset controller #2 switch setting. The time interval counter should give the number of seconds that the shutter was actually open.
    o. Press data acquisition OFF switch.
    p. On the tape unit, press the STOP switch and then the REVERSE switch to ready the tape unit for an actual run.

9.3 Regular Electrical Run for K Series

1. Complete prerun electrical routine for the K series. Instruments should warm up for at least 1 h before making measurements. Locate KPAR notebook and determine the set of parameters for this run.
2. The K series log book is divided into three sections according to the type of measurement run. Fill in the specified data in the electrical calibration section.
3. Remove the cork from the calorimeter that is being calibrated.
4. In the electrical calibration rack, set upper DVM sample rate to EXT. Set function switch to 100 or 1000 V dc.
5. Set lower DVM rate control to EXT. Set voltage scale to 1 or 10 V dc.
6. Set printer clock to 010 or 020 for a 1 or 2 s interval.
7. Press clock STOP/RESET switch.
8. Press printer POWER switch to turn instrument on.
9. Press NBS clock OFF switch.

10. Set NBS clock unit to 010 or 020 for a 1 or 2 s interval.
11. Set lower DVM rate control to EXT. Set DVM scale to 1 or 10 V dc.
12. Press POWER ON switch on the paper punch.
13. Press DC ON switch.
14. Press FEED HOLES switch to advance paper tape and tear off excess paper.
15. Press printer clock STOP/RESET switch.
16. Press NBS clock unit OFF switch.
17. Press lower DVM DATA OUTPUT switch to the depressed position.
18. Press printer PAPER switch to advance paper and tear off to start with a clean tape.
19. Set LOAD ADJUST to DUMMY. Set CALORIMETER to IN. Press RESET on timer panel. The OFF and READY lights should be lighted. Set timer thumbnail switches according to parameter Z4 in KPAR notebook.
20. Press RESET on the time interval counter.
21. In the K data acquisition rack, adjust the preset controller switch #1 setting to 32.
22. On PD-8, set switch to automatic timer. The laser shutter should be closed.
23. Set thumbnail switches to 010.000 s.
24. Press K data acquisition ON switch. Observe that the DVM connected to the calorimeter to be calibrated is taking a voltage reading every 10 s in the normal range of 0100 to 1000. A higher value would indicate that the calorimeter has not cooled down enough from a previous run. Starting a new run above a reading of 1000 may cause the DVM to go off scale during the run; wait until the calorimeter has cooled sufficiently.
25. Position K data acquisition rack so the count reading can be seen from the electrical calibration rack.
26. When satisfied that both data acquisition systems are ready, press K data acquisition OFF switch.
27. Insert magnetic tape cartridge I in tape slot in tape unit.
28. Reset controller for a zero count.
29. Record run data in log book.
30. On the tape unit press REVERSE switch. While pressing WRITE switch, press RUN switch. Red light above WRITE switch should come on.
31. Press the K data acquisition ON switch.
32. Observe that the tape cartridge I moves a portion of a turn every 8 or 9 s.
33. On a count of 30, press printer clock ON to start printer and punch. If both are operating normally, proceed to the next step. If not, the run can be stopped by pressing K data acquisition OFF switch.
34. On a count of 32, press START switch on timer panel. The sound of the laser shutter can be used as a reminder. The red IN light on the regulator panel will be lighted to indicate that power is being applied to the calorimeter calibration heater. As previously set, the voltmeter above the CALORIMETER will change to indicate 10 to 20 V, and the voltmeter above LOAD ADJUST will indicate the same as the main power supply.

42. The time-interval counter will indicate that it is counting by displaying a letter C on the readout panel.
43. At the end of the preset time, the timer will return the electrical power to the POWER resistors. The timer's red OFF and NO GO lights will be lighted. The calorimeter's red IN light will extinguish.

44. Press printer clock STOP/RESET switch to stop printer.
45. Press NBS clock unit OFF switch to stop punch.
46. Press FEED HOLES to run out a short length of punched tape and tear off.
47. Turn off punch by pressing POWER switch, to prevent accidental paper run out.
48. Turn teletype switch to LOCAL and place punched tape in tape reader. Press reader switch to begin a printout of voltage E2 on the teletype. E2 is the average voltage reading during the time that energy was applied to the calorimeter.
49. On printer, press PAPER switch to advance paper tape for a short length and tear off. E1 is the average voltage reading during the time that energy was applied.
50. Turn off printer by pressing POWER switch to prevent accidental paper run out.
51. The time interval counter will display the injection time of the electrical power input to the calorimeter. Record the displayed time in log book.
52. Continue recording data on tape I until the count reaches the total count N1 as determined from the parameter set in KPAR notebook. Press K acquisition switch OFF to stop run.
53. Press STOP on tape unit.
54. Press REVERSE on tape unit.
55. Remove tape cartridge I from tape unit.
56. Take tape I paper tape for E1 and teletype copy of E2 readings to room 3082 for processing.
57. Go to computer parameter routine for the K series to continue the run.

9.4 Regular Beamsplitter or Calibrated Beam Run for the K series.

1. Complete prerun routine. Instruments should warm up for at least 1 h before making measurements.
2. The K series log book is divided into three sections according to type of measurement run. Fill in specified data in the appropriate section.
3. Before starting a run, press data acquisition ON switch for a sample of the high- and low-level calorimeter voltage readings on the two DVMs. If the voltages are 1 V or less proceed to next step. If readings are higher, they may go off scale during the measurement run. If necessary, wait until the calorimeters have cooled down before starting a regular run.
4. When ready and when an integrating DVM is being used, make and record a preintegrator run according to specific instructions before going to step 5.
5. Press data acquisition OFF switch.
6. If necessary, turn on tape unit.
7. Insert magnetic tape I in tape unit.
8. Reset preset controller to zero.
9. Set shutter timer to AUTOMATIC TIMER.
10. Be sure laser shutter is closed (blocking the beam).

13. On tape unit press REVERSE switch.
14. While pressing WRITE switch, press RUN. Red light above WRITE should come on.
15. Press data acquisition ON switch.
16. Tape should move a portion of a turn on count 8 or 9.
17. On a count of 9, turn laser key to ARM and set MODE switch to RESET.
18. On a count of 10, press MASTER START button.
19. On a count of 12, put on safety goggles.

20. On a count of 14, instruct all other personnel in room to put on safety goggles.
21. On a count of 20, press H.V. ON button and turn MODE switch to CONT. The laser is now sending a laser beam into the shutter.
22. If an integrating DVM is being used for this measuring run, on the count of 30, start the integration run.
23. On count 32, the shutter will automatically open and the time interval counter will display a letter C.
24. The high- or low-level DVM meters should respond to the laser energy.
25. When the shutter closes, the time interval counter should display the time the shutter was actually open. Record this time interval.
26. Set MODE switch to RESET.
27. On laser control panel press MASTER STOP button.
28. Inform all personnel that they may take off their goggles.
29. The data acquisition system will continue taking data until manually stopped by the operator.
30. If an integrating DVM is being used, record the DVM reading as the gross integration value at the end of the integration time period.
31. Start the integrating DVM again to obtain a postintegrator value. Average the preintegrator and postintegrator values and algebraically subtract from the gross integrator value to find the net integration value. Record value in data book for later use.
32. The computer program requires at least 31 data points after the maximum calorimeter reading. See the total point table for the minimum number of data points needed for this run. When this count is reached, press the data acquisition STOP switch.
33. On tape unit press STOP switch. Then press REVERSE switch.
34. Remove magnetic tape I.
35. Take tape I and data book to the computer room. Use the following computer parameter routine for the K series to complete this run.

9.5 Computer Parameter Routine for the K Series

1. In the computer room locate dual disk unit.
2. Locate device 1. Press power switch on.
3. Locate device 0. Press power switch on.
4. Update toy block day-month-year display above computer.
5. Turn on computer and type in the day-month-year hout-minute format. For example, for September 5, 1981, at 8:16 a.m. type CALL "SETTIM," "05-SEP-81 08:16." For today's date, use toy block display and for today's time, read 24-hour clock on the right side of the computer. The clock light should go out on device 0.
6. Determine the parameter code number for this type of run as follows:
   a. For runs on NBS-owned instruments use notebook KPAR.
   b. For runs on non-NBS-owned instruments use notebook SXCQK.
8. For runs not listed, enter a new set of parameters in the appropriate notebook in pencil.
9. Turn on computer and insert disk named MAINPROG in device 0.
10. Type CALL "MOUNT," 0, A$.
11. If the set of parameters is marked with a red check in the above notebook, proceed to the next step. If not, load the program listed at the top of the notebook page, for example, OLD "SKCP." Multiply code number XX by 100. List XX00,XX99 on computer to check the status

of the stored parameters for code number XX. For code number 18, a LIST 1800, 1899 prints those line numbers being used to store the code 18 parameters. Retype or type new line numbers to change or input new numbers. LIST 900, 999 for a sample format. When ready to store the correct numbers LIST 1 for the correct name of the program. Type SAVE "XXXX" where XXXX is the name of the program.

12. Load and run program SOP. Follow the computer instructions. At the end of the run program MAG1 will be loaded and waiting for operator input.
13. Press user-defined key "LIST PARA" to list parameters on the screen. Check these values with the values in the notebook and the K series data book. For corrections, repeat steps 11 and 12 or use program EDITTS to make corrections on magnetic tape K.
14. Program MAG1 is the first program in a chain of programs for computer processing of a K series measurement run. Operator input is required to start program MAG1. Instructions are then printed on the computer screeen for inputting certain data. The computer then automatically processes the run and provides a hard copy record from the printer and a permanent computer record of this run by adding pertinent data for this run to previous calibration data, stored on floppy disk MAIN DATA or disk MAINFDATA.
15. At the end of the run control of the computer is returned to program MAG1.
16. Check the hard copy printout for any mistakes caused by incorrect parameters or for any other reason.
17. To edit beamsplitter data on the disk file, load and run program EDIT7BD and follow program instructions.
18. To edit calibrated beam data on the disk file, load and run program EDIT6D and follow instructions.
19. To edit electrical calibration data on the disk file, load and run either EDIT2D or EDIT7ED and follow instructions.

9.6 Shutdown Electrical Routine for the K Series

1. Turn voltage and current controls on main power supply fully counterclockwise.
2. Turn both of the LOAD ADJUST controls fully clockwise.
3. Switch the calorimeter IN-OUT switch to the OUT position.
4. Switch the POWER DUMMY switch to the POWER position.
5. Switch the power to current regulator, timer, and time interval counter to OFF position.
6. Close the input water supply valve to allow the flow switch interlock to open. The main power supply is now off and the fan has stopped. Close the drain valve.
7. Switch the main power supply switch to the OFF position.
8. Turn OFF the power terminal strip inside of the K calibration rack and close the cabinet door.
9. Disconnect the 4-wire 208 power cord to the main power supply.
10. Turn OFF main power switch on electrical calibration rack.
11. Turn off pwoer terminal strip for K data acquisition rack.
12. Turn off constant current supply for calorimeters being calibrated
13. Replace cork in calorimeter aperture.

9.7 Shutdown Laser Routine for the K Series

1. Set MODE switch to RESET.
2. Press master STOP button.

3. Turn off three main gas valves on top of cylinders.
4. Open laser door on right end.
5. Open nitrogen valve on the right.
6. Press master START button.
7. Pump out gases for a short time until gas pressure for all three gauges goes to zero.
8. Turn off three small valves on side of gas regulators.
9. Close nitrogen valve inside of laser.
10. Close laser door.
11. Press master STOP button.
12. Set control key to DISARM.
13. Turn off laser-cooling water.
14. Turn off shutter-cooling water.
15. Turn off data acquisition rack
16. Turn off integrating DVM equipment.
17. Turn off 110 V strip under control unit which turns off 0.6328 laser, CO_2 laser power meter, and pulse generator.
18. Turn off two main electrical power switches on the wall.
19. Cover molybdenum mirrors.
20. Cover beamsplitters.
21. Put a cork in both calorimeters.
22. Turn off constant current supply to each calorimeter.
23. Cover power meters, attenuators, etc.

10. Operating Procedure for the Q Series Calibration System

10.1 Prerun Electrical Routine for the Q Series

1. Turn on main power switch in Q series rack.
2. Set switch on PA-3 to ELECTRICAL.
3. Turn on power switch on calibrating unit AU-4B.
4. Locate notebook QPAR and determine the code number with the set of parameters for this particular type of electrical run.
5. Check and, if necessary, make connections or adjust instrument settings to agree with the above parameters.

   G1 gain setting for low-level calorimeter. If not being used, G1 must equal 0.

   G2 gain setting for high-level calorimeter. If not being used, G2 must equal 0.

   A$-Must be the correct designation for the low-level calorimeter, if it is the calorimeter being calibrated. For instance, A$ for calorimeter Q1B on the 1E5 scale would be Q1B5.

   B$-Must be the correct designation for the high-level calorimeter if it is the calorimeter being calibrated. For instance, B$ for calorimeter Q1C on the 1E4 scale would be Q1C4.

   Z4-Set scaler-timer thumbnail switches to the value specified by Z4.

   R5-On back side of Q series rack, in unit AU-4B, plug in standard resistor with the value of resistance specified by R5.
6. Remove the cork from the calorimeter being calibrated.
7. Turn on amplifier connected to the calorimeter being electrically calibrated.
8. Set switch SW-4A to the calorimeter being calibrated.

9. Reset scaler-timer and press start for a dry run test. A relay should operate and the scaler-timer should start counting. When the count equals the thumbnail switch setting, the scaler-timer should stop the count and operate the relay again.
10. Reset the time interval counter.
11. Press and hold the test counter switch on AU-4B for a few seconds and observe that the letter C appears on the time interval counter display. Release the switch and the count should appear on the display.
12. Place twin banana plug in MANUAL position on AU-4B panel.
13. Plug the twin banana plut from the Q data acquisition unit into the standard resistor terminals on the AU-4B unit. Set thumbnail switches to 02.0 s. Press start button. Adjust power supply to produce the following E2 voltage according to the gain setting for the calorimeter being calibrated.

For amplifier gain	Approx. E2 (V)
1E4	0.50
1E5	0.16

14. Complete the prerun computer and parameter routine for the C series at this time to allow at least 1 h warmup of the data acquisition equipment.

10.2 Prerun Beamsplitter or Calibrated Beam Routine for the Q Series

1. Safety precautions. Because of the high peak power, the YAG Q-switched laser is considered our most dangerous laser concerning possible eye damage. Goggles, specially designed to block 1.064 μm radiation, must be worn whenever the laser is turned on. Sometimes the laser will fire without being triggered in the normal way. As a safety precaution a manually-operated beam blocker is kept in front of the laser at all times except during beam alignment or an actual laser run.
2. Complete the prerun computer and parameter routine for the Q series so the equipment can be warming up. Return to step 3.
3. Proceed to Q series room and turn on main power switch in Q series rack.
4. Set switch on Panel PA-3 to LASER.
5. Turn on amplifier connected to the high-level calorimeter. Leave cork in calorimeter aperture.
6. Uncover beam splitter SF-61.
7. Turn on amplifier connected to the low-level calorimeter. Leave cork in calorimeter aperture.
8. If this is a calibration beam run, set the transfer instrument to the proper scale and place at the desired high or low position. Turn instrument on.
9. Plug in 110 V power cord to laser monitor control box.
10. Turn on safety light switch at door entrance.
11. Put on 1.064 goggles.
12. Be sure corks are in place in calorimeter apertures.
13. Locate laser power supply and turn on main power switch.
14. Check that the yellow light outside the room blinks when the manual shutter is in a position that would block the laser beam. The shutter is now in the closed position.
15. Check that the red light outside of the room blinks when the manual shutter is in a position that would not block the laser beam. The shutter is now in the open position.
16. Hook chain to block passageway.

17. On the laser power supply panel set pulses/second switch to 1.
18. On the same panel set amplifier switch to off position.
19. Set key switch to vertical position.
20. Press operate/standby switch to operate laser. Laser will fire one pulse per second until operate/standby switch is pressed again.
21. Use the IR phosphor card to align the laser beam through the center of the beamsplitter and to the centers of the calorimeters and transfer instruments being used.
22. Press operate/standby switch to stop laser.
23. Close the manual shutter.
24. On power supply panel set pulses/second switch to EXT.
25. Set amplifier switch to ON position.
26. Set key switch to the horizontal position.
27. Turn off main power switch on laser power supply panel.
28. All system instruments, except the laser, should have a warm up period of at least one hour before making a measurement run.
29. Remove chain from passageway.
30. For a calibrated beam run using an energy transfer meter, set switches to the desired energy and time scales. See specific instructions for the instrument being used. Make an integrator run without laser input to check and adjust instrument.
31. Locate the notebook with the set of parameters used in the prerun computer routine and compare the parameter values with the actual instruments and settings in the Q series room.
32. In particular, check for the correct designation and amplifier gain of each calorimeter. If a calorimeter is not being used, then the G1 or G2 parameter must set to zero.
33. Set Z4 time on scaler-timer thumbnail switches.
34. On CU-1 unit, set PPS switch to R5.

10.3 Prerun Computer and Parameter Routine for the Q series

1. In the computer room, locate the dual disk unit.
2. Locate device 1. Press power switch on.
3. Locate device 0. Press power switch on.
4. Update toy block day-month-year display above computer.
5. Turn on computer and type in the day-month-year hour-minute format. For example, for September 5, 1981, at 8:16 a.m., type CALL "SETTIM," "05-SEP-81 08:16." For today's date, use toy block display and for today's time, read 24-hour clock on the right side of the computer. The clock light should go out on device 0.
6. Turn on main power switch in data acquisition rack.
7. Determine the parameter code number for this particular type of run.
8. For runs on NBS-owned instruments, use notebook QPAR.
9. For runs on non-NBS-owned instruments, use notebook SXCQK.
10. For runs not listed, enter a new set of parameters in pencil in the appropriate notebook.
11. Turn on computer and insert disk named MAINPROG in device 0.
12. Type CALL "MOUNT," 0, A$.
13. If the set of parameters is marked with a red check in the above notebook, proceed to the next step. If not, load the program listed at the top of the notebook page, for example OLD "SQCE." Multiply code number XX by 100. List XX00, XX99 on the computer to check the status of the stored parameters for code number XX. For code number 18, a LIST 1800, 1899 prints

those line numbers being used to store the code 18 parameters. Retype or type new line numbers to change or input new numbers. LIST 400, 499 for a format. When ready to store the correct numbers, LIST 1 for the correct name of the program. Type SAVE "XXXX" where XXXX is the name of the program.

14. Load and run program SOP by typing OLD "SOP." When loaded, type RUN. Follow the computer instructions. At the end of the run program AMEM4 will be loaded and running.
15. Press user-defined key "LIST PARA" to list parameters on the screen. Check these values with the values in the notebook. For corrections, repeat steps 13 and 14 or use program EDITTS to make corrections directly on magnetic tape Q.
16. If this is not an electrical run, go to step 17. Otherwise, press user-defined key E1. The system DVM should read nearly zero. Press user-defined key E2. The power supply in the Q series rack should be adjusted to produce the following E2 voltages:

For amplifier gain	Approx. E2 (V)
1E4	0.50
1E5	0.16

17. Program AMEM4 will automatically start a measurement run at 15 min past the hour or at any time the user-defined key START RUN is pressed. For laser runs, control is transferred to the Q series room. To prevent AMEM4 from automatically starting a run, press break key on computer key board.

10.4 Regular Electrical Run for the Q Series

1. Complete prerun electrical and computer routines. Instruments should warm up at least 1 h before making measurements.
2. If program AMEM4 is not in control, type OLD "AMEM4." When loaded, type RUN. Check screen display for the correct parameters by pressing user-defined key LIST PARA. If not okay, either load and run program, EDITTS, or repeat prerun computer and parameter routine for the C series.
3. For an electrical run on a calorimeter in the low-level position, press user-defined key LOW LEVEL DVM. This voltage should show a normal negative value on the system DVM before starting a run. Normal values, according to amplifier scales, are as follows:

Amplifier scale	DVM voltage range
1E4	-0.3 to -0.6
1E5	-9.0 to -6.0

4. For an electrical run on a calorimeter in the high-level position, press user-defined key HIGH LEVEL DVM. This voltage should show a normal negative value on the system DVM before starting a run. Use the above values as a guide.
5. Press user-defined key E1. The system DVM voltage should read nearly zero.
6. Press user-defined key E2. The system DVM should read approximately 0.5 V for runs using a gain of 1E4 or approximately 0.16 V for runs using a gain of 1E5.
7. Place twin banana plug in RELAY position on AU-4B panel.
8. Program AMEM4 will automatically start a run every hour at 15 min past the hour or when the user-defined key START RUN is pressed.

9. At the beginning of a run the computer will reset the preset controller and scaler-timer.
10. The preset controller will then start the run and display the latest count at 4 s intervals.
11. The computer screen will display the count, the low- and high-level calorimeter voltage readings, and the electrical calibration voltages, E1 and E2. E1 is the voltage across the calorimeter heater. E2 is the voltage across the standard resistor.
12. This run and identical subsequent runs will continue every hour without further operator attention until 4:30 p.m.
13. On count 32, the scaler-timer will switch electrical energy to the calorimeter being calibrated for the time interval set on the thumbnail switches.
14. The computer will continue the run until a count of N1 points is displayed. The computer then processes the run and provides a hard copy record from the printer and permanent computer storage by adding pertinent data for this run to previous calibration data stored on floppy disk MAIN DATA.
15. At the end of the run control of the computer is returned to program AMEM4.
16. After the first run check the hard copy printout for any mistakes caused by incorrect parameters or any other reason. To correct parameter values, load and run program EDITTS or repeat the prerun computer and parameter routine for the Q series.
17. To edit electrical calibration data on the disk file, load and run either EDIT7ED or EDIT2D program and follow program instructions. Program Q1BCC and Q1CCC are 7-column electrical files for Q1B and Q1C. Q1B4, Q1B5, Q1C4, and Q1C5 are 2-column electrical calibration files.
18. To compare electrical runs with previous electrical runs, load and run program ELSCAN. A plot of percent variation of electrical calibration values from the average versus time in years will appear on the screen.
19. To continue with more identical runs, load and run program AMEM4.
20. For other types of runs go back to the prerun routines.

10.5 Regular Beamsplitter or Calibrated Beam Run for the Q Series

1. Complete two Q series prerun routines.
2. If necessary, load and run program AMEM4 on computer. When ready, press user-defined key START RUN to transfer control to Q series room. Go to the Q series room.
3. If this is a beamsplitter run, go to step 4. If a transfer instrument is being calibrated, remove aperture covers and take and record a preintegrator reading. See specific instructions for the instrument being calibrated. Reset instrument for a laser measurement.
4. Remove corks from calorimeter apertures.
5. Turn on the safety light switch at the door entrance.
6. Place chain to block the passageway.
7. Put on 1.064 μm goggles.
8. Locate the laser power supply and turn on the main power switch.
9. Set pulses/second switch to EXT.
10. Set amplifier switch to ON position.
11. Set key switch to vertical position.
12. Press operate/standby switch to put laser in OPERATE mode.
13. Press red START RUN switch in Q series rack to begin computer run.
14. Computer will reset dual preset controller and scaler-timer.
15. Preset controller should display latest count every 4 s.
16. On a count of 20, press start button on CU-1 unit.

17. On a count of 25, open manual shutter. Red light should go on.
18. If this is a beamsplitter run, go to step 20.
19. If measurements are being made on an energy transfer meter, press start measurement switch 1 or 2 s after a count of 31.
20. On a count of 32, the scaler-timer should fire the laser for the time period set by the thumbnail switches.
21. After the end of above time period, press reset switch on CU-1 unit.
22. Close manual shutter.
23. For a beamsplitter run go to step 27.
24. When ready light comes on, record meter reading as the gross integrator reading.
25. Reset integrator according to the specific instructions for this instrument.
26. Press START measurement switch for a postintegrator reading.
27. When preset controller reaches a count of 100, press operate/standby switch to stop laser.
28. Turn the key switch to the horizontal position.
29. Turn off main power switch on power supply panel. Remove safety goggles. For a beamsplitter run go to step 35.
30. When the ready light on the meter comes on, record meter as postintegrator value.
31. Average pre- and postintegrator readings and algebraically subtract from gross integrator value to obtain the net integrator value. Remove the safety chain.
32. Proceed to computer room and type net integrator reading on computer according to instructions.
33. If the computer asks for Z4, type in the number of seconds the scaler-timer thumbwheel switches are set to.
34. If the computer asks for R5, type in the pulse rate per second.
35. Computer should complete the run without further assistance.
36. At the end of the run, computer control is returned to control program AMEM4. Computer will automatically start next run at 15 min past hour or when START RUN key is pressed.
37. Check hard copy printout for any mistakes caused by incorrect parameters.
38. To edit beamsplitter data on the disk file, load and run program EDIT7BD and follow program instructions.
39. To edit calibrated beam data on the disk file, load and run program EDIT6D and follow instructions.
40. To compare beamsplitter runs with previous beamsplitter runs, load and run program BSCAN. A plot of percent variation of beamsplitter ratio from the average versus time in years will appear on the screen.
41. To compare calibrated energy beam runs with previous runs, load and run program ESCAN. A plot of percent variation of calibration factor from the average versus time in years will appear on the screen.
42. For more identical runs, load and run AMEM4 to prepare for the next run.

10.6 Shutdown Routine for the Q Series

1. In Q series room, move manual shutter to closed position.
2. On laser power supply panel, set key switch in horizontal position and turn off main power switch.
3. Turn off main power switch in Q series rack.
4. Place twin banana plug in manual position on unit. Turn off power switch on AU-4B unit.

5. Unplug 110 V power cord to laser monitor control box.
6. Turn off the amplifier connected to the low-level calorimeter. Insert cork in the aperture of the low-level calorimeter.
7. Replace cover for beamsplitter SF-61.
8. Turn off the amplifier connected to the high-level calorimeter. Insert cork in the aperture of the high-level calorimeter.
9. Turn off power to any transfer instruments or other equipment being used.
10. Turn off safety light switch at door entrance.
11. In computer room 3082, turn off main power switch in data acquisitiion rack.
12. Turn off printer switch.
13. Remove magnetic tape Q from the computer.
14. Turn off computer.
15. Remove all disks from device 1.
16. Remove all disks from device 0.
17. Turn off power switch on device 0.
18. Turn off power switch on device 1.

11. Operating Instructions for MAP Transfer Standards

11.1 Silicon Detector Measurements at 1 μW at 0.6328 μm

1. Operating instructions for laser power meters SIL 12.5, SIL 14, SIL 15, and SIL 16 with silicon photovoltaic detector heads.
2. Important! Be sure that the black plastic cap is always in place when the detector is not being used. Be careful not to touch the silicon detector with fingers or any other object. A windowless detector is being used because it is believed that it will offer the best precision and accuracy for an HeNe laser measurement. If dust particles interfere with a good measurement, remove dust from the detector surface with dry nitrogen gas from at least 30 cm away to avoid condensation on the detector.
3. This instrument has only been evaluated for measurements of approximately 1 μW and 1 mW of HeNe (632.8 nm) laser radiation; use at power levels above 1 mW may damage the instrument. The two calibration constants may not apply for powers signficantly different than 1 μW or 1 mW or at wavelengths other than 632.8 nm.
4. Be sure that flux per unit area never exceeds 250 ms/cm^2. If an imaging lens is used with a 1 mW HeNe laser, it is possible to exceed this limit without observing an off-scale meter reading. It will result in an inaccurate measurement, but more importantly, it could cause irreparable local damage to the silicon detector.
5. The switch on the back panel of the readout unit must be in the slow position.
6. The switch on the head must be set on position 5. This causes the automatic wavelength annunciator on the front panel of the readout unit to indicate a wavelength of 632.8 nm.
7. For 1 mW power measurements, set the watts switch to 0.001. Several meter readings are taken by eye and recorded doing a laser run. An average laser-on reading is calculated. Meter readings before and after the laser input are also taken and an average laser-off reading is calculated. Subtracting the average laser-off reading from the average laser-on reading gives the net meter reading to use for meter calibration. Ambient light is generally not a problem on the 0.001 W scale.
8. For 1 μW power measurements, the watts switch is set to 0.000001. It is necessary to reduce the ambient room light to nearly complete darkness to reduce the laser-off reading to a small

value (0.001, 0.002, or 0.003, for instance). It may be necessary to enclose the detector head in a light-tight box and/or use a tube in front of the head. We presently use a 79 cm-long tube with a diameter of 5.5 cm.

9. We use a laser beam size of 2 or 3 mm.
10. Calibration information for the two power levels for this instrument is on a label affixed to the unit unless some other arrangement has been made.
11. Normal baseline readings (laser off) for average room lighting on 1 mW scale should be plus or minus 0.050, or less. Readings greater than this can sometimes be reduced by removing the plastic cover on the meter face and blowing clean air or dry nitrogen on circuitry around the meter face. If you have further questions, call NBS.

11.2 Silicon Detector Measurements at 2 μW at 0.6328 μm

1. Operating instructions for laser power meters SIL 12.5, SIL 14, SIL 15, and SIL 16 with silicon photovoltaic detector heads.
2. Important! Be sure that the black plastic cap is always in place when the detector is not being used. Be careful not to touch the silicon detector with fingers or any other object. A windowless detector is being used because it is believed that it will offer the best precision and accuracy for a HeNe laser measurement. If dust particles interfere with a good measurement, remove dust from the detector surface with dry nitrogen gas from at least 30 cm away to avoid condensation on the detector.
3. This instrument has only been evaluated for measurements of approximately 2 μW of HeNe (632.8 nm) laser radiation. Use at power levels above 1 mW may damage the instrument. The calibration constant does not apply for powers signficantly different than 2 μW or at wavelengths other than 632.8 nm.
4. Be sure that flux per unit area never exceeds 250 mW/cm^2. If an imaging lens is used with a 1 mW HeNe laser, it is possible to exceed this limit without observing an off-scale meter reading. It will result in an inaccurate measurement, but more importantly, it could cause irreparable local damage to the silicon detector.
5. The switch on the back panel of the readout unit must be in the slow position.
6. The switch on the head must be set on position 5. This causes the automatic wavelength annunciator on the front panel of the readout unit to indicate a wavelength of 632.8 nm.
7. For 2 mW power measurements, set the watts switch to 0.00001. Several meter readings are taken by eye and recorded doing a laser run. An average laser-on reading is calculated. Meter readings before and after the laser input are also taken and an average laser-off reading is calculated. Subtracting the average laser-off reading from the average laser-on reading gives the net meter reading to use for meter calibration. It may be necessary to reduce the ambient room light to nearly complete darkness to reduce the laser-off reading to a small value (0.001, 0.002, or 0.003, for instance). It may be necessary to enclose the detector head in a lightproof box and/or use a tube in front of the head. We presently use a 79 cm-long tube with a diameter of 5.5 cm.
8. We use a laser beam size of 2 or 3 mm.
9. Calibration information for the 2 μW level for this instrument is on a label affixed to the unit unless some other arrangement has been made.
11. Normal baseline readings (laser off) for average room lighting on 1 mW scale should be plus or minus 0.050, or less. Readings greater than this can sometimes be reduced by removing the

plastic cover on the meter face and blowing clean air or dry nitrogen on circuitry around the meter face. If you have further questions, call NBS.

11.3 Silicon Detector Measurements at 1 mW at 0.6328 μm

1. Operating instructions for laser power meters SIL 12.5, SIL 14, SIL 15, and SIL 16 with silicon photovoltaic detector heads.
2. Important! Be sure that the black plastic cap is always in place when the detector is not being used. Be careful not to touch the silicon detector with fingers or any other object. A windowless detector is being used because it is believed that it will offer the best precision and accuracy for an HeNe laser measurement. If dust particles interfere with a good measurement, remove dust from the detector surface with dry nitrogen gas from at least 30 cm away to avoid condensation on the detector.
3. This instrument has only been evaluated for measurements of approximately 1 mW of HeNe (632.8 nm) laser radiation; use at power levels above 1 mW may damage the instrument. The calibration constant may not apply for powers signficantly different than 1 mW or at wavelengths other than 632.8 nm.
4. Be sure that flux per unit area never exceeds 250 mW/cm^2. If an imaging lens is used with a 1 mW HeNe laser, it is possible to exceed this limit without observing an off-scale meter reading. It will result in an inaccurate measurement, but more importantly, it could cause irreparable local damage to the silicon detector.
5. The switch on the back panel of the readout unit must be in the slow position.
6. The switch on the head must be set on position 5. This causes the automatic wavelength annunciator on the front panel of the readout unit to indicate a wavelength of 632.8 nm.
7. For 1 mW power measurements, set the watts switch to 0.001. Several meter readings are taken by eye and recorded doing a laser run. An average laser-on reading is calculated. Meter readings before and after the laser input are also taken and an average laser-off reading is calculated. Subtracting the average laser-off reading from the average laser-on reading gives the net meter reading to use for meter calibration. Ambient light is generally not a problem on the 0.001 W scale.
8. We use a laser beam size of 2 or 3 mm.
9. Normal baseline readings (laser off) for average room lighting on 1 mW scale should be plus or minus 0.050, or less. Readings greater than this can sometimes be reduced by removing the plastic cover on the meter face and blowing clean air or dry nitrogen on circuitry around the meter face. If you have further questions, call NBS.

11.4 Laser Power Measurements Using Transfer Meter, TC15

1. Operating instructions for cw laser power measurements using power meter TC15, with meter NBS number 145348.
2. Unpack the above instrument (hereafter referred to as TC15) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC15 has three power scales, 10, 100, and 1000 mW. Normally, a calibration number in meter reading units/mW is furnished only for the 100 and 1000 mW scales.
5. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 2 to 5 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window

is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.

6. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
7. Block laser beam.
8. See drawing of meter calibrator unit.
9. Set range switch to desired power range.
10. Set measurement selector switch to laser power not timed.
11. Set control in upper right hand corner to power or energy position.
12. Adjust calorimeter baseline potentiometer for a zero meter reading.
13. Allow 2 min for instrument to reach a steady state condition.
14. Record the sign and meter reading. This is the prelaser baseline reading.
15. Apply laser power. Allow at least 2 min for instrument to come to a steady state condition.
16. Record five laser power meter readings taken 40 s apart.
17. Average the five meter readings for an average laser meter value.
18. Block the laser beam and wait 2 min then record the meter reading. This is the postlaser baseline reading.
19. Average the two baseline readings and algebraically subtract from the average laser meter value.
20. Calculate the laser power by dividing the net meter value by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the laser power.

11.5 Laser Energy Measurements Using Transfer Meter, TC15

1. Operating instructions for Q-switched and continuous wave laser energy measurements using energy meter, TC15, with meter, NBS number 145348.
2. Unpack the above instrument (hereafter referred to as TC15) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC15 has three energy scales, 100 mJ, 1 and 10 J. Normally, a calibration number in meter reading units/J is either furnished for both the 1 and 10 J scales or only for the 10 J scale.
5. Energy can only be put into TC15 for a period of 10 s or less, or 100 s or less. TC15 then continues to integrate for 90 s more to complete the integral as shown on the meter. Generally, this means measuring the energy of a train of Q-switched pulses where the energy per pulse times the number of pulses in a 10 s or a 100 s period or less gives a total energy between 0.1 and 10 J.
6. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 5 to 10 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.
7. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.

c. Arrange timing of laser shutter or beam blockers to insure that the TC15 meter is integrating at least a short period of time before the laser beam is applied. With accurate timing this time period may be a few tenths of a second.

d. Arrange timing of shutters (beam blockers) so that laser input is terminated by the end of the 10 or 100 s period.

8. Block laser beam.
9. Set selector switch in upper right hand corner to power or energy position.
10. Set range switch to desired energy range.
11. Set toggle switch above adjust integrator baseline knob to up position.
12. Set measurement selector switch to laser power not timed position.
13. Adjust calorimeter baseline potentiometer for a zero meter reading.
14. Set measurement selector switch to laser 10 or 100 s position.
15. Momentarily set adjust integrator baseline toggle switch to down position and return to up position.
16. Adjust integrator baseline knob for a stable meter reading.
17. Repeat steps 14 and 15 until you get a stable reading.
18. To get a preintegrator reading, set toggle switch to down position.
19. Press start measurement button. The ready light will go out.
20. In 100 or 190 s the ready light will come on.
21. Record the sign and meter reading. This is the preintegrator offset value.
22. For a laser energy measurement, press restart meter button.
23. Press start button to start integrating just before applying laser input.
24. Apply laser energy for 10 s or less or 100 s or less depending on meter range.
25. The meter will continue to integrate for 90 s more to give a total integration time of 100 or 190 s.
26. At the end of the integration time, the red light will come on.
27. Record the laser energy meter reading.
28. Press restart meter button.
29. Repeat steps 18 and 19.
30. Record the sign and meter reading. This is the postintegrator offset value. Average the two values and algebraically subtract from the integrator reading.

20\. Calculate the energy by dividing the net integrator reading by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the energy.

11.6 Laser Power Measurements Using Transfer Meter, TC24

1. Operating instructions for cw laser power measurements using power meter, TC24, with meter, NBS number 145926.
2. Unpack the above instrument (hereafter referred to as TC24) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC24 has three power scales, 10, 100, and 1000 mW. Normally, a calibration number in meter reading units/mW is furnished only for the 100 and 1000 mW scales.
5. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 2 to 5 mm diameter. Alignment

is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.

6. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
7. Block laser beam.
8. Set laser-heater switch to laser position.
9. Set measurement mode switch to untimed power.
10. Set switch on back of instrument to average P.
11. Set meter display switch to calorimeter.
12. Set range switch to desired power range.
13. Adjust calorimeter baseline potentiometer for a zero meter reading.
14. Allow 2 min for instrument to reach a steady state condition.
15. Record the sign and meter reading. This is the prelaser baseline reading.
16. Apply laser power. Allow at least 2 min for instrument to come to a steady state condition.
17. Record five laser power meter readings taken 40 s apart for a total power input time of 300 s.
18. Average the five meter readings.
19. Block the laser beam and wait 2 min. Then record the meter reading. This is the postlaser baseline reading.
20. Average the two baseline readings and algebraically subtract from the average laser power reading.
21. Calculate the laser power by dividing the net meter value by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the laser power.

11.7 Laser Energy Measurements Using Transfer Meter, TC24

1. Operating instructions for Q-switched and continuous wave laser energy measurements using energy meter, TC24, with meter, NBS number 145926.
2. Unpack the above instrument (hereafter referred to as TC24) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC24 has three energy scales, 100 mJ, 1 and 10 J. Normally, a calibration number in meter reading units/J is only furnished for the 1 or 10 J scale on the 10 s range.
5. Energy can only be put into TC24 for a period of 10, 20, or 40 s or less. TC24 then continues to integrate for 90 s more to complete the integral as shown on the meter. Generally, this means measuring the energy of a train of Q-switched pulses where the energy per pulse times the number of pulses in a 10, 20, or 40 s period or less gives a total energy between 0.1 and 10 J.
6. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 5 to 10 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.

7. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
   c. Arrange timing of laser shutter or beam blockers to insure that the TC24 meter is integrating at least a short period of time before the laser beam is applied. With accurate timing this time period may be a few tenths of a second.
   d. Arrange timing of shutters (beam blockers) so that laser input is terminated by the end of the 10, 20, or 40 s period.
8. Block laser beam.
9. Set the laser-heater switch to off.
10. Set measurement mode switch to energy.
11. Set range switch to proper energy scale.
12. Set switch on back of instrument to 10, 20, or 40 s.
13. Set meter display switch to calorimeter.
14. Adjust calorimeter baseline potentiometer for a zero meter reading.
15. Set laser-heater switch to laser.
16. Set display switch to integrator.
17. Press start button. The ready light will go out.
18. In 100 or 140 s the ready light will come on.
19. Record the sign and meter reading. This is the preintegrator offset value.
20. Erase meter reading by switching display switch to calorimeter and back to integrator.
21. Make sure display switch is set to integrator.
22. Press start button to start integrating just before applying laser input.
23. Apply laser energy for 10, 20, or 40 s or less.
24. The meter will continue to integrate for 90 s more.
25. At the end of the integration time the red light will come on.
26. Record the laser energy meter reading.
27. Erase meter reading by switching display switch to calorimeter and back to integrator.
28. Repeat steps 15, 16, and 17.
29. Record the sign and meter reading. This is the postintegrator offset value. Average the two offset values and algebraically subtract from the integrator reading.
30. Calculate the energy by dividing the net integrator reading by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the energy.

11.8 Laser Power Measurements Using Transfer Meter, TC36

1. Operating instructions for cw laser power measurements using power meter, TC36, with meter, NBS number 146232.
2. Unpack the above instrument (hereafter referred to as TC36) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC36 has three power scales, high, middle, and low, which correspond, respectively, to 10, 100, and 1000 mW.
5. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 2 to 5 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter

input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.

6. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
7. Block laser beam.
8. Analog output is available on back panel.
9. Set range switch to desired power range. Use middle scale for 100 mW measurements.
10. Set meter switch to calorimeter.
11. Calorimeter heater toggle switch should be set to off position.
12. Adjust signal bias control for a zero meter reading.
13. Allow 2 min for instrument to reach a steady state condition.
14. Record the sign and meter reading. This is the prelaser baseline reading.
15. Apply laser power. Allow at least 2 min for instrument to come to a steady state condition.
16. Record five laser power meter readings taken 40 s apart.
17. Average the five meter readings for an average laser meter value.
18. Block the laser beam and wait 2 min. Then record the meter reading. This is the postlaser baseline reading.
19. Average the two baseline readings and algebraically subtract from the average laser meter value.
20. Calculate the laser power by dividing the net meter value by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the laser power.

11.9 Laser Power Measurements Using Transfer Meter, TC39

1. Operating instructions for cw laser power measurements using power meter, TC39, with meter, NBS number 147103.
2. Unpack the above instrument (hereafter referred to as TC39) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC39 has three power scales, high, middle, and low, which correspond, respectively, to 1 W, 100 and 10 mW.
5. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 2 to 5 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.
6. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
7. Block laser beam.
8. Set power-energy switch to power.
9. Set range switch to desired power range.
10. Set meter switch to repetitive read.

11. Calorimeter heater toggle switch should be set to laser position.
12. Adjust calorimeter baseline control for a zero meter reading.
13. Allow 2 min for instrument to reach a steady state condition.
14. Record the sign and meter reading. This is the prelaser baseline reading.
15. Apply laser power. Allow at least 2 min for instrument to come to a steady state condition.
16. Record five laser power meter readings taken 40 s apart.
17. Average the five meter readings for an average laser meter value.
18. Block the laser beam and wait 2 min, then record the meter reading. This is the postlaser baseline reading.
19. Average the two baseline readings and algebraically subtract from the average laser meter value.
20. Calculate the laser power by dividing the net meter value by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the laser power.

11.10 Laser Energy Measurements Using Transfer Meter, TC39

1. Operating instructions for Q-switched and continuous wave laser energy measurements at 1.064 μm using energy meter, TC39, with meter, NBS number 147103.
2. Unpack the above instrument (hereafter referred to as TC39) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC39 has three energy scales, 100 mJ, 1 and 10 J. Normally, a calibration number in meter reading units/J is only furnished for the 1 or 10 J scale on the 10 s range.
5. Energy can only be put into TC39 for a period of 10, 20, or 40 s or less. TC39 then continues to integrate for 90 s more to complete the integral as shown on the meter. Generally, this means measuring the energy of a train of Q-switched pulses where the energy per pulse times the number of pulses in a 10, 20 or 40 s period or or less gives a total energy between 0.1 and 10 J.
6. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 5 to 10 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.
7. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
   c. Arrange timing of laser shutter or beam blockers to insure that the TC39 meter is integrating at least a short period of time before the laser beam is applied. With accurate timing this time period may be a few tenths of a second.
   d. Arrange timing of shutters (beam blockers) so that laser input is terminated by the end of the 10, 20, or 40 s period.
8. Block laser beam.
9. Set the laser-heater switch to off.
10. Set measurement mode switch to energy.
11. Set range switch to proper energy scale.

12. Set switch on front of instrument to 10, 20, or 40 s.
13. Set meter display switch to repetive read.
14. Adjust calorimeter baseline potentiometer for a zero meter reading.
15. Set display switch to read hold.
16. Press start button. The ready light will go out. Meter reading should be zero. If not, wait until ready lights come on and repeat this step.
17. In 100 to 140 s the ready light will come on.
18. Record the sign and meter reading. This is the preintegrator offset value.
19. Do not erase meter reading by switching display switch to repetitive read and back to read hold.
20. For a laser energy measurement, set laser-heater switch to laser.
21. Make sure display switch is set to read hold.
22. Press start button to start integrating just before applying laser input.
23. Apply laser energy for 10 or 100 s or less depending on meter range.
24. The meter will continue to integrate for 90 s more to give a total integration time of 100 or 190 s.
25. At the end of the integration time, the red lights will come on.
26. Record the laser energy meter reading.
27. Set the laser-heater switch to off.
28. Erase meter reading by switching display switch to repetitive read and back to read hold.
29. Press start button. Ready light should go out. If not, wait until ready light comes on and repeat.
30. Record the sign and meter reading. This is the postintegrator offset value. Average the two values and algebraically subtract from the integrator reading.
20. Calculate the energy by dividing the net integrator reading by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the energy.

11.11 Laser Power Measurements Using Transfer Meter, TC45

1. Operating instructions for cw laser power measurements using power meter, TC45.
2. Unpack the above instrument (hereafter referred to as TC45) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC45 has three power scales, high, middle, and low, which correspond, respectively, to 1 W, 100 and 10 mW.
5. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 2 to 5 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.
6. Precautions:
   a. Avoid focusing the laser beam on very small area.
   b. Avoid heating up calorimeter absorbing glass with sustained laser input.
7. Block laser beam.
8. Set power-energy switch to power.

9. Set range switch to desired power range.
10. Set meter switch to repetitive read.
11. Calorimeter heater toggle switch should be set to laser position.
12. Adjust calorimeter baseline control for a zero meter reading.
13. Allow 2 min for instrument to reach a steady state condition.
14. Record the sign and meter reading. This is the prelaser baseline reading.
15. Apply laser power. Allow at least 2 min for instrument to come to a steady state condition.
16. Record five laser power meter readings taken 40 s apart.
17. Average the five meter readings for an average laser meter value.
18. Block the laser beam and wait 2 min, then record the meter reading. This is the postlaser baseline reading.
19. Average the two baseline readings and algebraically subtract from the average laser meter value.
20. Calculate the laser power by dividing the net meter value by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the laser power.

11.12 Laser Energy Measurements Using Transfer Meter, TC45

1. Operating instructions for Q-switched and continuous wave laser energy measurements at 1.064 μm using energy meter, TC45.
2. Unpack the above instrument (hereafter referred to as TC45) and allow calorimeter and meter to come to thermal equilibrium with room temperature, preferrably for several hours.
3. Turn on instrument and allow 1 h warmup time before taking measurements.
4. TC45 has three energy scales, 100 mJ, 1 and 10 J. Normally, a calibration number in meter reading units/J is only furnished for the 1 or 10 J scale on the 10 s range.
5. Energy can only be put into TC45 for a period of 10, 20, or 40 or less. TC45 then continues to integrate for 90 s more to complete the integral as shown on the meter. Generally, this means measuring the energy of a train of Q-switched pulses where the energy per pulse times the number of pulses in a 10, 20, or 40 s period or or less gives a total energy between 0.1 and 10 J.
6. The laser beam should enter the "input" end of the calorimeter and be centered in the aperture. Avoid very small beams. Try to measure a beam with a 5 to 10 mm diameter. Alignment is easier if the beam is brought through a hole in a 3x5 card. The calorimeter input window is a 1° wedge which gives two reflected beams. The glass volume absorber gives a third reflected beam. Adjust calorimeter so reflections are an equal distance from the main beam.
7. Precautions:
    a. Avoid focusing the laser beam on very small area.
    b. Avoid heating up calorimeter absorbing glass with sustained laser input.
    c. Arrange timing of laser shutter or beam blockers to insure that the TC15 meter is integrating at least a short period of time before the laser beam is applied. With accurate timing, this time period may be a few tenths of a second.
    d. Arrange timing of shutters (beam blockers) so that laser input is terminated by the end of the 10, 20, or 40 s period.
8. Block laser beam.
9. Set the laser-heater switch to off.

10. Set measurement mode switch to energy.
11. Set range switch to proper energy scale.
12. Set switch on back of instrument to 10, 20, or 40 s.
13. Set meter display switch to repetitive read.
14. Adjust calorimeter baseline potentiometer for a zero meter reading.
15. Set display switch to read hold.
16. Press start button. Both ready lights should go out. If not, wait until both ready lights come on and repeat this step.
17. In 100 to 140 s the ready light will come out.
18. Record the sign and meter reading. This is the preintegrator offset value.
19. Do not erase meter reading by switching display switch to repetitive read and back to read hold.
20. For a laser energy measurement, set laser-heater switch to laser.
21. Make sure display switch is set to read hold.
22. Press start button to start integrating just before applying laser input.
23. Apply laser energy for 10, 20, or 40 s or less depending on meter range.
24. The meter will continue to integrate for 90 s more.
25. At the end of the integration time, the ready lights will come on.
26. Record the laser energy meter reading.
27. Set the laser-heater switch to off.
28. Do not erase meter reading by switching display switch to repetitive read and back to read hold.
29. Repeat step 16.
30. Record the sign and meter reading. This is the postintegrator offset value. Average the two values and algebraically subtract from the integrator reading.
20. Calculate the energy by dividing the net integrator reading by the calibration factor supplied with the meter or calculate the calibration factor by dividing the net meter reading by the energy.

11.13 Laser Power Measurements Using Transfer Head, #1274

1. Operating instructions for using laser power head, serial #1274, with integrating digital voltmeter NBS-2.
2. In a MAP intercomparison, NBS sends an NBS transfer standard to a participant and asks the participant to treat the NBS instrument as an unknown and to calibrate the NBS unit using the participant's calibration facilities.
3. The instruments required for the intercomparison measurement are as follows:
   a. Laser head, serial #1274. This unit is furnished by NBS with a short cable.
   b. Low level amplifier. This item is to be furnished by the participant.
   c. Integrating digital voltmeter NBS-2. This is a specially built unit and is furnished by NBS for intercomparison.
   d. Some means, to be provided by the participant, are needed to accurately determine the time that the laser energy is applied to 1274.
4. Laser head 1274 has only been evaluated for the measurement of laser power at 5 and 50 W and only at a wavelength of 10.6 μm.
5. Important: Before applying a laser beam to laser head 1274, first apply laser beam to black painted test piece to check for visible damage. If it burns the paint it will damage the

head. The maximum allowable power density for the laser head is 200 W/cm^2. If one assumes a gaussian distribution and wishes to capture all the beam (say, 99.97 percent), it is necessary that beam diameter be carefully controlled. If the beam diameter is too small, we may damage the surface of the detector. If the beam diameter is too large, we would not capture all the beam. One way to roughly estimate the beam diameter is to observe the burn spot on a heat sensitive paper target stuck to a rubber stopper placed in 1274. A very short pulse (on the order of a millisecond) of laser energy will scorch a paper target without causing a flame. The spot size caused by the NBS laser is approximately 3/8 in. The paper target is very useful for aligning laser head 1274. One-inch circles cut from heat sensitive paper and marked with two perpendicular lines through the center give a good target for alignment.

6. Cable connections:
   a. Connect output of laser head 1274 with BNC cable to low-level amplifier.
   b. Connect output of amplifier to input terminals of NBS-2 integrating DVM.
7. Turn on amplifier and NBS-2 DVM and allow 1 h warmup before taking measurements.
8. Measurements at 5 W.
   a. Set gain to 1000.
   b. Set bias switch and gain to give a slightly positive output voltage.
   c. Set NBS-2 gain to VS-1.
   d. Set NBS-2 seconds to 300 s. This assumes applying laser energy to 1274 for a period of approximately 150 s or less.
   e. Before starting a run, press start and reset to clear instrument.
   f. Press NBS-2 off button. Press NBS-2 reset button.
   g. Five to ten seconds before applying the laser beam, press NBS-2 start button. NBS-2 start light should indicate green. A slow count should be observed. If not, check connections and that output voltage is slightly positive. NBS-2 will not count a negative voltage.
   h. Apply a cw laser beam of approximately 5 W for an accurately known time (120 to 150 s).
   i. NBS-2 will continue to count after laser input is removed for a total integration time of 300 s.
   j. When NBS-2 stop light shows red, record the DVM reading in V/s. This is the gross DVM reading.
   k. Repeat the 300 s integrating period but without any laser input. Record the DVM reading. This is the baseline DVM reading.
   l. Subtract the baseline reading from the gross reading to obtain a net DVM reading.
   m. The participant's calibration coefficient in μm/W equals the net DVM reading divided by the amplifier gain time laser power times laser time.
9. For measurement at 50 W follow the same procedure as above except:
   a. Set amplifier gain to 100.
   b. Laser input time could be varied from 60 to 90 s.

11.14 Laser Power Measurements at 0.5 mW Using Model ECPR, Serial #A4

1. Locate operating instructions for NBS pyroelectric laser power meter, model ECPR, serial number A4.
2. Carefully unpack instrument.
3. Don't stick anything into detector.

4. Don't attempt to clean detector.
5. Don't blow into detector unit.
6. If unit is to be used for measuring the average power of a train of laser pulses the pulse rate should be 600 Hz or greater to avoid chopper errors.
7. On back of instrument connect power, chopper, and preamp cables.
8. Set range switch to position 2.
9. Plug in 110 V power cord.
10. Turn on instrument and warm up for 1 h before making measurements.
11. Leave rubber cork in place for the present.
12. Important! Start out with very low power by using filters or attenuators to attenuate the laser beam to a very low level. Gradually increase beam power to the 0.5 mW level.
13. This instrument has only been evaluated to make measurements at approximately 0.5 mW average laser power radiation at 0.904 μm.
14. Avoid focusing the laser beam to a small spot. Adjust instrument to send beam through chopper unit and align beam on center of rubber cork. Try to adjust the laser beam to a diameter of 3 to 5 mm, while at the same time insuring that the instrument is capturing all of the beam.
15. Starting with very low power, remove rubber cork and observe if unlock light comes on for a short time and then goes out as digital meter reading stabilizes.
16. Slowly increase power for an average power reading of 0.5 mW.
17. Block laser beam and record no-signal reading after meter stabilizes.
18. Apply laser beam and after meter stabilizes (30 s or more), record meter readings every 4 or 5 s for the duration of the laser run (60 s or more).
19. At the end of laser run, block laser beam and again record no-signal reading after meter stabilizes (30 s or more).
20. Average the two no-signal readings and subtract from the average laser reading for a net meter reading.
21. Calculate the average laser power by dividing the net meter reading by the calibration factor furnished on a card attached to the ECPR instrument.
22. If you have further questions, contact NBS by calling telephone number 303-497-3741.

12. Analysis of Systematic and Random Errors

The following discussion refers to the material covered in reference 8. A set of tables exists for each system and wavelength.

12.1 Electrical Calibrations

Accurately known amounts of electrical energy are applied to a calorimeter heater to provide a paired set of data for each calorimeter and amplifier scale being used. The first column of values, the calorimeter output voltage, is designated as the Y values. The second column of values, the electrical energy input, is designated as the X values. A discussion of the linear relationships between two variables is given in reference 11. Computer program |SL| in reference 8 uses the same procedure to calculate the slope, electrical K, standard deviation of the residuals, and the 99 percent confidence interval in percent for the electrical calibration factor (1/slope). Each electrical data file is run on computer program SLOPE and the results tabulated in table A of reference 8.

12.2 Absorption

The absorption correction must be considered for each calorimeter since the calorimeter may fail to capture all the laser energy.

1. C series calorimeters. In the C series, the calorimeter absorber is deep enough that we assume that all of the laser energy is absorbed. Two sets of absorption measurements confirm this assumption.
2. K series calorimeters. The absorptance of the absorber of calorimeter K12 was measured directly and reported in reference 12 with a value of 0.986. The 0.986 value was also reported in reference 13 with a 99 percent confidence interval error of 0.59 percent. In a series of measurements the absorption value for K13 was determined to be 0.986, with a 99 percent confidence interval error of 1.36 percent.

   In additional measurements the absorption value for K22 was set at 0.989 with a 99 percent confidence interval error of 2.24 percent.
3. Q series calorimeter. In reference 10, table 4, the incomplete absorption of laser radiation, as determined by measurement, is considered negligible.

12.3 Inequivalence

Inequivalance is the difference in response between laser energy and electrical energy in the calorimeter absorber.

1. C series. The results of some measurements on C series calorimeters is given in reference 14. For the C series, the error due to inequivalence is estimated to be not greater than 0.2 percent.
2. K series. In reference 13, the inequivalence for a K series calorimeter was estimated to be not greater than 0.25 percent.
3. Q series. In reference 10, the inequivalence for a Q series calorimeter was estimated to be not greater than 0.4 percent.

12.4 Window Transmission

Window transmission errors only apply to the C series calorimeters since the K and Q series calorimeters do not use windows. Two windows are assigned to each C series calorimeter, one in use and one as a standby. Each window was sent to the National Bureau of Standards in Washington for a set of transmission measurements from 400 to 800 μm in 20 μm steps. The values of transmission were then interpolated from the Washington report for those laser wavelengths used in the C calibration system. Values of transmission were also obtained at 1.06 μm. In addition, the Washington report provided the uncertainty error for the window measurements.

12.5 Traceability

Section 2 of reference 8 gives some details on electrical traceability to the U.S. National Electrical Standards. Table E in the above reference lists the following sources of error:

1. Time Interval Measurement. Measurements of time interval are made with quartz controlled counters with such good accuracy that the percent inaccuracy is considered negligible compared to other sources of error.
2. Resistance of Standard Resistor. Calibration report gives an inaccuracy of 0.005 percent.

3. Standard Cell Voltage. Calibration report gives and inaccuracy of 0.005 percent.
4. Potentiometer. Calibration report gives and inaccuracy of 0.001 percent.
5. Standard DVM. Specifications quote an inaccuracy of 0.006 percent. Measurements with the standard cell, potentiometer, etc. confirm this inaccuracy.
6. DVM #1. A set of computer programs is used to compare DVM #1 with the standard DVM with a printout of inaccuracy in percent.
7. DVM #2. This is a repeat of step 6 with DVM #2.
8. Calorimeter Resistance. Program STRIP7E is used to print values of heater resistance from the various electrical files to data file A. Program PL is then used to plot percent variation of heater resistance from the average versus run number. For each calibration system, the point with the greatest percent deviation is considered the worst case for the calorimeter resistance.
9. Total. The above percent inaccuracies are added for the total percent inaccuracy for the traceability.

12.6 D Factor

The NBS laser standard for the C series is not a real instrument but a conceptual instrument formed by treating the three C series calorimeters equally to produce an average instrument. The D factor is a very small correction that is applied to each calorimeter to provide agreement with the conceptual instrument. The D factors are calculated from a series of beamsplitter measurements where the three calorimeters are interchanged in the high and low positions. Program ST12 is designed for twelve beamsplitter runs of two each for the six possible configurations of three C series calorimeters taken two at a time. The program calculates the absolute beam splitter ratio with a 99 percent confidence interval, and each D factor with a 99 percent confidence interval, treating each D factor equally.

The K and Q systems each use the above philosophy except each system has only two calorimeters that can be interchanged. With small changes, program ST2C in NBSIR 79-1619 was modified to accomodate the K and Q series. In the above reference, see appendix B for the beamsplitter ratio and D factor derivation.

12.7 Scale Errors

To get maximum precision with the C system the intercomparison uses only the 1E3 and 1E4 scales for the beamsplitter runs. Errors due to measurements on the 1E4 and 1E5 scales can contribute to an increased inaccuracy for a basic evaluation using the 1E3 scale in the laser beam measurements. To account for a laser beam calibration at each scale setting we take the largest inaccuracy of all three calorimeters for each scale setting and add it to the inaccuracy obtained for the 1E3 scale setting. The same comments apply to the Q system where they are appropriate. The K system only uses one scale.

12.8 Beamsplitter Ratio

The data and programs that were used for obtaining the D factor, as discussed above, will also give the beamsplitter ratio with the 99 percent conference interval uncertainty. In addition to this uncertainty, we must consider those errors due to the lack of control of the polarization of the laser beam. For the C system this error is estimated to be not greater than 0.2 percent when using the sapphire beamsplitter. For microwatt runs using the fused quartz beamsplitter and a polarized laser, the uncertainty from reference 9 is estimated to be 0.4 percent. Where only one laser is being used in a fixed position such as in the K and Q systems, and both the beamsplitter and calibrated beam runs use the same fixed position, the error due to polarization is diminished if it is assumed that polarization remains constant.

12.9 Summary of System Errors

A summary of the above errors gives the total uncertainty of a system for the different scales and wavelengths. This information is either stored in the C matrix data file or in the K or Q system programs. The system uncertainty is printed in the hard copy record for every measurement run. This information is used for preparing calibration and MAP reports.

12.10 Total Measurement Uncertainty

The 99 percent confidence interval was adopted in reporting statistical information because the use of confidence intervals follows a well defined procedure that includes the standard deviation, the t statistic, and the number of measurements for a given data set. A discussion of some of the different ways to report the arithmetic mean of n numbers with an error statement is given in reference 15. The remarks on page 75-74 indicate that the confidence interval method best suits our situation. For our measurements, the standard deviation σ is generally not known. The number of measurements n is not large and usually varies from 8 to 20. Our data points can be assumed to be normally distributed with a two-sided confidence interval.

Pages 77-76 and 78-77 in the above reference state that when neither the systematic error or the imprecision is negligible the report should separately state the bounds for each. For calibration and MAP reports the total uncertainty of the calibration system for the appropriate laser wavelength and scale is added to the uncertainty for the corresponding set of data for the particular transfer instrument being calibrated.

13. Procedure for Quality Control

Reference 8 covers in detail the procedures used to maintain quality control of the three calibration systems. Several additional computer programs have been written to give a more accurate screen plot of percent variation from the average versus time in years, portions of years, months, etc. These are the scan programs such as ELSCAN, BSCAN, PSCAN, ESCAN, and XSCAN which give the latest status of the individual instruments. Hard copy printout is also available for checking the status of the system and the transfer standards.

The results of all electrical, beamsplitter, and calibrated beam runs are appended to previous run data to provide an accumulation of calibration history for each calorimeter, beamsplitter, and transfer instrument. As the number of measurements n increases, the t statistic value slowly decreases, as does the $1/\sqrt{n}$ factor. Both of these factors decrease the 99 percent confidence interval of uncertainty to improve the system accuracy.

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This report provides a complete guide for the documentation of the NBS laser power and energy calibration systems. The report also describes a detailed procedure for operating the three (C, K, and Q) calibration systems under computer control.

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