

STANDARD OPERATING PROCEDURES MANUAL
FOR THE
BREWER SPECTROPHOTOMETER

Version: D.01

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1. DOCUMENT HISTORY

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3. PREFACE

This manual was written to provide an overview of Brewer spectrophotometer measurement principles and theory of operation, installation, maintenance, calibration, data analysis and troubleshooting.

This manual describes the minimum requirements and procedures needed to achieve high quality measurements. Documentation of all procedures and results from all instrument maintenance, tests and calibrations is critical in a world that is moving toward standardized practices and procedures. A number of Meteorological offices around the world have registered their organization to the ISO 9000 standard. The Meteorological Service of Canada is one of these offices and the Canadian Brewer Spectrophotometer Network will be registered to the ISO 9000 standard in the near future. In the ISO world, it has been said that if a process is not documented, then for all intents and purposes, it is considered not to have happened. This SOP document will describe the minimum information that must be recorded in order to properly describe a calibration or other form of instrument maintenance. Standardization of operational procedures will improve the credibility of information produced by Brewer spectrophotometers worldwide.

The size of this document is in part a reflection of both the versatility and complexity of the Brewer spectrophotometer. Each main section of the document is preceded by an “Overview” to highlight the issues relevant to that topic.

The section entitled “Safety Issues” must be read prior to installing and operating the Brewer spectrophotometer. Failure to take the precautions detailed in this section can lead to serious injury or death.

The sub-section entitled “Critical Safety Warnings” in the “Maintenance” section of this document must be read prior to handling the Brewer spectrophotometer. Failure to take the precautions detailed in this section may result in serious damage to the instrument.

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Thank you.

Toronto
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4. ABBREVIATIONS

AOD	Aerosol Optical Depth
Cd	Indium (in reference to the cadmium lamp)
CUT	Coordinated Universal Time (same as GMT and UTC)
CW	Clockwise
CCW	Counterclockwise
Double	Brewer model Mark III
GMT	Greenwich Mean Time (same as CUT and UTC)
Hg	Mercury (in reference to the mercury lamp)
In	Indium (in reference to the indium calibration lamp)
ISO	International Organization for Standardization
LED	Light Emitting Diode
MKII	Brewer model Mark II (also referred to as “single Brewer”)
MKIII	Brewer model Mark III (also referred to as “double Brewer”)
MKIV	Brewer model Mark IV (also referred to as “NO ₂ Brewer”)
MKV	Brewer model Mark V (also referred to as “red Brewer”)
MSDS	Material Data Safety Sheets
NiSO ₄	Nickel Sulfate (Nickel Sulfate filter used in all Brewers except MKIII)
NO ₂	Brewer model MKIV
PMT	Photomultiplier Tube
Red Brewer	Brewer model MKV
Single	Brewer model Mark II
UG11	filter in front of PMT
UTC	Coordinated Universal Time (same as GMT and CUT)
UV	Ultraviolet
WMO	World Meteorological Organization (www.wmo.ch)
WOUDC	World Ozone and UV Data Centre (www.woudc.org)
Zn	Zinc (in reference to the zinc calibration lamp)

5. SAFETY ISSUES

5.1. Overview

There are a number of potential hazards associated the installation and operation of a Brewer spectrophotometer. Failure to be aware of these potential hazards and take appropriate precautions can lead to serious injury or death. If you do not clearly understand any of the safety issues discussed in this document then please contact the manufacturer or other expert for clarification.

5.2. Material Safety Data Sheets (MSDS)

Material data safety sheets should be available at each Brewer installation, for all chemicals and products that may release chemicals, which are used for Brewer maintenance. Examples of chemicals and products that may be used for a typical Brewer installation include:

Table 1: Typical MSDS Information for a Brewer Station

Product Name	Application	Manufacturer and Website	MSDS Web Link
Mercury (Hg) lamp	Wavelength reference	Ushio Ushio.com	http://www.germicidal.com/dl/msds%20germ-2007.pdf
Methanol	Brewer quartz window and dome cleaner	Canadian Alcohol Company N/A	http://www.bu.edu/es/labsafety/ESMSDSs/MSMethanol.html
Windex	Brewer quartz window and dome cleaner	SC Johnson Scjohnson.com	http://scjohnson.com/msds_us_ca/windex.asp
Sorbead Orange Chameleon	Desiccant for drying air inside Brewer	Engelhard Corporation Engelhard.com	http://www.engelhard.com/msds/loadDoc.aspx?FileNav=P16540
Sorbead Blue	Desiccant for drying air inside Brewer	Engelhard Corporation Engelhard.com	http://www.varian.com/shared/oncy/msds/sorbeadblue.pdf

Krytox	Non-off gassing bearing and gear lubricant	Dupont Chemicals Dupont.com	http://msds.dupont.com/msds/pdfs/EN/PEN_09004a2f806d5e3c.pdf
MolySlip Grease	Grease for tripod foot bolts	The Slip Group of Companies Molyslip.com	N/A

5.3. Hazard—Electrocution

Brewer spectrophotometers and the azimuth trackers that they rest on are powered by AC electricity. It is important to note that Brewer spectrophotometers may have been assembled and maintained by various individuals, over the years, who have had different levels of electronics expertise. Furthermore, various instrument operators may have made their own repairs, modifications or upgrades over time. All of this can lead to instruments which may be hazardous to work with. If the instrument is not a relatively new one then it would be a good idea to carefully inspect all of the connections that transfer AC power both inside and outside the Brewer and its tracker including the power cables before proceeding with installation or working with the instrument. Ensure that all of the bulkhead connectors on the Brewer and the tracker are clearly labeled as to their purpose.

5.3.1. Power LEDs

The green power LEDs installed on some of the older Brewers and trackers were not hermetically sealed. This means that over time moisture will enter between the LED and its shroud and eventually lead to corrosion of the LED's electrical leads resulting in LED failure. It is important to replace burnt out LEDs immediately. Someone may see the LED as being off and begin maintenance procedures not realizing that the power is actually on.

Check to confirm that both the Brewer and tracker power LEDs are illuminated when power has been applied. If the LED(s) do not illuminate then replace them. To test if the LEDs work, connect the Brewer power cable to a wall outlet. Connect the other end to the Brewer by determining which of the three connectors on the Brewer the cable should mate to based on the number of matching pins and sockets in each connector. If the power LED is not illuminated then press the power switch. If the LED still does not illuminate then contact a qualified individual to determine whether the cable, power switch or LED have failed and then make the appropriate repairs.

Repeat the same procedure to determine if the tracker power LED is operational. Disconnect the power cable from the Brewer and connect it to the connector at the base of the tracker that is farthest from the tracker's power switch.

To prevent further damage from occurring to an LED that is not currently protected by a hermetic seal, it is strongly recommended that a thin layer of clear silicone may be applied over the entire surface of the LED and its shroud.

5.3.2. Power Switch Terminals

It is possible that some Brewers and trackers have exposed power terminals at the back side of their power switches. Contact with these terminals can lead to electrical shock. Ensure that the power to the Brewer is off and that the power cable is disconnected from the Brewer. Place a generous amount of clear silicone on the back terminals of these switches if there is none present to prevent accidental direct contact with live AC power.

5.3.3. Power Cables

Not all power cables shipped with older Brewers were UV or cold temperature-rated. Inspect the Brewer power cables and look for any cracks in the outer cable cover. Also ensure that individual wires are not exposed at the point where the wires go into the connectors. Replace any Brewer or tracker cables which show any sign of cracking or peeling of the cable covering or if individual wires are exposed at any point along the length of the cables.

5.3.4. Tracker Power Terminal Strip

Ensure that the power terminal strip inside the tracker has a cover in place to isolate AC power from accidental operator contact.

5.3.5. Maintenance and Weather

The Brewer and tracker covers should never be removed if there is any form of precipitation. Opening the instrument during precipitation can result in both electrical shock to the operator and damage to the instrument.

Any time maintenance is to be performed on the Brewer or tracker or the cables, the power to BOTH units should be shut off and the power cables should be removed from the wall outlet and from the Brewer and tracker power connectors. The power connector on the tracker is the one which is furthest away from the power switch.

5.4. Hazard—Permanent Damage to Eyesight from UV Irradiance

The Brewer contains a mercury bulb which emits a blue coloured light, and a halogen bulb which emits a white coloured light. Both bulbs emit UV irradiance which can result in damage to eyesight if viewed directly. Always wear UV protective goggles when working with the lamp housing or the lamps.

5.5. Hazard—Back Injury from Handling Brewer Spectrophotometer

A single spectrometer or MKII/MKIV/MKV model Brewer has one carrying handle suitable for carrying by one person and weighs about 30 kg or 65 lbs. A double spectrometer or MKIII Brewer has two carrying handles suitable for carrying by two individuals and weighs 34 kg or 75 lbs. While these weights may appear to be manageable for one individual it is always safer to have two people transport the instrument.

It is always best to have two people carry the instrument to minimize the risk of back strain. If only one person is available for the installation then it is a little safer to remove the Brewer cover and install the Brewer instrument on the tracker first. This makes the load lighter and less awkward. Bolt the Brewer to the tracker and then install the Brewer cover. Refer to Section XX on Installation of Brewer Hardware for details on how to assemble a Brewer.

5.6. Hazard—Injury due to Tripping over Cables or Tripod

Brewer cables placed on a walking surface can lead to a tripping hazard. It is best to install the Brewer cables so that they do not lie across a walking surface. If it is not possible to install Brewer cables below the level of the walking surface then a cable ramp should be installed over the cables. A cable ramp also serves to protect the cables from damage.

Tripod legs also present a significant tripping hazard when walking near a Brewer. Always walk slowly and proceed with caution around the instrument.

5.7. Hazard—Information from the Manufacturer

It is also very important to review all of the cautions expressed in the manuals which were provided by manufacturer with the instrument. If these manuals are not available then contact Kipp & Zonen BV for a copy of these manuals before proceeding with Brewer installation and operation. The manufacturer's contact information is located on the website www.kippzonen.com

6. INTRODUCTION

6.1. *Measurement Principles and Theory*

6.1.1. Ozone and sulfur dioxide

Measurements of ozone and sulfur dioxide with the Brewer spectrophotometer are based on the Beer's law.

6.1.2. UV

The Brewer spectrophotometers that are equipped with the UV dome are capable of measuring the global UV irradiance.

6.1.3. Umkehr

A special type of zenith-sky observations can be done during the sunset and sunrise to record what is called a "Umkehr effect", the reversal of the ratio between the intensities at a short and a long wavelengths. This observation can be interpreted by a separate computer program and a vertical ozone profile can be deduced.

6.1.4. Aerosol optical depth

Once both the ozone and the sulfur dioxide columns are known, the residual extinction in the Beer's law gives an estimate of the aerosol optical depth.

6.1.5. NO₂

One type of the Brewer spectrophotometer, referred to as MKIV, is capable of measuring light intensities in the visible region where nitrogen dioxide has absorption features (aprox.440 nm). These instruments can do the direct-sun and the zenith-sky measurements of NO₂ column.

6.2. *The Brewer Spectrophotometer*

The Brewer spectrophotometer is named after Alan W. Brewer, who began development of the instrument at the University of Toronto. David Wardle did the original optical design and J.B. Kerr and C.T. McElroy participated in its further development. Brewer brought the idea of the instrument to the attention of the ozone community and instigated the call for it to be made available as a replacement to the Dobson spectrophotometer.

The first commercial prototype Brewer, sometimes referred to as the "blue Brewer" because of the colour of its outer case, was designed and manufactured by SED Systems Ltd. in Saskatoon, Canada. This version turned out to be unsuitable for network use for a number of reasons so Kerr, McElroy and Wardle began developing a commercial version of the Brewer spectrophotometer in 1979 at the Experimental Studies Division of Environment Canada. This prototype was on display at the Quadrennial International Ozone Symposium in Boulder Colorado in 1980 where significant interest led to commercial production. Commercial production of the first Brewer instruments was undertaken in the early 1980's by SCI-TEC

Instruments Inc. in Saskatoon, Canada under license agreement with Environment Canada. In 2004 the license to build Brewers was transferred to Kipp & Zonen BV of Delft, The Netherlands. There are more than 190 Brewer instruments in over 43 countries worldwide including Antarctica.

6.3. Brewer Models and Measurement Capabilities

There are four different models of Brewer spectrophotometers. The first single monochromator MKII (pronounced “Mark 2”) model Brewers were built in 1982. MKII Brewers have an 1800 line per mm grating that is used in the second order to measure column ozone and column SO₂, in the UVB portion of the spectrum, as well as the vertical ozone profile using the Umkehr technique. A few years after the first MKII’s were introduced, they were upgraded to measure solar spectral UV irradiance as well. MKII’s are sometimes referred to as “single Brewers” because they have a single monochromator. Solar spectral UV irradiance measurements are made from 290 nm to 325 nm.

The first MKIV Brewer was built in 1985. MKIV Brewers have the same measurement capabilities as the MKII instrument as well as the ability to measure column NO₂. A 1200 line per mm grating is used to measure ozone and UV in the third order and NO₂ in the second order. A filter wheel, installed between the monochromator and the PMT, allows for the automated insertion of the appropriate order filter into the light path to switch to NO₂ measurement mode, which is performed in the visible portion of the spectrum. MKIV’s are sometimes referred to as “dual Brewers” because they have two separate modes of operation—an ozone measurement mode and an NO₂ measurement mode. Solar spectral UV irradiance measurements are made from 290 nm to 325 nm. With a modified grating arm, MKIV Brewers can be used to measure solar spectral UV irradiance from 286.5 nm to 363.0 nm. This type of Brewer is referred to as a “MKIV-e” or a MKIV instrument with extended UV measurement range capability.

MKIII Brewers were first introduced in 1992 as a replacement for the MKII Brewer. The primary advantage to the MKIII design is the use of a double monochromator. The top monochromator is used for dispersion of the incoming beam and the bottom half is used for recombining the spectrum to present it to the photomultiplier. This virtually eliminates stray light. Each monochromator uses a 3600 line per mm grating in the first order to measure ozone and UV. Elimination of stray light allows the MKIII to operate without the NiSO₄ and UG11 bandpass filters that are required by the MKII and MKIV models. Removal of the bandpass filters eliminates uncertainties caused by changes in filter characteristics with time and also removes the instrument temperature dependence that is associated with the NiSO₄ filter from the calculation of ozone and SO₂. MKIII’s make the same type of measurements as MKII’s and are sometimes referred to as “double Brewers” because they have a double monochromator. MKIII Brewers provide high quality column ozone measurements, in the UV portion of the spectrum, up to an airmass value of about 5.0 at an average ozone value of 300 DU or up to 1500DU of ozone in the path that the sun’s light travels through the atmosphere. All MKIII Brewers can measure solar spectral UV irradiance from 286.5 nm to 363.0 nm.

The first MKV Brewer was manufactured in 1991. The MKV Brewer is essentially the same as a MKII Brewer but with a filter wheel installed between the spectrometer and the PMT. The filter wheel contains an order filter that allows for column ozone measurements to be made in the “red” portion of the visible spectrum. Ozone absorption in the UV, large Rayleigh scattering attenuation and stray light degrade the quality of ozone measurements made in the UV portion of the spectrum with increasing airmass between the instrument and the sun. Ozone measurements in the visible portion of the spectrum are not as strongly affected by ozone absorption, Rayleigh scattering and stray light and as a result MKV’s are suited to the Arctic and Antarctic regions where low solar elevation angles prevail for much of the year. MKV column ozone measurements, made in the visible portion of the spectrum, are generally acquired between airmass values ranging from 5 to 10. MKV instruments are sometimes referred to as “red Brewers” because they measure ozone in the red portion of the visible spectrum. Solar spectral UV irradiance measurements are made from 290 nm to 325 nm.

Brewer model MKII, MKIII, MKIV and MKV instruments measure ozone in the UV portion of the spectrum to an accuracy of about $\pm 1\%$ when stray light is not an issue. The quality of ozone measurements made by these various models is equally accurate when the amount of ozone in path is less than 1000 Dobson units, which is equal to 1 cm of ozone at Standard temperature and pressure. This limit is determined by stray light and is calculated by multiplying the airmass value and the column ozone measurement. A MKIII instrument will maintain this same level of accuracy out to about 2000 Dobson units or 2 cm of ozone in the path. Beyond these thresholds, stray light begins to progressively degrade the accuracies of the ozone measurements made in the UV portion of the spectrum. MKV ozone measurements made in the visible portion of the spectrum have an accuracy of about $\pm 3\%$. The above-stated accuracies are subject to the proviso that the instruments are operating properly and are well maintained.

Stray light for a MKIII Brewer is normally 10^{-7} of peak intensity and in the 10^{-3} or 10^{-4} range for a MKII, MKIV and MKV Brewers as measured using a monochromatic source. Development of a stray light algorithm may improve MKII, MKIV and MKV Brewer column ozone measurements by factor of 10 but never will get close to MKIII Brewer ozone measurements for three reasons. MKIII Brewers measure column ozone in the first order of the grating and do not require a NiSO₄ and UG11 filter. Both of these factors increase the measured intensity relative to background noise. The MKIII does not require a stray light correction so there is no additional uncertainty added because of the application of this correction.

The versatility of the Brewer instrument is demonstrated by its ongoing evolution over the years, not only in terms of the different models, but also through the other improvements made to both hardware and software. An example of a more recent software routine being tested allows the extraction of aerosol optical depth information from direct sun measurements. Other examples include investigation into whether the Brewer is capable of measuring tropospheric ozone, improving the accuracy of NO₂ measurements as well as ongoing improvements to the Umkehr inversion algorithm. Brewer stray light properties are currently under investigation and may extend the measurement range for column ozone measurements made in the UV portion of the spectrum for all Brewers.

6.4. Basic Component Assemblies

The basic components of a Brewer spectrophotometer are shown in Fig. XX and include a foreoptics tube, spectrometer, photomultiplier tube (PMT), control electronics and primary and secondary power supplies. The Brewer itself rests on a rotating pedestal, often referred to as a “tracker” because its function is to track the sun during the day or the moon at night.

The controlling electronics in older Brewer instruments were housed in a card cage containing seven boards which are all plugged into a motherboard located at the back of the card cage. The photon counter board attached to the PMT counts the photonic energy from the light source and relays this information to the controlling computer through the analog to digital electronics board. The analog-to-digital converter board is also used for the collection of housekeeping data like temperature and power supply voltages. Other boards in the card cage include three boards which move the various motors in the Brewer including those attached to the tracker, zenith prism, iris, various filter wheels, wavelength-selecting micrometer and the shutter motor. The clock board contains temperature circuitry and can be used to maintain accurate time for the Brewer controlling software. The microprocessor board interprets and executes commands from the controlling computer and relays the resulting instrument status and measurement results back to the computer.

The original electronics configuration of the Brewer was maintained until 1998 when SCI-TEC began selling the Brewer with single-board electronics. The introduction of single board electronics also incorporated a number of improvements including built-in circuit redundancy, improved surge suppression, shielded ribbon cables to reduce noise, and reduced power consumption resulting in lower heat generation.

Replacement boards for the old Brewer multi-board electronics card cage are obsolete and are no longer being manufactured. Boards that fail can usually be repaired although the microprocessor board is one of the most difficult to repair. International Ozone Services has developed a replacement for the microprocessor board which fits into the existing multi-board electronics card cage. This board also has the advantage of communicating with the Brewer computer at 9600 baud compared to the old board which communicated at 1200 baud.

The foreoptics tube is used to direct various sources of light, including light from the sun, the sky, the horizontal diffuser, the moon or from the internal calibration lamps into the spectrometer.

The spectrometer disperses light into its component wavelengths and directs the light through a wavelength-selecting shutter onto the photomultiplier tube photocathode (PMT). The photon pulse amplifier and discriminator attached to the PMT counts the photon counts from the light source and divides them by 4 to reduce the bandwidth of the signal and relays this information along a differentially-driven twisted pair to the controlling computer via the photon counting electronics board.

The first Brewer instruments that were manufactured were not fully automated nor did they have UV measurement capability. An operator would manually configure the azimuth, zenith, iris and filterwheel positioning of the instrument for each ozone measurement. Soon after initial production, Brewers were fitted with the quartz dome and a port mounted onto the foreoptics to measure solar spectral UV irradiance. Motors were also added to fully automate the operation of the Brewer.

6.5. Communication Configuration

Brewer instrument electronics were designed to support RS232 communications through a computer's serial port. The GWBasic Brewer software is restricted to the use of COM1 and COM2 only. Most newer computers have USB ports instead of serial ports. It is possible to use a USB to serial adapter to connect the Brewer data cable to computer's USB port. It should be noted that not all serial to USB adapter cables work with the Brewer instrument.

In the early 1990's the capability of RS422 communication was added to the Brewer by installing a converter within the Brewer and another converter at the other end of the data cable at the computer. RS422 increases the communication distance over data cables from 15 m or 50 ft for RS232 communications to 90 m or 300 ft. Brewers with the single board electronics have RS422 capability built into them.

The distance between the Brewer and its computer is limited by the type of communication system used. The official limit for an RS232 communication cable is about 15m or 50ft. RS232 communication cable lengths of up to 90m or 300ft have been used successfully with the Brewer. The RS422/RS232 data set communications module, which may have been installed by the manufacturer into the Brewer, extends the communication range up to 1.2 km or 4000 ft. Wireless communication systems are also available for locations where it is not practical to run cable.

7. MAINTENANCE

7.1. *Critical Maintenance Warnings*

7.1.1. Overview

Routine instrument maintenance and care during instrument handling are required in order to prevent potentially serious and costly damage to the Brewer instrument.

7.1.2. Photomultiplier Tube

Saturation of the photomultiplier tube (PMT) with bright light can lead to a transient shock or permanent damage. Always power down the Brewer and disconnect its power cable before opening the spectrometer case. It is always best to avoid opening the spectrometer cover unless absolutely necessary to prevent excess light from entering the PMT and dust from settling onto the optics. If the spectrometer cover must be removed then it is best to do so in a clean dust-free room.

7.1.3. Excess Moisture

High levels humidity inside the Brewer can lead to the permanent damage of various optical components including the film polarizer(s) and the nickel sulfate (NiSO₄) and UG11 filters. Damage to these optical components will negatively impact data quality and likely require expensive repairs and instrument recalibration.

Excess moisture can also lead to the corrosion and shorting of solder traces on the various electrical boards, which can cause erratic behaviour of the instrument as well as operational failure. Accumulation of water inside the Brewer from a deteriorated seal can short out the primary power supply.

Section XX on Desiccant Check/Replacement in the Maintenance portion of this document describes how to control the humidity level within the Brewer.

7.1.4. Optical Surfaces

Do not touch or attempt to clean any of the optical surfaces inside the Brewer, especially the spherical mirror and the diffraction grating, which are located inside the spectrometer housing. Cleaning either the diffraction grating or spherical mirror, no matter how carefully, will result in permanent damage to the optical surfaces and may leave them unusable.

7.1.5. Lubricants

Several components in the Brewer require lubrication for proper operation. Only non-off-gassing lubricants should be used. One such lubricant approved for use in the Brewer is “Krytox”. Most other lubricants off-gas over time and deposit themselves on sensitive optical surfaces.

7.2. Routine Maintenance

7.2.1. Overview

The Brewer requires various types of maintenance to prevent damage to the instrument and ensure proper operation. Maintenance procedures will be described according to frequency required. Each section provides maintenance instructions in normal font. Text in italicized font indicates solutions to resolve problems that may occur. Note that once this maintenance information has been reviewed, the process of filling out the Brewer Log Form (to be described below) will summarize all of the required checks and their frequencies.

A summary of maintenance checks and their frequency are listed below. This information also appears on the Brewer Log Form so that it is always at hand for the station operator(s).

Daily Brewer Maintenance

Confirm that the Brewer is in scheduled operation mode.
Brewer software date check
Brewer software time check
Confirm that schedule is correct
Dome and window cleaning
Make appropriate entries into Brewer Log Form

Bi-Weekly (Every two weeks) Brewer Maintenance

Desiccant check/replacement
Steps per revolution check
Sighting check on sun (moon when sun not available during Arctic or Antarctic winter months)

Bi-Monthly (Every two months) Brewer Maintenance

Tracker drive plate cleaning

Detailed notes on the summary list shown above follow below.

7.2.2. Brewer Log Form

Reference is made to the “Brewer Log Form” rather than the “Station Log Form” because instruments can be moved from one station to another and because the information on the Log Form is primarily related to the Brewer instrument and not the station.

The purpose of the Log Form (refer to Appendix XX for a sample Log form) is to document all human interaction with the Brewer spectrophotometer system including its control computer. The Log Form is ideally an electronic document that facilitates copying, backup, transfer and archival. The form itself would ideally exist within the Brewer directory structure so that if the Brewer software were to be copied or transferred to another computer the Brewer Log Form would be copied or transferred at the same time.

Key elements of a Log Form include:

- Contact information—experts who are available to assist Brewer operators.
- Space for the operator to note all routine checks and maintenance performed.
- A summary of procedures required to perform all routine maintenance along with maintenance frequencies.
- An area to Log all system changes, upgrades, errors etc. including the date, time and initials of person who noted the condition or performed the work.

The form shown in the Appendix is set up so that it can be readily printed on a single sheet of paper or displayed entirely and legibly on a computer screen all at once. The Log Form represents one month of information per worksheet. One Microsoft Excel workbook file can easily hold many years worth of data.

If a station uses various schedules during the course of a year then it is a good idea to enter the name of the schedule in the day entry of the appropriate monthly worksheet in advance to remind the station operator of the change in schedule.

One possible naming convention for the Log Form spreadsheet file is “Log### YYYY.xls” where “###” is the three digit Brewer serial number and “YYYY” is the four digit year.

7.2.3. Daily Maintenance

7.2.3.1. Confirm that the Brewer is in Scheduled Operation Mode

Ensure that Brewer is in scheduled operation mode. This can be confirmed by noting the information in the second line of the software window header. During scheduled operation a two-letter short form of the measurement name is followed by the name of the schedule in use.

If the message “Brewer not responded 5 times” or some other message indicating communication failure appears in the center of the software window then refer to Section XX in Appendix XX for the diagnostics procedure to resolve this issue.

If the Brewer is on menu (as indicated by the word “menu” located in the second line of the software window header) then check the current day’s B-file to determine why scheduled operation was aborted. If there is no indication for the reason for failure in the current day’s B-file then check the end of the previous day’s B-file to ensure that “ed” is the last piece of information in the file. An “ed” indicates that the file was closed properly at the end of the day. The primary reasons for the software aborting scheduled operation are: a) the lamp intensity of either the mercury or standard lamps was below the acceptable threshold (“lamp not found” message), b) there was an azimuth tracker or zenith prism zeroing failure (“azimuth/zenith zeroing failure” message), or c) someone pressed the “home” key and did not return the software to scheduled operation mode. If the current and previous day’s B-files do not indicate why scheduled operation was aborted then type the command string “pdrefrhphgpf” and press “Enter”. Once this command string has completed execution check the B-file to determine if

there were any errors logged. If there were no errors logged then type “skc” and press “Enter” to display the list of available schedules. Type in the name of the schedule that was in use before scheduled operation was aborted (refer to the Log Form) and press “Enter” to resume scheduled operation. If the error message refers to a lamp intensity problem or a zeroing failure then refer to Appendix XX for the diagnostics procedure to follow to resolve these issues.

7.2.3.2. Brewer Software Date Check

Check the calendar day as well as the Julian day. Note that the displayed calendar day changes to the next day at Greenwich Mean Time 00 hours. The displayed Julian Day changes with the change of the local day as determined by the sun; not the time of day. Confirm that the date is correct using a date and time reference such as that at the National Institute for Standards and Technology at www.time.gov and select the UTC time zone.

If the date is incorrect then refer to the Log Form to note the name of the schedule that is currently in use. Press the “Home” key to exit scheduled operation and go to the menu list. Type “da” and press “Enter” to change the date. Enter information as prompted (two digit day, two digit month and two digit year). If the date was wrong then confirm that the time is correct as described below. When done type “skc” and press “Enter” to display the list of available schedules. Type in the name of the schedule that was in use before scheduled operation was aborted and press “Enter”.

7.2.3.3. Brewer Software Time Check

Check the C.U.T. value in the Brewer program window. (C.U.T. = U.T.C. = Coordinated Universal Time = G.M.T. = Greenwich Mean Time). Confirm that the time is correct to within +/- 5 seconds using a C.U.T. date and time reference such as that at the National Institute for Standards and Technology at www.time.gov and select the UTC time zone.

If the time is incorrect then refer to the Log Form to note the name of the schedule that is currently in use. Press the “Home” key to exit scheduled operation and go to the menu list. Type “ti” and press “Enter” to change the time. Enter the information as prompted. When done type “skc” and press “Enter” to display the list of available schedules. Type in the name of the schedule that was in use before scheduled operation was aborted and press “Enter”.

7.2.3.4. Confirm that Schedule in use is Correct

If multiple schedules are in use during the course of a year then confirm that the Brewer is running the correct schedule for the given day of the year. The name of the schedule currently in use appears on the second line of the program window after the two-letter short-form name of the current measurement.

If the schedule is not correct then press the “Home” key to exit scheduled operation and go to the menu list. Type “skc” and press “Enter” to display the list of available schedules. Type in the name of the correct schedule and press “Enter”.

7.2.3.5. Dome and Window Cleaning

Clean the entire UV dome and the entire zenith prism window using a non-abrasive tissue for optical surfaces moistened with methyl alcohol.

Remove snow from the window and dome using a soft bristled non-abrasive brush. A thin layer of ice may be removed by very gently scraping (not chiseling) the glass surface with a plastic car window type scraper. A thicker layer of ice may be removed by using gentle heat from a blow dryer.

7.2.3.6. Fill Out the Brewer Log Form

Make entries into the station Log Form as required. A sample station Log Form appears in Appendix XX.

7.2.4. Bi-Weekly Maintenance (every two weeks)

7.2.4.1. Desiccant Check/Replacement

The nickel sulfate filter is very sensitive to humidity and changes its optical characteristics when subjected to high levels of humidity resulting in unstable standard lamp test results. Over time, excess moisture in the Brewer can cause damage to the nickel sulfate, UG11 and polarizing filters resulting in a degradation of data quality. High moisture levels can also cause shorting between traces on the various electronics boards resulting in erratic instrument operation or operational failure. A description of two methods for controlling moisture within a Brewer spectrophotometer along with their respective check/replacement procedures follows.

Typical Desiccant Drying System

The most commonly used type of drying system involves two desiccant systems that work together to keep the internal components dry. The first desiccant system is the “breathing” system and consists of a lexan cylinder of desiccant that is attached to a tube connected to a hole in base of the instrument or alternatively connected directly to an opening at the base of the instrument without the use of a tube. This breathing system serves to dry air that passes into and out from the instrument due to changes in atmospheric temperature or pressure compared to internal temperature or pressure.

The second desiccant system is simply a bag or other container of desiccant that is typically placed over the secondary power supply (or other free space within the instrument) and serves to dry the internal space of the instrument. This second system helps to remove moisture that enters the instrument from one of the various seals, which may have developed a leak. It also helps with the drying of the interior space each time the Brewer cover is removed—for example, during desiccant check and replacement.

There are several types of desiccant media that are typically used in the Brewer. The first and least desirable type is desiccant that is designed for single use only (ex. Calcium Sulfate). This desiccant is typically blue in colour when fresh and turns pink when expired. This type of

desiccant is not preferred because it often breaks down into a powder when saturated with moisture. This powder can settle on instrument optics.

There are typically several desiccant media types whose moisture capacity can be regenerated (almost indefinitely) by heating the media to release the moisture. The first of these types consists of self-indicating beads and turns from a dark blue colour, when fresh, to a pink colour when saturated (ex. “Trochenperlen”, “Sorbead Blue” or “Sorbead Orange Chameleon”). To regenerate this desiccant, heat it to 140 degrees Celsius (not exceeding 180 degrees Celsius) for a few hours or so depending on moisture content. Once dry, the desiccant needs to be placed into a dry airtight container. A second type of desiccant often used in the Brewer consists of small beige-coloured beads and does not change colour but rather contains a separate strip of indicator paper in the desiccant tube that turns from blue when dry to pink when moist. The best of these desiccant media is the one that is self-indicating so that an operator can easily assess the state of all of the desiccant in the container, not just the desiccant adjacent to the strip.

The least desirable desiccant media type is the type that is supplied in a closed opaque packet. These packets typically require a desiccant indicator card to be placed somewhere in the instrument in order for the operator to judge the level of moisture in the instrument. An operator has no idea as to how much drying capacity this packet has left or how long it would take to dry in an oven. Over time most desiccant types lose their ability to be regenerated by heating. The packet type would provide no clear indication of this situation. The indicator card, whose measuring capability may also deteriorate with time, is often placed under the iris/entrance slit viewing window inside the Brewer to provide an operator with an indication of the moisture level in the instrument. While this may be helpful for the operator to see what the card indicates without taking off the Brewer cover it should be noted that at least one of the manufacturers of these cards suggests that the card not be placed in direct sunlight. Heating the card in the sunlight might burn off the moisture from the indicator and thus provide misleading information. In this case it would be best to check the card on a cloudy day or even better, cover the viewing window so that sun does not normally enter the instrument. Note that all Brewers referred to as “MKIV” or “Dual” or “NO₂” as well as those referred to as MKV or “Red” Brewers should have an opaque cover placed on the iris/entrance slit viewing window because diffuse visible light can enter the viewing tubes and contaminate NO₂ or red spectrum ozone measurements that are made in the visible portion of the spectrum.

To check the condition of the desiccant containers inside the Brewer:

1. Press “Home” to abort scheduled operation and wait until the software displays its menu.
2. Place a protective plastic cap over the UV dome.
3. Remove the Brewer cover and examine desiccant condition or indicator condition.
4. Replace any desiccant that indicates that it is more than 50% expired or if the Brewer internal humidity is above 50%.
5. Re-install the Brewer cover.
6. Remove the protective plastic cap from the UV dome.
7. Type “skc” and press “Enter” to display the list of schedules.

8. Type in the name of the schedule currently in use and press “Enter” to resume scheduled operation.
9. Make the appropriate entry into the Log Form indicating the date that the desiccant was checked/replaced, the percentage expired and a notation indicating if the desiccant was replaced.
10. Regenerate the desiccant as specified by the manufacturer.

Advanced Drying System

A less commonly used but generally better moisture control system involves the removal of the above-mentioned desiccant tube and tray/packet systems and rather forces dry air or dry nitrogen into the instrument under very low pressure. The flow of dry gas is adjusted to a level that provides a slight positive pressure within the instrument so that moist air is never drawn into the instrument. Dry air or dry nitrogen can be provided from a gas cylinder. Dry air can also be made by pumping ambient air through a desiccant container.

When using a gas cylinder the only requirement is to periodically monitor tank pressure to ensure that it is still capable of providing dry gas to the Brewer. Checking or changing of the desiccant in a system that uses ambient air is best done when the desiccant is about 50% expired. Again, the best desiccant to use for this system is one that is self-indicating for the reasons mentioned above.

The significant advantage to the advanced drying system is that it does not require interruption of Brewer operation and removal of the Brewer cover, which introduces moisture and dust into the instrument.

Note: If desiccant is found to be completely or almost completely expired then it is likely that one of the seals inside the instrument has failed. Bring the Brewer indoors immediately to prevent damage to the instrument and correct problem—see Appendix XX on Brewer Seal Maintenance, Diagnostics and Repair/Replacement.

Note: Most spectrometer cases have a desiccant holder mounted on the case. It is best to empty this container and not use it since it may encourage opening the case and to check and change it periodically. It is best to avoid opening the spectrometer case unless absolutely required to prevent moisture from entering the spectrometer and dust from settling on the optics. If the desiccant tube and box are properly maintained then the spectrometer case will remain dry.

7.2.4.2. Steps Per Revolution Test

The steps-per-revolution test is used to determine the number of steps in one revolution of the azimuth tracker. The tracker first moves counter-clockwise to find its reference position. Then it will move clockwise and count the number of steps taken to reach its reference position. When completed the computer indicates both the new and current steps per revolution values. The number of steps per revolution is typically about 14670 steps.

To run this test press “Home” to go to the menu. Type “sr” and press “Enter”. Log the new steps per revolution value into the Log Form. If the new value is within 5 steps of the most recent previous value then press “y” to accept the new value.

If the new value is greater than 5 steps from the most recent previous value in the Log Form then repeat the test two more times to determine if the new results are both within 5 steps of the first test. If the three measurements are not all within 5 steps of one another then clean the tracker azimuth drive disk as described below in the “Monthly Maintenance” section on “Azimuth Drive Plate Cleaning”. Log the disk cleaning in the Log Form. After the disk has been cleaned repeat the steps per revolution test two times to determine if the new results are both within 5 steps of each other. If the two measurements are not within 5 steps of one another then refer to Appendix XX for information on checking and adjusting drive plate tension. After tension check and adjustment repeat the steps per revolution test two more times to determine if the new results are both within 5 steps of the first test. If the two measurements are not within 5 steps of one another then the disk may be out-of-round and require replacement.

7.2.4.3. Sighting the Brewer on the Sun

Note: When the daily minimum solar zenith angle is less than 86 degrees then it is better to perform a moon sighting. The daily minimum solar zenith angle can be determined by noting the value of the zenith angle, as displayed on the top right hand corner of the Brewer window just below the software version, near solar noon. An alternate way to do this is to use the “sa” command (refer to the section on “Brewer Commands” above). Refer to the section below on “Sighting the Brewer on the Moon” when the daily minimum solar zenith angle is greater than 85 degrees.

The Brewer orientation procedure during installation requires the approximate alignment of the north sticker on the tracker to “true north”. The Brewer will use the solar ephemeris routine in its software to calculate where the sun is. The software will then point the Brewer to where it thinks the sun is based on the year, Julian day, time of day and the latitude and longitude that were entered by the operator as well as on the default value of the north correction and horizon correction in the instrument constants file.

The Brewer needs to be manually targeted on the sun to determine its north and horizon correction values. The north correction is used to correct for the difference between the orientation of the instrument on the ground when it was installed compared with the “true north” orientation. The horizon correction corrects for the difference between the number of steps between the zenith drive reference position to where the software believes the horizon is compared to the zenith drive step position where the horizon is determined to be from the sighting.

It is best to perform sun sightings as close to solar noon as possible. This ensures that the Brewer is tracking as good as possible during the portion of the day when the solar elevation is near its maximum and direct sun ozone measurements are of the highest quality. Atmospheric scattering of sunlight is reduced with lower solar airmass values thus reducing contamination of

direct sun measurements by scattered light. It is also good to periodically check the Brewer sighting at other times during the day. Ideally one good sighting is all that is required to keep the Brewer tracking correctly almost indefinitely. In reality, however, changes in the various levels and alignments within the instrument may cause the quality of tracking to deteriorate progressively from the time of day that the sighting was taken. Please refer to Appendix XX to diagnose the reason for the deterioration in the quality of tracking as the Brewer moves further away from the time that the sighting was taken.

It is assumed that the Brewer latitude and longitude (in degrees) are accurate to two decimal places (as can be determined by a GPS device). Coordinate in current use can be determined by pressing “Home” to go to menu. Type “pdpopf” and press “Enter” to print currently used constants to the D-file. Examine the latitude and longitude information at the end of the D-file. If these values are not accurate to two decimal places then refer to Section XX on Brewer configuration.

To perform a sun sighting:

1. Press the “Home” key to go to the menu.
2. Confirm that the date is correct and that the time is accurate to the second.
3. Type “ze” to zero the zenith motor and eliminate any accumulated step discrepancy.
4. Note—this step can be omitted if the steps per revolution test was completed immediately before this sighting process. Type “sr” to determine the number of steps per revolution and to zero the azimuth motor and eliminate any accumulated step discrepancy. Log the new steps per revolution value into the Log Form. If the new value is within 5 steps of the most recent previous value then press “y” to accept the new value. Refer to the section above entitled “Steps per Revolution Test” if the new result is not within 5 steps of the most recent previous result.
5. Type “si” and press “Enter” to activate sun sighting mode.
6. Go to the Brewer and look into the Iris Viewer to confirm that the sun light is passing through the iris. Ensure that you are not blocking the sun light from entering the quartz window. If the sun’s image appears on the iris surface or the Brewer is not oriented toward the sun then use the four sighting push buttons to move the sun’s image into the center of the iris opening so that the sunlight can pass on to the entrance slit.
7. Look into the Entrance Slit Viewer to confirm that the sun’s image is centered uniformly over the entrance slit. Correct any offset of the sun’s image from the slit by using the sighting push buttons.
8. Go to the computer and press the “Ctrl” and “End” keys at the same time to exit sighting mode.
9. Record the date, time and the new sighting corrections into the Log Form. Then press “y” to accept the new sighting values.
10. Type “skc” at the menu prompt and type in the correct schedule name and press “Enter” to resume scheduled operation.

If the north correction has changed by more than 10 steps or the horizon correction has changed by more than 5 steps from the previously recorded corrections then repeat the above

steps again to confirm that there is a significant change compared to the previously recorded values. If the change is more than 10 steps for the north correction or 5 steps for the horizon correction then refer to Appendix XX to diagnose and resolve this problem.

7.2.4.4. Sighting the Brewer on the Moon

Note: When the daily minimum solar zenith angle is greater than 85 degrees then it is better to perform a sun sighting. The daily solar minimum solar zenith angle can be determined by noting the value of the zenith angle, displayed on the top right hand corner of the Brewer window just below the software version, near solar noon. An alternate way to do this is to use the “sa” command (refer to the section on “Brewer Commands” above). Refer to the section above on “Sighting the Brewer on the Sun” if the daily minimum solar zenith angle is less than 86 degrees.

The Brewer orientation procedure during installation requires the approximate alignment of the north sticker on the tracker to “true north”. When the Brewer is run for the first time in a new location, it will use the lunar ephemeris routine in its software to determine where moon is and then point the Brewer to where it thinks the moon is based on the year, Julian day, time of day and the latitude and longitude that were entered by the operator as well as on the default value of the north correction and horizon correction in the instrument constants file.

The Brewer needs to be manually targeted on the moon to determine its north and horizon correction values. The north correction is used to correct for the difference between the orientation of the instrument on the ground when it was installed compared with the “true north” orientation. The horizon correction corrects for the difference between the number of steps between the zenith drive reference position to where the software believes the horizon is compared to the zenith drive step position where the horizon is determined to be from the sighting.

It is best to perform moon sightings as close to the moon’s upper transit as possible. This ensures that the Brewer is tracking as good as possible during the portion of the day when the moon elevation is near its maximum and focused moon ozone measurements are of the highest quality. Atmospheric scattering of moonlight is reduced with lower lunar airmass values thus reducing contamination of focused moon measurements by scattered light. It is also good to periodically check the Brewer sighting at other times during the day. Ideally one good sighting is all that is required to keep the Brewer tracking correctly almost indefinitely. In reality, however, changes in the various levels and alignments within the instrument may cause the quality of tracking to deteriorate progressively from the time of day that the sighting was taken. Please refer to Appendix XX to diagnose the reason for the deterioration in the quality of tracking as the Brewer moves further away from the time that the sighting was taken.

It is assumed that the Brewer latitude and longitude (in degrees) are accurate to two decimal places (as can be determined by a GPS device). Coordinate in current use can be determined by pressing “Home” to go to menu. Type “pdpopf” and press “Enter” to print currently used constants to the D-file. Examine the latitude and longitude information at the end

of the D-file. If these values are not accurate to two decimal places then refer to Section XX on Brewer configuration.

To perform a moon sighting:

1. Press the “Home” key to go to the menu.
2. Confirm that the date is correct and that the time is accurate to the second.
3. Type “ze” to zero the zenith motor and eliminate any accumulated step discrepancy.
4. Note—this step can be omitted if the steps per revolution test was completed immediately before this sighting process. Type “sr” to determine the number of steps per revolution and to zero the azimuth motor and eliminate any accumulated step discrepancy. Log the new steps per revolution value into the Log Form. If the new value is within 5 steps of the most recent previous value then press “y” to accept the new value. Refer to the section above entitled “Steps per Revolution Test” if the new result is not within 5 steps of the most recent previous result.
5. Type “sim” and press “Enter” to activate moon sighting mode.
6. Go to the Brewer and look into the Iris Viewer to confirm that the moon light is passing through the iris. Ensure that you are not blocking the moon light from entering the quartz window. If the moon’s image appears on the iris surface or the Brewer is not oriented toward the moon then use the four sighting push buttons to move the moon’s image into the center of the iris opening so that the moonlight can pass on to the entrance slit.
7. Look into the Entrance Slit Viewer to confirm that the moon’s image is centered uniformly over the entrance slit. Correct any offset of the moon’s image from the slit by using the sighting push buttons.
8. Go to the computer and press the “Ctrl” and “End” keys at the same time to exit sighting mode.
9. Record the date, time and the new sighting corrections into the Log Form. Then press “y” to accept the new sighting values.
10. Type “skc” at the menu prompt and type in the correct schedule name and press “Enter” to resume scheduled operation.

If the north correction has changed by more than 10 steps or the horizon correction has changed by more than 5 steps from the previously recorded corrections then repeat the above steps again to confirm that there is a significant change compared to the previously recorded values. If the change is more than 10 steps for the north correction or 5 steps for the horizon correction then refer to Appendix XX to diagnose and resolve this problem.

7.2.5. Bi-Monthly (every two months)

7.2.5.1. Azimuth Drive Plate Cleaning

A friction interface inside the tracker is used to transfer power from the tracker motor to the azimuth drive plate to rotate the Brewer. The stainless steel drive shaft connected to the motor is tensioned against the aluminum drive plate. Normal movement of this drive system causes microscopic aluminum particles to be worn off of the drive. These particles need to be cleaned off every two months. Failure to clean the drive plate causes the particles that are worn

off of the plate to become larger and larger over time until they appear as flakes of aluminum. These flakes then score the surface of the drive plate edge. The wear on the drive plate becomes progressively worse and results in permanent damage to the plate—it becomes “out of round” and will require replacement. Failure to replace a worn drive plate will result in poor tracking and both less “acceptable” data and lower quality data.

To clean the drive plate:

1. Press the “Home” key to abort scheduled operation.
2. Power down the tracker using the switch on the side of the tracker—the Brewer can be left powered. The stepper motor in the tracker allows for free rotation of the Brewer once the tracker is turned off.
3. Remove the back cover of the tracker. The “back of the tracker” refers to the side of the tracker that has the cover that is furthest from the tracker’s power switch.
4. Note roughly the Brewer’s current position. Slowly rotate the Brewer counter-clockwise to a North position. Clean the tracker drive plate edge using a non-abrasive tissue or cloth moistened with methyl alcohol while slowly moving the Brewer clockwise to North in small increments (a full 360 degree clockwise rotation). At each rotational increment, clean the plate until a fresh portion of the tissue or cloth no longer removes any grayish coloured deposit from the plate edge. During tracker rotation, be careful not to break the string that connects the large post in the center of the tracker to the internal shut off switch. This switch exists to prevent the tracker from winding up and breaking the power and data cables if the tracker moves beyond its zero position (in either the clockwise or counter-clockwise direction). If this string is broken then it must be replaced. Refer to the section on “Tracker Shutoff String Replacement” below under “Unscheduled Maintenance”.
5. Manually rotate the Brewer counter-clockwise to a position roughly near where it was before the tracker was powered down.
6. Re-install the tracker cover after ensuring that each of the spacers on the cover bolts are screwed in toward the head of the bolts. The bolts contain an “undercut” portion where there are no threads. The washers must be rotated down into this area in order for the tracker cover seal to mate properly with the tracker body.
7. Power up the tracker.
8. Type the “az” command at menu and press “Enter” to eliminate the Brewer’s step discrepancy from the drive plate cleaning process.
9. Type “skc” and press “Enter”.
10. Type in the name of the current schedule in use and press “Enter” to resume scheduled operation.
11. Make the appropriate entry into the Log Form indicating the date that the drive plate was cleaned.

Note: While it is recommended that this cleaning be performed at least every two months, it is much better to perform this cleaning more frequently if the drive plate is dirty. A drive plate that is very dirty every two months is likely an indication that the drive tension requires adjustment. Refer to the “Tracker Drive Plate Tension Adjustment” in Appendix XX to correct this problem.

It is recommended that when a drive plate cleaning is required that it be performed immediately before other bi-weekly maintenance procedures. This will allow for the plate cleaning to be followed by a steps per revolution test and then a sighting that will help to ensure optimum tracking.

7.2.6. Unscheduled Maintenance

7.2.6.1. Mercury Lamp Replacement

Note: The mercury lamp emits UV radiation when it is powered on. A powered mercury lamp will emit a blue coloured glow. Always wear UV protective goggles when working with the mercury lamp.

Mercury lamps typically require replacement after one and a half to three years depending on the quality of the lamp and frequency of lamp use. Lamp test failure can result either from lamp burnout or from degradation of the lamp intensity that occurs as the mercury vapour forms a progressively thicker deposit on the inner surface of the lamp. If lamp intensity (measured as the difference in counts between slits one and four) is less than 498 counts then the software will first try to reset the micrometer and then repeat the mercury lamp test. If the lamp intensity threshold is not reached for a second time then scheduled operation is aborted. Scheduled operation will continue to be automatically aborted until the lamp is replaced.

The second column in the Hgoavg.### file in the Brewer data directory shows the maximum lamp scan intensity for each day of Brewer operation. If the mercury lamp intensity is in the range of a few thousand counts then the lamp should be replaced before it causes the Brewer to terminate scheduled operation.

If lamp replacement is due to filament burnout or due to low lamp intensity then skip the instructions that follow and go directly to the instructions “To replace the mercury lamp” that follow.

Several days prior to planned mercury bulb replacement due to low counts:

1. Insert several sunscan “sc” measurements into the schedule starting at zenith angles 66 and lower for both the morning and afternoon periods. Refer to section XX for details on schedule editing.
2. Examine the sunscan data to confirm that there are sufficient data points to determine the instrument’s existing calibration step number. Refer to section XX for the procedure to determine the calibration step number.
3. Press the “Home” key to abort scheduled operation.
4. Type in the name of the current schedule in use and press “Enter” to run the schedule with the added sunscan measurements.

To replace the mercury lamp (refer to Fig. XX above):

1. Press the “Home” key to abort scheduled operation.

2. Type “co” and press “Enter” to enter a comment.
3. Type “old hg lamp” and press “Enter” to make a note in the B-file to indicate that the bulb is about to be replaced.
4. Type pdhphgslslslpf to run a mercury lamp test followed by three standard lamp tests. The standard lamp ratios R5 and R6 are used to correct SO₂ and ozone ETC values for changes in instrument response with time. Having knowledge of these ratios immediately before and after bulb replacement will allow for removal of any changes in R5 and R6, and subsequently to ETCs, due solely to bulb replacement during data processing.
5. Wear UV protective goggles.
6. Close the Brewer software window.
7. Power down the Brewer using the power switch on the side of the Brewer near the quartz zenith prism window.
8. Place a protective plastic cap over the UV dome.
9. Remove the Brewer cover.
10. The lamp housing is located below the zenith prism. The mercury lamp holder can be removed from the lamp housing by loosening the two thumb screws located on either side of the housing and then sliding the holder out of the housing.
11. Use a non-abrasive tissue to handle mercury lamps. Unscrew the old bulb from its socket and then install the new bulb.
12. The lamp holder contains a guide pin that helps to ensure that the holder is being installed correctly into the lamp housing. Hold the lamp holder with the guide pin facing up. Note the position of the lamp filament holder. The filament holder should not be directly above or very close to being directly above the lamp filament otherwise it will reduce the light intensity as measured by the Brewer. If the lamp filament holder is directly above the lamp filament when the guide pin is facing up then pry the chrome coloured spring clip, on which the lamp socket is mounted, away from the lamp holder using a wide blade slot screwdriver. Rotate the spring clip within the lamp holder until the filament holder is clearly offset from the filament (about 30 degrees or so from the vertical). Press the spring clip back into the lamp holder and confirm correct positioning of the filament holder. Re-insert the lamp holder into the lamp housing while ensuring that the guide pin is fully inserted correctly into the lamp housing. Tighten the lamp screws.
13. Replace the Brewer cover.
14. Remove the protective plastic cap from the UV dome.
15. Power on the Brewer—you should hear the shutter click if you listen carefully.
16. Restart the Brewer software.
17. Type “co” and press “Enter” to enter a comment.
18. Type “new hg lamp” and press “Enter” to make a note in the B-file to indicate that the bulb has been replaced.
19. When the Brewer has finished its reset and returned to menu type pdhphgslslslpf to run a mercury lamp test followed by three standard lamp tests.
20. Type “skc” and press “Enter”.
21. Type in the name of the current schedule with the added sunscan measurements and press “Enter” to resume scheduled operation.

22. Make the appropriate entry into the Log Form indicating that the mercury lamp was changed. Also note the date, time and initials of the individual who changed the lamp.

Several days after bulb replacement:

1. Examine the sunscan data to confirm that there are sufficient data points to determine the instrument's new calibration step number. Refer to section XX for the procedure to determine the calibration step number.
2. If the new calibration step number is within +/- 2 steps different from the old one then the lamp replacement process is complete and the following steps can be ignored.
3. Press the "Home" key to abort scheduled operation.
4. Type "cf" to access the constants file.
5. Scroll the cursor down to the entry next to "WL cal step number" and enter the new value.
6. Press the "Ctrl" and "End" keys at the same time to exit constants file editing mode.
7. Press "y" to write the constants to a new file.
8. Enter the new filename using the format "icfJJYY" without using an extension and press "Enter"
9. Type "skc" and press "Enter".
10. The previously added sunscan measurements may be removed from the schedule.
11. Type in the name of the current schedule in use and press "Enter".

7.2.6.2. Standard Lamp Replacement

Note: The standard lamp is a 20 Watt tungsten halogen bulb and it emits UV radiation when it is powered on. Always wear UV protective goggles when working with the standard lamp.

Standard lamps typically do not require replacement for many years. Lamp test failure usually results from lamp burnout. Lamp intensity often changes significantly during the first few hours or days of lamp use, after which there is a much more gradual decline over time due to normal lamp aging. If lamp intensity (measured as the difference in counts between slits one and four) is less than 498 counts the standard lamp test aborts scheduled operation. Scheduled operation will continue to be automatically aborted until the lamp is replaced.

The eleventh column in the Sloavg.### file in the Brewer data directory shows the mean intensity of lamp scans for each day of Brewer operation. Replace the standard lamp if its intensity is less than half of its original intensity (lamp intensity after the first few days of lamp burn-in). Also replace the lamp if lamp counts are less than 300,000. The reason to replace the lamp if counts decrease significantly is that changes in lamp intensity can produce changes in the wavelength spectrum emitted by the lamp. Changes in the emitted wavelength spectrum can result in undesirable changes to the standard lamp ratios that are used to correct for changes in instrument response with time.

To replace the standard lamp (refer to Fig. XX above):

1. If lamp replacement is due to filament burnout or due to low lamp intensity then skip this step and proceed to step 5.
2. Type “co” and press “Enter” to enter a comment.
3. Type “old sl lamp” and press “Enter” to make a note in the B-file to indicate that the bulb is to be replaced.
4. Type pdhphgslslslpf to run a mercury lamp test followed by three standard lamp tests. The standard lamp ratios R5 and R6 are used to correct SO₂ and ozone ETC values for changes in instrument response with time. Having knowledge of these ratios immediately before and after bulb replacement will allow for removal of any changes in R5 and R6, and subsequently to ETCs, due solely to bulb replacement during data processing.
5. Wear UV protective goggles.
6. Press the “Home” key to go to abort scheduled operation.
7. Close the Brewer software window.
8. Power down the Brewer using the power switch on the side of the Brewer near the quartz zenith prism window.
9. Place a protective plastic cap over the UV dome.
10. Remove the Brewer cover.
11. The lamp housing is located below the zenith prism. The standard lamp holder can be removed from the lamp housing by removing either one or two hex head bolts or one or two thumbscrews (depending on the lamp holder version) from the rectangular plate directly below the zenith prism opening in the foreoptics tube.
12. Always Use a non-abrasive tissue to handle standard lamps. The standard lamp is held into its socket by a spring clip. Simply pull the lamp straight out to remove it from its socket.
13. Pick up the new bulb using a non-abrasive tissue and insert it into the lamp socket.
14. Replace the lamp holder into the lamp housing.
15. Replace the Brewer cover.
16. Remove the protective plastic cap from the UV dome.
17. Power on the Brewer—you should hear the shutter click if you listen carefully.
18. Restart the Brewer software.
19. Type “co” and press “Enter” to enter a comment.
20. Type “new sl lamp” and press “Enter” to make a note in the B-file to indicate that the bulb has been replaced.
21. When the Brewer has finished its reset and returned to menu type pdhphgslslslpf to run a mercury lamp test followed by three standard lamp tests.
22. Type “skc” and press “Enter”.
23. Type in the name of the current schedule in use and press “Enter” to resume scheduled operation.
24. Make the appropriate entry into the Log Form indicating that the standard lamp was changed. Also note the date, time and initials of the individual who changed the lamp.

8. HARDWARE INSTALLATION

8.1. Overview

It is important to read the entire Installation section of this manual before proceeding with installation.

8.2. Brewer System Requirements

The computer system which controls the Brewer will require shelter from the environment as specified by its manufacturer. Brewer data downloads as well as software update and instrument remote control for testing or diagnostic purposes is facilitated by an Internet connection.

Power-related requirements for the Brewer and its tracker are specified by the manufacturer to be:

Voltage and current: 3 A @ 80 to 240 VAC or 1.5A @ 160 to 264

Frequency: 47 to 440 Hz

The Brewer's operating temperature range has been specified by the manufacturer as 0C to +40 degrees Celsius in still air. The temperature range can be extended to -20C with an internal heater and further to -50 degrees Celsius with a cold weather cover. A further extension of the upper limit to the operating range may be possible by installing a white-painted aluminum sheet mounted on standoffs above the top and front of the Brewer in such a way as not to obstruct the zenith prism viewing window or the UV dome's view of the horizons. This plate serves to reflect sunlight and improve convective cooling of the instrument by allowing air to pass between the aluminum sheet and the Brewer.

A good quality uninterruptible power supply can provide both the Brewer instrument and its computer with stable power and reduce the incidence of operational failure due to power outages.

The power cables for both the Brewer and its computer system should be plugged into the same power circuit—preferably the same outlet on the same circuit—to prevent ground loops. Ground loops can cause the Brewer computer program to hang up at random intervals.

The minimum recommended surface space allocated for Brewer installation is about 2m X 2m. It is better to allocate more space if possible as this would facilitate operator access from all directions.

A port through a wall, roof or floor may be required to connect the power and data cable between Brewer and computer system.

If the Brewer is to be installed at a remote station then it might be useful to consider a means to connect to the instrument's computer system for diagnostics purposes. There are a

number of remote access software packages available for remote communications. It is also useful to have a means for the instrument to transfer its daily data files, and possibly near-real time information as well, to a centrally located server. This allows for data backup and archival as well as provides real time feedback on the Brewer's operational status which can help to minimize operational down time. This can be accomplished by having a scheduled job on the computer which sends files from the Brewer computer via FTP for example.

8.3. Site Selection

The ideal site for a Brewer spectrometer would afford it an unobstructed view of the whole hemisphere of the sky right down to the horizon (in all directions). The WMO (World Meteorological Organization) specifies that no obstruction should be greater than 10 degrees for the purpose of solar radiation measurements. The same applies for Brewer UV measurements. In higher latitudes, where the sun spends a good deal of time at lower elevations, it would be much more important to have a completely unobstructed horizon (especially to the south, east and west). In some cases the availability of necessary infrastructure, such as electrical power, and shelter, as well as cost issues, may prevent fully satisfying this criterion.

The site selection criterion is less critical for Brewer direct sun ozone measurements since these measurements are generally not performed at zenith angles greater than 72 degrees for MKII and MKIV Brewers or at zenith angles greater than 80 degrees for MKIII Brewers. MKIV or NO₂ Brewers and MKV or Red Brewers are specifically designed to take NO₂ and ozone measurements, respectively, at high zenith angles so horizon constraints should be taken into account more carefully.

8.4. Installation Surface

The Brewer should be installed on a surface that is sufficiently rigid so that the Brewer will not shift its position when it is walked around. Because of the shock associated with the motion of the stepping motor that drives the azimuth mount, situating the instrument on loose material will lead to continual creep in the instrument alignment.

The installation area should be able to comfortably accommodate at least two Brewers-- one space for a permanently installed Brewer and the other space for a visiting traveling standard Brewer for ozone calibrations. The size of the installation area should also allow for safe access to each of the at least two Brewers in all directions. A recommended minimum surface area for two Brewers is about 2.5 m X 4.5 m or about 8 ft. by 14 ft.

The ideal orientation of the installation area would be to have the longer dimension of the area positioned north-south. This would allow the operational Brewer to occupy the south spot and a traveling standard Brewer to occupy the north spot without either Brewer obstructing the other's view of the sunrise/sunset portion of the horizon. . The instrument situation is just opposite in the southern hemisphere. Calibrations are normally done in the summer season so that the traveling standard will have a clear view throughout the day.

8.4.1. Building Roof Top Installation

If the building roof top is a flat surface then the tripod may be installed directly onto the roof surface. If the surface is made of loose gravel then the tripod feet may be placed on concrete slabs or blocks of sufficient size to prevent shifting of the slab or block if it is stepped on.

8.4.2. Ground Installation

If the ground is not subject to freeze/thaw action and is relatively firm then the tripod feet may be placed on concrete slabs or blocks of sufficient size to prevent shifting of the slab or block if it is stepped on. If the ground is subject to freeze/thaw action then the Brewer should be installed onto a platform which may be constructed of wood or metal and stabilized with piles to prevent seasonal shifting.

8.4.3. Platform installation on Building Roof Top or on Ground

A rigid platform, constructed of wood or metal is required when the ground is subject to freeze/thaw action. It is also useful in other circumstances such as to provide the Brewer with a height advantage compared to nearby obstructions to view. A platform is also helpful when a location is subject to blowing snow. A raised platform generally allows most low level blowing snow to pass under the platform. Snow drifts can build up around the tracker and tripod and prevent the tracker from rotating properly because the cables and/or the tracker become bound in the snow.

A raised platform should be surrounded by a safety railing. A relatively safe recommended railing height is about 107 cm or 42 inches. Refer to local regulations for railing height specifications.

If a railing is higher than 115 cm or 40 inches above the surface on which the Brewer is to be installed then it may be necessary to elevate a Brewer's tripod feet so that the top of the railing is at or below the height of the bottom edge of the Brewer zenith prism window. Concrete slabs or blocks may be used to elevate the Brewer.

8.5. Brewer Spectrophotometer Assembly Instructions

Once the installation site and surface have been selected, as described above, the Brewer is ready to be assembled.

Note: Do not plug the Brewer system into a power outlet until instructed to do so below.

1. Assemble the tripod so that it appears as shown in Fig. XX. Place the tripod over the area where it is to be installed.
2. Place the tracker onto the tripod so that the "N" sticker on the tracker post or on the tracker base plate (as shown in Fig. XX) are oriented toward the north in the northern hemisphere and toward the south in the southern hemisphere. If the north stickers on the tracker post or the tracker base plate are faded or missing then remove the tracker covers and locate the north sticker on the surface of the drive plate. Rotate the tracker on the tripod to line up the holes of the tracker post

base and the holes in the tripod. Attach the tracker to the tripod using three bolts as shown in Fig XX.

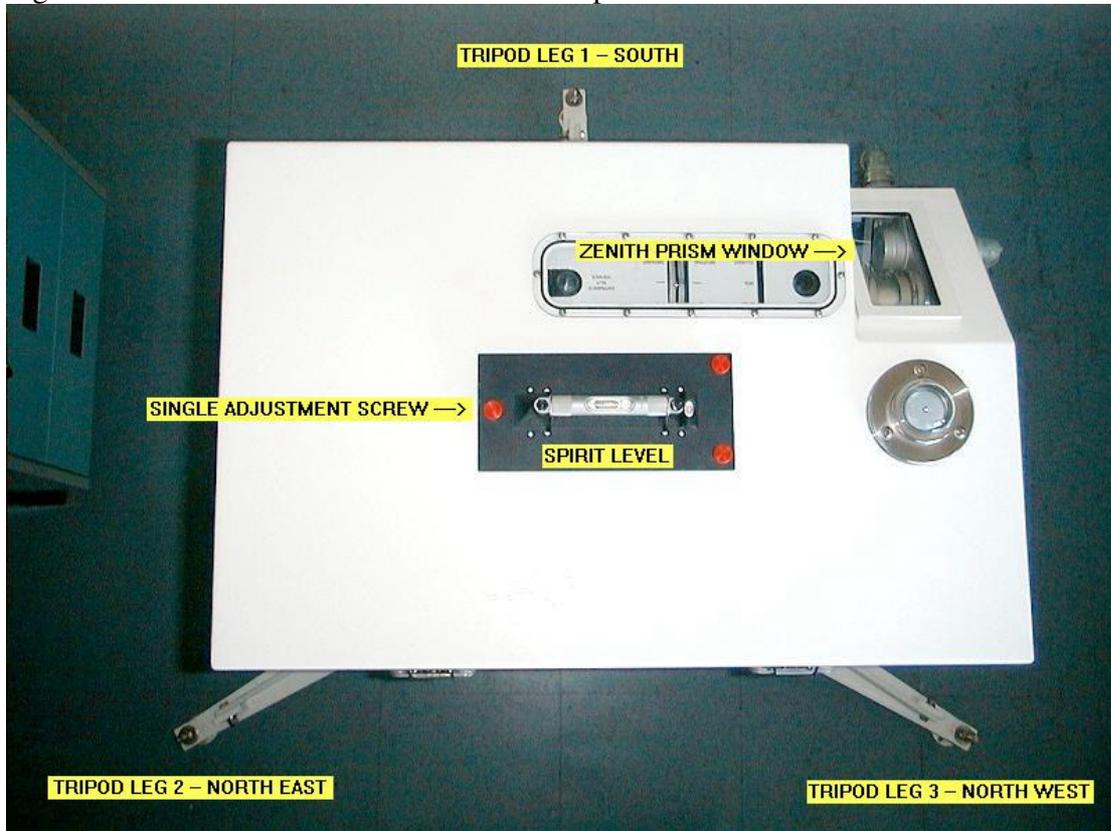
3. Rotate the tripod so that the “N” sticker is facing north (or south in the southern hemisphere).
4. Place the protective plastic UV dome cover over the Brewer’s UV dome.
5. Place the Brewer onto the tracker so that both of their power switches are facing the same direction.
6. Ensure that the Brewer’s rubber feet are centered on the tracker’s angle brackets. Loosely insert the four bolts, by hand, through the angle brackets and into the Brewer feet. Do NOT force the bolts into the feet. If there is ANY tightness in the movement of the bolt, before it is fully inserted up against the base of the angle bracket, then loosen the bolt and manually shift the Brewer foot on the angle bracket by pressing on the foot until there is no tightness in screwing in the bolt. These bolts cross-thread easily and can damage the aluminum threads. Forcing the bolts may also prevent proper operation of the Brewer by preventing the Brewer from being properly seated on the tracker’s angle brackets. Tighten all four bolts only when all of them have been properly inserted into the Brewer feet.
7. There will be either two or three cables extending from the base of the tracker, not including the auxiliary power extension. Each of these cables needs to be connected to the appropriate bulkhead connector on the Brewer. Examine the number of pins / sockets and attach each cable, in turn, to the appropriate mating bulkhead connector on the Brewer. Attach each of the cables coming from the base of the tracker to the Brewer. Note that the screw-on connector nuts may appear to be tight but the connector will remain improperly attached. When the nut feels tight, push the connector in toward the Brewer and then tighten the nut again. Repeat this process until the connector cannot be pushed in any further and the nut is tight.
8. Attach the power cable from the power outlet to the power bulkhead connector at the base of the tracker (the bulkhead connector furthest from the tracker power switch). Attach the data cable to the other bulkhead connector at the base of the tracker (nearest the power switch) only if all three of the connectors on the Brewer have a cable attached to them. Otherwise attach the data cable directly to the remaining bulkhead connector on the Brewer.
9. It is a good idea to have a means of stabilizing the Brewer tripod against strong winds which can upset the Brewer. The manufacturer may include a “tie-down” kit with the instrument for this purpose. The tripod feet can be bolted to a wood, metal or concrete platform. Weights can be placed over each tripod leg. Metal straps can be placed around the tripod leg and bolted down. Note that the Brewer should be leveled as discussed in the following section before legs are strapped down.
- 10.

8.6. Leveling the Brewer Tripod

The following procedure will outline the steps required to align the azimuth axis of rotation of the Brewer tracker with the local vertical. It is essential that the axis be vertical to better than 0.1 degrees and that the azimuth and elevation axes be perpendicular to each other to better than 0.1 degrees to achieve adequate pointing accuracy for all types of observations. The tracker leveling requirements are summarized in Figure XX and the leveling procedure is outlined in Figure XX. As outlined, the procedure is based on the underlying assumption that all

adjustments are free and the system is operating properly. A summary of problems and solutions associated with the leveling operation is included at the end of this section.

Figure XX: View of Brewer from above with spirit level.



Tools Required: One large slot screw driver, one adjustable wrench and a sensitive spirit level (0.01 degree or better precision) with two vials mounted on a plate with three adjustment screws. This level has a ground and graduated main vial and a cross test vial. With the cross test vial, it is possible to simultaneously level in both directions. This prevents inaccuracies in the main vial reading caused by canting the level sidewise.

Caution:

1. During the leveling procedure care must be taken not to move the spirit level with respect to the surface of the Brewer.
2. During manual rotation of the Brewer, be careful not to rotate the Brewer through the North facing position by more than about 30 degrees. If this occurs, the string that connects the large post in the center of the tracker to the internal shut off switch may break. This switch exists to prevent the tracker from winding up and breaking the power and data cables if the tracker moves beyond its zero position by about 60 degrees (in either the clockwise or counter-clockwise direction). If this string is broken then it must be replaced with 40 pound test nylon braided line or equivalent.

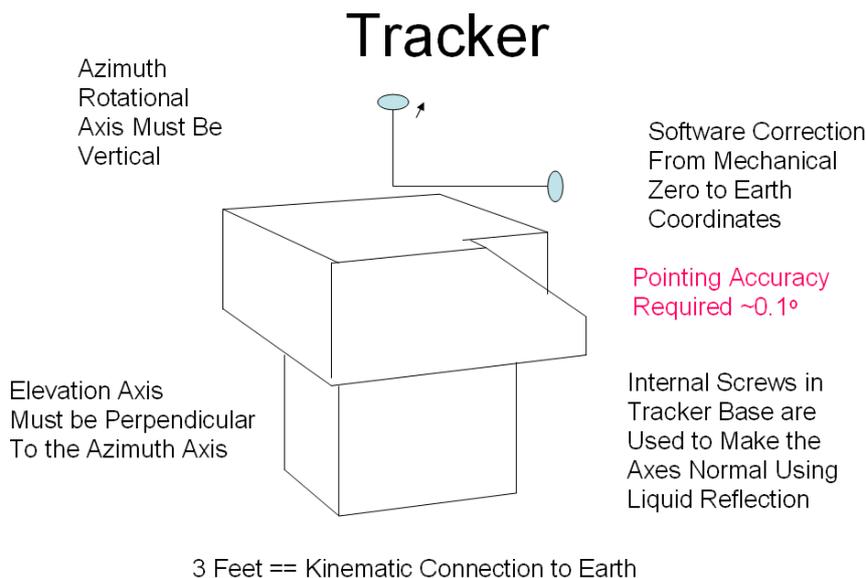
This is why it is a good practice to rotate the Brewer slowly so that if it is accidentally moved in the wrong direction, the click of the shutoff switch can be heard and rotation can be stopped before the string is broken. If the tracker cover must be removed to replace the string then re-install the cover after ensuring that each of the spacers on the cover bolts are screwed in toward the undercut portion of the bolts just below the bolt head.

Notes:

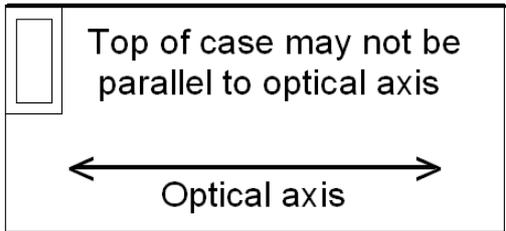
1. Omit steps 1 to 3 if the computer has not yet been set up to run the Brewer program.
 2. Rotating a tripod bolt screw clockwise (CW) raises the corresponding tripod leg while rotating a tripod bolt screw counterclockwise (CCW) lowers the corresponding tripod leg.
 3. While this procedure has been written up assuming that the Brewer is fully assembled onto the tracker, if the tracker is being set up prior to installing the Brewer, it is useful to simply level the tracker with a regular spirit level before installing the Brewer. Performing this preliminary level will have the axis very nearly vertical since the top surface of the tracker is machined accurately relative to the main bearings.
 4. It is recommended that the covers of the tracker be removed before leveling so that the position of the tracker relative to the safety switch can be monitored during the leveling operation.
-
1. If the Brewer program displays the status message “Waiting until HH:MM:SS for lamp warm-up”, Press “DELETE” to stop the lamp warm-up.
 2. Press the “HOME” key to place the Brewer program in the main menu.
 3. Close the Brewer program window. Click on the “End Task” button when the dialog window box appears.
 4. Turn off the power to the Brewer and tracker.
 5. Loosen the locking nuts on each of the tripod leg leveling bolts by several turns to allow for adjustment.
 6. Rotate the Brewer so that its zenith prism window is facing approximately south (north in the southern hemisphere) – i.e., parallel to the line connecting the ends of legs 2 and 3 and perpendicular to leg 1, which is the one pointing north as shown in Figure XX.
 7. Place the spirit level on top of the Brewer, over the axis of tracker rotation, so that it is parallel to the line through legs 2 and 3 as shown in Figure XX.
 8. Adjust the two screws near the small spirit level until the bubble in the small spirit level is leveled. Adjust the “single adjustment screw” as indicated in Fig. XX until the bubble in the larger spirit level is leveled.
 9. Rotate the Brewer manually clockwise 180 degrees until it is again parallel to legs 2 and 3 but with the zenith prism facing north (south in the southern hemisphere).
 10. Turn the single adjustment screw, while counting the turns, on the spirit level plate until the plate is level.
 11. Back off toward the original setting by half the number of turns and fractional turns counted.

12. Level the bubble in the large spirit level, by adjusting tripod feet 2 and 3. Note the position of the slots in the tripod adjustment bolts and use them as a reference for the amount of the adjustment that is made.
13. Rotate the Brewer through 180 degrees (staying clear of the safety switch). Repeat steps 10 through 13 until the large bubble stays level when the Brewer is rotated through 180 degrees.
14. When the adjustment sequence above is completed, rotate the Brewer so that it is parallel to the leg pointing north with its zenith prism window facing east. Adjust the large bubble to show full level using the leveling bolt in leg 1.
15. As a final check, rotate the Brewer so that it is parallel to legs 2 and 3 with the zenith window oriented north as shown in Figure 3. Now slowly rotate the Brewer through 360 degrees in 90 degree increments ensuring that the large bubble always indicates that the Brewer remains level as the Brewer is rotated. If the Brewer is not level then repeat the leveling procedure.
16. Tighten each tripod leg nut while using the screwdriver to hold the corresponding bolt in place.
17. Rotate the Brewer so that it is pointing south. Ensure that the Brewer can rotate one-half of a turn in either direction without the cables winding around the tracker post so as to restrict rotation. If the tracker rotation is obstructed by the cables then remove the cables, unwind them and then re-attach them in such a way as to ensure tangle-free operation.
18. If the tracker covers were removed, replace them and power up the Brewer and tracker.

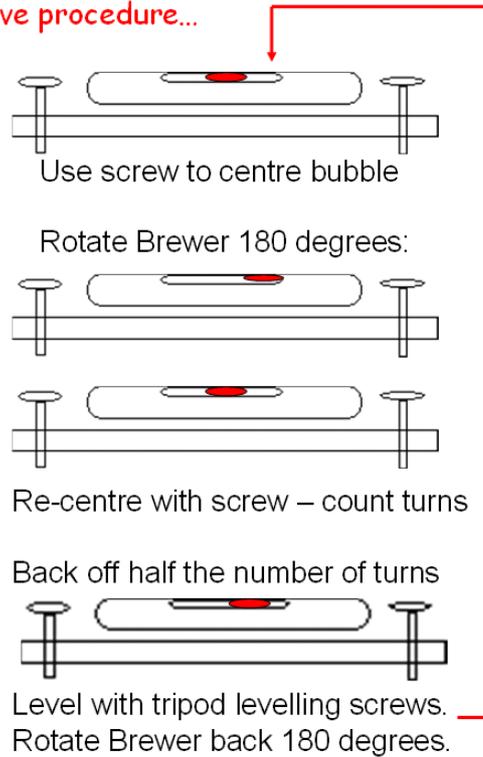
Problem: Seized tracker leveling bolts. A second adjustable wrench may be necessary if the stainless steel bolts are seized in the threads of the aluminum tripod leg. If one or more of the bolts are seized then remove the nut from another tripod leg bolt and place it onto the seized bolt near the top of the threads. Rotate the nut on the seized bolt up to the nut just placed on the bolt. Spread some low-temperature grease on the bolts threads. Place the adjustable wrench onto the top nut and rotate it clockwise to force the seized threads of the bolt to turn out from the tripod foot. Spread some low-temperature grease on the portion of the threads that were seized and place the wrench on the lower nut and rotate it counter-clockwise to work the grease into the tripod foot.



Levelling one Axis



An iterative procedure...



8.7. Leveling the Brewer's Optical Assembly

Once the Brewer's tripod has been leveled, it may be necessary to level the Brewer's optical assembly in order to ensure proper tracking. While the primary goal of this alignment procedure is to make the axis of rotation of the zenith prism exactly perpendicular to the azimuth axis of rotation, the secondary goal of making the optical axis of the UV diffuser viewing prism vertical is also addressed.

The instrument's optical assembly rests on three shock mounts. When the Brewer is mounted on the tracker, the main mounting screws pull the Brewer case down onto the tracker so that the optical assembly is resting solidly on three bolts that contact mounting surfaces located inside the shock mounts. The height of the optical assembly above the tracker surface is set by these three bolts which protrude from the top of the tracker. The separation between the optical assembly and the tracker at those three points can be adjusted to set the height of the optical assembly as well as the angle between the axis of the foreoptics and the tracker azimuth axis.

Before beginning the alignment procedure, install the protective plastic cap onto the UV dome. When removing the Brewer cover, rotate the latch handles counter clockwise one-half

turn to release the latch from its catch. Then turn the latch clockwise back to their original position, while holding the latch away from the catch, so that the latch hook is fully retracted and cannot get caught on the latch catch when the Brewer cover is lifted off. Place the cover flat on a horizontal surface. If the cover is stood on its end or on its side there is a very high probability that the cover will fall over and suffer damage.

The procedure used to adjust these bolts requires the removal of the tracker covers as well as the Brewer cover. The adjustment process is made much easier if the locknuts on the tracker bolts are installed on the inside of the tracker instead of on the outside. If the nuts are moved from the outside to the inside of the tracker longer bolts may be required to properly support the optical assembly. Note that the bolts used to level the optical assembly must have spherical ends machined onto them which mate with the surfaces inside the shock mounts.

Note: When the tracker bolts are properly adjusted, the Brewer optical assembly will be lifted relative to the base of the case by a few mm (compared to the situation when the instrument is resting on a horizontal surface rather than on the tracker) when the case is screwed down to the tracker. This force is required to ensure that the optical assembly alignment is properly maintained. (ref. problem description at the end of this section.) However, excessive lift on the optical assembly can cause damage to the rubber seals inside the shock mounts. A quick check to ensure that the optical assembly is sitting properly is to push down on the assembly over each of the three bolts in turn. If any motion can be felt, the bolts should be adjusted. This procedure is described in the problem description at the end of this section.

Required tools: Allen keys and a high accuracy circular spirit level that fits onto the surface of the zenith prism.

1. If the nuts on tracker-head leveling bolts are on the outside of the tracker then the Brewer needs to be taken off of the tracker to loosen the nuts. Place an allen wrench in the socket head of one of the leveling bolts on the inside of the tracker to hold it in place. Use a wrench to loosen the corresponding nut on the outside of the tracker by a few turns. Repeat this process for the remaining two bolts. Place the Brewer back onto the tracker and insert and tighten the 4 retaining screws.
2. If the nuts are on the inside of the tracker then place an allen wrench in the socket head of one of the leveling bolts on the inside of the tracker to hold it in place while using a wrench to loosen the corresponding nut on the bolt by a few turns. Repeat this process for the remaining two bolts.
3. If there is reason to believe that the Brewer has not been properly aligned before, if this is the first time the instrument has been set up on the tracker being used, or if the Brewer optical assembly is observed to be sitting clear of the adjustment screws (as per the test in the introduction), carry out the 'Initial setup of the optical assembly alignment' procedure below.
4. Place a high-accuracy circular spirit level on the surface of the UV diffuser prism.
5. Screw in one or other of the two bolts furthest away from the zenith prism to make the prism horizontal in that axis. Screw in the third bolt (nearest the zenith prism) as needed to keep the level operating properly.

6. Place the circular spirit level on the surface of the zenith prism and manually rotate the brass gear in the zenith drive system to bring the bubble as close to the centre as possible.
7. Adjust the tracker bolts until the bubble is centered within the target area. In order to ensure that the optical assembly remains firmly on the three adjustment bolts, make the adjustment by either screwing in the bolt nearest the zenith prism or screwing in equally the two bolts furthest away from the prism depending on which way the optical assembly needs to be tilted. The brass gear can be rotated manually as needed to keep the bubble in the centre of the target. Ensure that the three adjustment bolts are never lowered such that they are not supporting the optical assembly.
8. If the nuts are on the inside of the tracker then place an allen wrench into the socket of each of the leveling bolts on the inside of the tracker in turn to hold it in place while using a wrench to tighten the corresponding nuts to set the level position.
9. If the nuts on tracker head leveling bolts are on the outside of the tracker then the Brewer needs to be taken off of the tracker to tighten the bolts. Place an allen wrench in the socket head of the of the leveling bolts on the inside of the tracker in turn to ensure that they do not change their adjustment while using a wrench to tighten the corresponding nut on the outside of the tracker.
10. Remove the circular spirit level from the surface of the zenith prism.
11. Place the Brewer cover back onto the Brewer. If the latches do not close properly, check to make sure that Brewer cover is not resting on latch catch instead of slipping down behind it. If the Brewer cover is resting on the latch catch then push the Brewer cover in toward the Brewer in the area of the latch and off of the catch. Place the Brewer onto the tracker and screw it down.
12. Flip the Brewer cover latch handles down to draw rain water away from the latch centre and to prevent gradual corrosion and seizure of the latch.
13. Power up the Brewer and the tracker.

Problem: The Brewer may not be sitting properly on the optical assembly adjustment screws.

Initial setup of the optical assembly alignment.

1. The Brewer should be mounted on the tracker and fastened down with the 4 attachment screws. The Brewer optical frame will lift up compared to the position it has relative to the bottom of the case when it is sitting on a horizontal surface.
2. One by one, back out the three bolts until they are just free of the mounting surfaces inside the shock mounts. This can be determined by pushing down on the optical frame over top of each of the three screws as they are adjusted. When the screw is just free of the optical frame it will be possible to feel motion when the optical frame is pushed down.
3. With all three screws just free of their mounts, place the circular level on the Brewer.
4. Turn each screw in until the circular level just shows motion. The screws will then all be just touching the mounts.
3. Advance the 3 bolts by 1 turns each.
4. Complete the optical assembly alignment procedure.

8.8. Protective Covers for NO₂/Red Brewer Viewers

All Brewers referred to as “MKIV” or “Dual” or “NO₂” Brewers as well as those referred to as “MKV” or “Red” Brewers should have an opaque cover placed on both the iris and entrance slit viewers. Alternatively, a cover can be placed on the entire lexan viewing window. The cover(s) prevent diffuse visible light from entering the viewing tubes and contaminating NO₂ or red spectrum ozone measurements which are made in the visible portion of the spectrum. The prism in these viewers is made of glass so it absorbs UV light and thus is not a problem for regular ozone and UV measurements. Any simple blue glass can also be used to filter out this light. This blue glass would work for both NO₂ and red ozone measurements.

8.9. Computer System Installation and Connection

Assemble the computer system as specified by the computer manufacturer. Plug the Brewer power cable into the same outlet and circuit as the Brewer computer. Connect the Brewer data cable to the RS232 port labeled “COM1” on the back of the computer. If the number of pins on the data cable is different from the number of sockets on the computer’s RS232 port then an interface adapter is required. If the computer has no RS232 ports then an RS232 card may have to be installed into the computer. An RS232 to USB interface adapter cable may also be an option if the computer has a USB port. Note that there has not been much experience to date using this latter option so there is no guarantee that it will work in all cases.

9. SOFTWARE INSTALLATION AND CONFIGURATION

9.1. Overview

It is important to install the most recent version of Brewer software since each new version not only enhances both software and hardware operational capabilities but also operational reliability through correction of software errors.

At the time this document was last updated International Ozone Services Inc. (IOS) has taken it upon itself to maintain the DOS-based GWBasic version of the Brewer software. The most recent version of the Brewer software can be downloaded from their website at www.io3.ca.

The original software for the Brewer was written in the early 1980s using the GWBasic programming environment. The GWBasic environment is a predecessor of QBasic which in turn has been replaced by Visual Basic. The GWbasic version of the Brewer software is still the commonly used form of the Brewer control software. This version of the software works relatively well within the business versions of the Microsoft operating system environment including Windows NT and Windows XP Pro.

The GWBasic version of the Brewer program was written so that it has a “main” component, which represents the core of the program, and a series of “routines”. This is because GWBasic is a 64 KB interpreter. Each routine is loaded into memory and appended to the main program as it is required and is then on completion of its execution it is overwritten by the next required routine.

9.2. Installation of current version of the Brewer GWBasic Software

To simplify operations and installation the Brewer directory (ex. Br####, where #### is the last three digits of the Brewer serial number) can be installed in the root directory of a hard drive. Two subdirectories can be created under this Br#### directory—one is a “Program” directory and the other is the “Data” directory. A #### directory is created as a sub-directory in the Data directory. Copy the GWBasic software program and routines into the Program directory. Copy the instrument’s five constant files into the #### directory.

The following directories must be created if you install in the root of disk C (Brewer number #046 is used for this example):

```
C:\Br#046  
C:\Br#046\program  
C:\Br#046\data  
C:\Br#046\data\046
```

Edit the Op_st.fil in the \Program directory and the Op_st.### file in the \Data\### directory, using a text editor, to ensure that the information is correct. The first line in both of

these files should contain only the last three digits of the Brewer serial number. The second line in both of these files is the path to the data directory. The following is an example of how the first two lines of both of these files should look like:

```
046  
c:\Br#046\data\
```

Edit the Brewer.bat file in the \Program directory using a text editor to confirm that all of the information correct with respect to the hard disk on which the software resides as well as the Brewer program directory path. The following is an example of how the entries in this file should appear:

```
c:  
cd\Br#046\Program  
set brewdir=c:\Br#046\Program  
setdate  
echo on run brewer program  
gwbasic main /f:10
```

It may be useful to copy a shortcut to the Brewer.bat file onto the computer desktop so that the program can be started without having to find the Brewer.bat file in the program directory.

9.3. Computer and Brewer Software Configuration for Autoboot

Refer to the computer operating system's reference manual to configure the computer for automatic boot up in the event of a power failure and to simplify Brewer program start up.

A copy of the Brewer.bat file can be placed into the operating system's startup directory so that the Brewer software can also start up the Brewer to automatically resume operation in the event of a power failure. For Microsoft Windows XP this can be achieved by placing a copy of the Brewer.bat file into the C:\Documents and Settings\[username]\Start Menu\Programs\Startup directory.

9.4. Start the Brewer Software

Start the Brewer software by double-clicking on the Brewer.bat icon which is located either on the desktop or in the Brewer program directory. If the Brewer, computer, cables and software have been installed correctly then the software will attempt to communicate and reset the powered up Brewer in preparation for operation. When the reset cycle is completed then main menu will appear along with a "cm>" prompt at the main menu which can be used to enter commands to control the Brewer. If the Brewer does not reset properly or the software displays an error message then refer to Appendix XX to diagnose the problem.

9.5. Setting the Buffer Delay (if required)

New computers with fast processors may require a “buffer delay” value to be entered into the Brewer software to ensure proper communication between the Brewer and its computer. To determine if a buffer delay is required, press the “c” key several times and watch how fast the letters appear at the command prompt in the Brewer software window. If the response is immediate then no buffer delay is required.

If the response to repeated keystrokes is not immediate then set the buffer delay using the “cf” command as follows:

1. Hold down the “c” key until at least one “c” appears at the command prompt. The software may print many “c” characters on the screen because it empties the buffer all at once. Simply press the “Backspace” key to delete all of the “c” characters except one.
2. Repeat the same process to place one “f” character after the “c”. When “cf” after the command prompt then press “Enter” and wait for the constants file to be displayed.
3. Cursor down to the “Buffer Delay (s)” value near the end of the file and type “0.2” over the existing entry.
4. Press the “CTRL” and “END” keys to exit the constants file. Press “n” when prompted if you want to save the information into a new constants file.
5. Hold down the “c” key at the command prompt to determine if the display response has improved. If this process does not yield an immediate response then repeat the above steps and increment the delay by another 0.1 and so on until the response to keystrokes is immediate.

9.6. Brewer Time-Keeping Options

Maintaining the Brewer software window clock to within +/-5 seconds from the correct time is important to ensure proper tracking of the Brewer instrument.

There are a few time-keeping options which may be used to maintain correct Brewer time. The Brewer itself contains a clock card which is installed inside its card cage. The time, as maintained by this clock card, can be set by typing the “ti” command at the main menu and pressing the “Enter” key. This clock card contains two batteries that are used to maintain the Brewer clock in the event that there is a power failure or when the power to the Brewer has been turned off. A second time-keeping option is to use the computer clock to update the GWBasic environment clock. A third option is to use the computer clock which is automatically kept correct by using some combination of hardware and/or software as discussed below.

Most computer clocks are fairly poor at keeping time and can be off by 15 seconds or more each day. The Brewer internal clocks tend to be much better than computer clocks but still require periodic use of the “ti” command to correct any time drift beyond 5 seconds from the correct time. The best option for keeping time is to use some means to automatically maintain the computer clock’s time so that it is always correct. There are a number of options available to maintain the accuracy of the computer clock. A few of these options include: a) a high accuracy time keeping card, which is installed into the computer, b) a GPS receiver card which is installed into the computer that polls the time from GPS satellites or c) time server software which

automatically polls a time reference website and then updates the clock of a computer which has been connected to the Internet.

To determine which time-keeping option is currently in use, note the letter located immediately after the "C.U.T." and before the time in the top left corner of the Brewer software window. If this letter is an "I" then this indicates that the "internal" Brewer clock is being used. An "E" indicates that the "external" (to the Brewer) computer clock is being used. The external clock is the clock maintained by the GWBasic program environment. Note that this GWBasic clock is not the same as the computer's clock. To change the Brewer software to use the "internal" clock if it is currently set to use the "external" clock, or vice versa, type "ic" at the main menu and press "Enter". Cursor down to the "Clock board" option. Press "y" to select the internal Brewer clock or press "n" to select the external GWBasic environment clock. Press the "Ctrl" and "End" keys at the same time to return to the main menu.

The "td" command can be used at the main menu prompt or in a schedule (refer to Section XX on Schedule Writing below) to automatically update the GWBasic environment clock from the computer clock. Note that "td" option should only be used when the Brewer clock has been set to "E" for external otherwise the Brewer software clock will be updated by both the GWBasic clock and the computer clock.

To use the "td" command, the td.rtn file must be located in the Brewer's program directory. If the td.rtn is not located in the program directory then use a text editor and copy the following section of code into the editor window.

```
10000 REM ***** td routine 26/11/97 *****
10001 REM          MKII/MKIII/MKIV This Routine
10002 REM
10003 REM gets TRUE time from PC clock by going to RIGHT!! dos shell and back
10004 REM julian groebner 26 11 97 julian
10004 REM *****
10005 DATA td
10070 PRINT#4,TIMES$
10080 PRINT#4,"Getting time from PC clock..."
10100 shell("cmd /C")
10110 PRINT#4,TIMES$
10200 return
65529 REM *** proper last line ***
```

After the above section of code has been copied into the text editor window, save it as "td.rtn" and place it into the Brewer's program directory.

9.7. Configure Software for Brewer Location and Station Pressure

The best way to enter station latitude, longitude and station information is to use a text editor to open the loc.fil located in the Brewer program directory. The first number in this file is

the index number and it represents the number of existing station entries in the file. To add another station to the list, add one to this first entry. Insert four blank lines after the index number. On the first blank line type the station name and press "Enter". It is best to use GPS-determined coordinates for the Brewer location. The latitude and longitude values should be entered using two decimal places on the second and third blank lines respectively. Note that for longitudes up to 180 degrees east of the Greenwich meridian the longitude values are entered as negative numbers. Note that latitudes south of the equator are also entered as negative numbers. Type the station latitude accurate to two digits after the decimal place and press "Enter". Type the station longitude accurate to two digits after the decimal place and press "Enter". Type the mean station pressure value to the nearest millibar. Save the file. At the main menu type "LL" and press "Enter" to display the list of stations preceded by an index number. Type the index number of the station that was added to the loc.fil and press "Enter" two times. The header at the top center of the Brewer program window should now show the name of the new location that was selected using the "LL" command.

9.8. Configure Software for Date and Time

Refer to Section XX: Brewer Software Date Check and Section XX: Brewer Software Time Check in the maintenance section for instructions on how to enter date and time information into the Brewer software.

9.9. Sighting

Refer to Section XX: Sighting the Brewer on the Sun in the Maintenance section to prepare the Brewer to track the sun and moon.

9.10. Place the Brewer on Schedule

After a sighting, the Brewer is ready to be placed on schedule to begin automated collection of ozone and UV data. If there is schedule already written for the station where the Brewer is to be operated then type the command "skc" from the main menu and press "Enter". When prompted, type in the name of the schedule at the command prompt and press "Enter" to execute it.

For more information about schedules and about writing schedules refer to Section XX: Writing Schedules.

A simple generic schedule for collecting ozone and UV data that should work with any Brewer model is shown below. Refer to Appendix XX for schedules which are better suited to a particular Brewer model. To use this schedule simply copy the entries into a text editor and save the file into the Brewer program directory using the naming convention: "test.skd" where "test" can be any string of up to eight characters followed by the ".skd" file extension. If the name used for the schedule is not "test.skd" then be sure to replace the word "test" in the last line of the schedule with the name used without the ".skd" extension.

```

-106
pdt dpofrhphgslmdpf
-97
pdt dpfhphg uvm dw2uvmdw2uv99
-83
pdt dpfhphg dsz s uvm ddsz s uvm ddsz s uvm d99
0
pdt dsrzehphg dsb2zssl uvm dschphg dsb2zssl uvm d pfm3
83
pdt dpfhphg uvm dw2uvmdw2uv99
95
pdt dpfhphg slpf
98
pdt dpfmdfmdthphgfmfmfmfmfmfmfm30
180
test

```

For the above schedule to work properly use a text editor to copy the following text into a text editor and save the file as "m3.rtn" in the Brewer program directory.

```

10000 REM ***** m3 routine 20/10/95 *****
10010 REM          MKII/MKIII/MKIV Set Up and Repeat Auto Sequence
10020 REM
10030 REM *****
10500 DATA m3
10510 IF Q1%+Q2%+Q3%+Q4%+Q5%<>5 THEN RETURN:REM return if not automatic
10520 IF ED%=2 THEN ED%=3
11000 '
11001 ' *** Set up command sequence ***
11002 '
11010 UC%=0:JJ=0:QC=0:REM reset command counter to zero
11020 IF MDD$<>"o3" THEN MDD$="o3"
11022 QC=QC+1:G$(QC)="p"+"d"
11030 QC=QC+1:G$(QC)="t"+"d"
11032 QC=QC+1:G$(QC)="p"+"f"
11040 IF TYP$="mkiii" THEN QC=QC+1:G$(QC)="h"+"p"
11050 QC=QC+1:G$(QC)="h"+"g"
11060 QC=QC+1:G$(QC)="d"+"s"
11070 QC=QC+1:G$(QC)="z"+"s"
11090  QC=QC+1:IF TYP$="mkii" OR ZERO=3469 THEN G$(QC)="u"+"v" ELSE
G$(QC)="u"+"x"
11100 QC=QC+1:G$(QC)="m"+"d"

```

```

11110 QC=QC+1:G$(QC)="d"+"s"
11120 QC=QC+1:G$(QC)="z"+"s"
11140 QC=QC+1:IF TYP$="mkii" OR ZERO=3469 THEN G$(QC)="u"+"v" ELSE
G$(QC)="u"+"x"
11150 QC=QC+1:G$(QC)="m"+"d"
11160 QC=QC+1:G$(QC)="d"+"s"
11170 QC=QC+1:G$(QC)="z"+"s"
11190 QC=QC+1:IF TYP$="mkii" OR ZERO=3469 THEN G$(QC)="u"+"v" ELSE
G$(QC)="u"+"x"
11200 IF TYP$="mkiii" THEN QC=QC+1:G$(QC)="b"+"2" ELSE G$(QC)="b"+"1"
11210 QC=QC+1:G$(QC)="m"+"d"
11215 QC=QC+1:G$(QC)="d"+"s"
11220 QC=QC+1:G$(QC)="m"+"3"
11230 QR=1:IF G$(0)="" THEN G$(0)=C$:SK$=C$
11400 IF G$(0)="m3" THEN ZF=85:REM set to stop at zenith angle=85
11410 IF ZA>85 AND G$(0)="m3" THEN G$(1)="e"+"d":SK$="":REM end day to follow
11420 IF RM%=1 THEN RETURN:REM if called from command sequence
11430 GOTO 3400
65529 REM proper last line

```

To execute the schedule type the schedule name at the command prompt, without the extension “.skd”, and press “Enter”.

10. DATA ACQUISITION

10.1. Overview

The Brewer software can execute various measurement, diagnostic and calibration functions by typing the appropriate two letter command sequence at the command prompt and pressing "Enter".

The software also accepts a string of two-character commands for automatic execution of the entire command string. Refer to the manufacturer's Operator's Manual for more detailed information on the commands available and their function.

A schedule is simply an ASCII text file which contains a series of command strings, each of which are executed as a function of the zenith angle specified on the preceding line in the file. Morning zenith angles are preceded by a negative sign. Schedules are invoked at the menu prompt by typing either the "sk" command for one day only, or the "skc" command which runs the schedule continuously.

The final line in the schedule is the name of the schedule, without a file extension, to be run on the next day. This can either be the name of the schedule itself or the name of another schedule. This feature allows for the execution of different schedules.

The ed.rtn (end of day routine) automatically executes at the end of each day and creates a summary of the diagnostic and measurements performed during the day.

To exit scheduled operation:

If the computer displays the message "press home to stop" then do so.

If the computer displays the message "lamp warm-up" then press the "DELETE" key to abort the warm-up and then press "HOME" to exit when prompted.

10.2. Scheduled Operation and Writing Schedules

To execute a command at solar noon type "0" as the zenith angle. Specifying a zenith angle as "1" (if there is no 0 line before it) instructs the software to execute the following command string soon after solar noon. Specifying a zenith angle of "180" instructs the software to execute the following command string at the time of solar midnight. Note that the command sequences following a "0", "1" or "180" will be executed even though none of these solar angles are actually achievable due to latitude or season.

To write commands to the D-file, which provides a formatted version of information that appears in the B-file, place a "pd" command immediately before the commands that are to be written. A "pf" can be used to stop the writing of information into the D-file.

If the next zenith angle occurring in the schedule has been achieved then the software will continue executing its current command to completion before proceeding to the next command string. If a command string is completed before the next zenith angle in the schedule is reached then the Brewer will sit idle and display the message “waiting until HH:MM:SS for [next measurement]” until the next zenith angle is achieved.

A number between 1 and 99 can be placed at the end of a command string to indicate the number of times to repeat the sequence to save writing the same commands again. Alternately, there is a routine called au.rtn (automatic routine) which can execute a series of commands and repeat it automatically just by inserting “au” as a command in the schedule. This routine can be copied and given a different name so that different automatic routine command sequences can be executed at different zenith angles. Note that the name of the new routine should be two letters followed by the extension “.rtn” because the software parses the command strings into two letter commands. It is also important to ensure that the name of the new file is not the same as the name for any of the existing routines in the program directory to prevent existing files from being overwritten. If the au routine is copied then it is important to do a search for the “au” string within the au.rtn file and change all occurrences of “au” to the new two letter name for consistency.

10.3. Scheduling Commands

The following Tables describe the duration, frequency and recommended airmass ranges for measurement and diagnostic commands as a function of Brewer model. Note that it is assumed that the Brewer version of software being used is 3.75f which allows simultaneous movement of both micrometers for a multi-board MKIII Brewer.

Since instrument hardware and software configuration may not fall into one of the table categories below or may change with time, one fairly easy way to accurately determine measurement duration is to go to menu and run a command string containing each measurement type separated by “td” commands (ex . ptdhptdhgtdsltdaptddttdrstdtdzstduvtdpf). Examine the D-file and determine the time differences for timestamps preceding and following each measurement.

10.3.1. Scheduling Measurement Commands

[Create a table for each Brewer model w and w/o new electronics for time taken for all obs.]

[Table]

Minimum Recommended Measurement Frequencies

→Specify minimum # ds #uv #zs / hr during daylight hours—specify using reasons—ex. Statistical, satellite overpass...discuss with Volodya and Vitali. Add this info to meas duration chart?

Set up the same schedules at all sites so that data is the same at each site for a given zenith angle. Then uv and ozone observations can be compared and other related site factors can be studied—ex. Site altitude, window/ dome cleanliness etc. can be studied

10.3.2. Scheduling Diagnostic Commands

[Create a table for each Brewer model w and w/o new electronics for time taken for all obs.]
[Table]

10.4. Writing Schedules

In order to make measurements in an optimal manner, different schedules will likely have to be written for different time periods of the year, especially for mid-latitude and high-latitude stations, due to the significant changes to solar elevation during the course of the year. Different schedules will also have to be written to take full advantage of different measurement capabilities of various Brewer models.

The “sa” command can be used to display zenith angles and airmass values for both the sun and the moon for any given day of the year as a function of time. First type the “pd” command to log the information to the D-file and press <Enter>. Then type the “sa” command, press <Enter> and respond to the information requested. Generally, entering “0” for the start time, “24” for the end time and “5” minutes for the time increment provides sufficient resolution for schedule writing. A comment can be entered at the comment prompt if desired otherwise just press <Enter>. The tables generated using the “sa” command along with the tables above showing measurement duration, frequencies and recommended airmass ranges.

10.5. Tips for Schedule Writing

10.5.1. Micrometer Movement

Commands which involve micrometer movement include hp, hg, sc, uv, ux, um, n2, and o3. It is best to place commands which do not move the micrometer (ex. ds, zs, etc.) directly after an hphg to prevent loss of data in the event that a micrometer movement issue develops and is not addressed immediately.

10.5.2. Lamp Commands

It is best to schedule an “hphg” command with sufficient frequency to ensure that important to ensure that this string is always executed before instrument temperature changes by 3 degrees Celsius in order to compensate for temperature-induced spectrum shifts.

It is good practice to use “hphg” instead of just “hg” even for MKII, MKIV, and MKV instruments to make schedules more generic and to prevent data degradation due to mis-alignment of the two micrometers in the event that the schedule is ever installed on a MKIII Brewer or shared with someone who has an MKIII Brewer.

It’s a good idea to have a take a few sl measurements at various times during the day, in order to collect instrument response data at various temperatures.

Scheduling more than about 30 hphg commands and more than 6 sl commands is likely excessive and will lead to premature aging and burn out of the hg and sl lamps without providing any more useful information.

It is better not to place any command that measures light from the sun or sky between a lamp warm up command (i.e., b1 or b2) to prevent light from reflecting off of the quartz window and contaminating the signal.

Newer versions of the Brewer software perform a micrometer and filter wheel #3 reset (fr) automatically after each instrument reset (re) command. As a result, it is necessary to run an hphg to properly position the micrometer to disperse the correct wavelengths onto the exit slits of the spectrometer.

It is recommended that about ten standard lamp measurements be scheduled evenly throughout each day and night so they occur at various temperatures and can be used to monitor instrument response changes with temperature.

10.5.3. DS, ZS, FZ and UV Measurements

UV measurements at zenith angles greater than 90 degrees may contain useful information. There is likely no value in measuring UV for zenith angles greater than 95 degrees. Measurements can be taken at $90 < \text{zenith angle} < 95$ if the instrument has nothing else to do. The absolute minimum is two UV measurements per hour for zenith angles less than 90 degrees and it would be nice to have three to four measurements per hour around solar noon.

It is also useful to take DS and ZS measurements at high zenith angles. At present, we do not use measurements taken at $\mu > 3.5$ (or 4 - depending on the site). Focused sun measurements can be used down to an airmass of 8.2 or to a zenith angle of 85 degrees. With new algorithms that help to correct for stray light it is hoped that MKIII instruments will produce useful ozone values to an airmass of 8.0 and that MKII, MKIV and MKV Brewers will produce useful ozone measurements in the UV down to an airmass of 5.0.

10.5.4. Focussed Moon Observations

Focussed moon (fm) observations can be contaminated by sunlight if sun is near or above horizons so it is best not to schedule these measurements for zenith angles less than 92 degrees.

10.5.5. Umkehr Commands

A "um" command runs indefinitely so it is best to schedule desired measurement commands before it. It is better to use the u5 routine which collects the required amount of data for umkehr processing purposes since the runtime of this command is known in order to facilitate the scheduling of other commands. If "um1" is typed in a schedule after an angle (and nothing else) then only one um scan will be done.

10.5.6. CI and CZ Scans

Ci scan of entire 290 to 325 should be done say once a week. Does not have to be too fine. Cz scan of hg line should be done at about same frequency.

10.6. Sample Schedules

Recommended generic sample scheds in appendix for mod/mid-lat—min rec # uv and ds per hour for Global network. Write schedules for 20, 40, 60 and 80 degrees with min number of ds,zs,uv,um meas. for the various seasons. Reverse for southern hemisphere.

11. ROUTINE DIAGNOSTICS

11.1. Overview

The Brewer generates a significant amount of diagnostic information during routine operation. Results from diagnostic tests can be found on the computer screen, in the instrument's B-files, D-files as well as in the various average files. The information from these files can be used to determine the current operational state of the instrument as well as to address any concerns before they begin to have negative implications for both data quantity and data quality.

11.2. Daily Error Checks

There are three classes of errors that may occur during Brewer operation. The first class of error will result in the error message being written to the software window and immediate failure of Brewer operation. Examples of these types of error messages include "Brewer failed to respond 5 times" or "reset in ## seconds", which are displayed on the screen and result from an instrument power or communications failure.

The second class of errors result in an error message being written to the B-file at the time that the instrument was last in scheduled operation mode and cause the software to abort scheduled operation and display the command prompt at the main menu. Examples of these types of errors include a motor zeroing failure or a lamp not found error. These errors will cause the Brewer software to exit scheduled operation because continued operation would not yield useful information. As long as the software is on menu, it will create small daily B-files with file header information only.

The third class of errors, which are not as serious, do not cause the software to exit scheduled operation but simply generate warning messages in the B-file. One example of a warning message results from an unrecognized character string in the schedule file. The B-files must be examined in order for the operator to be aware of this type of error.

A software package called "BrwRprt.exe" can be used to extract error and warnings information from B-files. This software also extracts any text from the "B-file" that does not reflect normal Brewer operation. The list of recognized text strings is user-editable. Refer to Appendix XX for more information about this free software and on how to access it.

Please refer to Appendix XX for the procedures to deal with each type of error or warning message. Log all types of errors into the Brewer Log Form along with the action(s) taken to resolve them.

11.3. Weekly Diagnostic Checks

Various diagnostic parameters should be monitored in order to ensure that the Brewer is operating optimally. Each of the following diagnostic tests topics provides the two letter

command used to invoke the test, the location of the diagnostic information, a brief description of the purpose of the test, acceptable limits, and potential problems and recommendations. Software like BrwrRprt.exe can be used to extract diagnostic information from Brewer B-files as well as from the various average files. Refer to Appendix XX on Troubleshooting for detailed instructions on resolving any variances from recommended limits for each diagnostic parameter. Refer to Appendix XX for more information about this free software and on how to access it.

11.3.1. Mercury Lamp Test (hg)

Information location: Mercury lamp intensity information can be found in the second column of the Hgoavg.### file.

Purpose: Spectral shifts occur in the spectrometer as the instrument's temperature changes. The mercury lamp test is used to locate either the 302.15 nm or 296.73 nm mercury spectral emission line (depending on software configuration) and then re-position the grating to disperse the five operational wavelengths onto the spectrometer's corresponding exit slits.

Acceptable limits: Mercury lamps last about one to three years depending on the bulb and frequency of use. Lamp intensity gradually declines with use due to deposition of a mercury film on the inner surface of the lamp. Lamp intensities of new mercury bulbs can range from about 40,000 counts to about 150,000 counts, as measured by the hg routine, depending on the sensitivity of Brewer and neutral density attenuation filter in place during the test. It is common for mercury lamp intensity to decline by as much as 10,000 to 20,000 counts during the first few hours or days of use before starting a slower rate of decline in intensity levels.

Potential problems and recommendations: It is a good idea to replace mercury lamps once their lamp intensity deteriorates to about 20% of their original value. At this point there is generally not much life left in the bulbs and the intensity check performed at the beginning of each test can cause the test to fail and the Brewer to abort scheduled operation if the lamp intensity falls below 400 counts.

11.3.2. Standard LampTest (sl)

Information location: Standard lamp R5, R6 and intensity information can be found in the ninth, tenth and eleventh columns, respectively, of the Sloavg.### file.

Purpose: The standard lamp test is used to monitor the stability of the instrument's response to light over time. Standard lamp tests produce two diagnostic ratios, the R5 and R6 ratios, which can be used to correct the instrument's SO₂ and ozone extraterrestrial coefficients respectively.

Acceptable limits: The R5 and R6 ratios should remain stable over time and remain within +/- 20 and +/-10 units, respectively, of their nominal values.

Standard lamps can last for many years depending on the bulb and frequency of use. Lamp intensity generally decreases slowly over time and can be further reduced by the deposition of a black or white film on the inner surface of the bulb. Lamp intensities of new standard lamps can

range from about 500,000 counts to about 1,200,000 counts, as measured by the sl routine, depending on the sensitivity of Brewer and on the neutral density attenuation filter in place during the test. It is common for standard lamp intensity to decline by as much as 50,000 to 100,000 counts during the first few hours or days of use before starting a slower rate of decline in intensity levels.

Potential problems and recommendations: It may be a good idea to replace the standard lamp if lamp intensity declines to about 50% of its initial value. Lamp intensities below 350,000 counts can lead to higher standard deviations in the measurement results of other diagnostic tests.

The neutral density filter in place during the test is recorded after each “sl” scan. If lamp intensities of new standard lamp bulbs is below about 500,000 counts and the filter in place is 1 or two, settings 64 and 128 respectively, then the neutral density filter can be reduced to the next lowest settings, 0 and 64 respectively, using the “cf” command to increase lamp counts and also effectively increase the useful life of the bulb.

11.3.3. A/D Information Checks (ap)

Information location: PMT high voltage and primary power supply 5 volt level information can be found in the second and third columns, respectively, of the Apoavg.### file.

Purpose: Stability of the high voltage level supplied to the PMT and the +5 volt level from the primary power supply are critical to proper instrument operation.

Acceptable limits: The PMT high voltage level should remain within two increments or about +/- 22 units of its nominal value.

The +5 volt level on the primary power supply, with lamps on, should be between +4.95 to +5.10 volts.

Potential problems and recommendations: Variation in the PMT high voltage level above acceptable limits should be investigated.

Primary power supply voltage levels below 4.8 volts can lead to erratic Brewer operation including operational failure. The potentiometer on the power supply can be used in an attempt to bring the +5 volt level within acceptable limits. If there is not enough adjustment available in the potentiometer to bring the +5 volt level to within acceptable limits then it is likely that contact corrosion is the cause.

11.3.4. Dead Time Test (dt)

Information location: The high intensity dead time test results and the low intensity dead time test results can be found in the second and third columns, respectively, of the Dtoavg.### file.

Purpose: The dead time test measures the dead time of the PMT and the photon counting circuitry. The dead time is the time during which the PMT is not able to count a second photon

after the first photon has been detected. The dead time constant is used to correct for the Brewer's non-linear response to light. A correct response curve (counts as a function of light) would be a linear curve (i.e. counts directly proportional to level of irradiance). However, the curve actually begins to move below the ideal at higher irradiance levels. Three percent to four percent of the counts have to be added back to the signal at the 1 million count level (i.e., real count rate is 3 to 4% higher than measured value at 1 million count level). About 6% of the counts have to be added back at the 2 million count level. The ideal operating range is between one and two million counts. The dead time correction depends on the count rate and on the dead time itself. $30 \text{ nanoseconds (dead time constant)} \cdot 10^6 \text{ (count rate)} = 3\% \text{ correction}$. The correction is calculated, using Poisson's law, as $= \exp^{-\lambda \cdot x}$ where λ is the dead time constant and x is the count rate. The value in the brackets is 0.03.

Acceptable limits: The high intensity dead time test value should be within +/- 2 ns of the current dead time setting in the instrument's constants file.

The high and low dead time means should agree to within an acceptance tolerance of two high intensity dead time test standard deviations and lie in the range of 30 to 45 ns.

Acceptable standard deviation values for dead time tests are up to 2.5 for high intensity and up to 20 for low intensity.

Standard deviation values for high and low intensity dead time tests can be found in the D-files.

Potential problems and recommendations: Failure to satisfy the acceptable dead time test criteria suggest that the shutter motor operation, high voltage circuitry and the photon counting circuitry should be examined. Variable dead time test results can be due to a failing heat sink assembly.

If both dead time and run/stop results are poor then the positioning of the spherical mirror may have to be adjusted to focus the light correctly onto the exit slits.

If the dead time means are variable and run stop test values are good and the dead time test standard deviations consistently follow the normal pattern (i.e., high intensity dead time test standard deviations less than those of low intensity dead time test standard deviations) then the neutral density filter applied during the dead time test may be too high.

Poor instrument grounding can result in bad dead time test results.

Poor slit mask alignment may cause the high and low intensity dead time test numbers to be different from each other.

It has been observed that high humidity can lower dead time test results probably by changing the transmission properties of the UG11 and/or Nickel Sulfate filters.

Negative dead time values can result from low standard lamp counts. Items to be checked include the zenith offset constant, the condition of the standard lamp, the standard lamp voltage and current values, which should multiply together to yield 16 Watts or slightly more. Higher voltages may lead to premature lamp burnout. The standard lamp voltage may be adjusted using the appropriate potentiometer on secondary power supply. Refer to the manufacturer's maintenance manual for the location of the standard lamp potentiometer.

If there is poor dead time test or standard lamp ratio stability then ensure that the high speed amplifier ground wire is in place.

Unstable dead time test values might be solved problem by increasing the high voltage setting.

A new dead time value should not be entered into the constants file unless it is consistently more than +/- 2 ns different from the old value and the instrument is working properly. A change in the dead time constant value will impact standard lamp test results, measured ozone values and may require a new ozone calibration.

If the dead time constant is changed then check the standard lamp ratios after a few weeks to see if there is any change in their values. If there is a significant change then correct the SO₂ and ozone ETC's using the corresponding change between the old and new R5 and R6 values.

11.3.5. Run Stop Test (rs)

Information location: The run stop ratios appear in the second through ninth columns of the Rsoavg.### file.

Purpose: To confirm that the slit mask motor is operating correctly. The RS test produces a report on the operation of the Slit Mask Motor by taking measurements in the "running" and "stopped" modes of the Slit Mask Motor.

Acceptable limits: Position zero of the slit mask is used for the mercury lamp test. Position one is blocked and used for dark count measurements. Positions 2 to 6 are used to measure intensities for the five operational wavelengths. Position 7 is allows light from positions 2 and 4 to pass simultaneously and is used for the dead time measurement. Run stop ratios for wavelength 0 and 2-6 (columns 2 and 4 to 8) should always be within 1.000 +/- 0.003. An instrument that is operating optimally will have ratios that are consistently within 1.000 +/- 0.001. The dark count ratio, "wavelength 1" (column 3) should be within the range of 0.2 to 5.0.

Potential problems and recommendations: A malfunction in the slit mask motor circuit or in the alignment of the slit mask itself can result in improper counting, which reduces data quality.

It has been found that shutter motors mounted to the spectrometer chassis with nylon nuts and bolts may loosen over time resulting in erratic movement of the slit mask. The nylon hardware should be well tightened, or even better, replaced with a stainless steel bolt held in place with a lock nut.

If the run stop ratios are outside of the acceptable range then the shutter alignment, the shutter motor, power supply drive circuitry, the shutter motor timing constant should be examined. One sure sign of a failing shutter motor is excess play in the shutter motor's shaft, which is an indication of worn bearings. Worn shutter motor coils may be diagnosed by continually running the shutter motor back and forth from position zero through 7 and looking for any erratic behaviour, which may indicate weakened motor coils. If both dead time and run/stop results are poor then the positioning of the spherical mirror may have to be adjusted to focus the light correctly onto the exit slits.

12. DATA ANALYSIS AND ARCHIVAL PROCEDURES

13. DATA QUALITY CONTROL AND DATA QUALITY ASSURANCE

14. CALIBRATIONS

14.1. Instrument Calibration for Ozone Measurement

Introduction

This section of the document is intended to provide guidance for the characterization and calibration of Brewer Ozone Spectrophotometers. It outlines the series of tests, and their sequence, which must be completed in order to post-calibrate or re-calibrate a Brewer. A list of characterization information which results from the tests and must be retained as documentation for the calibration exercise (and which should be lodged with the WOUDC as well as national data centres) is also included.

The methodology of measurement, when examining a time-series of data collected by an observing instrument which depends on an absolute calibration, must be based on the following. It must be assumed that, however high a quality instrument that is being used, and given that the initial calibration was correct and exact, the possibility exists that long-term drift or step changes in the response of the instrument may occur at any time between calibration events. For this reason, a data set is only complete after a post-calibration has been made and the information so determined has been used to reprocess the measurements from the raw data recorded between calibrations.

14.2. The Information Collected During a Calibration

The information collected includes is outlined in the following sections. Table 14.1 provides a summary fo the information collected during a calibration exercise.

14.2.1. Instrument Performance History

It is noted whether the instrument is being calibrated at the normal measurement site, or transported to or from the observing location to the calibration site. Instrument data files are first analyzed to determine the stability and performance of the spectrometer over the time period since the last calibration. The elements analyzed include the standard lamp record, the mercury lamp performance, the micrometer calibration setting history, the dead time test record, run/stop test performance, the sighting record and the housekeeping data.

The original data, analysis and interpretation of the results is a deliverable.

Table 14.1 Information collected during a calibration exercise.

14.2.1	Instrument Performance History
14.2.2	Data Comparison

14.2.3	Optics Mechanical Check
14.2.4	Optical Surface Visual Inspection
14.2.5	Alignment Check
14.2.6	Motor Inspection and Electro-mechanical Testing
14.2.7	Azimuth and Elevation Motor Functionality Test
14.2.8	Elevation Axis Alignment and Instrument Levelling
14.2.9	Wavelength Dispersion Constants
14.2.10	Slit Function.
14.2.11	Relative Sensitivity
14.2.12	Absolute temperature coefficients
14.2.13	Delay Constant
14.2.14	Run/Stop Test Results (test of chopper dynamics)
14.2.15	Dead Time
14.2.16	Relative Dispersion Constants
14.2.17	Calibration Step Number
14.2.18	Grating offset(s) (2 in double spectrometer)
14.2.19	Photomultiplier High Voltage Setting
14.2.20	Calibration of Temperature, Humidity and Pressure Sensors.
14.2.21	Measurement of Temperature Dependence of Absolute Sensitivity
14.2.22	Determination of the Neutral Density Filter Properties
14.2.23	Sun Scan to Determine Proper Wavelength Setting
14.2.24	Calculation of Effective Ozone Absorption Coefficients
14.2.25	Determination of Extraterrestrial Constant

14.2.2. Data Comparison

Any minor maintenance of the instrument needed make it operational for comparison measurements is done and then comparison data are collated and analyzed. Ozone, SO₂, aerosol and UV measurements can all be compared to derive calibration constants if an accurate reference (travelling standard) is available

14.2.3. Optics Mechanical Check (all optical surfaces properly constrained)

Ensure that the optical alignment surfaces are all in contact with the screws that define their position and that adequate spring tension is available to maintain that relationship.

Record description of instrument status.

14.2.4. Optical Surface Visual Inspection

All optical surfaces are inspected for damage and dirt. Cleaning is recommended only in cases where the visual impact of dirt or damage is extreme. Generally, cleaning makes the surfaces' performance worse, not better. Cleaning of optical surfaces is very difficult and the outcome is always considerably worse than the original un-contaminated surface.

Deliverable: Status report. Cleaning only if required. Replacement if needed.

14.2.5. Alignment check

A suitable laser and alignment jigs are used to ensure that the optics are properly aligned and that the spectrum at the exit slits is centred and travels parallel across the exit slits when the grating is rotated. A visible light focus check and adjustment (if necessary) is done using the laser light. The final focus is done using the UV.

14.2.6. Motor Inspection and Electro-mechanical Testing

All of the motors must be inspected visually, and manually operated to ensure that the bearings are free and the drive trains clear. They must be run through the range of motion electrically and checked to ensure that the full range of operational positions can be accurately and repeatably accessed.

14.2.7. Azimuth and Elevation Motor Functionality Test

The Brewer azimuth and elevation pointing performance must exceed 0.1 degrees absolute accuracy or some measurement types will fail. This performance level is assured if the system can be reliably zeroed, calculate the steps per revolution and maintain a sighting after a reset. In order to meet these requirements the motors should be inspected and the azimuth tracker cleaned and properly adjusted. Any excessively worn parts, particularly the main drive disk, should be repaired or replaced. Local problems with the drive disk can be polished out with emery cloth. The steps per revolution for the azimuth tracker is a deliverable. The elevation drive uses a gear train and has a fixed number of steps per revolution.

14.2.8. Elevation Axis Alignment and Instrument Levelling

The Brewer and sun tracker assembly must be accurately levelled so that the azimuth axis of rotation is parallel to the Earth radius vector. The instrument-to-tracker interface must be set so that the elevation axis of rotation, which is defined in the fore-optics assembly, is exactly

perpendicular to the azimuth rotation axis. The azimuth axis of rotation is set parallel to the Earth radius vector by using a sensitive bubble level and adjusting the feet of the tracker to set the axis so that the tracker can be rotated through 360 degrees with no change in the bubble level. It is convenient to level one axis at a time, adjusting the screws on 2 feet in opposition and then adjusting the third foot to level the perpendicular axis. The elevation axis is adjusted using a laser beam which is known to be vertical and centred on the elevation prism face (accomplished by adjusting the laser until its beam retraces itself when reflected off a liquid surface at the location of the prism face). The beam reflected from the face when the liquid surface is removed is adjusted to retrace itself by adjusting the three screws inside the tracker which support the Brewer optical subassembly.

No explicit deliverable. Note only if an elevation axis adjustment was necessary.

14.2.9. Wavelength Dispersion Constants

Scans using a variety of discharge-lamp emission lines, such as mercury, cadmium and indium, are analyzed to produce a polynomial dispersion relationship relating wavelength to grating stepper motor step number. The deliverables include the coefficients of the polynomials for each spectrometer exit slit and the RMS uncertainty with which the relationship fits the observed lines and an error formula which predicts the uncertainty with which the relationship will provide the wavelength of any step position within the operating range of the instrument.

14.2.10. Slit Function.

The intensity of a line located as closely as possible to the ozone operational wavelength of each slit is scanned and reported as a function of wavelength determined using the dispersion relationship for each slit. The slit function is parameterized for use in the algorithm that determines the effective ozone and sulphur dioxide differential absorption coefficient at each wavelength.

14.2.11. Relative Sensitivity (among wavelengths)

The relative sensitivity among wavelengths is tracked by observing the internal quartz-halogen lamp (the 'internal standard lamp'). Any calibration will include sufficient observations of the lamp to provide a mean reference value to compare with those measured at other times.

Deliverable: The standard lamp mean ratios and standard error.

14.2.12. Absolute temperature coefficients

Absolute temperature coefficients for the sensitivity of the instrument are required in order to correct the absolute counts detected at any particular temperature, to equivalent counts measured at the effective calibration temperature. Corrections are done using the temperatures recorded by the thermistor located near the photomultiplier cathode. In instruments equipped with nickel sulphate and cobalt glass order filters much of the temperature coefficient is due to the temperature dependence of the transmission of the filters.

Deliverable: Absolute temperature coefficients of sensitivity as a function of wavelength and slit number.

14.2.13. Delay Constant

Stepper motor armatures form a quasi-resonant system in the magnetic field of the stator. The frequency of the oscillation is determined by the inertia of the system and the strength of the magnetic field (i.e.: moment of inertia, the field current and motor magnet strength). As a result, the rotor tends to oscillate when it is stepped from one position to the next with a simple square-wave drive pulse. This tendency is reduced by driving the motor with a waveform that does not excite the oscillation as much as a square wave. The time constant for this waveform is determined experimentally using the dl.rtn command.

The value of the delay constant is a deliverable in the calibration process.

14.2.14. Run/Stop Test Results (test of chopper dynamics)

Once the shutter delay constant is determined, the dynamic performance of the shutter can be evaluated using the shutter test routine (sh.rtn). This test uses the internal standard lamp as a source and makes observations of the intensity of light on each of the slits in 'static mode', that is with the shutter held fixed with one slit open, and with the shutter sampling the light on each slit at a rate of 0.83 samples per second in the normal Brewer observing mode. The routine determines the ratio of the static test to the dynamic operation. For all illuminated positions the ratio should be equal to approximately 1.0 ± 0.0001 . The ratio at the dark position will not be as precise because of the poor statistics of the dark count measurement, but should not be different from 1.0 by more than ± 0.1 .

The test results are a deliverable. If the test fails, it is likely that there is a problem with the shutter motor or the associated electronic drive circuitry. The high voltage power supply for the PMT could also contribute to a problem, as could the photon counting electronics.

14.2.15. Dead Time

Provided that the run/stop test has shown that the shutter motor is operating properly, the dead time test can use the exit slit chopper (shutter) to perform a 2-source linearity test. The shutter

has openings that allow two slits alone or both at once to let light into the photomultiplier. Comparing the sum of the individual intensities on their own to the total seen when both slits are open at the same time allows the determination of the dead time of the counting system. The dead time must be determined at a rate close to the maximum count rate to be used in practice. For example, a 50 ns dead time requires a counting correction of approximately 5% at a counting rate of 1.0E6 c/s. This is approximately the maximum counting rate that should be permitted so that a knowledge of the dead time to 5% makes an error in the corrected intensity of less than 0.25%. (Ratios will generally be a little more accurate.) In addition to the primary dead time test at high count rate, an additional test should be done at 1/3 to 1/10 that rate to ensure that the counting system behaviour is independent of count rate. The low-intensity dead time value should agree with the high intensity result within the respective uncertainties of the two measurements (as indicated in the test printout).

The value of the dead time is expected to be in the range 35 to 50 ns. It is assumed that the instrument dead time obeys the following relationship:

$$C = C_o \exp(-C_o \vartheta)$$

Where	C	is the observed count rate (c/s)
	C _o	is the true count rate (c/s)
	ϑ	is the dead time (s)

The dead time is a deliverable from calibration.

14.2.16. Relative Dispersion Constants (grating 2 v. grating 1 in double)

The double spectrometer, like the single, has a dispersion function for each exit slit which relates the wavelength passing through the slit to the step number of the micrometer relative to its reference position. In addition, the double spectrometer has a second polynomial function which relates the setting of the grating in the recombining half of the instrument to the position of the grating in the dispersing half. The constants defining this polynomial are deliverables from the calibration process.

14.2.17. Calibration Step Number (on sun and relative to mercury lamp)

The calibration step number is determined by calculating the ozone and SO₂ absorption functions for a range of step positions near the nominal (theoretical) calibration point. The optimum step position minimizes the sensitivity of the ozone and SO₂ readings to small wavelength shifts (at an extreme point). This position is the setting that is used for making ozone and SO₂ measurements using the standard Brewer weighted-ratio measurement. The

grating micrometer step offset between the mercury calibration position and this optimal measurement point is an essential calibration constant for the instrument and is a deliverable from the calibration procedure.

14.2.18. Grating offset(s) (2 in double spectrometer)

The lever arms which rotate the diffraction gratings in the Brewer are moved by the action of a stepping-motor-driven micrometer. The mechanical reference for the position of the motor is 'remembered' through power off by leaving the instrument always set at the nominal ozone measurement step position. In the event that a mercury calibration test fails, the gratings can be approximately reset relative to a mechanical reference defined by a photo-diode-LED pair. The distance from the reference point to the nominal ozone measuring position is called the 'grating offset' and is stored in the instrument constants file. Double spectrometers have two offsets, one for the dispersing and one for the re-combining spectrometer.

The grating offsets are deliverables from the calibration procedure.

14.2.19. Photomultiplier High Voltage Setting

The photomultiplier must be set to a voltage setting which maximizes the signal-to-noise ratio and minimizes the rate of change of sensitivity of the instrument with respect to voltage. These are usually slightly conflicting requirements. The minimization of sensitivity change with respect to voltage is more important. In order to determine the correct voltage setting it is necessary to observe the dark count and the sensitivity as a function of voltage setting. There is a Brewer routine to help do this, however, the voltage setting must be manually adjusted, although it is read out by the computer.

The optimal setting of the high voltage is a deliverable from the calibration.

14.2.20. Calibration of temperature, humidity and pressure sensors.

High-accuracy calibration of these sensors is not important. However, it is useful if the relative temperatures between different sensors agree and if the readings are comparable to those made by other instruments. The calibration of the temperature sensors must be fixed before the temperature dependence of the sensitivity of the instrument is determined in order to avoid having to recalculate the constants when the instrument is put into operation.

The values of the calibration constants is a deliverable of the calibration process.

14.2.21. Measurement of Temperature Dependence of Absolute Sensitivity

Operationally, the temperature dependence of the absolute sensitivity of the Brewer (for ozone and SO₂ measurements) is usually determined from an analysis of a large amount of data collected by the instrument when measuring the internal standard lamp under normal operational conditions. The temperature range encountered over the year is representative of the range of temperatures the data must be corrected for. The determination of the temperature corrections for UV scans is normally done with an external reference standard lamp. A more accurate set of coefficients will result if the data analyzed is over a large temperature range, but collected over a short time period.

The deliverables are the temperature coefficients as a function of slit number and wavelength.

14.2.22. Determination of the neutral density filter properties

A Brewer test routine is available which compares intensity readings from the internal standard lamp on various filter settings as a function of wavelength and determines the relative transmission as a function of wavelength. These data are used in normal operation to correct data collected using the N.D. filters to the equivalent value which would have been observed with no filter in the path (if the instrument were able to measure directly light that bright accurately).

14.2.23. Sun Scan to Determine Proper Wavelength Setting

If the wavelength setting of the spectrometer varies, each of the slit positions will vary and both the effective ozone absorption cross-section and the extraterrestrial constant for the instrument will shift. (The change in ozone absorption coefficient is the larger effect.) This change can be minimized if the operational grating angle is set so that the ozone value is at a local extreme point. The ozone absorption function and the SO₂ absorption function both have extreme points at very near the same grating angle setting. In order to determine the appropriate position, a trial set of ozone absorption coefficients and extraterrestrial (usually the 'old' calibration constants) is used and the ozone amount is measured at a number of micrometer step positions (grating angles and wavelength settings) with the instrument measuring in the direct-sun mode. These sunscan (sc.rtn command) data are plotted up and the best calibration position is selected. Once this position is known, the exact ozone coefficients for that particular grating angle are calculated using the slit function data and the dispersion polynomials. (see 14.2.17 above.)

The calibrated ozone and SO₂ measurement step position is a deliverable from the calibration procedure.

14.2.24. Calculation of Effective Ozone Absorption Coefficients

Because of minor optical and mechanical variations from instrument to instrument the precise placement of the slits in any instrument and the exact slit function will be slightly different. These differences are accounted for in the characterization of the instrument by using a measured slit function and the dispersion relations for the slits of the Brewer to calculate *a priori* the effective absorption coefficient of each slit. These numbers are then weighted to produce the effective differential absorption coefficient for ozone and SO₂ measurement using the Brewer absorption function weighting constants.

The effective absorption coefficients are deliverables of the calibration procedure.

14.2.25. Determination of Extraterrestrial Constant

The extraterrestrial constants for the instrument (the 'zero-ozone' and 'zero-SO₂' absorption function values) can be determined in two different ways. The usual procedure for network instruments is to compare observations made with the Brewer to be calibrated to those of a well-calibrated reference instrument. The other method is to take the Brewer to a suitable location, such as Mauna Loa, Hawaii, and make solar observations over a range of solar zenith angles and deduce the extraterrestrial constant from a Langley analysis. The data collected in either case must be sufficient in volume and obtained under appropriately stable atmospheric observing conditions to permit an accurate analysis. The analysis of 50 to 100 comparison or Langley observation points in a half day is required to determine an accurate calibration constant.

The extraterrestrial constants for both ozone and SO₂ are deliverables from the calibration procedure.

14.3. Post Calibration

Post calibration is carried out to determine the stability of the instrument over the period since the last calibration and to provide the information needed to re-process the data collected in that interval to provide accurate ozone results. The information needed to recalculate the ozone and SO₂ results includes: changes to the operational wavelength setting, changes in the slit function, absorption coefficients, standard lamp ratios and extraterrestrial constants. The nature of the changes and an analysis of the behaviour of the instrument (particularly the standard lamp ratios) should lead to a description of how the instrument probably changed since the last calibration. This in turn determines the formula to use in re-analyzing the raw data collected in the period between calibrations.

For example, if the standard lamp record includes a jump change a some time in the measurement period and this jump agrees with the change in the extraterrestrial ratios for the instrument, then a simple correction applied after the time of the jump would be appropriate and the data can be recalculated using the extraterrestrials so determined. If the lamp record shows a long-term drift, then a smoothed lamp record could be used to determine a correction on a day-to-day basis. The exact formula applied will depend on the physical nature of the changes detected in the refurbishment and re-calibration process. In general, it may not always be possible to correct all parts of a data record, although usually a high-quality product is accessible.

14.4. Reporting

The deliverables, in terms of calibration results as outlined in section 2 above, are reported to the instrument operator in two distinct ways. First, a calibration information sheet is provided that includes the results (e.g.: numbers) produced in all of the tests and the recommended values to be used in the operation of the instrument and for the analysis of data. Those constants used the Brewer control software are also provided in the form of updated instrument constants files (e.g.: icf.dat). Once the calibration is completed the instrument should be left operational making ozone measurements with an accuracy of <1% and SO₂ measurements with an accuracy and precision of ~1 DU.

Tables should be developed that provide the capability of providing the previous and current calibration constants for each instrument and for each calibration event entered into the system. These data can then be used to:

1. Update national and international data bases (e.g.: WOUDC).
2. Analyze and plot the calibration history of the instruments.
3. Generate the instrument constants files for the instrument.

If calibrations are paid for using WMO or Environment Canada funds, there is a requirement that the data be lodged in the WOUDC.

14.5. Sample calibration report as currently provided by IOS to customers.

15. LIST OF AVAILABLE COMMANDS

15.1. Overview

This section provides a list of available Brewer commands in alphabetical order. “(int)” comment indicates the internal, or built-in, command and “(ext)” indicates the external command. External commands are those for which an appropriate .RTN file is required. With the exceptions of UX and UA commands, the corresponding RTN file has the same name as the command.

Where appropriate a sample output (result) of the command is also provided.

15.2. AP (ext) Monitor Voltages Printout

This command prints to the line printer, the monitor screen, or to disc, a number of diagnostics that are continuously available in the Brewer. The diagnostics include power supply voltages, test lamp voltages and currents, temperatures, and Brewer moisture content, if the Brewer includes the “Moisture” option.

Sample AP output:

A/D Values for APR 03/07 at 00:52:54 for instrument number 145

Channel#	Name	Value (Lamps off)	Value (Lamps on)
0	Brewer temp 1 (deg C)	11.26	11.26
1	Brewer temp 2 (deg C)	11.26	11.26
2	Brewer temp 3 (deg C)	10.89	10.89
3	H.T. voltage (V)	1260.48	1260.48
4	+15V power supply (V)	14.97	14.87
5	+ 5V power supply (V)	5.08	5.05
6	-15V power supply (V)	-14.85	-14.85
7	+24V power supply (V)	23.52	23.75
8	Rate meter (kc/s)	0.00	89.70
9	Not used (bits)	0.00	0.00
10	Not used (bits)	0.00	0.00
11	Not used (bits)	0.00	0.00
12	+ 5V ss (V)	5.03	5.00
13	- 8V ss (V)	-7.92	-7.92
14	Std lmp current (A)	0.06	1.73
15	Std lmp voltage (V)	0.00	10.48

15.3. AS (int) Azimuth Tracker to the Sun

The AS command moves the Azimuth Tracker to the azimuth angle where the Ephemeris has calculated the sun to be for the current location and time. The North Correction from the most recent Siting (see SI command) is applied.

15.4. AU (ext) Automatic Operation

The AU command results in the Brewer executing a series of commands which are imbedded the AU routine (HP HG DS ZS DS ZS DS ZS B1 UV (or UX)). The sequence continues until interrupted by an operator, or until the sun reaches $ZA = 85$. At $ZA = 85$, the system executes the ED command.

15.5. AZ (ext) Azimuth Tracker Zeroing

The AZ command causes the Azimuth Tracker to return to its zero reference (North) position, and then move the Brewer to the solar azimuth as calculated by the Ephemeris according to the Location, the Time, and the current North Correction, as determined by the most recent Siting (see SI command).

15.6. B0 (int) Turn off Lamps

B0 ensures that the Standard Lamp and Mercury Lamps are both off.

15.7. B1 (int) Mercury Lamp ON

B1 turns on the internal Mercury Calibration Lamp, and is useful in a command sequence (i.e. B1DSHG) where a DS measurement is taken while the Mercury lamp is warming up B1. Note that if the HG does not execute for some reason, the lamp may be left on and should be turned off with the B0 command.

15.8. B2 (int) Standard Lamp ON

B2 turns on the internal Standard test Lamp and is useful in a command sequence (i.e. B2ZSSL) where the ZS measurement is taken while the Standard Lamp is warming up. Note that if the SL does not execute for some reason, the Lamp may be left on and should be turned off with the B0 command.

15.9. CF (ext) Instrument Constants File Update

CF accesses the Brewer's Instrument Constants File and allows the operator to make changes. Note that the constants in this file affect the operation and calibration of the instrument, and normally are not changed unless the instrument is undergoing recalibration or has undergone

repairs. This command requires operator input, and changes should be made or approved only by qualified personnel.

15.10. CI (int) Lamp Scan on Slit #1

CI is used to perform a wavelength scan from 286.5 nm to 366 nm on one of the two internal test lamps. Filter Wheels are set to positions 1 and 0, and the Iris is open. The increment of the scan is user selectable with choices of 1, 2, or 5 Angstrom. Data can be compared with the data contained in the Final Test Record, and is stored in the file CIJJYY.NNN in the \BDATA directory. A typical command sequence might be B1W1CI, where B1 turns on the HG lamp, W1 produces a 5-minute lamp warm-up delay, and CI executes the wavelength scan.

15.11. CO (int) Comments

CO allows the operator to enter a comment (up to 75 characters) into the Brewer data file. This command is useful to record information about a measurement, current weather, sky conditions, and so on. This command requires operator input. CS (ext) Command Sequence CS is similar to a command line entry at the cm->__ prompt. The operator may enter a sequence of commands to be executed, followed by an integer which indicates the number of times the sequence is to be repeated. This command requires operator input.

15.12. CY (int) Slitmask Cycles

The default value for slitmask cycling for most observations is 20. The CY command may be used to increase or decrease this number if better statistics, or a faster measurement (with degraded statistics) is desired. This command requires operator input.

15.13. CZ (ext) Custom Scan

CZ allows the operator to define a custom scan. Sources may be one of the internal lamps, the UV port, or the quartz window. The scan may be over any wavelength range within the Brewer's UV scan limits, have any wavelength increment, and use any filterwheel combination.

15.14. DA (int) Date Set

The Brewer ephemeris requires GMT (both date and time) for proper operation. Under normal, uninterrupted operation, the computer, and Brewer, dates will change at 00:00:00 UT, and are displayed on the monitor screen. Under some conditions (power failure at 00:00:00 UT), the date

may not update, and may have to be corrected manually. The pointing system updates automatically when a new date is entered. This command requires operator input.

15.15. DS (ext) Direct Sun Observation

DS results in an O3 observation being taken using the direct sun as a radiation source. The Brewer Zenith Prism and Azimuth Tracker are oriented toward the sun, the Iris is closed, FW#1 is rotated to the Ground Quartz Disk (position 1), and FW#2 is adjusted for maximum intensity (starting from position 2) without overdriving the PMT detector. Data is recorded on disk and is printed as previously determined by PN, PD, and PF commands. A DS observation consists of five sets of 20 cycles of the slit mask (a measurement), each cycle taking a reading for 2*0.14 seconds on each wavelength. Intensity data for six wavelengths, and the dark count, is recorded for each of the five measurements. The Azimuth and Zenith positions are updated after each measurement. After each measurement O3 are calculated. After the fifth measurement all data is processed, resulting in a single summary set for the total observation. As a safety feature to prevent damage to the detector, the measurement may terminate if, as a result of varying cloud conditions, FW#2 has initially been set to a low attenuation value and clouds suddenly move out of the field of view. A DS measurement takes slightly more than three minutes to complete. A sample DS command output:

```

10:09:38 DEC 17/04 Brewer temp = 9C ( 2.43V)
ds0 10:09:57 20 75.70 2 1 19 91 272 488 456
      O3 = 247.4 SO2 = 7.3
ds0 10:10:36 20 75.61 3 2 24 88 300 506 465
      O3 = 294.8 SO2 = -16.1
ds0 10:11:14 20 75.52 4 1 27 84 303 527 494
      O3 = 306.2 SO2 = -27.8
ds0 10:11:53 20 75.43 3 3 18 98 308 543 528
      O3 = 247.9 SO2 = 15.4
ds0 10:12:32 20 75.34 0 1 29 86 319 586 525
      O3 = 354.2 SO2 = -39.1
***** data summary *****
10:11:14 DEC 17/04 75.52201 3.822 9 c deg ds 0
      11392 6213 1722 -1028 14683 7100 SO2= -12.1 O3= 290.1
      1026 423 141 130 736 561 23.0 44.7

```

15.16. DSP (ext) Dispersion Test

DSP allows for the collection of data for a dispersion test analysis wherein absorption coefficients, wavelength vs. step number and resolution vs. step number equations for each slit is determined. This is a command generally reserved for factory use or for use during an instrument recalibration.

15.17. DSSUM (ext) Direct Sun Data Summary

DSSUM reads the daily Data (B) file and printouts out the summary of the day's DS measurements. An entry is also made to the OZOAVGYY.nnn file. The DSSUM command is usually used as part of the ED command.

Summary of Brewer direct sun measurements for APR 02/07 (092)

Measurements made at TORONTO with instrument # 145
 Latitude = 43.781 Longitude = 79.468
 ETC Values (O3/SO2) = 1581/ 300 Absorption (O3/SO2) = 0.348/ 1.155

Type	Time (GMT)	Temp	Airmass	Ozone	Error	SO2	Error
...							
ds 0	12:34:40	12	3.382	333.4	+32.5	-1.0	+10.4
ds 0	12:38:10	12	3.272	356.1	+7.5	1.7	+2.4
ds 0	12:47:32	12	3.010	353.0	+10.1	-5.8	+1.7
ds 0	13:13:20	12	2.477	361.8	+21.5	10.6	+6.0
ds 0	13:16:50	12	2.421	324.2	+51.1	23.3	+24.6
ds 0	13:20:19	12	2.367	344.8	+28.1	12.2	+10.3
ds 0	13:23:49	12	2.316	343.8	+25.5	13.8	+11.0
ds 0	13:27:18	12	2.268	351.2	+11.3	7.5	+6.2
ds 0	13:30:48	12	2.222	358.6	+9.4	7.2	+6.3
....							
ds 0	22:27:17	14	4.115	282.2	+14.8	-6.1	+7.1
ds 0	22:30:46	14	4.291	281.5	+31.0	-7.3	+12.2
ds 0	22:34:15	14	4.482	273.1	+22.4	-16.6	+4.9
ds 0	22:37:45	14	4.690	285.5	+28.4	-20.8	+11.1
ds 0	22:41:15	14	4.917	272.1	+41.7	-19.1	+10.4

Daily means: Ozone: 369.8 +3.8 SO2: 2.8 +1.1
 Observations: Ozone: 7 of 153
 ETC values: Ozone: 1640.9 SO2: 719.1
 153 observations.

15.18. DT (ext) Dead Time Measurement

Dead Time is a measure of how long a photon counting circuit is “dead” (or cannot count a second photon) after a first photon has been detected. This characteristic of counting circuits can lead to counting errors especially at high photon rates if not compensated for. The DT command initiates a test for the measurement of the dead time of the Photon counting circuits of the Brewer. The DT command is normally executed as part of the ED routine and the test results are recorded in the DTOAVG file. Times differences of greater than 5% should be investigated. The dead time for each instrument is manually record in the Instrument Constants File and can be seen on the PO command printout. For this test the iris is closed, FW#1 is put to position 1. Measurements are made at high intensities (FW#2=0), and at low intensities (FW#2=1).

```
05:22:04 APR 02/07 Brewer temp = 10C ( 2.31V)
o3 DEADTIME TEST AT 05:27:03, APR 02, 07
Deadtime (ns) for filter position 1 (high intensity)
2.87409E-08 (at 05:27:24)
3.210756E-08 (at 05:27:43)
2.990096E-08 (at 05:28:03)
2.915534E-08 (at 05:28:23)
```

```

2.944959E-08 (at 05:28:43)
  Mean = 29.87      Std Dev = 1.3
Deadtime (ns) for filter position 2 (low intensity)
1.727843E-08 (at 05:29:23)
1.484916E-08 (at 05:29:43)
2.057535E-08 (at 05:30:03)
2.82178E-08 (at 05:30:22)
3.517561E-08 (at 05:30:42)
2.992695E-08 (at 05:31:02)
3.447449E-08 (at 05:31:21)
4.2262E-08 (at 05:31:41)
2.146486E-08 (at 05:32:01)
2.698413E-08 (at 05:32:20)
  Mean = 27.12      Std Dev = 8.7

```

15.19. ED (ext) End of Day

At the end of each solar day (solar midnight) it is desirable to summarize, sort, and print out the results of the tests and observations taken the previous day. This may be achieved by using the ED command.

The ED routine:

- . summarizes data into an "S" file (see SUM).
- . sorts and prints data from observations and tests (see OZSUM, FMSUM, FZSUM, HGSUM, SLSUM, UVSUM, ZSSUM).
- . prints constants and monitored values (see PO, AP).
- . executes a series of tests (see HP, HG, SL, DT, RS, SR, RE, FR)

The first command in ED is a print command, which directs the printout to the printer (see PN) or to a disk file (see PD). If the operator wishes to change the printing path, either the ED-PD.RTN or ED-PN.RTN must be copied to ED.RTN. An operator may run ED at any time. If the Brewer is running in a schedule (see SKC), the ED command is initiated automatically at solar midnight. See also ED-PD and ED-PN.

15.20. END_DAY (ext) End of Day (past day)

Command Syntax: END_DAY Feb29/98 or END_DAY 06098

END_Day performs an End of Day on a previous day's data. For the command syntax example: if the raw data file B06098.nnn exists, a Summary file (S06098.nnn) will be created and summary files printed.

15.21. FM (ext) Focused Moon Observation

FM results in an O3 observation to be taken with the moon as the radiation source. The Brewer Zenith Prism and Azimuth Tracker are oriented to the moon, the Iris is opened, FW#1 is rotated to the position 3, and FW#2 is adjusted for maximum intensity, starting at position 2. Data is

recorded on disk and is printed as previously determined by PN, PD, and PF commands. An FM observation consists of five sets of 80 cycles of the slit mask (a measurement), each cycle taking a reading for 2*0.14 seconds on each wavelength. Intensity data for six wavelengths, and the dark count, from the five measurements is recorded. The Azimuth and Zenith positions are updated after each measurement. After each measurement O3 is calculated, and after the final measurement all data is processed, resulting in a single summary set for the total observation. An FM measurement takes approximately 15 minutes to complete. Note that FM observations are not valid for ZA>75O and the message "Waiting for the Moon to Rise above ZA=75" may appear prior to this angle condition being met.

15.22. FMSUM (ext) Focus Moon Data Summary

FMSUM results in the daily Summary (S) file being read and a printout of the 'summary' results of the day's FM measurements being made. An entry is also made to the FMOAVG.nnn file. The FMSUM command is usually invoked as part of the ED command.

15.23. FR (ext) Micrometers Reset

FR performs a reset of the wavelength adjust micrometers. The micrometers are moved to reference points, and then moved to the operating points as dictated by offset values contained in the instruments constants file. The FR command is invoked as part of the RE command, or the operator may manually send the FR command if the positions of the micrometers are suspect. The FR command may be used to determine new micrometer offset values, but these values should only be changed under the supervision of qualified personnel. FR results are recorded in the average file, MIOAVG.nnn.

```
11:00:05 APR 02/07 Brewer temp = 12C ( 2.45V)
```

```
Reset for mkiiii o3 - Searching for micrometer #1 reference  
Micrometer #1 reference found at step 8012(+CAL)= 8979 Now set to o3 offset =  
8982
```

```
Searching for micrometer #2 reference  
Micrometer #2 reference found at step 8135 Now set to offset = 8135
```

```
Zeroing filterwheel #3  
Found reference at step -179 Moving filterwheel #3 to o3 position at 178
```

15.24. FZ (ext) Focused Sun Observation

As the sun drops lower in the sky, the high Mu values result in an increasing amount of scattered radiation in the field of view of a DS observation. The FZ command allows ozone to be determined at solar angles greater than which can be achieved with a traditional DS. Scattered

radiation is measured by offsetting the solar image by 1 degree from the entrance slit, and observing radiation in the vicinity of the solar disk. This scattered radiation is then subtracted from the direct sun result to give a more accurate measure of the direct radiation, before the Ozone determination is made. This method will give reasonably accurate O3 values to ZA of 85O (Air Mass =8.2) as compared to the DS which has cut-off angles of 70 to 80O (Air Mass 3.2 to 5) without corrections. This is a useful command at high latitudes and is normally not used where DS readings are available. For the FZ measurement the iris is closed, FW#1 is set to position 3, and FW#2 is set to position 5. The minimum zenith angle at which an FZ may be taken is 73 degrees. See also DS command.

15.25. FZSUM (ext) Focused Sun Data Summary

FZSUM command reads the daily Data (B) file and printouts out the 'summary' results of the day's FZ measurements. The FZSUM command is usually invoked as part of the ED command.

15.26. GS (ext) Gratings Data Collection

GS initiates a routine that collects data required to calculate Grating Slope and Grating Intercept values, which ensure that the two gratings are synchronized during scanning. The routine performs a scan on slits 1 through 5. Data is written to a GSJJYY.nnn file, and can be processed by the RD_GS.EXE program to calculate the Grating Slop and Grating Intercept to ensure that the two gratings are synchronized during scanning operations. GS and RD_GS.EXE are normally run by as part of factory set-up operations or when problems are experienced with the micrometers or gratings.

15.27. HG (ext) Mercury Wavelength Calibration

HG is used to accurately locate the 302.15 nm line of the Mercury spectrum, and then adjust the diffraction grating such that the five ozone operational wavelengths fall onto the appropriate exit slits. The zenith prism rotates to the test lamps (position 0), the iris is opened, FW#1 is rotated to the quartz disk (position 1), FW#2 to ND=0 (position 0). Following the initial set-up and lamp warm-up, the grating is scanned in the forward and reverse direction and the resulting combined spectrum is compared to a stored spectrum. Corrections to the micrometer position are made, and if the adjustment required is greater than 2 steps (.012nm) then the scan is repeated. A test for the presence of Hg lamp radiation is made prior to the beginning of the scan, and if it is not there, an FR test is done to reposition the micrometers to pre-set initialization values and the test is redone.

```
Using wide slit0 on line 296.7 nm HG line ...
**** HG Calibration ****
05:57:19 APR 02/07 Brewer temp = 11C ( 2.35V)
05:58:58 ( 0.9984 ) corr est for step 971.05 target is step 967 18149
405.96
micro is moved by 4 steps
```

```
06:00:42 ( 0.9999 ) corr est for step 967.28 target is step 967 20837
350.29
micro is moved by 0 steps
```

15.28. HGSUM (ext) Mercury Lamp Summary

HGSUM reads the daily Data (B) file and prints out the 'summary' results of the day's HG calibrations. In addition an entry is made in the HGOAVG.nnn file. The HGSUM command is usually invoked as part of the ED command.

Summary of Brewer mercury lamp calibrations for APR 02/07 (092)

```
Measurements made at TORONTO with instrument # 145
Latitude = 43.781 Longitude = 79.468

Time (GMT)   Temp   Correlation   HG Cal Step #   Setting   Peak Intensity
05:58:58     11     0.9968        971.05          971        18149.0
06:00:42     11     0.9997        967.28          967        20837.0
06:06:19     11     0.9997        967.26          967        22554.0
06:21:24     11     0.9997        967.23          967        21966.0
08:04:41     11     0.9997        967.08          967        16792.0
09:11:54     12     0.9997        967.02          967        15767.0
10:11:50     12     0.9998        967.01          967        15727.0
...
00:43:14     11     0.9997        967.25          967        15239.0
01:43:31     12     0.9978        967.72          968        15500.0
02:52:27     10     0.9999        966.45          966        14925.0
04:41:33      8     0.9990        967.49          967        15364.0
```

29 observations.

15.29. HP (ext) Grating Synchronization

It is important that the two micrometers remain synchronized such that they are both set to the same wavelength. The HP test tests for this condition and makes an adjustment, if necessary. For this test the Standard lamp is used as a light source. The Standard Lamp is turned on, the prism is pointed to lamps, the Iris is opened, FW#1 is set to position 1, and FW#2 is set to position 0. Micrometer #2 is then moved relative to Micrometer #1, and is adjusted such that maximum intensity will occur – an adjustment of more than 10 steps results in the test being repeated.

```
**** 2nd Spectrometer Alignment - HP Test ****
05:52:23 APR 02/07 Brewer temp = 11C ( 2.35V)
Maximum intensity found at step: 76.1 156047.3 R^2: .9983718
```

15.30. HV (ext) High Voltage Test

The HV command invokes a test used to determine the optimum high voltage setting for the photomultiplier. The HVSET command can then be used to set the High Voltage. This test is normally used in the factory during the final set-up stages of manufacture, or in the field if it is suspected that the setting is not correct. The Standard Lamp is turned on, the iris is opened, FW#1 is put to position 1, and FW#2 is set to position 0. See the HVSET command, and Appendix F for more details on the HV test.

15.31. HVSET (ext) High Voltage Set-up

The HVSET command can be used to adjust for the optimum High Voltage as determined by the HV test.

15.32. IC (ext) Instrument Configuration File Update

The IC command results in a display of the Instrument's current configuration and allows changes to be made by the operator.

15.33. LF (ext) Location File Update

The LF command displays a list of some of the known locations of Brewer sites throughout the world. The geographical co-ordinates of the current site may be entered and/or modified.

15.34. LL (ext) Location Update

The LL command allows an operator to change the co-ordinates of a Brewer location, or for the selection of another site contained in the location file.

15.35. NO (ext) Change Instrument

The NO command allows the instrument number of the Brewer to be changed. Each Brewer has a set of files which are stored in the C:\BDATA\NNN subdirectory, and which are necessary for proper operation of Brewer NNN. When the NO command is issued, the software is made aware of which Brewer is connected.

15.36. OZSUM (ext) Ozone Summary

OZSUM reads the daily Date (B) file and prints out the summary results of the day's O3 observations. In addition an entry is made in the OZOAVGY.Y.nnn file. The OZSUM command is usually invoked as part of the ED command.

```

Summary of Brewer ozone measurements for DEC 17/04 (352)
Measurements made at Punta Arenas with instrument # 017
      Latitude   = -53.137                Longitude    = 70.88
      ETC Values (O3/SO2) = 3350/ 3300    Absorption (O3/SO2) = .34110/ 1.1444

Type Time(GMT)  Temp  Airmass  dsO3      zsO3      Error  dsSO2  zsSO2  Error
zs 0  09:57:15   9     4.339    323.0     +0.8
zs 0  10:03:53   9     4.079    318.6     +1.0
ds 0  10:07:57   9     3.933    239.5     +39.6     2.5     +20.7
ds 0  10:11:14   9     3.822    287.6     +44.7    -11.2    +23.0
ds 0  10:16:38   9     3.652    233.3     +50.9     3.4     +11.5
ds 0  10:21:52   9     3.500    319.6     +32.3    -5.2     +9.5
zs 1  15:53:19  17     1.165    290.8     +4.5     10.0    +1.1
ds 0  15:57:28  18     1.163    294.7     +16.8     3.7     +4.9
ds 0  16:00:13  18     1.161    281.3     +46.7     6.2     +9.2
ds 0  16:08:44  18     1.157    248.1     +79.0    11.0    +17.9
ds 0  16:12:09  18     1.155    280.5     +22.4     7.1     +7.6
ds 2  16:17:40  18     1.154    291.6     +15.8     1.7     +3.5
ds 3  16:21:02  18     1.153    303.8     +1.6    -0.7     +0.4
zs 1  16:25:09  18     1.151    291.1     +2.8     10.1    +0.5
ds 2  19:50:45  22     1.447    300.7     +1.0    -1.9     +0.2
ds 3  19:54:06  22     1.460    292.4     +1.4     0.1     +0.2
ds 3  20:08:16  22     1.517    296.3     +2.1    -0.6     +0.5
ds 1  20:11:36  22     1.532    288.2     +7.1     0.9     +1.6
ds 0  20:16:39  21     1.554    278.5     +21.1     3.1     +4.7
ds 2  20:20:21  21     1.572    297.6     +3.1    -1.1     +0.6
ds 3  20:23:41  21     1.588    242.6     +73.6    20.9    +27.3
ds 0  22:58:39  18     3.516    292.5     +18.8    -12.7    +16.9
ds 0  23:01:56  18     3.611    284.9     +68.4    -10.6    +40.3
ds 0  23:05:13  18     3.711    253.0     +51.5    13.4    +17.3
ds 0  23:08:33  18     3.817    267.9     +32.1    -0.2     +9.7
ds 0  23:13:48  18     3.997    282.8     +1.7    -2.3     +0.6
zs 0  23:24:03  18     4.395    323.8     +0.8     -48.0    +1.4

Daily means:                296.0    297.5        -0.7     7.2
Standard deviation:         5.8     11.2         0.6     4.2
Number of observations:    29 /153     8 / 14     167 observations.

```

15.37. PB (ext) Data Playback

Command Syntax: PB BJJYY. The PB command allows any previous day's data to be printed using the current temperature coefficients.

15.38. PD (int) Print to Disk

PD directs printing to a "D" file on the data drive rather than to the line printer. See also PN, PF.

15.39. PF (int) Printer Off

PF turns off all printing. Raw data continues to be recorded. See also PN, PD.

15.40. PN (int) Printer ON

PN directs printing to the line printer. See also PD, PF.

15.41. PO (ext) Printout Instrument Constants

PO generates a printout of the instrument constants file. An example of PO output Values:

```

                    MKIII BREWER INSTRUMENT #145
                    -----
                    04-02-2007  11:00:04

*****
* Ozone Values      *   1   *   2   *   3   *   4   *   5   *   hg   *
*****
Wavelength(nm) * 306.290  310.029  313.479  316.763  319.958  303.198
Temp. Coeff      *  0.0000  -0.7458  -1.3065  -1.4900  -1.8563   0.0000
Disp. Coeff #1   * 2845.570 2885.260 2922.020 2957.400 2991.690 2812.390
Disp. Coeff #2   *  0.081125 0.080329 0.079543 0.078609 0.077790 0.081985
Disp. Coeff #3   * -0.701E-6 -0.716E-6 -0.730E-6 -0.727E-6 -0.740E-6 -0.715E-6
*****

ETC Values      :      O3 =      1581 ;      SO2 =      300

O3 Absn Coeffs :      O3 =      0.3476 ;      SO2 =      1.1550
SO2 Absn Coeffs :      O3 =           0 ;      SO2 =      2.3500

Micrometer steps/deg =      0.00  WL cal step number      =      967
Micrometer Zero      =      1777  Umkehr offset          =      2282
Iris Open Steps      =      250   Zenith steps/rev       =      2816
                               Slit mask motor delay     =      96

Micrometer 1 Offset O3 =      8982  Micrometer 2 Offset =      8135
Grating Slope        =           1  Grating Intercept   =           -8
Filterwheel 3 Offset O3 =      178

Dead Time(ns)       =      32      Zenith Offset      =           23
Buffer Delay(s)     =           0.2  Zenith UVB Dome Position =      2091

Note:  Faster Processors May Require a Longer Buffer Delay
       (Typically 0.2 to 0.8 Seconds)
```

15.42. PZ (int) Point to Zenith

PZ results in the Zenith Prism being pointed to a Zenith angle of 0 (straight upwards).

15.43. QS (ext) Quick Scan

QS is used in conjunction with the UV Stability Check Kit, and gives an indication of the stability of the instrument in the intensity measurement of UV over the range 290nm to 325nm. When the equipment has been set up as per the instructions in Section of this manual, and the QS command issued, a report is generated which shows the stability of the instrument at 3.5nm increments using the first generated set of readings as a reference. For the test, the iris is opened, FW#1 is set to position 3, and FW#2 is set to position 1.

15.44. RE (ext) Reset

RE initializes all of the Brewer motors (similar to the Power On initialisation), and moves them to positions as defined in the Instruments Constants File. Following a RE, the iris is closed, FW#1 is in position 1, and FW#2 is in position 3.

```
Zenith diode found at :-21
Zenith zeroed at 05:42:20 Zenith discrepancy = -2
-10509          2931          13448
Azimuth diode found at : 13440
Azimuth zeroed at 05:44:02 Azimuth discrepancy = 8
Trying to zero filterwheel #3
Found diode at step -177 Moving filterwheel #3 to o3 position at 178

05:44:33 APR 02/07 Brewer temp = 11C ( 2.35V)

Reset for mkiii o3 - Searching for micrometer #1 reference
Micrometer #1 reference found at step 8008(+CAL)= 8975 Now set to o3 offset =
8982

Searching for micrometer #2 reference
Micrometer #2 reference found at step 8133 Now set to offset = 8135

Zeroing filterwheel #3
Found reference at step -179 Moving filterwheel #3 to o3 position at 178
```

15.45. REP (ext) Report

REP displays (or prints) the SLOAVG, HGOAVG, APOAVG, DTOAVG, MIOAVG, and RSOAVG over a user selected range of days.

15.46. RS (ext) Slit Mask Run/Stop Test

A malfunction in the slit mask motor circuit or in the slit mask itself can result in improper counting and consequently incorrect data. The RS test produces a report on the operation of the

Slit Mask Motor by taking measurements in the “Running” and “Stopped” modes of the Slit Mask Motor. The RS command is normally executed as part of the ED routine and the test results are recorded in the RSOAVG file. For the RS test, FW#1 is set to position 1, FW#2 is set to position 0 and the iris is open. RS values consistently outside the range of 0.997 to 1.003 for slitmask positions 2 to 6 should be investigated.

Sample RS output:

```
05:32:41 APR 02/07 Brewer temp = 10C ( 2.33V)

o3 RUN/STOP TEST AT 05:41:33, APR 02, 07
      0      1      2      3      4      5      6      7
RUN  554430      7 667967 793964 989402 1114448 1239538 1878390
STOP 554327      2 668448 793959 989020 1115841 1238147 1878342
RUN/STOP 1.0002  3.5  .9993      1  1.0004  .9987  1.0011      1

ratios(run)  .2223  .1473  .0517  .0462  .0745  .0429  -.0211
ratios(stop) .2225  .1478  .0524  .0452  .078   .0448  -.0221
```

15.47. SA (ext) Solar Angle Printout

SA will generate a printout of GMT vs. air mass, solar zenith angle and lunar zenith angle for the day and location currently in use. Printouts for pasts and future dates are possible by simply changing the Brewer system date.

15.48. SC (ext) Direct Sun Scan

Normally a factory or pre-calibration test, the SC determines the correct operating position of the diffraction grating.

```
19:01:19 DEC 17/04 Brewer temp = 21C ( 3.17V)
Scanning test from micrometer step# 848 to 876
step# 848
sc3 19:01:49  10  39.99    2633    5  129389  196998  396166  429865  371567
              O3 = 242.3  SO2 = 12.9
step# 850
sc3 19:02:10  10  40.03    2658    3  129739  195258  395679  429771  371251
              O3 = 251.3  SO2 = 9.0
step# 874
sc3 19:06:17  10  40.55    3736    3  131698  208605  412469  454915  380830
              O3 = 287.1  SO2 = 11.0
step# 876
sc3 19:06:37  10  40.59    3823    2  132246  212148  415155  458217  382375
              O3 = 282.7  SO2 = 14.3
step# 876
sc3 19:06:58  10  40.63    3836    1  131787  212167  415151  458261  382738
              O3 = 280.9  SO2 = 15.1
...
step# 852
sc3 19:11:05  10  41.16     429    2   21038   31617   65147   71637   61419
```

```

                O3 = 262.6   SO2 =   5.0
step# 850
sc3 19:11:26  10  41.20           5   2           90       122       253       290       249
                O3 = 293.2   SO2 = -13.0
step# 848
sc3 19:11:46  10  41.24           6   3           48       90       151       173       134
                O3 = 269.8   SO2 =  53.4

```

15.49. SE (ext) Schedule Edit

SE is used to create or modify Brewer operating schedules, which are stored as “.SKD” files in the Brewer directory. Brewer schedules consist of two columns of data - a solar zenith angle, and a string of commands. The string of commands is executed at the corresponding solar zenith angle. The SA command is useful for converting GMT to solar angle. See also the SK and SKC commands.

15.50. SH (ext) Slit Mask (shutter) Motor Timing Test

Normally a factory test, the SH command is used to determine the timing constant used in the control of the slit mask motor.

```

DELAY CAL DARK WAVELENGTH 1
10 1737768 7557 92828
12 1738031 480 93450
14 1737408 39 93100
16 1738864 37 93422
18 1738388 44 93318
20 1737191 28 93579
22 1738692 36 93580
24 1742088 40 93713
26 1737650 34 93666
28 1737937 32 93596
30 1739330 35 93605
32 1738615 41 93749
34 1738849 33 94036
36 1737947 35 93859
38 1738791 34 94128
40 1738398 39 93948
42 1710601 43 94193
44 1738853 41 94077
46 1737273 42 94555
48 1737608 44 94805
50 1735986 41 95543

```

15.51. SI (ext) Solar Siting

Brewer observations using the solar disc as the radiation source require that the Zenith Prism of the instrument be pointed very accurately toward the sun. The SI command is used in the initial

set-up of the instrument and for subsequent checking of pointing accuracy. After the date, time, and station co-ordinates have been set accurately, a set of four controls on the front of the instrument are used to introduce 'Horizon' and 'North' corrections which compensate for any offsets that may occur. These corrections are saved and used by the software in future pointing calculations.

15.52. SIM (ext) Lunar Siting

Brewer observations using the lunar disc as the radiation source require that the input window of the instrument be pointed very accurately toward the moon. (Normally the SI command is used if at all possible, as a siting using the moon is much more difficult task than a siting using the sun.) The SIM command is used in the initial set-up of the instrument and for subsequent checking of pointing accuracy in the event that the SI command cannot be used. After the date, time, and station co-ordinates have been set accurately, a set of four controls on the front of the instrument are used to introduce 'Horizon' and 'North' corrections which compensate for any offsets that may occur. These corrections are saved and used by the software in future pointing calculations.

15.53. SK (ext) Scheduled Operation

SK allows an operating schedule, created by the SE command to be run for the current day. At the end of the schedule, the program returns to the main menu and must be restarted the next day.

15.54. SKC (ext) Continuous (scheduled) Operation

SKC allows an operating schedule, created by the SE command, to be run continuously - that is, at the end of the local day a set of summary records is produced (see ED), and the schedule waits for the beginning of the next day and the schedule starts again.

15.55. SL (ext) Standard Lamp

SL initiates the most important quality assurance test in the Brewer command set. This test essentially performs an ozone measurement using an internal quartz halogen lamp as the source. The test should be run at least at the start and end of the day and should be preceded by an hp and an hg. The values of R5, R6, and F1 should be monitored carefully, and any changes should be noted and investigated. For the SL test, the iris is opened, FW#1 is set to position 1, and FW#2 is set to position 0.

```
**** o3 Standard Lamp SL Test ****
00:48:20 APR 03/07 Brewer temp = 11C ( 2.39V)
s11 00:48:38 20 101.88 365818 4 440902 524277 653185 736909 817945
s11 00:49:17 20 101.99 366343 4 440972 524274 653177 736581 818724
```

```

s11 00:49:55 20 102.10 365614 3 441489 524873 653319 737192 819365
s11 00:50:33 20 102.20 366308 2 441977 525114 654266 737982 819058
s11 00:51:11 20 102.31 366889 4 441917 525329 654678 737287 820192
s11 00:51:49 20 102.42 366923 6 441431 524944 654813 737965 819994
s11 00:52:27 20 102.53 366614 3 442342 526503 654565 738070 820902
***** data summary *****
00:50:33 APR 03/07 102.202 4.418 11 c deg sl 1
 441576 819454 2248 1494 530 464 762 439
   570 999 3 5 3 4 15 10

```

15.56. SLSUM (ext) Standard Lamp Summary

SLSUM reads the daily Data (B) file and prints out the 'summary' results of the day's SL tests In addition entries are made in the SLOAVG.nnn file. The SLSUM command is usually invoked as part of the ED command.

Summary of Brewer standard lamp measurements for APR 02/07 (092)

```

Measurements made at TORONTO with instrument # 145
Latitude = 43.781 Longitude = 79.468

Type Time (GMT) Temp R1 R2 R3 R4 R5 SDR5 R6 SDR6 F1 SDF1
s1 1 06:13:38 11 2247 1491 528 464 762 13 438 7 444673
474
s1 1 06:28:43 12 2245 1489 526 462 765 13 440 7 445562
591
s1 1 08:12:00 11 2245 1491 527 465 757 14 437 9 443456
524
s1 1 09:19:13 12 2247 1492 529 462 769 10 442 6 443407
612
s1 1 10:19:08 12 2244 1491 530 462 767 13 441 7 443747
670
s1 1 11:22:28 12 2245 1492 530 460 772 17 445 10 443728
790
s1 1 13:09:05 12 2248 1495 531 462 768 6 443 4 443041
591
s1 1 14:50:35 13 2242 1490 527 463 762 19 439 9 443238
500
s1 1 16:32:55 13 2243 1489 529 462 764 8 439 6 443105
707
s1 1 18:15:19 14 2240 1489 525 465 750 9 435 4 442976
670
s1 1 19:52:34 16 2240 1490 530 458 776 19 447 10 445031
316
s1 1 21:31:41 16 2241 1489 529 460 767 5 441 2 442778
447
s1 1 23:01:27 14 2244 1491 532 462 765 13 440 8 441284
547
s1 1 23:56:35 12 2244 1491 528 465 755 10 436 6 441290
591
s1 1 00:50:33 11 2248 1494 530 464 762 15 439 10 441576
570
s1 1 01:50:49 12 2246 1490 529 464 762 20 437 9 442713
500

```

```

sl 1 02:59:46 10 2249 1497 528 461 772 18 448 9 442042
689
sl 1 04:48:52 8 2253 1497 531 461 779 15 449 10 442880
670

Daily means: 2245 1492 529 462 765 441 443140
Standard dev: 3 3 2 2 7 4 1188
18 observations.

```

15.57. SR (ext) Azimuth Tracker Steps Per Revolution

SR initiates a test that determines the number of motor steps required for one complete revolution (3600) of the Azimuth Tracker. The tracker is first zeroed in the counter clockwise direction, and a discrepancy between where the software thought it was, and where the zero reference was found, is output. The Tracker is then moved a full revolution clockwise and the total number of steps required for this movement is output, and the operator is given an opportunity to save the new value. A progressive change of value over time may suggest that Tracker maintenance is required.

15.58. SS (ext) Direct Sun UV Scan

SS results in the Brewer performing a UV scan of the sun through the quartz window. The scan is in 0.5nm steps over the range 290nm to 363nm. Data is stored in a SSJJYY.nnn file. No response file is available for this mode of UV scanning.

15.59. ST (ext) Status and Control

ST permits the operator to switch the Brewer's internal lamps off and on, and to control all Brewer stepper motors except the Slit Mask Motor.

15.60. SUM (ext) Summary Data File

SUM reads the daily raw data (BJJJYY.nnn) file and generates a new (SJJJYY.nnn) file which contains only data summary information. In addition, Umkehr data is processed and put into a separate (UJJJYY.nnn) file. The SUM command, and the various summary printout commands are generally performed at local midnight as part of the ED command.

15.61. TE (int) Temperature Printout

TE results in the Brewer temperature (Thermistor #1) in degrees Celsius, along with its equivalent (0 to 5.00v) voltage, to be printed. If the Brewer has a moisture sensor option, the moisture (in grams/m3) is also printed or displayed.

15.62. TI (int) Time Set

TI allows the operator to set the internal clock of the Brewer, provided the clock option is turned on in the instrument configuration File. Brewer time is GMT or CUT and is entered as a six digit string (hhmmss). If the internal clock has been turned off in software, there will be an "E" (external) displayed on the computer screen, and the operator will be given the opportunity to turn the internal clock back on. An "I" is displayed on the screen if the system is using the Brewer's internal clock.

15.63. TT (int) TeleType Communications

TT sets the Brewer program to its teletype mode, whereby the operator may communicate directly with the Brewer via the computer keyboard and a set of low level commands. Exit from teletype mode with the home key. Ctrl-x will allow you to retype a line.

TU (ext) Test UV Port Alignment

TU uses an external quartz-halogen lamp mounted over the UV dome to find the zenith motor step position for which the radiation intensity is a maximum through slit #1 of the spectrometer slit mask. This is an alignment test and should be performed if alignment of the UV optics is suspect. The results of the factory tests are found in the Final Test Record and are nominally 2112+/- 4 steps.

15.64. UM (ext) Umkehr Observations

UM results in data being collected which can be processed to produce an Ozone vs. Height profile. Data is normally collected between solar zenith angles of 60 O and 90O in the morning and in the afternoon. The zenith prism is pointed to a solar zenith angle of 0O, FW#1 is set to the 0 position, FW#2 is set to the 0 position, the iris is opened, and the Tracker is rotated CCW until it is perpendicular to the sun. Intensity measurements are made at two sets of wavelengths - long (320-330nm) and short (310-320nm), and continue until they are interrupted by the operator, or by the next zenith angle in a schedule. Raw data is put into the BJYY.nnn file, and is processed to a UJYY.nnn file by the SUM command.

l	um0	08:33:26	40	88.05	6	12714	17856	23890	29576	18625
s	um0	08:34:44	40	87.91	3	1348	2980	8096	15540	16700
l	um0	08:36:02	40	87.77	4	12298	17575	23352	28367	17927
s	um0	08:37:20	40	87.62	7	1265	2710	7510	14781	16061
l	um0	08:38:37	40	87.48	4	13567	19358	25829	31122	19499

15.65. UV Related Commands

There are a number of Brewer commands that are related to measurements taken through the Ultra Violet (UV) Dome, and they are grouped together here for convenience. There are typically two UV scan lengths - 'short' UVB scans, which cover the range from 290nm to 325nm, and 'extended' UV scans which cover the range 286.5nm to 363nm.

15.66. UA (ext UV.RTN) Timed UX scan

UA performs an Extended UV scan in 0.5nm increments and stores the data to a UVJJYY.nnn file. This is a 'timed' routine in that it starts on the next half hour after the command is given. On execution of the command, the prism is rotated to the UV dome, FW#2 is moved to the 1 position, FW#1 is moved to the 3 position, the iris is opened, and the tracker is pointed at the sun.

15.67. UB (ext) UV Summary for Schedules

Raw UV scan data is stored in a UVJJYY.nnn data file. The UB scan instructs the program to process and print the daily summary for UV measurements taken throughout the day. Damaging Ultra-Violet values are calculated for each scan and written to a DUVJJYY.nnn.

15.68. UF Fast UVB scan

UF results in a UV scan being done in the ascending wavelength direction only. The zenith prism is rotated to the UV dome, FW#2 is set to the 1 position, FW#1 is set to the 3 position, the iris is opened, and the tracker is pointed to the sun. The UV spectrum is scanned in steps of 0.5nm, with an integration of 4 shutter cycles for wavelengths less than 300nm, and an integration of 1 shutter cycle for wavelengths greater than 300nm. All data is normalised to a 1 cycle observation and recorded in a UFJJYY.nnn data file. When scanning is complete, a calculation of the UVB/UVA McKinley - Diffey weighted irradiance is computed and sent to the printer and written to the DUVJJYY.nnn data file.

15.69. UL (ext) UV Lamp Scan

UL is a test command that results in a UV scan being performed with a Lamp (rather than the sky) being the source of radiation. The zenith prism is rotated to the UV dome, FW#2 is set to the 1 position, FW#1 is set to the 3 position, the iris is opened, and the tracker is rotated to the

sun. The operator is asked for lamp number, and lamp-diffuser separation, and the radiation intensity is measured in 1.5nm increments over the UVB range. Data is stored in a ULJJYY.nnn file.

15.70. UV (ext) UV(B) Observation

UV results in the irradiance over the “B” region of the spectrum to be measured. The zenith prism is rotated to the UV dome, FW#2 is set to the 1 position, FW#1 is set to the 3 position, the iris is opened, and the tracker is pointed toward the sun. The UV spectrum is then scanned in steps of 0.5nm from 290nm to 325nm, and then back to 290 nm. The data is appended to a UVJJYY.nnn data file. When scanning is complete, a calculation of the UVB/UVA McKinley-Diffey weighted irradiance is computed, sent to the printer and to the monitor screen, and appended to the DUVJJYY.nnn data file. A correction is made to the Diffey action spectrum to include the effects of the UVA region 325-400nm).

15.71. UVSUM (ext) UV Data Summary

This command initiates activity which processes and prints the daily summary of all UV measurements made during that day. DUV values are also calculated for each measurement and data is appended to the UVOAVG.nnn file.

15.72. UX (ext UV.RTN) Extended UV Wavelength Scan

UX causes the irradiance over the 286.5nm to 363nm range to be measured in 0.5nm increments in ascending wavelength. The zenith prism is rotated to the UV dome, FW#2 is set to the 1 position, FW#1 is set to the 0 position, the iris is opened, and the tracker is pointed toward the sun. The UV spectrum is scanned, and the data is appended to a UVJJYY.nnn data file. When scanning is complete, a calculation of the UVB / UVA McKinley- Diffey weighted irradiance is computed, output to the printer and to the monitor screen, and appended to the DUVJJYY.nnn data file.

15.73. W0-W4 (ext) Time delays

These five commands result in time delays of 1, 5, 10, 20, and 30 minutes respectively and can be used in command strings or in schedules.

15.74. XL (ext) Extended External Lamp Scan

XL is a test command that results in an extended UV scan being performed with a Lamp (rather than the sky) as the source of radiation. The zenith prism is rotated to the UV dome, FW#2 is set to the 1 position, FW#1 is set to the 3 position, the iris is opened, and the Tracker is rotated to the sun. The operator is asked for lamp number and lamp-diffuser separation, and the radiation intensity is measured in 0.5nm increments over the extended UV range. Data is sampled for 30 cycle time increments through slit #1 for wavelengths less than 300nm and 20 cycle time increments through slit #5 for higher wavelengths. Data is stored in an XLJJYY.nnn file and is normalised to 1 cycle observations.

15.75. ZB, ZC, ZS (ext) Zenith Sky Observations

ZB, ZC, and ZS are variations of the same command, and are used when sky conditions are known and it is desirable to keep the observations separated. ZB is usually used in clear sky conditions (Zenith Blue), ZC is used under cloudy conditions (Zenith Cloud), and ZS is used when conditions are unknown (as is a schedule). The zenith prism is pointed to a Zenith Angle of 00, the iris is opened, FW#1 is set to position 0, FW#2 is set to position 2, and the azimuth tracker is pointed toward the sun. FW#2 is adjusted according to sky intensity. Data is recorded on disk and is printed as previously determined by PN, PD, and PF commands. A ZS observation consists of seven sets of 20 cycles of the slit mask (a measurement), each cycle taking a reading for 2*0.14 seconds on each wavelength. Intensity data for six wavelengths, and the dark count, from the seven measurements is recorded. The Azimuth and Zenith positions are updated after each measurement. After each measurement O3 is calculated, after the seventh measurement all data is processed, resulting in a single summary set for the total observation. As a safety feature to prevent damage to the detector, the measurement may terminate if, as a result of varying cloud conditions, FW#2 has initially been set to a low attenuation value and clouds suddenly move out of the field of view. ZP initiates a variation of the ZS command in which the Azimuth Tracker is rotated to an angle perpendicular to the sun. A ZS measurement takes slightly more than five minutes to complete.

```

09:55:01 DEC 17/04 Brewer temp = 9C ( 2.41V)
zs0 09:55:19 20 77.73 14 1 593 2287 7583 14254 14011
           O3 = 324.1 SO2 = -45.2
zs0 09:55:58 20 77.65 8 1 632 2364 8050 14883 14911
           O3 = 323.8 SO2 = -47.4
zs0 09:56:36 20 77.56 7 2 625 2361 7792 14544 14432
           O3 = 323.4 SO2 = -46.0
zs0 09:57:15 20 77.47 7 1 697 2557 8614 16016 15736
           O3 = 323.0 SO2 = -44.7
zs0 09:57:53 20 77.38 13 3 696 2685 8977 16705 16506
           O3 = 322.6 SO2 = -43.0
zs0 09:58:32 20 77.29 9 1 640 2374 7842 14484 14164
           O3 = 322.2 SO2 = -43.3
zs0 09:59:10 20 77.20 11 2 627 2280 7581 13893 13613
           O3 = 321.8 SO2 = -43.6
***** data summary *****
09:57:15 DEC 17/04 77.469 4.339 9 c deg zs 0
           13661 7914 2682 -73 13895 6697 SO2= -44.7 O3= 323.0
           132 55 36 37 127 48 1.6 0.8

```

15.76. ZE (ext) Zero Zenith Prism

ZE positions the zenith prism to its zero-step position, or $ZA=1800$. The zenith reference is found, and the prism is then moved back a constant number of steps from the zero-step position.

16. DIAGNOSTIC AND TROUBLESHOOTING PROCEDURES

16.1. *Aligning and focussing a Single Brewer*

16.1.1. Preparing for Alignment - Removing the Optical Frame

Equipment Required:

Assorted hand tools. Spacer blocks to support the Brewer optical frame so that it does not rock on the screw heads and grating supports that protrude under the main plate of the optical frame.

The Brewer should be removed from the tracker and transported to a suitable clean, dry location. The cover is removed (see Appendix A.2). The fore-optics of the Brewer are removed (see Appendix A.2). The cover is taken off the spectrometer housing (see Appendix A.3). Remove the optical frame from the bulkhead (see Appendix A.4). In the case of the double Brewer, separate the two halves of the optical frame by removing the three links that join them (Appendix A.5). The subsequent alignment steps must be done on both of the separated optical frames. The optical frame can be set down on a table if there are three suitable blocks to put underneath to prevent the grating mount from touching the surface.

16.1.2. Setting up

Equipment Required:

Assorted hand tools. Alignment blocks (3): 1 cm x 2 cm x 6 cm aluminum blocks with 1-mm holes centred on the cm face 5 cm above the base.

If this is a 'first-time' alignment, adjust the alignment screws if necessary and appropriate to have opposite ends of the main mirror the same distance from the slit mounting bulkhead at a distance of approximately 15 cm.

Set up a laser source on the work table and adjust its height so the light hits the centre of the entrance slit of the Brewer running parallel to the table. Rotate the optical frame to make this beam run parallel to the edge of the optical frame. Place an alignment block just behind the tilted correction lens and adjust the laser and optical frame to have the beam go through the hole. Put a second block in front of the mirror and adjust the laser and optical frame to ensure that the beam goes through the holes in both of the blocks and remains parallel to the side of the optical frame.

16.1.3. Input side alignment.

Equipment Required:

Assorted hand tools. Alignment blocks (3): 1 cm x 2 cm x 6 cm aluminum blocks with 1-mm holes centred on the cm face 5 cm above the base.

Without disturbing the alignment, move the second alignment block from in front of the mirror and check to see that the beam bouncing from the mirror hits the diffraction grating at the correct height. This can be done by moving the second alignment block near to the grating and seeing that the beam clears the hole and strikes the grating near the centre (± 2 mm). Exercise extreme care to ensure that neither the block nor any part of the body touches the mirror. If the test fails, then an adjustment of the main mirror maybe necessary. If the main mirror needs to be adjusted , re-check the laser with the two alignment blocks to be sure that it is still aligned properly, and then adjust the top screw of the mirror to bring the beam to the correct height to go through the hole. The locking screw above the adjusting screw must be loosened slightly before the adjustment can be made.

16.1.4. Grating rotation.

Equipment Required:

Assorted hand tools. Alignment blocks (3): 1 cm x 2 cm x 6 cm aluminum blocks with 1-mm holes centred on the cm face 5 cm above the base.

Once the incoming beam is hitting the grating at the right point, it is necessary to remove the push rod and swing the grating. Depending on the diffraction grating used, it is possible to see at least 3 beams coming from the grating. One is at the specular reflection angle (angle of incidence equals angle of reflection; sometimes normal to the grating surface depending on the grating angle). With the grating arm at an appropriate angle, the grating tilt adjustment should be used to put the reflected beam into the correct plane so that it reflects back and goes through the hole on the first alignment block or through the second alignment block placed on the frame where it can intersect the mirror reflection from the grating.

The tilt of the grating is adjusted using the top adjustment screw accessed from behind the grating. It is necessary to loosen the two locking screws (which also secure the pulling springs that load the grating in the tilt direction) before the tilt adjustment can be made.

With the grating in this position, the -1 or +1 order of the grating should be checked with an alignment block to see that those beams are also in the same plane. If they are not, then the rotation of the grating lines should be adjusted to bring the +1 and -1 orders into the same plane with the reflected beam.

The rotation of the grating is accomplished by rotating the vertical support screws accessed through the grating mounting blocks from underneath the grating. The locking screws are loosened first and then the two rotating screws are adjusted in opposite directions. Begin with a 1/4 turn and determine the correct amount needed by watching the motion of the diffracted beam.

Once the necessary adjustments are complete, re-tighten the three locking screws and re-check the alignment. Repeat the process as necessary so the beams are centred where they belong to less than 1/5 of the diameter of the alignment block holes (to about 1/5 mm).

With the beams properly aligned up to the point where they leave the diffraction grating, it is necessary to swing the grating so that the diffracted beam on the exit slit side reflects from near the centre of the exit side of the main mirror. A small adjustment of the top main mirror adjusting screw should then be made to cause the beam to hit the exit slits at the horizontal centre-line. (In the case of the re-combining half of the double instrument, it is necessary to place a paper screen with a centre-line and a reference point at the focus of the spectrometer as a substitute for the slit plate - include a figure to print to paper to use as the reference plane. Need dimensions for where to place it.). At this point, a piece of cellotape (frosted) should be placed on the outside surface of the entrance slit light shield. This will diffuse the laser beam so that the full area of the entrance slit is filled. The mirror then should be adjusted to centre the image at the exit slits in the vertical direction.

16.1.5. Focussing.

Equipment Required:

Assorted hand tools. In a properly focussed instrument, rays coming from any part of the aperture (point on the grating) should wind up at the same point along the length of focal plane. This can be tested using the laser by sending it into the entrance slit from different angles in the horizontal plane with no diffuser in place, and using the micrometer to make accurate, relative position measurements.:

Remove any alignment blocks and re-install the push rod before proceeding with the focussing step. The laser should be moved around in the horizontal plane and the position of the image of the of the entrance slit on the exit slit plate observed. First the laser position is marked on the bench with the beam entering along the optical axis of the instrument as in the alignment procedure above. Then the beam is made to enter the entrance slit at an angle so that the laser spot hits the grating about 3/4 of the way to the edge of the useful grating surface. This position should be marked on the bench so it can be repeated. A similar mark is made with the laser entering at an angle from the other side.

16.1.6. Beam along the Optical Axis

Starting with beam along the optical axis (hitting the centre of the main mirror and the grating), adjust the micrometer to position the image of the entrance slit exactly on the edge of one of the exit slits, preferably the middle one. The most accurate adjustment is to set the beam to be consistently just beginning to illuminate one side of the exit slit. Record the micrometer reading to the nearest 1/10 of a division.

16.1.7. Beam entering the right of the Optical Axis

Set the laser up so that the beam enters from the extreme right-hand side as marked in Step 2. Find the micrometer setting that illuminates the edge of the slit as in Step 3. Record the setting.

16.1.8. Beam entering the Left of the Optical Axis

Set the laser up so that the beam enters from the extreme left-hand side as marked in Step 2. Find the micrometer setting that illuminates the edge of the slit as in Step 3. Record the setting.

16.1.9. Make a Plot

Plot the number recorded in Steps 3 to 5 against left, right and centre. The plot may look like a straight line or a parabola. If it is a fairly symmetrical parabola then the instrument is in good focus. Otherwise an adjustment is needed. If an adjustment is needed go to Step 7. Otherwise jump to Step 10.

16.1.10. Adjusting the focus.

The first adjustment will just be a trial to assess the sign of the error and calibrate the sensitivity of the adjustment. It may go the wrong way and make things worse. For the first adjustment move both the bottom two mirror screws by $\frac{1}{2}$ turn in the same direction. Subsequently adjust by the amount estimated in Step 8. Adjust the top screw to vertically centre the image of the entrance slit on the exit slit centre-line again. (If this step is being done as part of the re-focussing of the dispersing half of the instrument in the UV, then the half power points must be found by adjusting the top screw each way to half-power and then setting it at the mid-way point before adjusting anything else. See Appendix A.6 for instructions on how to read out the intensity.)

16.1.11. Repeat the Focus Measurement

Repeat steps 3 to 6. Examine the plot. Did the line get steeper or more shallow? By how much? If it got steeper, the screws were turned the wrong way. Adjust the opposite direction by 1 turn and repeat 3 to 6. If the curve became shallower compute the change in end-to-end amplitude of the line and adjust by $\frac{1}{2}$ turn times the remaining amplitude divided by the change in amplitude that occurred because of the adjustment. (Figures.) Repeat the adjustments until a parabola results with the left and right end points at approximately the same position.

16.1.12. Re-assembly

Perform the operations in Appendix A.5 in reverse order.

16.1.13. UV Focus

Because the spectrometer focus is slightly different in the visible and the UV, once the laser alignment is done, the focussing steps (steps 5 to 11) must be repeated once the spectrometer and fore-optics are replaced in the instrument. The internal mercury lamp is used as a source and a two-hole plate in the diffuser filter wheel is used to provide the left-right-centre illumination sequence or, alternatively, the fore-optics can be left out and an external mercury lamp used to scan across the field-of-view. The alignment should be very close to the optimal settings at this point, so a mercury lamp test should be done to get the instrument near the correct calibration point.

If the alignment of the instrument has already been done in the past, the mercury line should be very close to the last micrometer setting recorded. If this is the first alignment of a new instrument, then the line will have to be 'found' manually. In the case of the double Brewer, it is best to do an HP test first so that the formula linking the two instruments is available for the program so that wavelength scans can be done. (Both gratings must be move in synchronism in order for the instrument to have useful throughput.)

16.1.14. Spectrum Position - Double Spectrometer

At this point it is assumed that the two instruments are aligned relative to each other sufficiently accurately that light will pass completely through the system to the detector. The dispersing half is assumed to be very close to optimal alignment after the Rere-install the fore-optics by following the steps in Appendix A.2 in reverse.

Once the fore-optics are re-installed, re-install the cover of the spectrometer section of the instrument. Power up the instrument and do a reset via the Brewer control program.

16.1.15. This needs more - setting the mechanical reference

Doing the hp.rtn

Do hg
Do the vertical mirror alignment in the re-combining half
Do the UV focus on the dispersing half
Iterate the centring of the spectrum
Focus the re-combining half (??)
Re-do hp
Re-do hg
Find reference diodes in both halves

16.1.16. UV Focus - For single spectrometer

Perform successive adjustments as in steps 2 to 5 to fuocusfocus in the UV using routine xxxx to find the hg line positions.

16.1.17. Lock all adjustments.

Ensure that all the locking screws for the adjustment screws are snug. The apply varnish or nail polish to the screws to lock them in place.

16.1.18. Re-assembly.

Follow the instructions in A.4, A.3 and A.2 in reverse to re-assemble the instrument.

16.2. *Removing the Brewer Fore-optics from the Spectrometer Housing*

16.2.1. Unlatch the cover of the spectrometer weatherproof housing

Release all four cover latches and unlatch. Re-close the latches while holding them free of the base. Re-closing the latches in the unlatched position prevents them from catching as the spectrometer housing cover is lifted off the base.

16.2.2. Lift off the cover.

Lift the housing cover straight up until it is well clear of the optical assembly within. Set the cover down flat on a flat surface. **DO NOT STAND THE COVER ON END.** It will surely fall over and break the quartz dome. The dome is very expensive and difficult to replace.

16.2.3. Remove the sight cover plate.

Remove the three screws that secure the sight cover plate to the bulkhead and fore-optics clamp. Remove the plate.

16.2.4. Disconnect the fore-optics motors.

Unclip the three motor connectors along the edge of the foreoptics assembly. Disconnect the ribbon cables and free them from the fore-optics tube.

16.2.5. Unclip lamb housing and zenith motor connectors

Unclip the connector leading to the lamp housing under the prism end of the fore-optics tube. Unclip the connector leading to the zenith motor. Disconnect both connectors and place them where they will not interfere with the removal of the fore-optics.

16.2.6. Remove clamp.

Remove the two screws that attach the retaining clamp that holds the fore-optics in place. Completely remove the clamp and set it aside.

Grasp the tube of the fore-optics assembly and lift the prism end gently until it is free of the locating pin under the location of the retaining clamp. Move the whole assembly away from the main bulkhead while lifting further. The bulkhead end of the assembly should easily slide free from the entry hole in the bulkhead. Set the assembly down on a protective pad on a table.

16.3. *Remove the Cover of the Optical Frame.*

There are two latches, one on each side of the optical frame cover. Open the latches and then re-close them with the latches unlatched. Grasp both sides of the cover end slide it carefully straight back. If it catches on something, gently move it from side to side or up and down until it pulls completely free of the optical frame. Set it aside.

16.4. *Removing the Optical Frame*

16.4.1. Disconnect the motors.

There are two stepping motors on the optical frame. One operates the micrometer drive motor (wavelength adjustment) and the other operates the wavelength selector (shutter motor). Disconnect both motor connectors at the top of the bulkhead.

16.4.2. Disconnect the Optical Frame from the Bulkhead.

The optical frame is secured to the bulkhead by three screws. Two are accessed from the fore-optics side of the main mounting bulkhead. One is accessed from the right-hand side of the optical frame as viewed from the optical frame side looking toward the bulkhead. There is a proper order in which to proceed. First slightly loosen, but do not remove, the top screw which enters the long thin support leg at the very top of the optical frame. This screw is accessed from the fore-optics side of the bulkhead. Fully remove the single screw from the apex of the triangular mounting bracket on the right-hand side of the optical frame. Fully remove the large countersunk screw from the fore-optics side of the main bulkhead that enters the conical mounting fixture on the left-hand side of the optical frame. While holding the optical frame with one hand, completely remove the first screw loosened above. The optical frame can be slid back slightly and lifted clear of the spectrometer housing.

16.5. Separating the Optical Frames in the Double Brewer

Remove the three links between the two halves and separate and place them on a table.

16.6. Setting up the program to continuously monitor intensity.

Enter the 'teletype' mode by typing 'tt' and <enter>.

Type in the string "R,0,0,1;O;A;". This command will cause the Brewer to make one-cycle observations of Slit 0, nearby where the mercury line is found when the instrument has been calibrated. Other slits can be measured if the 'RUN' command parameters are modified according to the description of the 'RUN' command. The third parameter (1 here) is the number of cycles to co-add for the observation.

When the necessary tests are complete, press <HOME> to return to the Brewer operating program.

16.7. Finding the lines. Double spectrometer.

After the instrument is assembled, it is necessary to find a rough relationship between the wavelength settings of the two halves of the instrument. Since the start of an HP or HG routine for the double is approximately setting the gratings near the correct operating position using the diode offset constants for both halves of the instrument, the automatic method cannot be used until the

instrument is approximately calibrated. This means finding the relationship between the two spectrometers by hand (essentially a manual HP test) and then finding the HG line manually.

16.7.1.

Put the instrument in teletype mode.

Enter the command TT. Turn on the standard lamp with command B2.

Put the instrument in intensity readout mode according to Appendix A.6.

Set both micrometers to about 1 mm. Move the recombining micrometer to 0.0 mm and scan forward until the

17. **APPENDIX C: MANUFACTURER'S INFORMATION**

18. APPENDIX D: ISO IMPLEMENTATION FOR BREWER OPERATION