2. SUV-100 UV Spectroradiometer Instrumentation Description

The NSF UV Spectroradiometer system (SUV-100), manufactured by Biospherical Instruments Inc., is designed for permanent installation and continuous operation 24 hours a day. The system is also designed for all-weather operation in any climate including Polar Regions. The fully automated system only needs operator attention for periodic manual calibrations, operational checks, data transmission, and occasional service.

2.1. Automated Spectroradiometer

The spectroradiometer is based on a temperature-stabilized, scanning double monochromator coupled to a photomultiplier tube (PMT) detector (Figure 2.1). The system is optimized for operation in the UV. A vacuum-formed Teflon® diffuser serves as an all-weather irradiance collector and is conductively heated by the system to minimize ice and snow buildup. The instrument has internal wavelength (Hg) and intensity reference (tungsten-halogen) lamps for automatic system performance characterizations at programmed intervals (typically once each per day). A data acquisition system and control instrumentation accompany the instrument. Starting in mid-1996, Pentium microprocessor-based personal computers (PC), using the Windows NT® operating system, were put into use for system control and data collection.

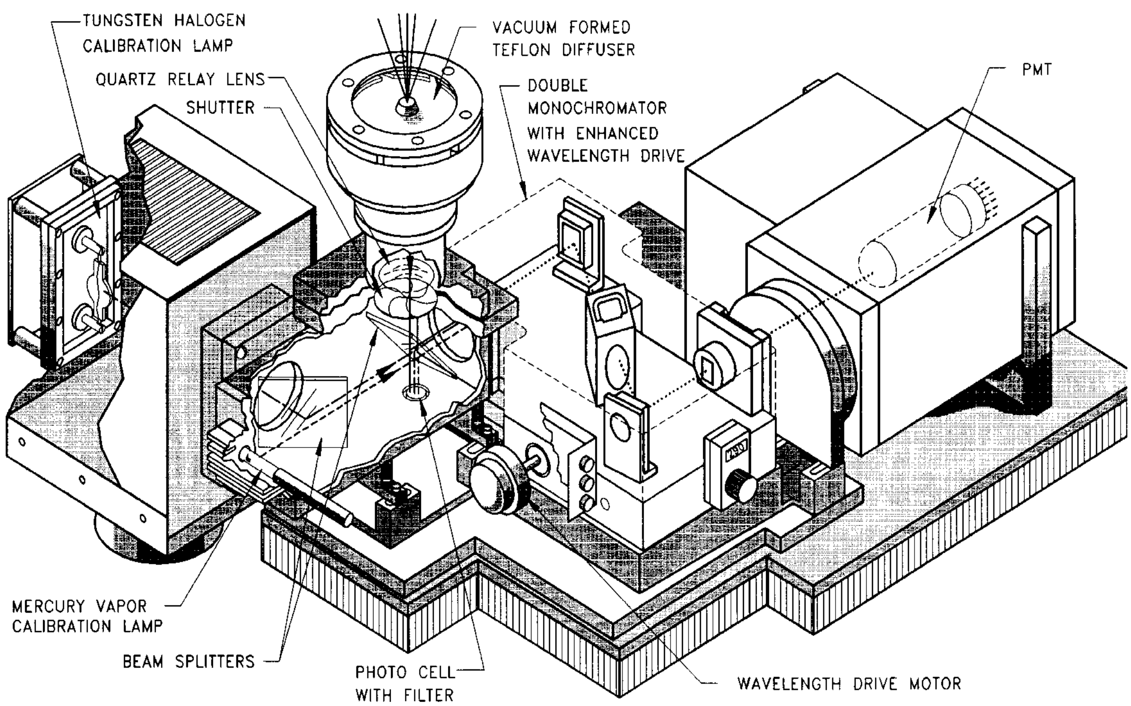

***Figure 2.1**. Cutaway diagram of the monochromator and collection optics.*

A typical instrument installation is shown in the following figure. The system hardware is divided into two main sections. The first section—the irradiance collector, monochromator, PMT, High Resolution Analog

Digitizer (HRAD) unit, thermal management components, and internal reference sources—are housed in the roof box. This insulated, fully weatherproof enclosure is designed to be built into the roof of an existing building, trailer, or other portable structure. The remainder of the system, consisting of power supplies, temperature controllers, electronic interfaces, and a PC, is located up to 15 meters away. In addition to the internal, automatically controlled reference sources for wavelength and response sensitivity calibration, a calibration fixture mounted above the irradiance collector is provided for periodic manual calibrations.

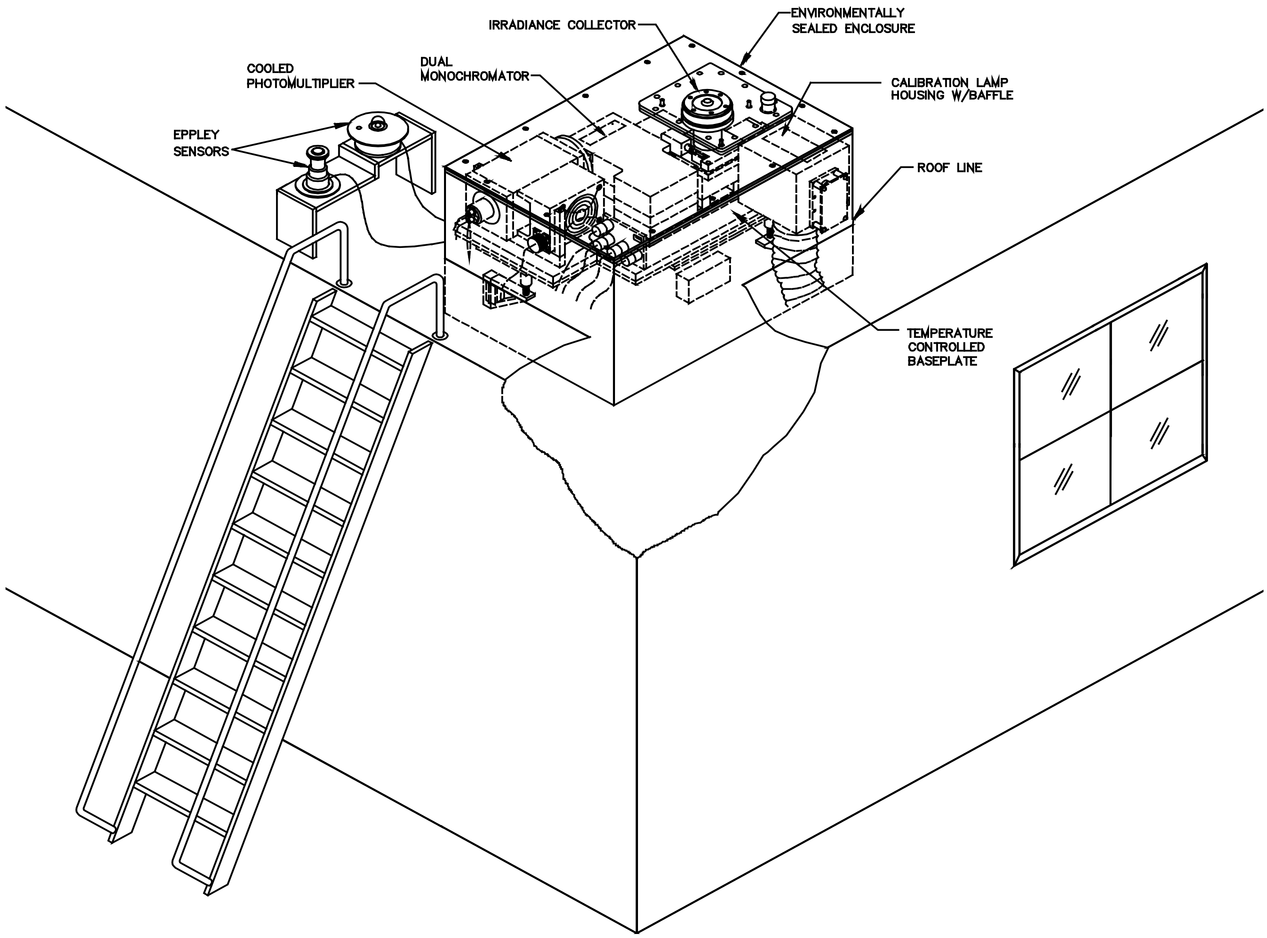

***Figure 2.2**. The spectroradiometer is shown in a typical installation.*

The f/3.5 0.10 meter double monochromator is the heart of the system and is configured with 167-micron (10^{-6} Meter) wide input/output slits and a 250-micron wide intermediate slit. The monochromator's holographic gratings have 1200 grooves/mm, and are blazed at 250 nm. The resulting spectral bandwidth is a nominal 1.00 nm. A stepping motor, with a minimum step size of 0.1 nm, drives the monochromator. The PMT is a 28-mm diameter, 11-stage device with a bialkali cathode and a quartz window. The PMT is housed in a Peltier®-cooled enclosure that is maintained at approximately 0°C to reduce dark current and noise. The temperature of the monochromator is carefully controlled and monitored. It is typically stable to ±1.0°C. In addition to the daily calibrations with the internal sources, the system is ultimately calibrated periodically (typically biweekly) using a 200-Watt tungsten-halogen Standard of Spectral Irradiance, traceable to the National Institute of Standards and Technology (NIST).

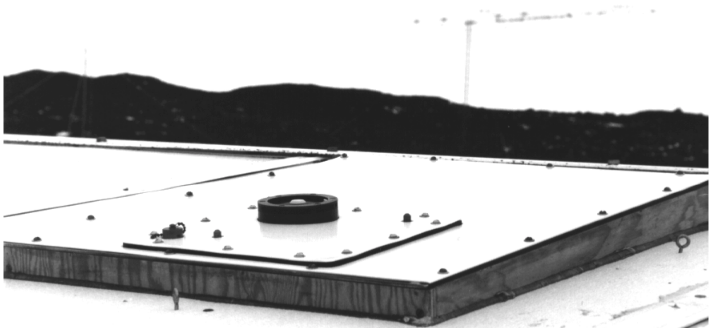

Figure 2.3.

The irradiance collector on the McMurdo installation. At the left of the collector is a connector for the external calibration fixture.

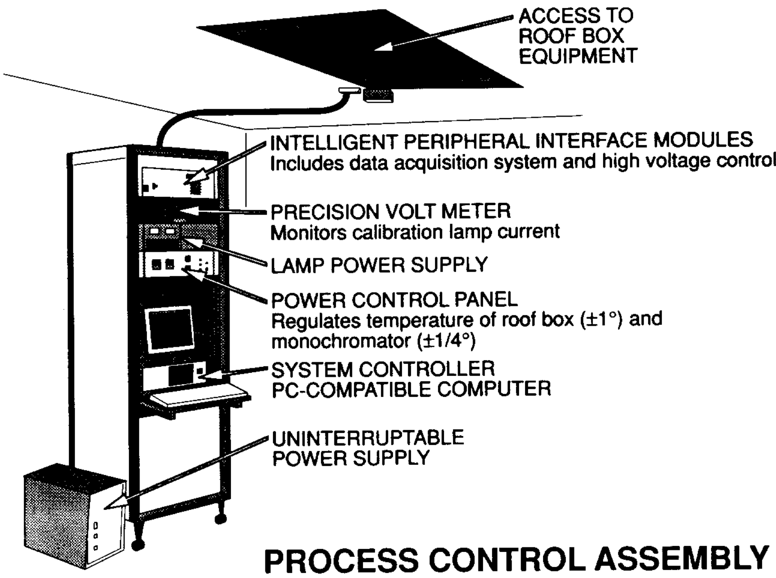

Figure 2.4.

Diagram of electronic support components and computer. Access to the instrument mounted on the roof is typically provided above the installation.

2.2. Operational Requirements

2.2.1. Installation

The systems were designed and conveniently located to perform data transmission, daily verifications of the system operation, inspections/cleanings of the irradiance collector, and both routine and emergency service. Daily maintenance activities typically require 15 minutes or less. The biweekly, complete system calibrations typically take 1-2 hours. Most on-site instrument service and upgrades are conducted during annual site visits.

The front panel of the Windows-based *SUV-100 System Control Software* has an indicating alarm system, with error messaging describing a variety of conditions that may demand operator intervention. These conditions include failures in specific system operations and functions.

2.2.2. Calibration

Each SUV-100 systems has a built-in mercury discharge lamp, which serves as an internal wavelength standard, and a built-in 45-Watt tungsten halogen lamp, which is used to monitor changes in the spectral responsivity of the system (Figure 2.1.). Scans with the mercury lamp and the 45-Watt lamp are performed daily by the system control software in a fully automated fashion. No intervention by the system operator is required. The "ultimate" irradiance calibration is performed biweekly with 200-Watt Standards of Spectral Irradiance, which are traceable to standards of the National Institute of Standards and Technology (NIST).

For the automatic wavelength calibration, the output of the internal mercury lamp is scanned in 0.1 nm steps in several wavelength segments. This scan first indexes on the location of the 253.65 nm Mercury line and then on the location of the 296.73 nm line, with which the scan is registered. Next, the locations of several longer wavelength lines are examined to characterize the wavelength transfer function of the monochromator. In a similar fashion, once a day, the 45-Watt lamp is energized and the spectrum of the lamp is measured.

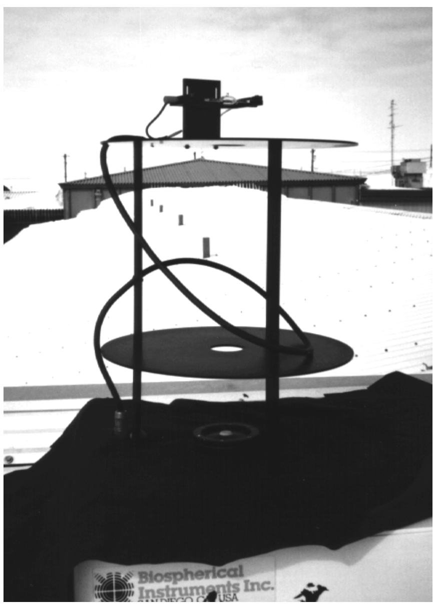

Figure 2.5.

Calibration stand with the 200-Watt lamp mounted on top of the Barrow Spectroradiometer. The lamp power is connected to the roofbox immediately below the fixture. Baffles limit stray light. During operation, an internally-blackened barrel covers this fixture.

For the purpose of an irradiance calibration with the NIST-traceable 200-Watt standard, the operator mounts a specially designed fixture (or stand) on top of the instrument (see Figure 2.5). To reduce systematic errors in the process, the stand is designed so that it can only be mounted onto the system in one configuration. This stand has a feature such that the lamp holders are keyed to the calibration stand, also to fit in only one configuration. In the next step, the lamp is energized and, after a 10-minute warm-up period, a spectrum of the lamp is measured by the SUV-100. This measurement is then used to determine the spectral responsivity of the system. The whole procedure is described in more detail in Section 3.

In order to maximize the accuracy of calibrations, each SUV system includes an IEEE-488 controlled power supply (PS) and a high-precision digital multimeter (DMM) for monitoring the applied currents used to operate both the internal 45-Watt and external 200-Watt lamps. In addition, calibrations with a "travelling" Standard of Spectral Irradiance are performed during the annual site visit. Thus, drifts of the lamps kept on-site are inspected with an independent calibration standard. Since the same travelling standard is used at all network sites this helps to ensure consistent calibrations at all network locations.

2.3. Specifications

Table 2.1. SUV-100 spectroradiometer specifications, revision 1997/98.

Spectral Range	280-610 nm
Monochromator	ISA DH-10UV, 0.10-meter double monochromator with focal ratio f/3.5, equipped with holographic gratings, 1200 grooves/mm 250 nm blaze wavelength. (Note 1)
Bandwidth	1.0 nm ±0.1 nm (bandwidth varies from instrument to instrument; individual instruments are stable to ±0.015 nm). (Note 2)
Stray Light	Out-of-band rejection determined with a HeCd laser at 325 nm: $1x10^{-6}$. (According to specifications of the monochromator's manufacturer, out-of-band rejection is $2x10^{-9}$ at 8 band passes from a HeNe laser line at 632.8 nm.)
Wavelength Calibration	Based on combination of internal Mercury discharge lamp measurements and post-correction with a Fraunhofer-line correlation method. See Section 3.3.1.2. for details.
Minimum Useable Wavelength Increment	0.1 nm
Wavelength Precision	±0.025 nm (±1σ) (Note 3)
Wavelength Uncertainty	±0.04 nm (±1σ) (Note 4)
Detector	11-stage photomultiplier tube R269 from Hamamatsu with bialkali photocathode; thermoelectrically cooled
Measurement Mode	PMT operated in DC mode. PMT anode-current converted to frequency with variable integration time; 10^6 count maximum; 1 MHz count rate maximum.
Integration Times	0.1 – 10 seconds under software control, typically set to 0.2 to 0.5 seconds
Dynamic Range	10^6, defined by the digitization scheme
Detection Limit	0.0005 μW cm^{-2} nm^{-1} for SZA > 70°, 0.001 μW cm^{-2} nm^{-1} for SZA < 70°; values refer to a signal-to-noise ratio of one (Note 5)
Offset Stability	Typically 10^{-5} relative to full scale, plus the contribution of PMT dark current
System Responsivity Stability	See Section 5.
PMT High voltage	0-1000 Volts under software control
Irradiance Collector	Cosine-corrected Teflon®-covered quartz
Operating Temperature Range	+40° to –80° C outside environment
Utility Requirements	115 VAC, 15 Volt-Amps, telephone line (Note 6) and/or Internet access, uninterruptable power supply provided for 1 hour minimum operation in the event of power failure.
Internal Response, Wavelength, and Time Sources	45 watt Tungsten-Halogen Lamp, Hg discharge lamp, and GPS.
Primary System Calibration Sources	200-Watt Tungsten-Halogen irradiance standards, NIST traceable
Signal Range	Maximum 250 microwatts cm^{-2} nm^{-1}, minimum limited by noise level. (see above)
Monitored System Parameters	Monochromator temperature, enclosure temperature, TSI, monochromator wavelength position, and lamp current.
Auxiliary Sensors	Short-wave (0.3 μm-3 μm) Pyranometer (Eppley PSP), UV-Pyranometer (Eppley TUVR), and temperature and humidity sensors. (System allows connection of up to 56 auxiliary sensors.)
Data Formats	Data recorded in binary Microsoft Visual Basic® format. Programs provided for conversion to ASCII MS-DOS/Windows format with full application of calibration data. Normal retrieval of data via modem (9600 baud) and telephone line, or Internet.

Note 1: Monochromator is modified and temperature stabilized.
Note 2: Testing indicates that the bandwidth, as measured with a HeCd laser or an external Hg lamp, completely illuminating the cosine collector, is approximately 1.0 nm. The specification on bandwidth stability was derived from all internal Mercury scans of Volume 7.
Note 3: Wavelength *precision* specifies the change in the registered position of the 296.728 nm Mercury line within one day. The value is the standard deviation of the difference in the position derived from two consecutive wavelength scans, which are performed on a daily basis. The wavelength precision is similar for all sites.
Note 4: Wavelength *uncertainty* is the square-root-sum of two components: The first component (±0.035 nm (±1σ)) is the standard deviation of the wavelength offset (measured minus target wavelength position) after the solar data have been corrected for wavelength errors. The residual offset was determined with the "Fraunhofer-line correlation method" described in Section 3.3.1.2. The second component (±0.02 nm (±1σ)) is the uncertainty of the correlation method.
Note 5: Detection limit is defined as the standard deviation of the measured spectral irradiance at 285 nm. At this wavelength, all solar radiation is filtered out by the Earth's ozone layer. The measured value at 285 nm therefore reflects the magnitude of instrument noise, which causes the detection limit. At large solar zenith angles, the PMT is operated at a higher voltage, leading to better sensitivity and a lower detection limit.

Note 6: A telephone line is dedicated to Remote Access Service (computer to computer) modem communications, or direct Internet access. At Antarctic continent locations, the computers are locally networked and established as FTP servers, allowing for direct data access from San Diego and/or transmission by operators - limited only by satellite windows.

2.4. Auxiliary Sensors

The SUV-100 is both hardware and software compatible with a variety of radiometric and meteorological sensors, which can be monitored during the high-resolution spectral scans and between scans. This is particularly important for network applications where high spectral resolution scans are compared with broadband or lower spectral resolution sensors located at the same site. Since these sensors can be directly interfaced with the SUV-100, data sets may be fully synchronized without the need for additional data recording or handling. Compatible sensors include Eppley Laboratory, Inc. Precision Spectral Pyranometer (PSP) and UV Radiometer (TUVR). Measurements at all sites include temperature of the monochromator housing and instrument enclosure, UV-A (TSI, see Section 2.4.1), monochromator position, and Eppley sensors (see below). Typically, auxiliary sensor data are recorded during the high-resolution spectral scans (several sets of readings per minute) and between the scans at an operator -selected rate ranging from a reading every one to sixty minutes. A Global Positioning System (GPS) receiver was added to the auxiliary sensor system during the 1992-1993 season's site visits. The GPS is principally used as an automatically updated, high-accuracy time base for the system control computer clock. The GPS also records latitude and longitude, important in the real-time calculation of the solar zenith and azimuth angles, used in the system software algorithm in automatic determination of PMT high voltage adjustments. Some sites use other diagnostic sensors, as needed, such as outside temperature, roofbox enclosure humidity, for example.

2.4.1. TSI (UV-A Band Sensor)

For quality control purposes, a stable filtered-photodetector with response in the UV-A, a "Total Scene Irradiance sensor" (TSI), is integrated into the system (see Figure 2.1.). It serves several functions. As an independent measure of UV-A, the TSI is used to indicate system drifts. The stability of the internal 45-Watt response lamp is monitored daily by the TSI and thus drifts of these lamp can be detected. Similarly, the TSI is also used to track changes in 200-Watt calibration standards that are used biweekly for the instrument's irradiance calibration. The TSI also provides an indication of changes in irradiance that may occur during a solar scan (e.g., due to changes in cloud cover). The TSI is not a calibrated sensor, but used referentially; its results are expressed in Volts. TSI readings from one season to another, or from one site to another, are not directly comparable, however. In Figure 2.6, the spectral response of the TSI is shown.

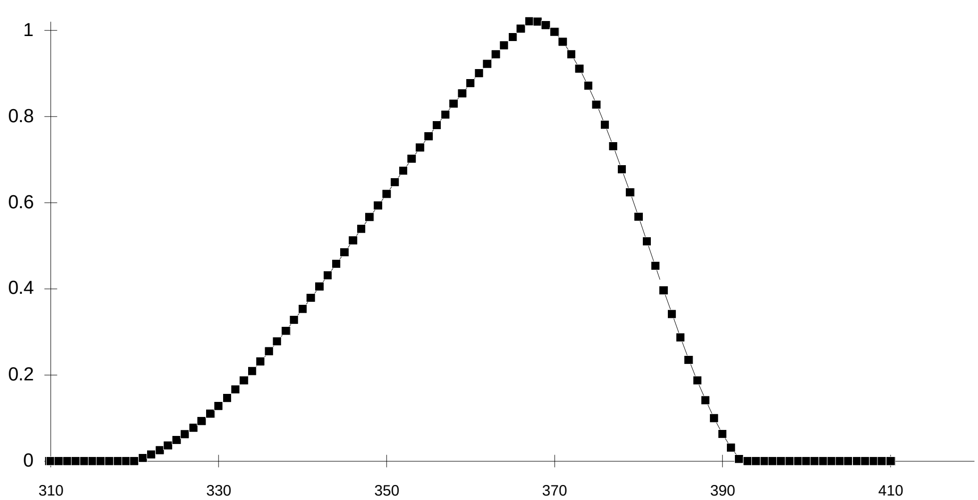

***Figure 2.6**. Spectral response of the TSI sensor (typical).*

2.4.2. Eppley Sensors

Two independent irradiance sensors are mounted alongside the SUV, the Eppley Laboratory, Inc.'s Precision Spectral Pyranometer (Model PSP with WG7 hemisphere) and UV Radiometer (Model TUVR). Data from these sensors are presented in mW/cm². The output of these sensors is collected automatically with the *SUV-100 System Control Software* via the HRAD, and a BSI designed pre-amplifier.

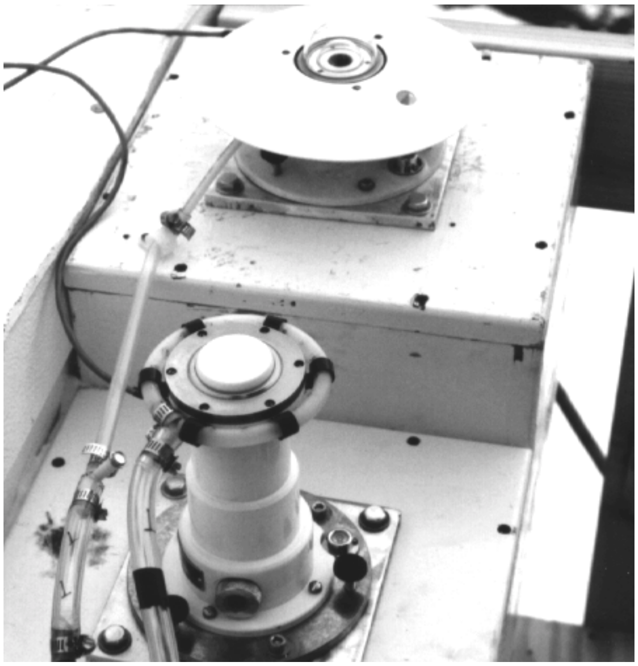

Figure 2.7.

Eppley PSP (top) and TUVR (bottom).

2.5. Software

Network operation software is comprised of two major elements: *SUV-100 System Control* (SUV.exe) and *SUV Read* (SUV_read.exe). The *SUV-100 System Control Software* is installed on the system control computers and automatically controls the instruments and records data. Compiled in Visual Basic®, the software offers ease of control, with a minimum of training, and runs on the Windows NT® operating system. *SUV-100 System Control Software* and accompanying computers were installed at all sites over a period of seven months, beginning in June 1996 at the Barrow, Alaska site. The software features Windows®-based menu operation, user-selectable graphic and numeric display of raw data in real-time, and alarms with an indicating status bar. A "front panel" scrollable event log informs the operator of system malfunctions (achieved by defining a series of different alarms utilizing settable limits). This program also offers real-time display of data from the suite of auxiliary sensors, with the built-in capability for additional sensors.

Biospherical Instruments Inc. staff, site operators, and designated researchers can use *SUV Read* to manage calibration factors, perform data processing, display processed data, and create databases. Also developed in Visual Basic®, the software can read and decode raw data, apply wavelength and irradiance calibration constants, and display both calibration and data results graphically. It can also be used to calculate solar zenith and azimuth angles, spectral integrals, weighted doses, and column ozone. Descriptions of the databases created by the software are found in the appendices. *SUV Read* was developed to read the data file formats of both the previously used DOS-based *Newsptlk* and the *SUV-100 System Control Software*, while incorporating further advances in data processing.