daedalus
Daedalus Enterprises, Inc.
Environmental Remote Sensing Technology

NASA CR-189303

May 22, 1992

IN-74-CR

(NASA-CR-189303) MODIS-N AIRBORNE SIMULATOR Final Report, 1 Feb. - 1 May 1992 (Daedalus Enterprises) 36 p

N94-13719

Unclas

G3/74 0185611

Mr. Ken Brown, Technical Officer
Mail Code 925
NASA Goddard Space Flight Center
Greenbelt Road
Greenbelt, MD 20771

Dear Mr. Brown:

Subject: Contract No. NAS5-31334 Final Report
Modis-N Airborne Simulator

All required work associated with the above referenced contract has been successfully completed at this time. The Modis-N Airborne Simulator has been developed from existing AB184 Wildfire spectrometer parts as well as new detector arrays, optical components, and associated mechanical and electrical hardware. The various instrument components have been integrated into an operational system which has undergone extensive laboratory calibration and testing. The instrument has been delivered to NASA Ames where it will be installed on the NASA ER-2. The following paragraphs detail the specific tasks performed during the contract effort, the results obtained during the integration and testing of the instrument, and the conclusions which can be drawn from this effort.

## TASKS PERFORMED

1. A 9-channel Visible/Near IR Port was added to the spectrometer. The original AB184 Wildfire spectrometer did not have a port designed for operation over this wavelength range. Therefore, this task included design, procurement, manufacture, integration, alignment, and testing activities. An optical design and development effort was undertaken which resulted in the addition of a Visible/Near-IR imaging lens, 9-element silicon detector array, and preamplifier circuit boards to the instrument. After the components of the Visible/Near-IR port had been integrated and tested, detailed spectral response curves for each of the 9 channels were collected.

2. A new 9-channel Thermal IR port was added to the instrument. The required spectral response of the new 9-channel Thermal IR port was quite ambitious.

Spanning from 8.35 to 14.55 $\mu$m, the port almost covered a complete diffraction order with the last three channels (48-50) required to respond to energy at wavelengths greater than 13 $\mu$m. Beyond 13 $\mu$m, the performance of industry standard MCT detectors and optical anti-reflection coatings degrade dramatically. A significant amount of time and effort was expended during this contract effort in an attempt to boost performance in the long wavelength channels of this port. This effort primarily focused on the spectral response of the MCT detector array and the optical efficiency of the thermal IR imaging lens. After detailed discussions with several detector vendors (the discussions included visits by Daedalus employees to the facilities of two of the candidate vendors), a demanding but realistic array specification was generated and a vendor selected. During the array fabrication process, the detector vendor was forced to produce approximately eight generations of the array before a product meeting the array specifications had been produced. In the end, the final MCT detector array delivered to Daedalus consisted of several discrete elements/sub-arrays each doped to enhance its performance over a selected wavelength range. The large number of iterations required before an acceptable array had been produced caused the detector vendor to miss his original delivery date by about 1-1/2 months. Despite the scheduling pressure placed on Daedalus because of this late delivery, we feel that the long wavelength response of the delivered detector array more than justifies the slip in schedule. In terms of long wavelength response, the array is far superior to any MCT detector ever purchased by Daedalus.

The other area which received concentrated effort during this task was the optical efficiency of the thermal IR imaging lens. While high performance, anti-reflection (AR) coolings for thermal IR transmitting materials exist, they are primarily designed for use in the 8-12 $\mu$m atmospheric transmission window. Their performance degrades significantly beyond 13 $\mu$m. Because of this, an effort was made to identify AR coatings which extended the useful transmission of the materials contained in the thermal IR imaging lens (germanium and Amtir 1). After some discussion with our lens vendor, special coating formulas were suggested which would provide the desired long wavelength performance. The added performance was achieved, however, at the expense of coating durability. Based on the information which was available, a decision was made to coat the thermal imaging elements with special extended wavelength AR coatings. Upon testing, it was determined that the coatings did provide a measurable improvement over standard AR coatings. However, the coatings were unable to hold up to repeated temperature cycling in the environmental chamber. After several cycles, the coatings began to lose their adhesion to the lens elements. As a result, the newly designed thermal IR imaging lens had to be replaced with the original AB184 Wildfire thermal IR imaging lens. The new lens elements will be returned to the vendor for recoating. This issue needs to be addressed by both the lens/coating vendor and Daedalus. The availability of an acceptable spare (original AB184 thermal IR imaging lens) allows this issue to be resolved independent from the MAS flight program.

After the components of the thermal port had been integrated and tested, detailed spectral response curves for each of the nine Thermal IR port channels were collected.

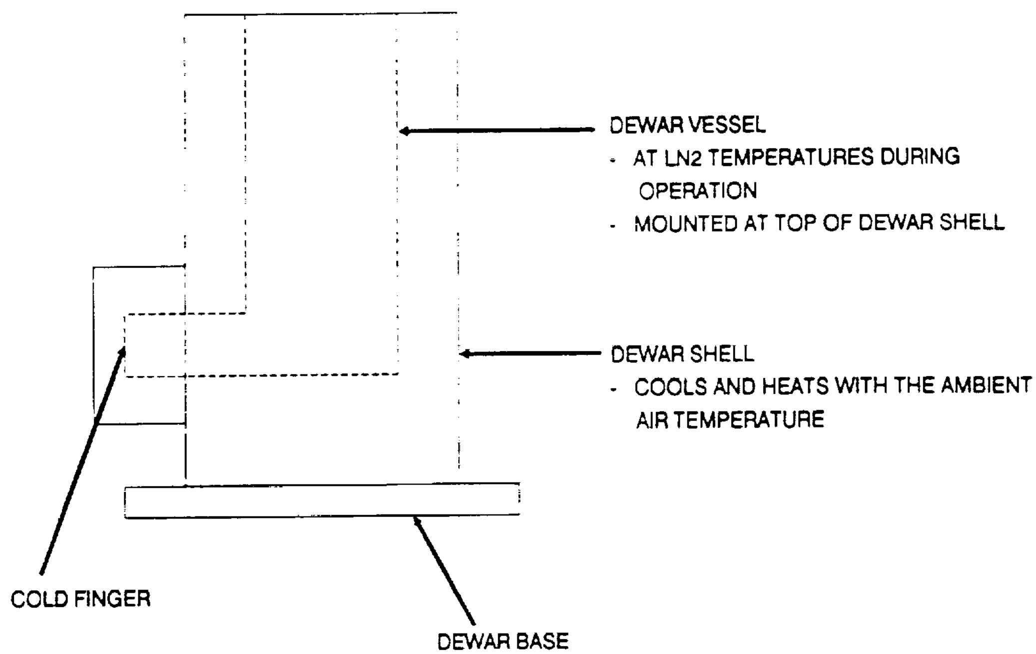
3. A new summing amplifier circuit board was designed and fabricated. The goal in doing so was to make the board easier to configure and less susceptible to radiative noise sources. These goals were achieved.

4. The Midband and Near-IR2 parts were rewired to make them less susceptible to radiative noise sources. The two detector arrays were spectrally aligned and spectral response curves were collected for the subset of channels within these ports which were identified as Modis-N channels.

5. A summing amplifier circuit board for the first set of MAS flights was configured and tested.

6. The presence of a temperature dependent system gain function was identified as an operational deficiency of the instrument during the interim MAS flights. Of most concern was the gain change versus temperature behavior of the Near-IR2 port. With no integral visible or near-IR signal reference sources, Daedalus scanner systems rely on accurate lab oratory calibration in order to provide useful quantitative results in the visible and near-IR regions of the electromagnetic spectrum. If the end-to-end system gain changes as a function of temperature, it makes it very difficult to quantify the scanner output. As a result, it is highly desirable for the system gain in Visible and Near-IR2 ports to be temperature independent.

   To identify the cause of the observed system gain change, a series of laboratory tests were performed on the instrument shortly after the interim MAS flights. During these tests, a large component of the temperature dependence of overall system gain function was traced to thermal contraction occurring in the Near-IR2 and Midband dewar shells. In these dewars, the dewar cold finger (place where detector array is mounted) is mechanically supported at the top of the dewar as shown below:




The detector arrays contained in these dewars are aligned when the dewar shell is at room temperature. As the dewar shell is cooled, thermal contraction which occurs in the shell causes the arrays to move physically closer to the dewar base.

When this occurs, the detector arrays move in the vertical dimension relative to the focal plane spectral distribution of the scene energy. This lowers the percentage of scene energy incident on the arrays. This loss of signal can be interpreted as an effective system gain change with temperature. This is what was happening in the case of the Near-IR2 and Midband dewars. The experimental set-up which was used to determine this phenomenon is sketched below.

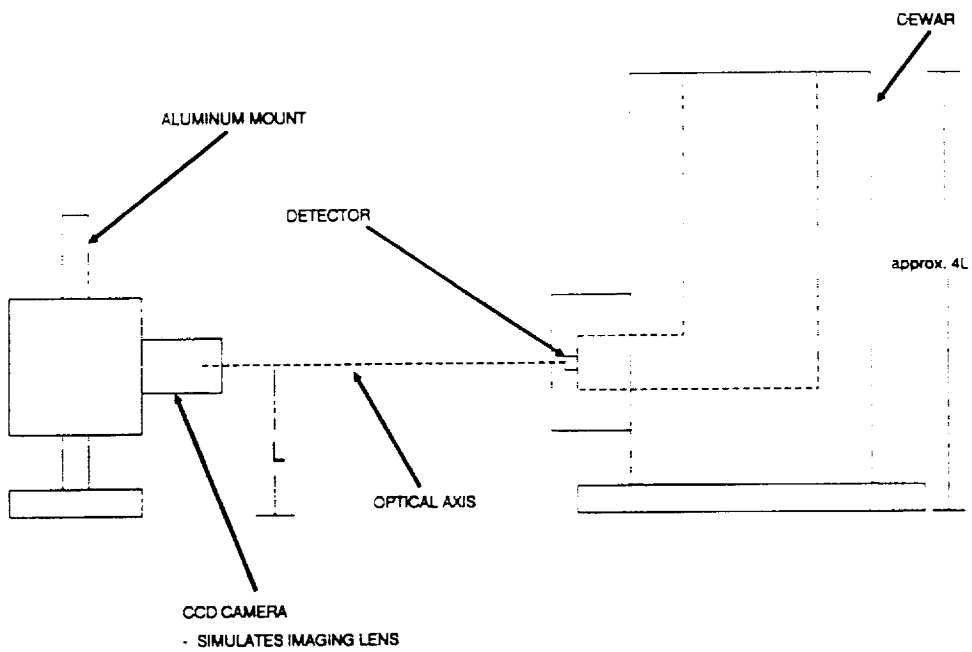
$\alpha$ = coefficient of thermal expansion of aluminum

$\Delta T$ = temperature change

height of CCD camera after contraction = $L' = \left[L - \alpha L \Delta T\right]$

height of detector after contraction = $L' = \left[L - \alpha\, 4 L \Delta T\right]$

shift in vertical position of detector
relative to focal plane of CCD camera = $|L' - L''| = 3\alpha L \Delta T$




When the array is aligned at room temperature, the optical axis of the CCD camera corresponds to the height of the detector array as measured from the dewar base. However, as the temperatures of both the aluminum mount and dewar shell are reduced, the detector array becomes lower than the CCD camera optical axis by a factor of approximately $3\alpha L\Delta T$. The same test was performed while proportionally controlled heaters were mounted to the dewar shells. With the dewar heaters on, the amount of observed vertical shift in the position of the detector arrays relative to the optical axis of the CCD camera were reduced dramatically. Based on these experiments, a scheme for controlling the temperature of the dewar shell was implemented in time for the operational MAS flights.

The same tests were performed on the Thermal port dewar. This dewar type is fabricated using a base-mounted bellows construction. This type of dewar has been specifically designed to minimize the amount vertical focal plane shift caused by changes in the external temperature of the dewar. The results of our tests verified the utility of this type of dewar construction. The amount of vertical shift which was measured for this dewar was an order of magnitude less than that measured in the Midband and Near-IR2 dewars.

Another bit of information which has become available as a result of our tests is that in either dewar type, the amount of focal plane shift in the horizontal or spectral dimension of the array which results from external cooling of the dewar shell is negligible. The dewars are primarily vertical structures and, thus, any thermally induced shifts in detector position are in this dimension.

# RESULTS

This section of the report gives the detailed results of three areas of instrument performance: spectral response, measurement sensitivity, and instrument gain versus temperature.

**Spectral Response**

A total of 23 instrument channels have been characterized in terms of their spectral response. The response versus wavelength curves which have been generated document the behavior of that subset of the total number of instrument channels which have been configured with high gain preamps and are to be used for looking at normal terrestrial reflection and emission scenes. These curves are included in Appendix A.

**Measurement Sensitivity**

As stated earlier, a summing amplifier board has been assembled, configured, and tested. This summing amplifier board connects 11 of the instrument's 50 channels to the system digitizer where the signals will be digitized and prepared for recording. The measurement sensitivity performance of these 11 channels was measured as part of the instrument's final acceptance test procedure (ATP). Because there were very obvious qualitative improvements in the Midband and Thermal port sensor output data as the instrument was cooled to its steady-state ER-2 operational temperature of -35°C, an attempt was made to quantify instrument performance at two instrument/background temperatures. This data is provided below:

| OUT-PUT CH # | BAND EDGES ($\mu$m) | CALIB. SOURCE RADIANCE (note 1&2) | MEASURED SIGNAL (mV) | MEASURED RMS NOISE @ 6.25 SCANS/SEC (mV) | CALCULATED NER @ 6.25 SCANS/SEC (note 3) |
|---|---|---|---|---|---|
| 1 | 0.635 - 0.688 | 4.12E-06 | 866 | 1.0 | $4.76 \times 10^{-9}$ |
| 2 | 0.852 - 0.875 | 5.58E-06 | 853 | .8 | $3.81 \times 10^{-9}$ |
| 3 | 0.926 - 0.969 | 5.69E-06 | note 5 | note 5 | note 5 |
| 4 | 1.595 - 1.652 | 2.82E-06 | 1057 | .8 | $2.13 \times 10^{-9}$ |
| 5 | 2.126 - 2.173 | 1.29E-06 | 575 | .8 | $1.79 \times 10^{-9}$ |

| OUT-PUT CH # | BAND EDGES (μm) | DELTA TEMP (deg C) | MEASURED SIGNAL (mV) | | MEASURED RMS NOISE @ 6.25 SCANS/SEC (mV) | | CALCULATED NETD (deg C) (note 4) | |
|---|---|---|---|---|---|---|---|---|
| | | | 25°C | 5°C | 25°C | 5°C | 25°C | 5°C |
| 6 | 3.659 - 3.810 | 15.5 | 850 | 910 | 42 | 34 | .77 | .58 |
| 7 | 11.799 - 12.246 | 15.5 | 1050 | 1250 | 34 | 34 | .50 | .42 |
| 8 | 8.342 - 8.738 | 15.5 | 1250 | 1500 | 16 | 15 | .20 | .16 |
| 9 | 10.791 - 11.239 | 15.5 | 1420 | 1840 | 24 | 25 | .26 | .21 |
| 10 | 13.023 - 13.375 | 15.5 | 1100 | 1250 | 160 | 145 | 2.25 | 1.80 |
| 11 | 13.630 - 14.147 | 15.5 | 1200 | 700 | 220 | 100 | 2.84 | 2.20 |

NOTES:
1. Calibration source for channels 1-5 AB532 S/N 11
2. In $W/cm^2 * nm * sr$
3. NER = Noise Equivalent Radiance: in $W/cm^2 * nm * sr$
   NER = RADIANCE/(SIGNAL/NOISE)
4. NETD = Noise Equivalent Temperature Difference
   NETD = DELTA TEMP/(SIGNAL/NOISE)
5. Due to oversight during integration, SNR of this channel was not measured.

As one can see from these tables, the instrument data channels which are background radiation limited experience a decrease in measured NETD (improved performance) as the temperature of the instrument goes down. In addition, the degree of measured improvement agrees quite well with theoretical predictions based on the decrease in background radiation and the increase in the imaging lens transmission which should be taking place over the documented temperature differential. Due to a lack of required test equipment, the NETD performance of the Midband and Thermal port sensor channels was not measured at the ER-2 operational temperature of -35°C. However, as stated earlier, a significant qualitative improvement in these channels was observed when the instrument was cooled and operated at -35°C. Using the room temperature NETD measurements as a reference point, it is possible to extrapolate to an estimated NETD performance at -35°C. This extrapolation takes into consideration the expected decrease in background radiation and increase in imaging lens transmission which occurs as the instrument temperature is decreased. The estimated NETD performance of these background limited channels is given below.

| CHANNEL NUMBER | BAND EDGES ($\mu m$) | ESTIMATED NETD PERFORMANCE AT -35°C, 6.25 SCANS/SEC (degrees C) |
|---|---|---|
| 7 | 3.659 - 3.810 | 0.26 |
| 8 | 11.799 - 12.246 | 0.25 |
| 9 | 8.342 - 8.738 | 0.10 |
| 10 | 10.791 - 11.239 | 0.13 |
| 11 | 13.023 - 13.375 | 0.75 |
| 12 | 13.630 - 14.147 | 0.95 |

**Gain-versus-Temperature Performance**

Analysis of the data collected during the interim MAS flights indicated that the instrument was experiencing an effective system gain change as a function of temperature. This fact was later verified during subsequent laboratory tests of the instrument. The Thermal port experienced an effective system gain increase of approximately 1.5-2.2 as the instrument was cooled from an ambient laboratory temperature to the operational instrument temperature of -35°C. The Midband and Near IR2 ports experienced an effective system gain decrease of approximately 0.6-0.7 over the same temperature differential. The gain change which was measured in the Thermal port was not thought to be a major problem. The reasons for this are: 1) an effective system gain change as a function of instrument background temperature can be predicted from the Thermal port detector preamplifier circuit, and 2) the Thermal port detectors sample two temperature monitored blackbody reference sources every scan line allowing the user to calibrate the data channels on a per-scan-line basis. The Midband and Near-IR2 ports posed more of a problem (especially the Near-IR2 port). First of all, anytime an effective system gain decrease is detected, it can imply that a loss of signal is taking place somewhere in the system. This is never a desirable feature. Secondly, in the case of the Near-IR2 port, the lack of an internal near-IR reference source makes the port dependent on accurate laboratory calibration. The validity of laboratory calibrations become suspect if the effective system gain is a function of the instrument operating temperature.

As was stated in some detail earlier, the decrease in effective system gain which was measured for both the Midband and Near-IR2 ports was traced to a loss in system signal caused by a vertical shift in the position of the detector array relative to the optical axis of the imaging lens. To correct for this condition, a dewar heater scheme was prototyped and tested. The following table documents the temperature stability of the 11 instrument channels to be recorded during the initial MAS flights. The data was collected as the system was operated in the Daedalus temperature chamber and with the dewar heaters activated. A lamp/reflectance panel setup provided the constant radiation source for the Visible and Near-IR ports while the internal blackbody references provided the constant signal reference for the Midband and Thermal ports. The analog voltage measurements which were recorded were taken at the input to the digitizer A/D's.

| OUTPUT CHANNEL # | BAND EDGES ($\mu$m) | 22.8° | -3.3° | -27.5° (degrees C) | -40.8° | -41.3° |
|---|---|---|---|---|---|---|
| 2 | 0.635 - 0.688 | 1.3V | 1.35 | 1.35 | 1.35 | 1.3 |
| 3 | 0.852 - 0.875 | 1.3 | 1.35 | 1.4 | 1.35 | 1.35 |
| 4 | 0.926 - 0.969 | note 1 | note 1 | note 1 | note 1 | note 1 |
| 5 (Near IR Port) | 1.595 - 1.652 | 1.6 | 1.7 | 1.75 | 1.6 | 1.6 |
| 6 (Near IR2 Port) | 2.126 - 2.173 | 0.8 | 0.8 | 0.85 | 0.8 | 0.8 |
| 7 (Midband Port) | 3.659 - 3.810 | 0.7 | 0.8 | 0.7 | 0.8 | 0.8 |
| 8 | 11.799 - 12.246 | 1.3 | 1.7 | 2.3 | 2.5 | 2.6 |
| 9 | 8.342 - 8.738 | 1.9 | 2.7 | 3.5 | 4.0 | 4.0 |
| 10 | 10.791 - 11.239 | 2.0 | 2.5 | 3.1 | 3.5 | 3.5 |
| 11 | 13.023 - 13.375 | 1.0 | 1.3 | 1.6 | 1.6 | 1.8 |
| 12 | 13.630 - 14.147 | 0.8 | 1.1 | 1.3 | 1.3 | 1.3 |

NOTES:

1. Due to oversight during integration, temperature stability of this channel was not measured.

As the table indicates, the temperature stability of the Midband and Near-IR2 ports have improved significantly when compared to the interim MAS performance.

## CONCLUSIONS

From an instrument design and development perspective, the dominant conclusion drawn from this contract effort is that thermal management of the instrument should be given a high priority during the design stage of any quantitative scanner system. Proper thermal management can both prevent temperature induced instrument performance degradation as well as, through completely different mechanisms, increase the fundamental instrument measurement sensitivity performance. Proper thermal management can also increase the maintenance lifetime of the instrument, especially in the area of optical coatings.

Each of these aspects of instrument thermal management were highly visible during this contract effort. Uncontrolled cooling of the Midband and Near-IR2 port dewars was determined to be the cause of the effective system gain change behavior of the instrument. A thermal management scheme for these key system components was tested and implemented and will, Daedalus believes, dramatically improve the instrument's operational temperature stability. In addition to the controlled dewar heaters, Daedalus seriously considered implementing an uncontrolled spectrometer heating capability which would be activated just prior to aircraft descent. The goal here would be to apply enough power to the instrument to raise its temperature above the dew point, thus preventing condensation from occurring as the instrument returns to the ground. Such a capability would increase the operational lifetime of the instrument. Wiring changes were made to the system to accommodate such a capability, mounting locations were machined into the spectrometer mechanics in order to accommodate the placement of the required heaters, and resistive heaters were purchased. However, a decision was made to hold off the implementation of the heating scheme. The reason this was done was that it became obvious during testing of the instrument that the heating capability which Daedalus was prepared to implement was not going to be enough to provide any useful heating of the spectrometer. In addition to the 180 watts which was provided to heat the Midband and Near-IR2 dewars, Daedalus was prepared to provide 180 watts for general spectrometer heating. Without having done any significant analysis on the problem, it is our opinion that it would require approximately 10 times this amount in order to provide any useful instrument heating.

The last area of thermal management which will be discussed is the effect of background temperature on the fundamental performance of the Midband and Thermal port detectors. Despite the operational problems which it introduces, the cold operational environment of the ER-2 platform allows the instrument to achieve a level of measurement sensitivity performance in the Midband and Thermal ports it would not be capable of achieving at ambient laboratory temperatures. Based on the results of this contract effort, active cooling of the components within the detectors field-of-view should be considered for all applications which require the use of background limited detectors. This is especially true for channels whose predicted SNR performance at room temperature operation is marginal.

Another conclusion which can be drawn from this effort is that, ideally, a visible near-IR reference should be integrated into the system. This would better facilitate the radiometric quantification of the Visible and Near-IR2 ports. While the injection of a DC current or voltage into the signal processing chain would provide the user with a good reference for use in characterizing the performance of the system electronics over time or temperature, it does not allow the user to monitor the behavior of the instrument's optical and detector subsystems. Using the MAS instrument as an example, it is perhaps more important to monitor the operational performance of these subsystems rather than concentrating only on the electrical subsystems. If a reliable internal visible/near-IR reference source is impractical, extensive laboratory radiometric calibration is the best alternative. For laboratory calibration to be useful, the effective system gain has to be independent of the operating temperature of the instrument or accurately characterized at all possible operational temperatures. Related to this, accurate radiometric calibration is best achieved by measuring the system output at several known radiance inputs. By doing so, the dependence of the measured radiometric transfer function on any one particular data point is reduced. This calibration technique is especially useful if there is a significant amount of uncertainty in some of the data points being measured.

The final comments related to this contract effort address some of the component failures which have occurred during instrument integration and operation. During both the interim and final instrument integration efforts, a single MCT detector element within the Thermal port array failed. In both instances, failure came after the arrays had been spectrally aligned and tested. The current procedure which is used to spectrally align the detector channels is very time-intensive. Failures which occur after an array has been spectrally aligned result in a loss of several integration/alignment days. To recover from such a failure, this same amount of realignment time must then be added to the time required for the detector vendor to repair, re-assemble, or replace the detector array itself. Though regrettable, it is Daedalus' opinion that the type and magnitude of the sensor failures which have already been experienced are to be expected from a system such as the MAS instrument. To date, starting from the development of the original AB184 Wildfire spectrometer through its evolution into its current MAS configuration, 69 discrete detector elements have been aligned, tested, and operated. Over this period of time, only a single detector element has been permanently lost. Despite the fact that, in general, detector failures are minimal, any detector failure which might occur in the future will have a significant impact on the operational availability of the instrument and will place a great deal of pressure on those individuals responsible for maintaining the system. To ease the risks of operating a multispectral system such as this, two things are recommended. First, serious consideration should be given to purchasing spare detector arrays. Secondly, an alternate method of spectral alignment needs to be adopted for field operations. Ames sensor group has recently purchased a single, narrow bandpass filter which has shown a lot of promise in allowing relatively easy spectral alignment of the instrument. The purchase of similar narrow bandpass filters at several selected wavelengths within each of the four spectrometer ports should be considered with the goal of making the system field alignable.

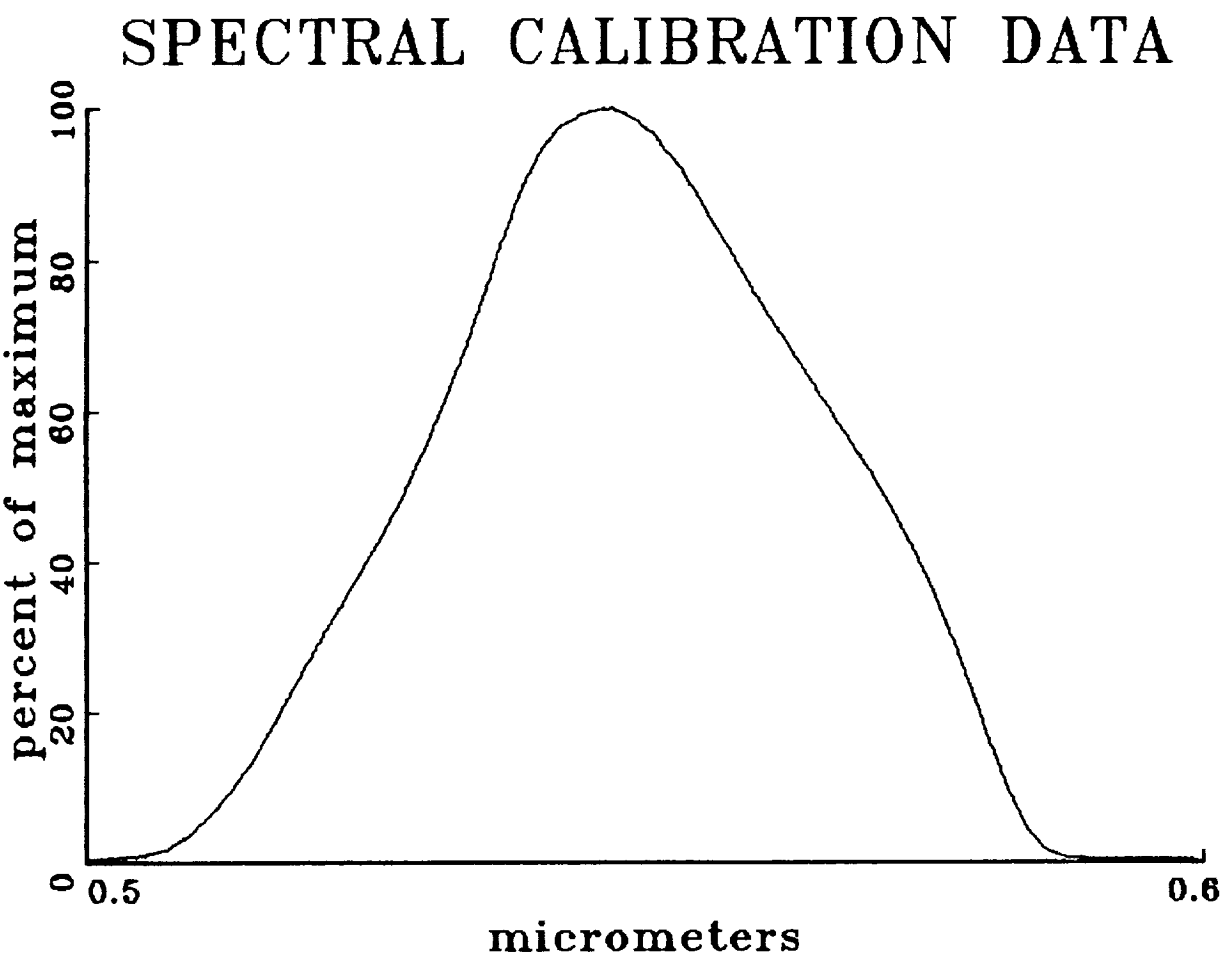
Sincerely,

Steven D. Cech
Principal Investigator

SDC/mrv

header 1

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .41-.72 um filter |
| Operator Comment(s): | 1mm slits,1sec. pre,1sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 5000 |
| Monochromator End Reading: | 6000 |
| Grating Identification: | 600 g/mm, 7500 blaze |
| Source Identification: | t.h. lamp, 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch1 |
| Normalization Data File | modisn.rf1 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.529 micrometers |
| UPPER HALF POWER POINT AT | 0.572 micrometers |
| PEAK POWER AT | 0.547 micrometers |

100% of the energy is between 0.510 and 0.596 nm

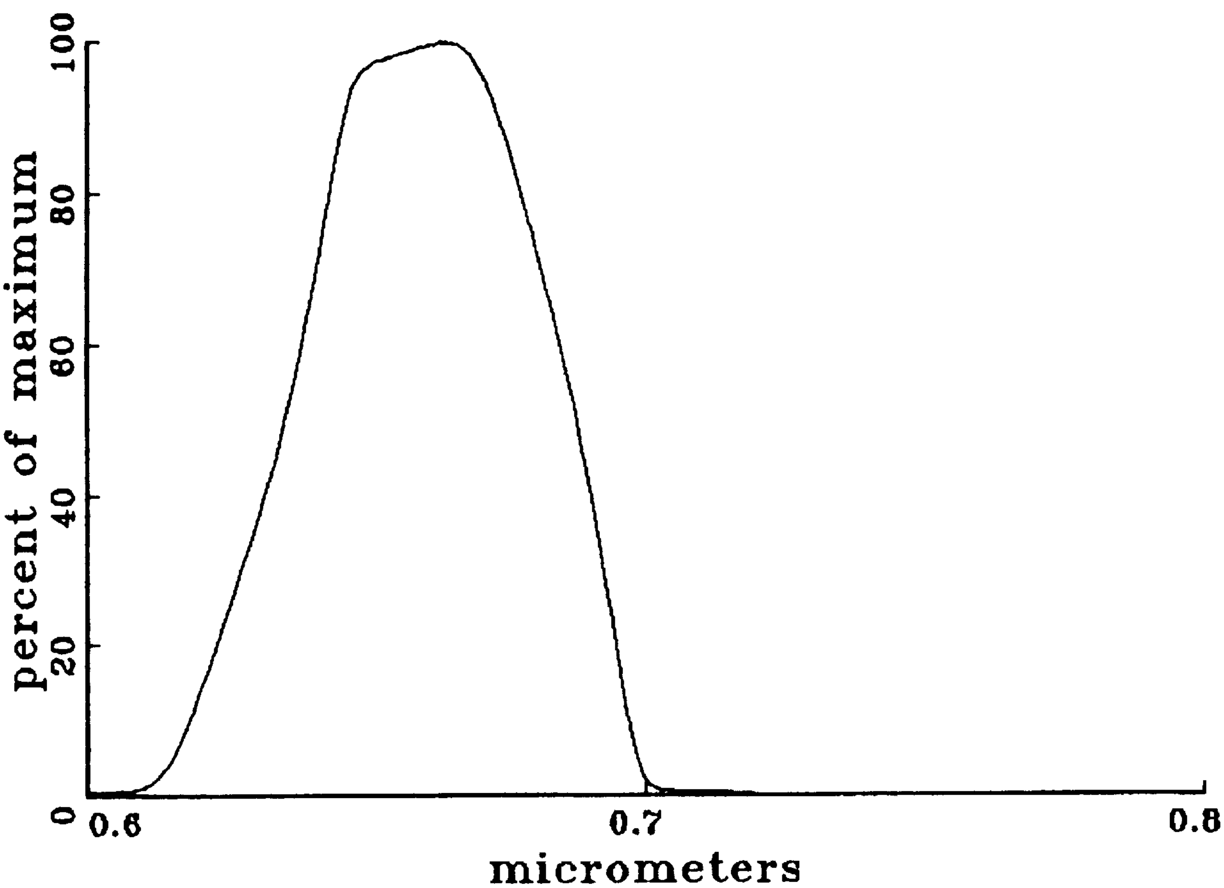
SPECTRAL CALIBRATION DATA

File: Nab184.ch2    Tue Apr 14 07:27:17 1992    Page 1

leader 2

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1mm slits,1sec. pre,1sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 6000 |
| Monochromator End Reading: | 7200 |
| Grating Identification: | 600 g/mm, 7500 blaze |
| Source Identification: | t.h. lamp, 145 V t.h. 145 V |
| Number of Readings: | 1193 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch2 |
| Normalization Data File | modisn.rf2 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.635 micrometers |
| UPPER HALF POWER POINT AT | 0.688 micrometers |
| PEAK POWER AT | 0.664 micrometers |

100% of the energy is between 0.607 and 0.713 nm

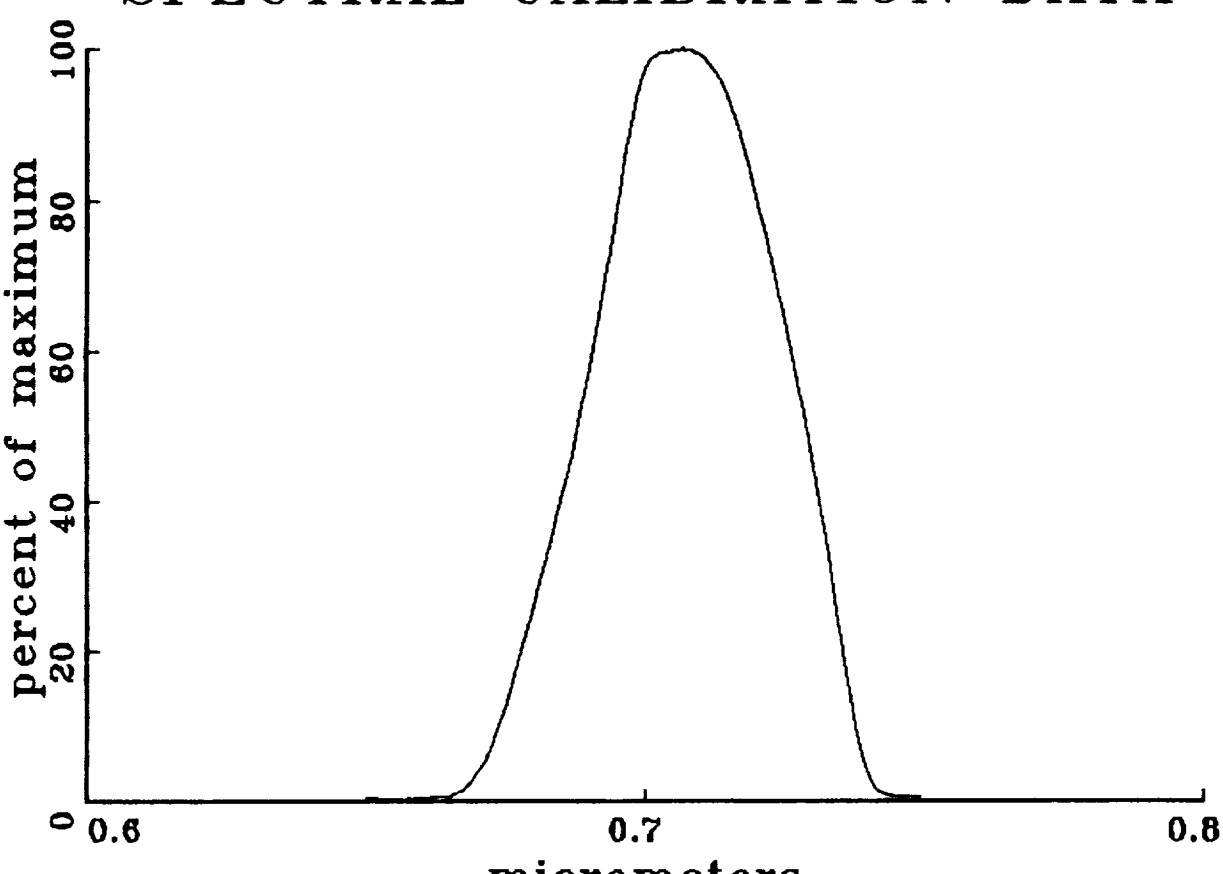
SPECTRAL CALIBRATION DATA

File: Nab184.ch3    Tue Apr 14 07:59:01 1992    Page 1

header 3

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1mm slits,1sec. pre,1sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 6500 |
| Monochromator End Reading: | 7500 |
| Grating Identification: | 600 g/mm, 7500 blaze |
| Source Identification: | t.h. lamp, 145 V    t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch3 |
| Normalization Data File | modisn.rf3 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.688 micrometers |
| UPPER HALF POWER POINT AT | 0.729 micrometers |
| PEAK POWER AT | 0.707 micrometers |

66% of the energy is between 0.669 and 0.752 nm

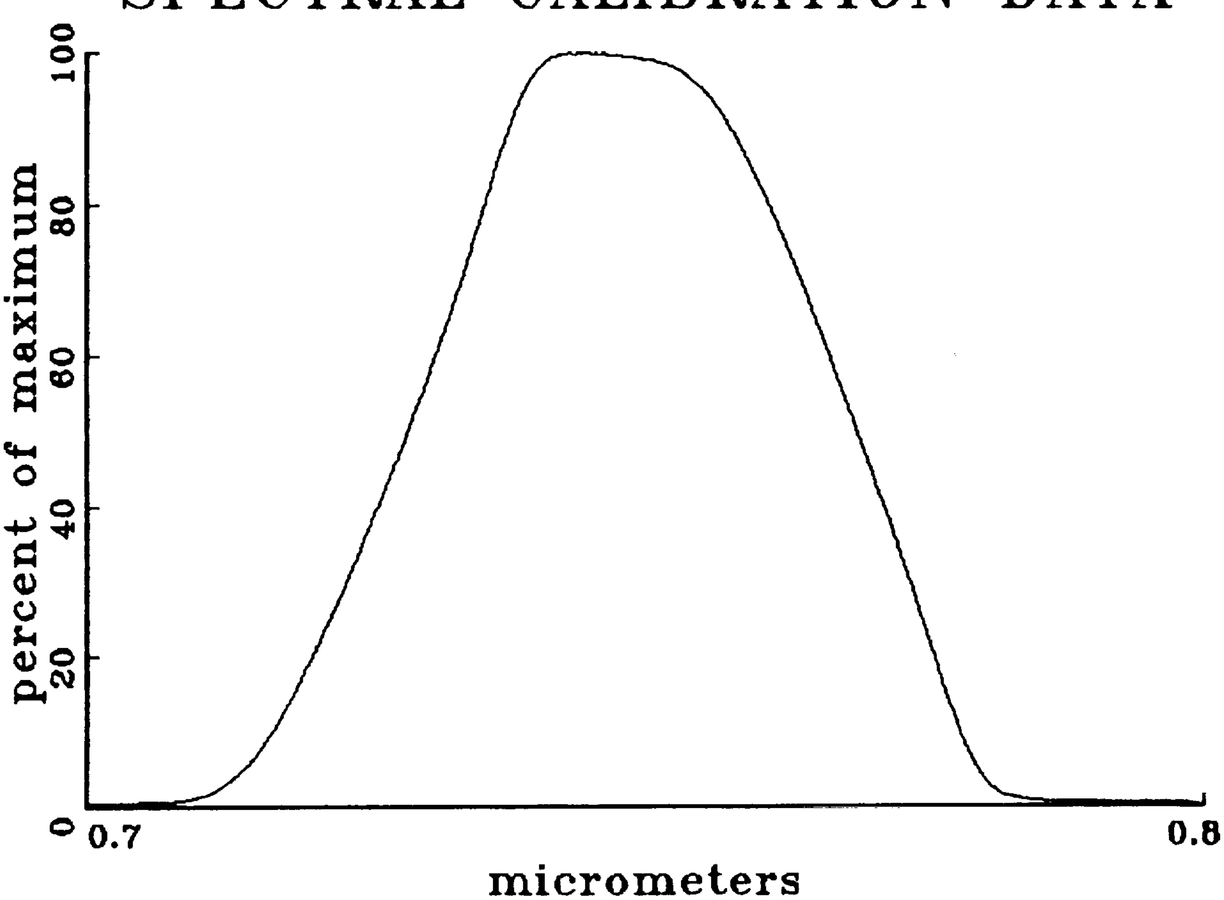
SPECTRAL CALIBRATION DATA

File: Nab184.ch4 Fri Jan 04 00:05:30 1980 Page 1

header 4

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03um filter |
| Operator Comment(s): | 1mm slits,1sec. pre,1sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 7000 |
| Monochromator End Reading: | 8000 |
| Grating Identification: | 600 g/mm, 7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch4 |
| Normalization Data File | modisn.rf4 |

# SPECTRAL CALIBRATION DATA



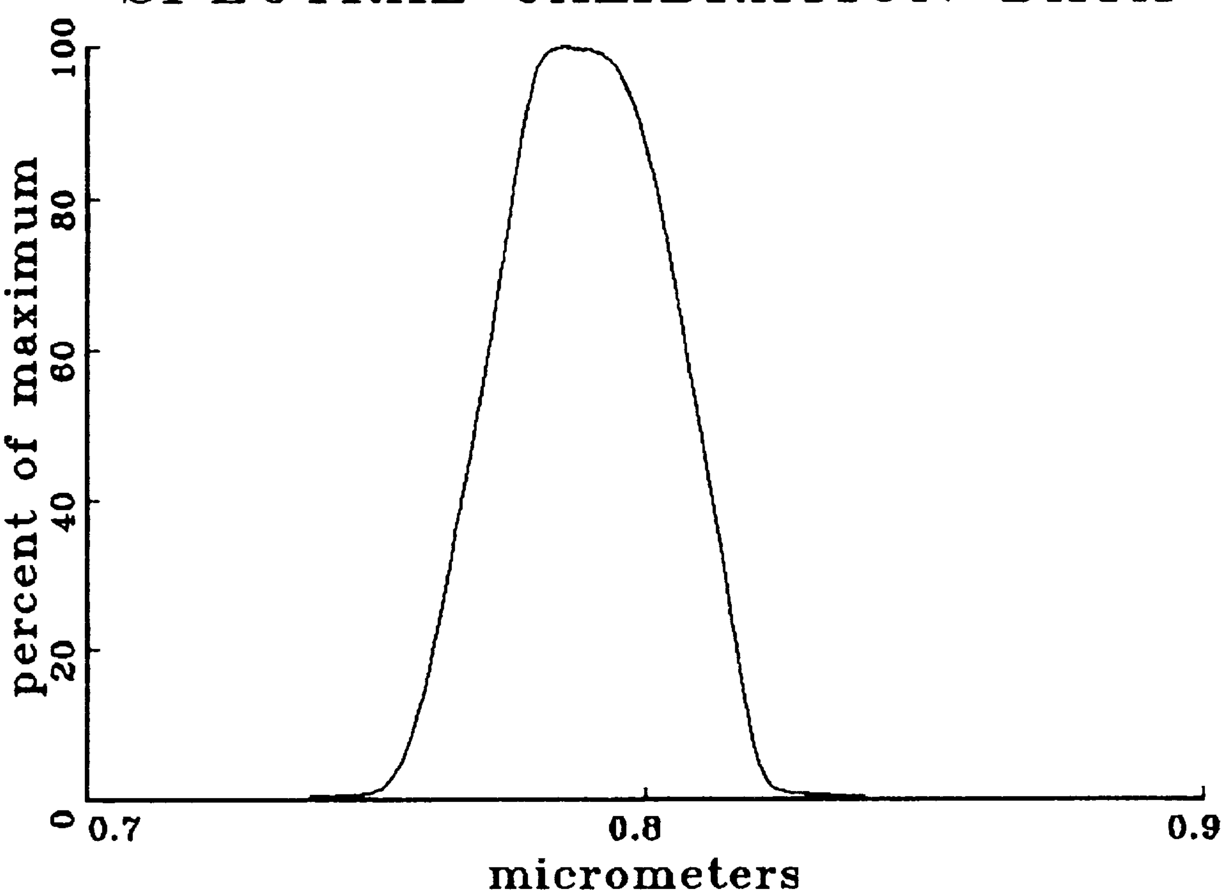

| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.729 micrometers |
| UPPER HALF POWER POINT AT | 0.769 micrometers |
| PEAK POWER AT | 0.745 micrometers |

100% of the energy is between 0.713 and 0.794 nm

header 5

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03um filter |
| Operator Comment(s): | 1mm slits,1sec. pre,1sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 7400 |
| Monochromator End Reading: | 8400 |
| Grating Identification: | 600 g/mm, 7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch5 |
| Normalization Data File | modisn.rf5 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.770 micrometers |
| UPPER HALF POWER POINT AT | 0.810 micrometers |
| PEAK POWER AT | 0.786 micrometers |

100% of the energy is between 0.754 and 0.835 nm

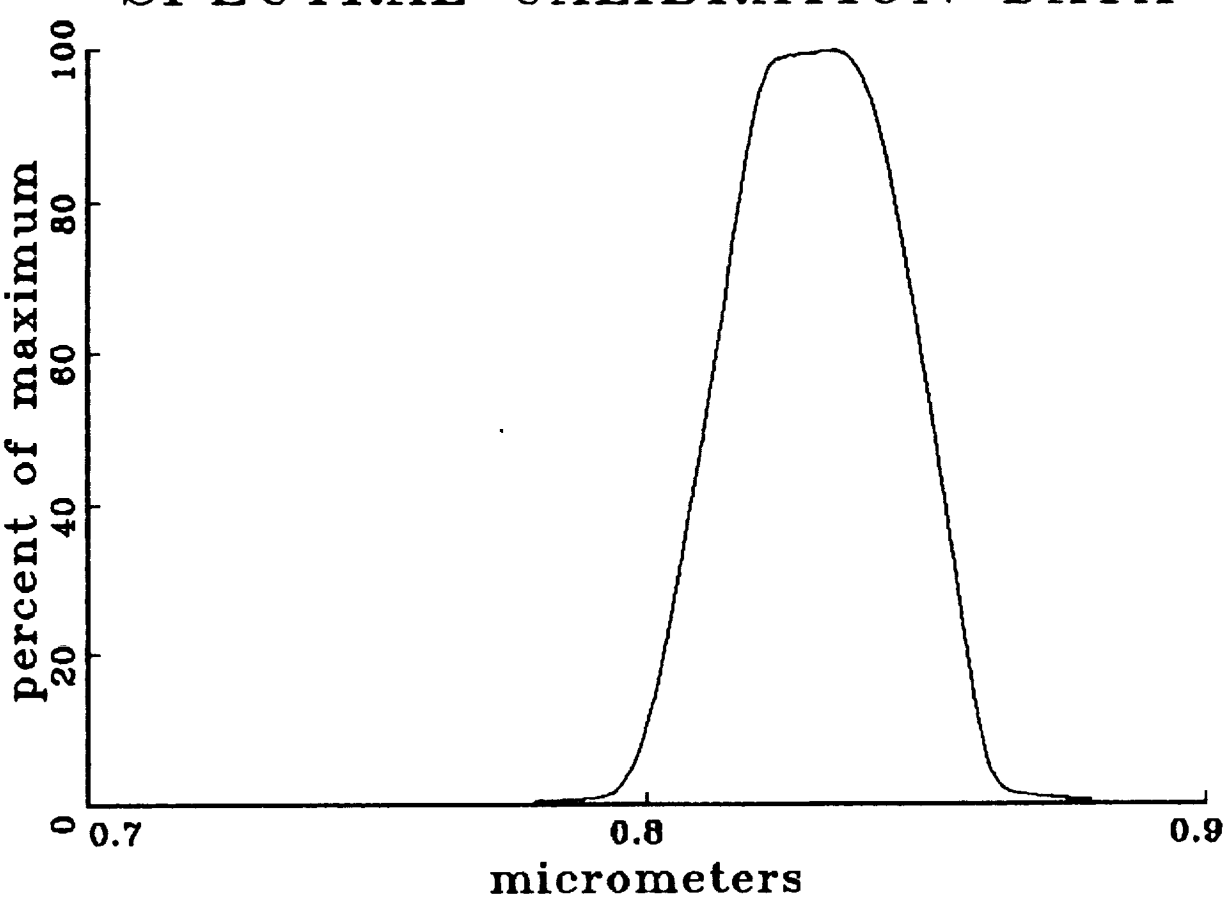
SPECTRAL CALIBRATION DATA

File: Nab184.ch6 Fri Jan 04 00:59:54 1980 Page 1

header 6

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1 mm slits,1sec. pre,1sec post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 7800 |
| Monochromator End Reading: | 8800 |
| Grating Identification: | 600 g/mm,7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch6 |
| Normalization Data File | modisn.rf6 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.810 micrometers |
| UPPER HALF POWER POINT AT | 0.852 micrometers |
| PEAK POWER AT | 0.834 micrometers |

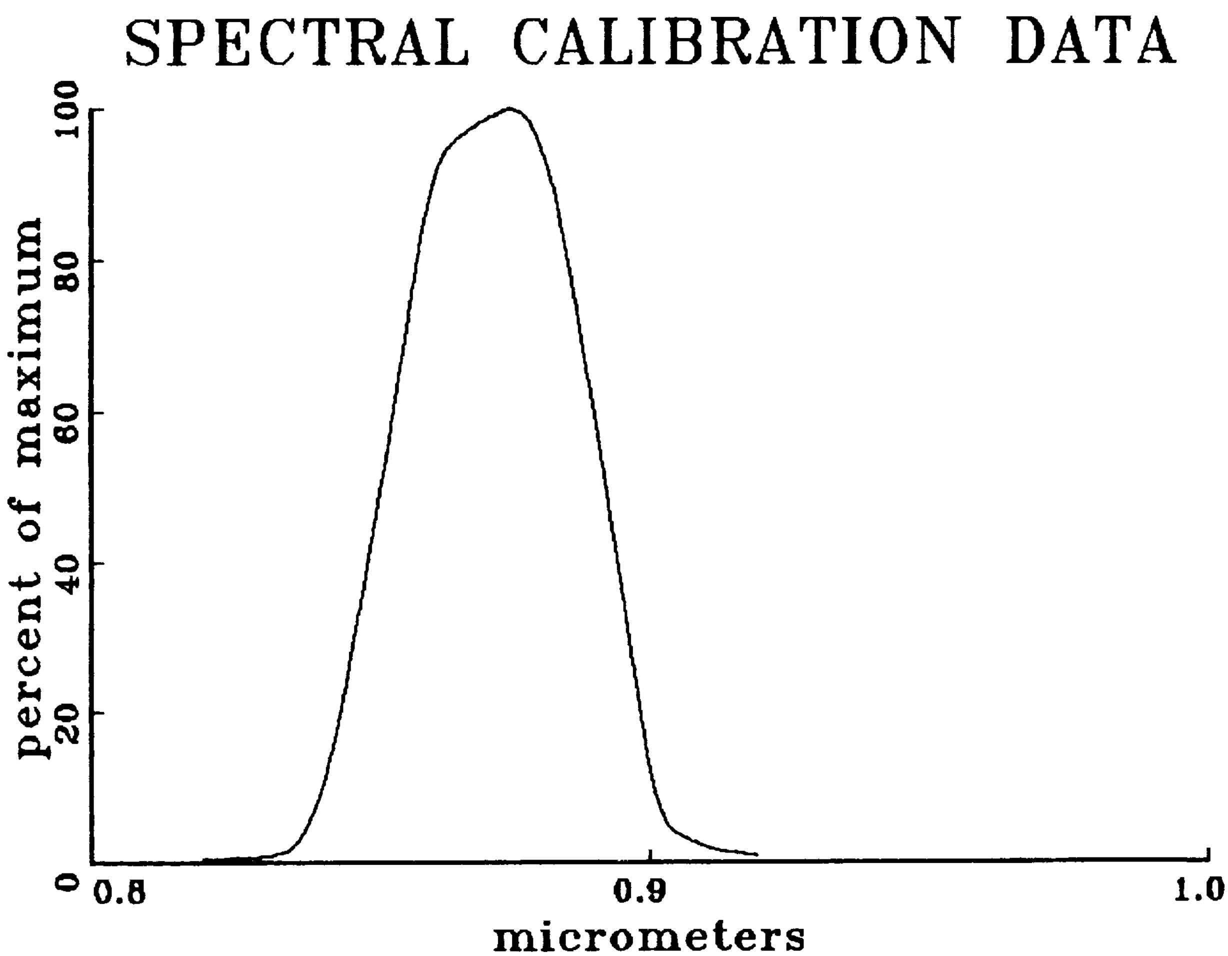
100% of the energy is between 0.787 and 0.869 nm

SPECTRAL CALIBRATION DATA

File: Nab184.ch7 Fri Jan 04 01:19:46 1980 

header 7

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1 mm slits,1sec. pre,1sec post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 8200 |
| Monochromator End Reading: | 9200 |
| Grating Identification: | 600 g/mm,7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch7 |
| Normalization Data File | modisn.rf7 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.852 micrometers |
| UPPER HALF POWER POINT AT | 0.893 micrometers |
| PEAK POWER AT | 0.875 micrometers |

100% of the energy is between 0.829 and 0.910 nm

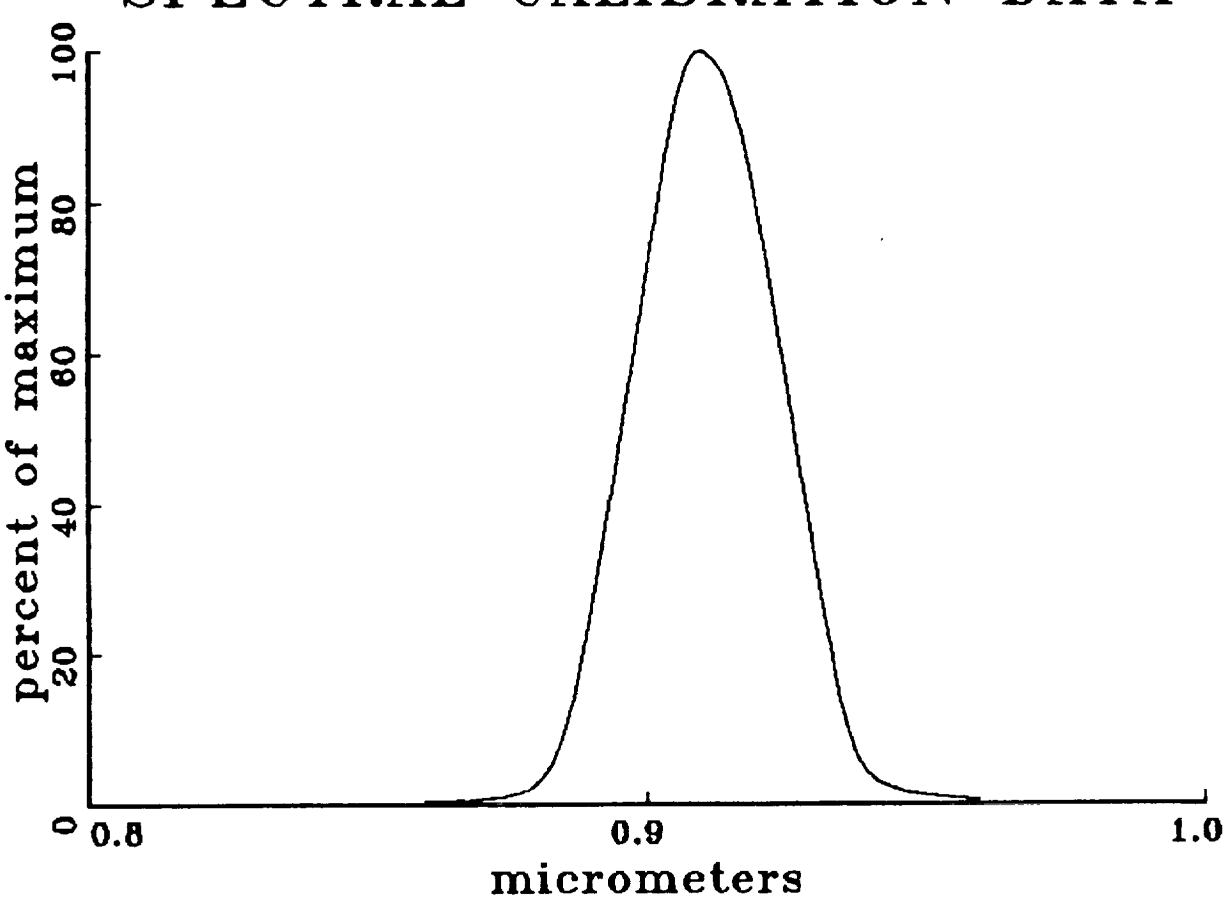
# SPECTRAL CALIBRATION DATA

File: Nab184.ch8 Fri Jan 04 01:49:41 1980 Page 1

header 8

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1 mm slits,1sec. pre,1sec post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 8600 |
| Monochromator End Reading: | 9600 |
| Grating Identification: | 600 g/mm,7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch8 |
| Normalization Data File | modisn.rf8 |

## SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.896 micrometers |
| UPPER HALF POWER POINT AT | 0.927 micrometers |
| PEAK POWER AT | 0.910 micrometers |

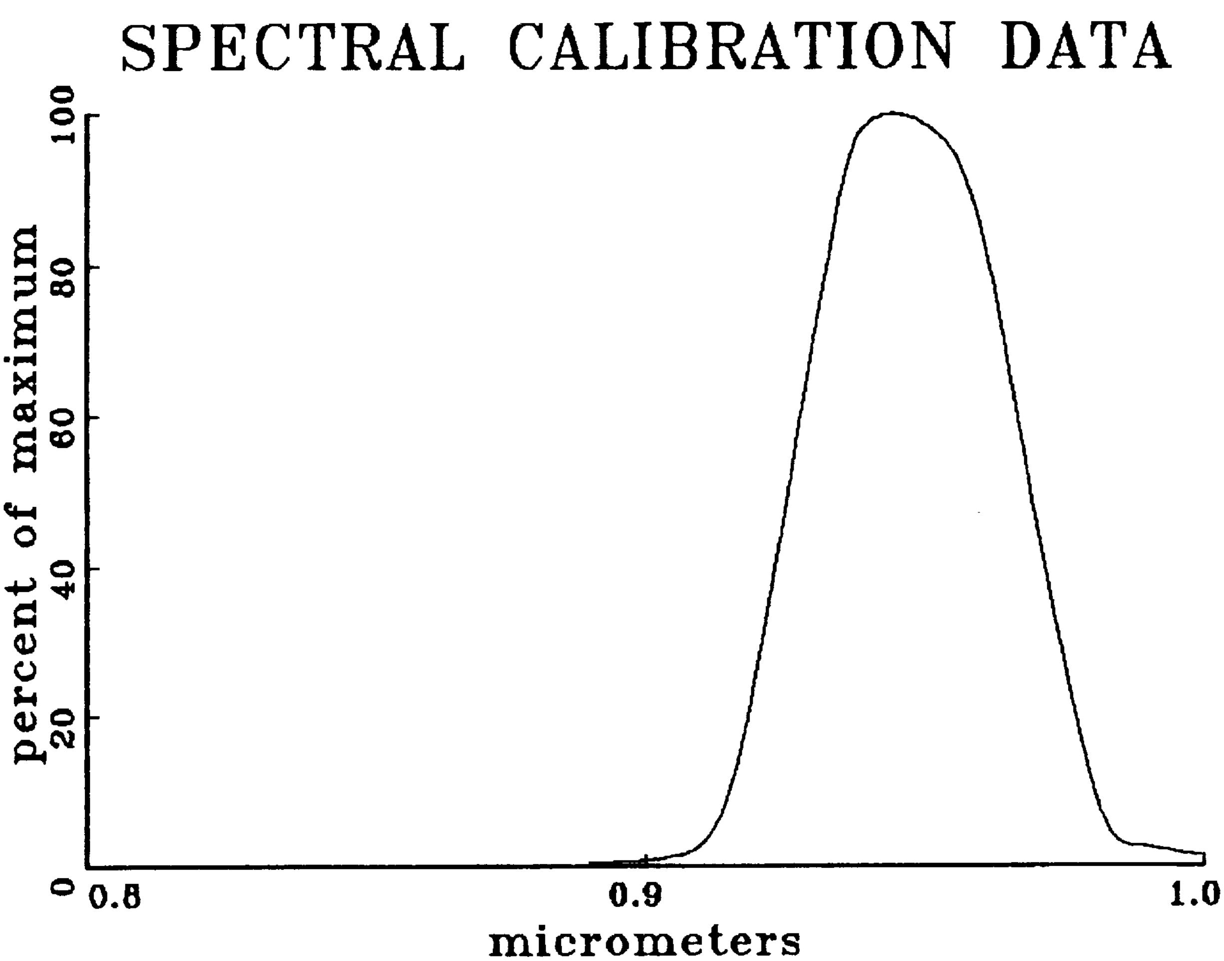
99% of the energy is between 0.882 and 0.944 nm

SPECTRAL CALIBRATION DATA

File: Nab184.ch9 Fri Jan 04 02:04:20 1980 

header 41

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | .56-1.03 um filter |
| Operator Comment(s): | 1 mm slits,1sec. pre,1sec post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18404 s/n 1 |
| Monochromator Speed: | 100 |
| Monochromator Start Reading: | 8900 |
| Monochromator End Reading: | 10000 |
| Grating Identification: | 600 g/mm,7500 blaze |
| Source Identification: | t.h. lamp 145 V t.h. 145 V |
| Number of Readings: | 1094 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.ch9 |
| Normalization Data File | modisn.rf9 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 0.926 micrometers |
| UPPER HALF POWER POINT AT | 0.969 micrometers |
| PEAK POWER AT | 0.945 micrometers |

100% of the energy is between 0.907 and 0.994 nm

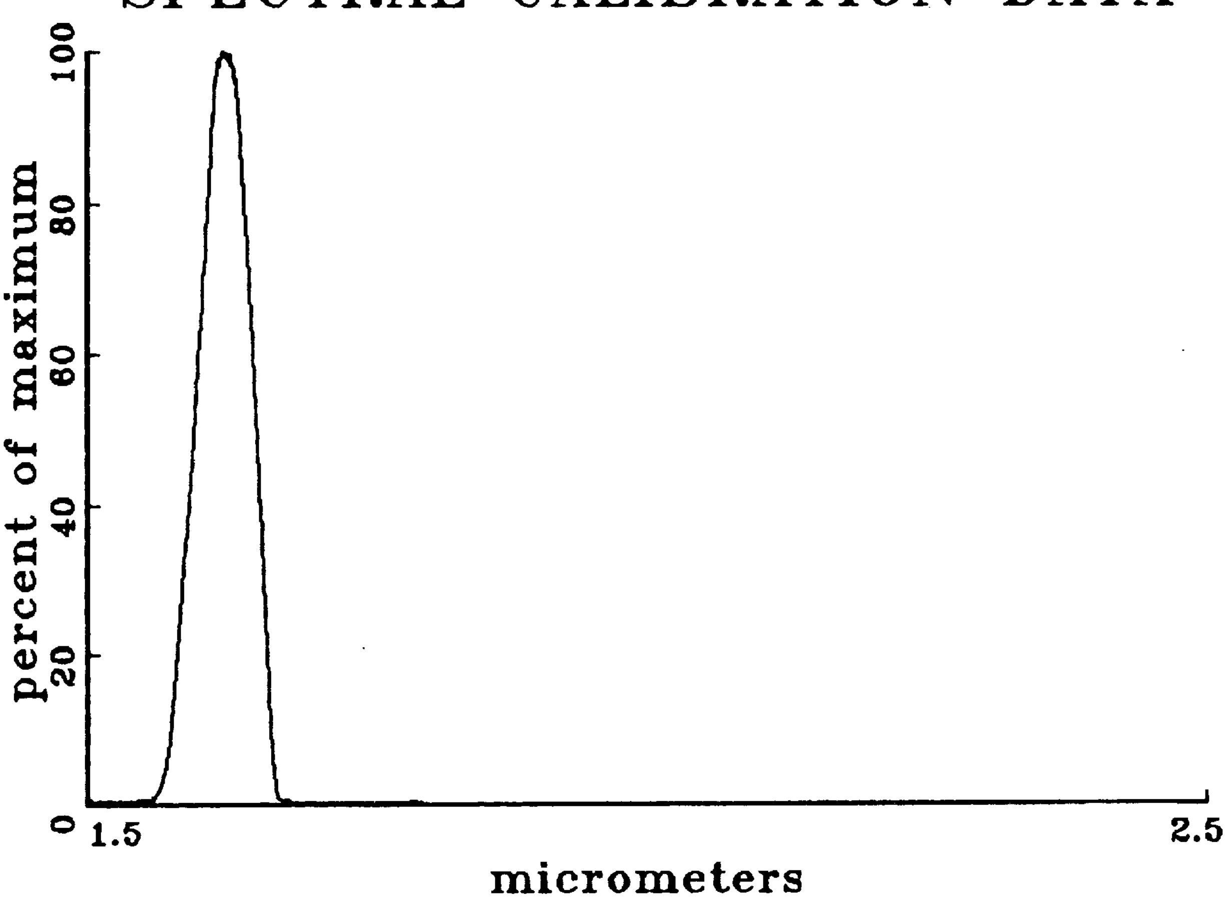
SPECTRAL CALIBRATION DATA

File: Nab184.c10 Mon Apr 27 12:12:46 1992 Page 1

heater 9

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 1 mm slits,1.2-2.0um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18402 |
| Monochromator Speed: | 200 |
| Monochromator Start Reading: | 15000 |
| Monochromator End Reading: | 18000 |
| Grating Identification: | 300 g/mm,3um blaze |
| Source Identification: | t.h. 142 V th 142v |
| Number of Readings: | 1491 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c10 |
| Normalization Data File | sept19.rf1 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 1.595 micrometers |
| UPPER HALF POWER POINT AT | 1.652 micrometers |
| PEAK POWER AT | 1.623 micrometers |

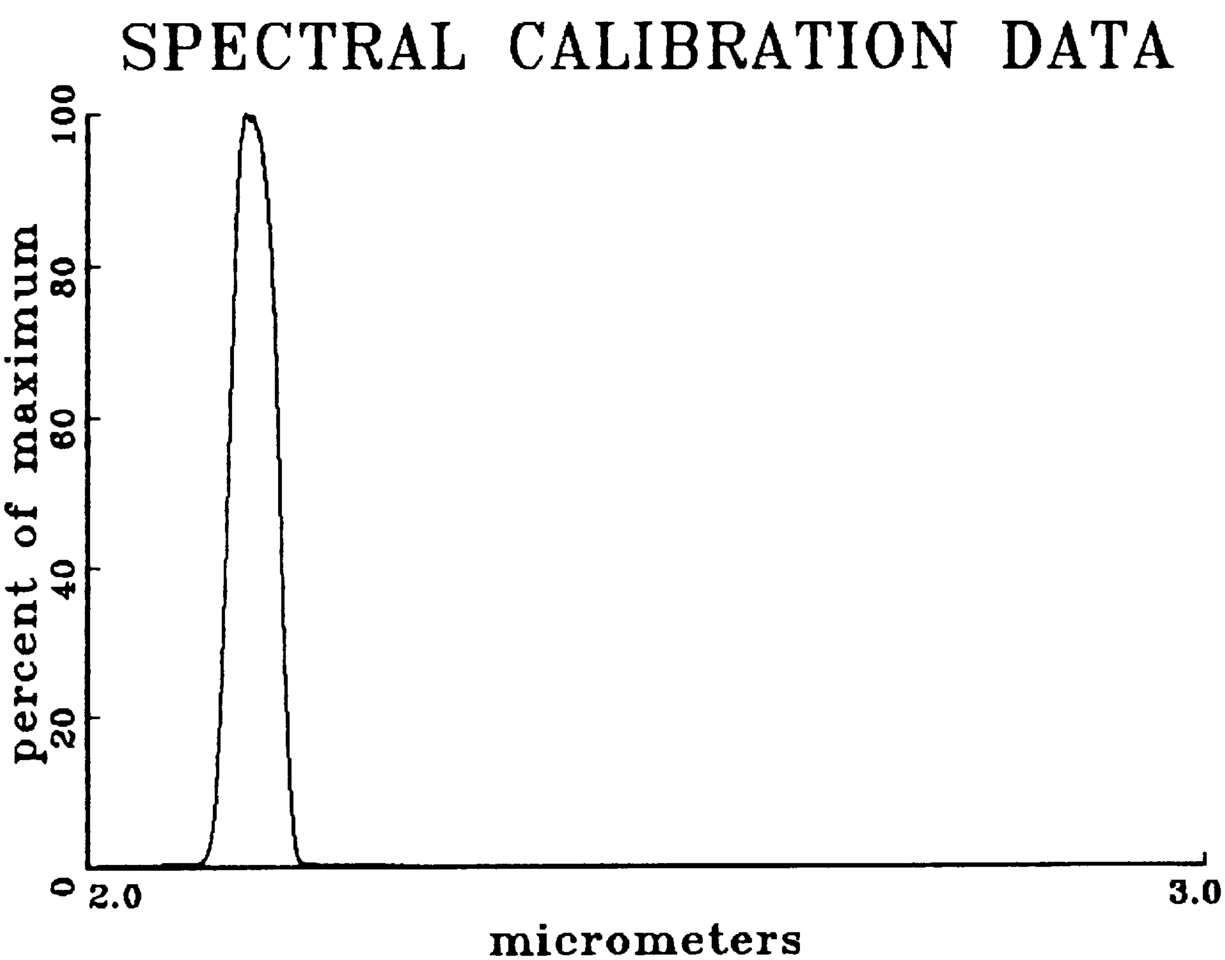
99% of the energy is between 1.568 and 1.681 nm

# SPECTRAL CALIBRATION DATA

File: Nab184.c20 Mon Apr 27 12:41:08 1992 

header 19

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 1 mm slits,1.8-3.0um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18402 |
| Monochromator Speed: | 200 |
| Monochromator Start Reading: | 20000 |
| Monochromator End Reading: | 23000 |
| Grating Identification: | 300 g/mm,3um blaze |
| Source Identification: | t.h. 142 V th 142v |
| Number of Readings: | 1491 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c20 |
| Normalization Data File | sept19.rf2 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 2.126 micrometers |
| UPPER HALF POWER POINT AT | 2.173 micrometers |
| PEAK POWER AT | 2.142 micrometers |

99% of the energy is between 2.110 and 2.203 nm

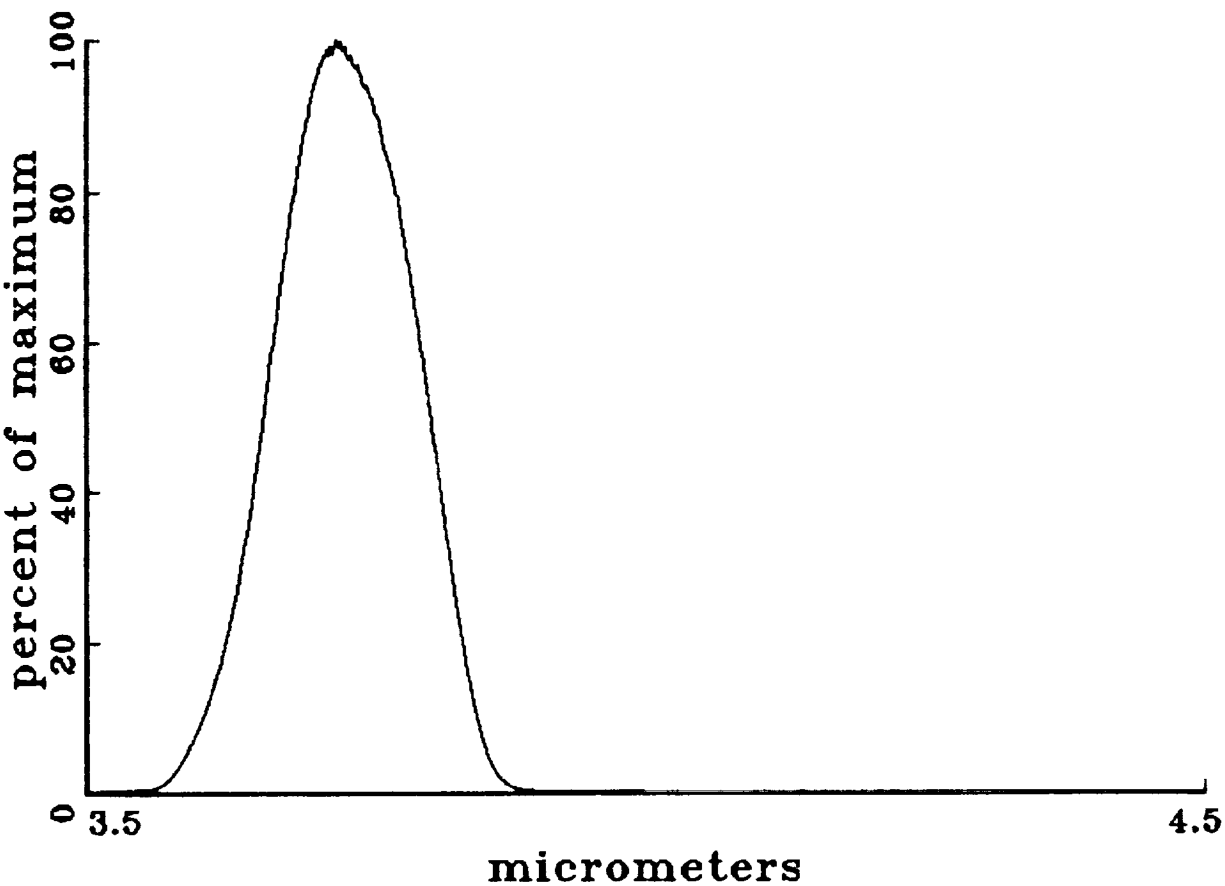
SPECTRAL CALIBRATION DATA

File: Nab184.c31 Fri Apr 24 14:17:40 1992 Page 1

heater 30

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits, 2.7-4.5um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18403 s/n 1 |
| Monochromator Speed: | 500 |
| Monochromator Start Reading: | 35000 |
| Monochromator End Reading: | 40000 |
| Grating Identification: | 150 g/mm, 6um blaze |
| Source Identification: | t.h. 145 V t.h. 145 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c31 |
| Normalization Data File | modisn.r31 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 3.659 micrometers |
| UPPER HALF POWER POINT AT | 3.810 micrometers |
| PEAK POWER AT | 3.725 micrometers |

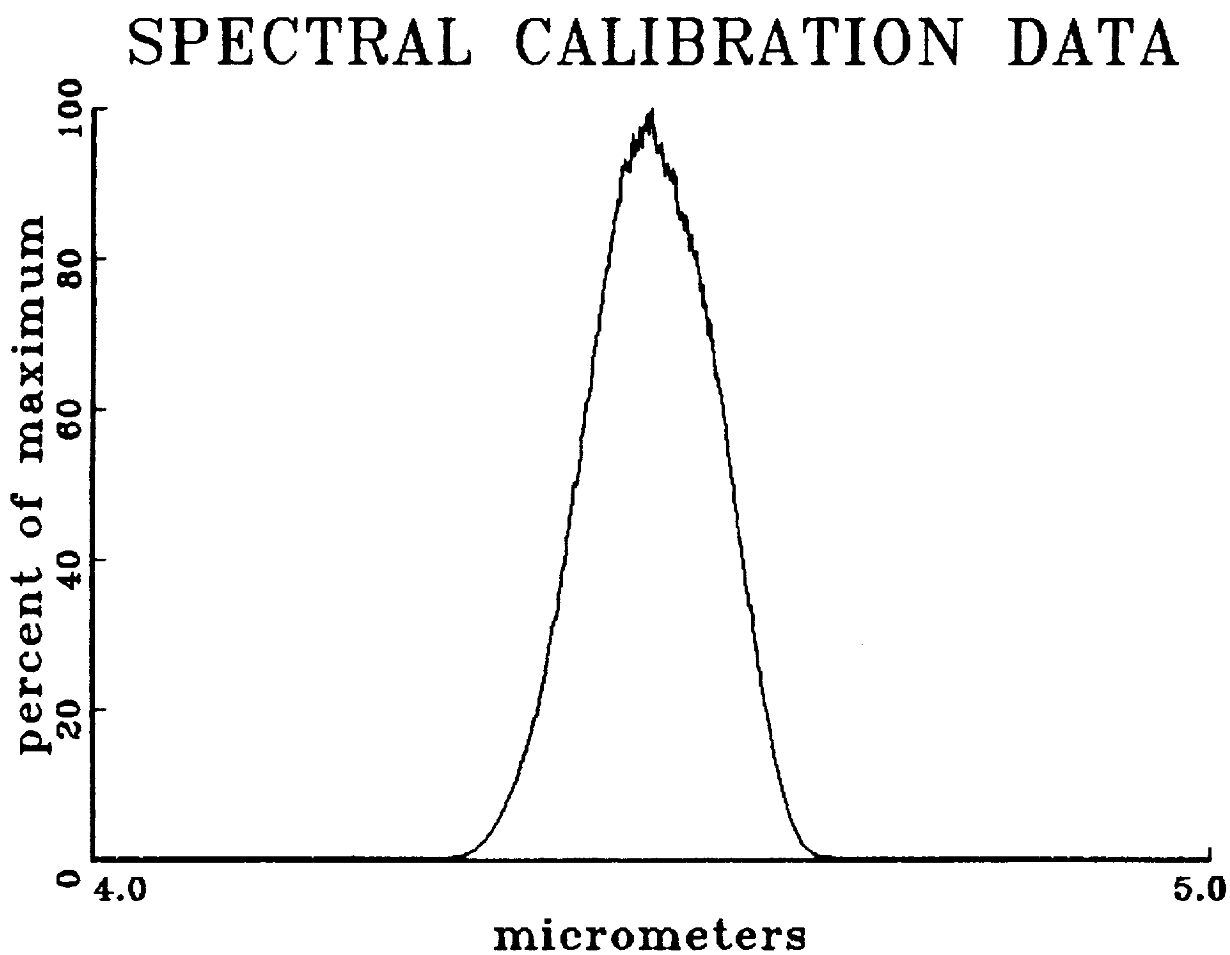
99% of the energy is between 3.593 and 3.896 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c36 Fri Apr 24 13:04:50 1992 Page 1

header 35

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits, 3.8-6.5um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18403 s/n 1 |
| Monochromator Speed: | 500 |
| Monochromator Start Reading: | 40000 |
| Monochromator End Reading: | 50000 |
| Grating Identification: | 150 g/mm, 6um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 1988 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c36 |
| Normalization Data File | modisn.r36 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 4.436 micrometers |
| UPPER HALF POWER POINT AT | 4.578 micrometers |
| PEAK POWER AT | 4.503 micrometers |

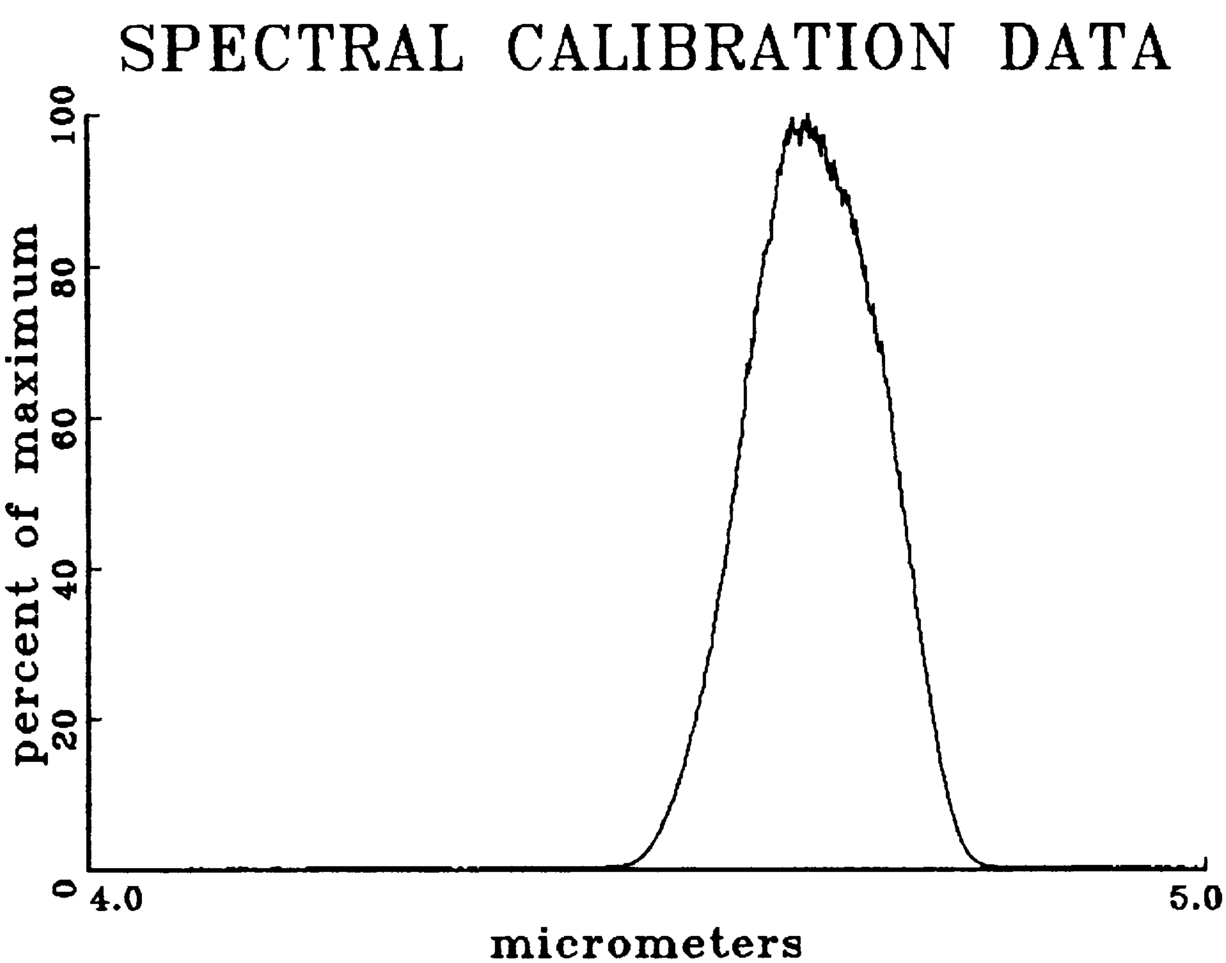
99% of the energy is between 4.368 and 4.653 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c37 Fri Apr 24 13:42:55 1992 

Leader 36

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits, 3.8-6.5um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | mt18403 s/n 1 |
| Monochromator Speed: | 500 |
| Monochromator Start Reading: | 40000 |
| Monochromator End Reading: | 50000 |
| Grating Identification: | 150 g/mm, 6um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 1988 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c37 |
| Normalization Data File | modisn.r36 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 4.582 micrometers |
| UPPER HALF POWER POINT AT | 4.732 micrometers |
| PEAK POWER AT | 4.651 micrometers |

99% of the energy is between 4.514 and 4.814 nm

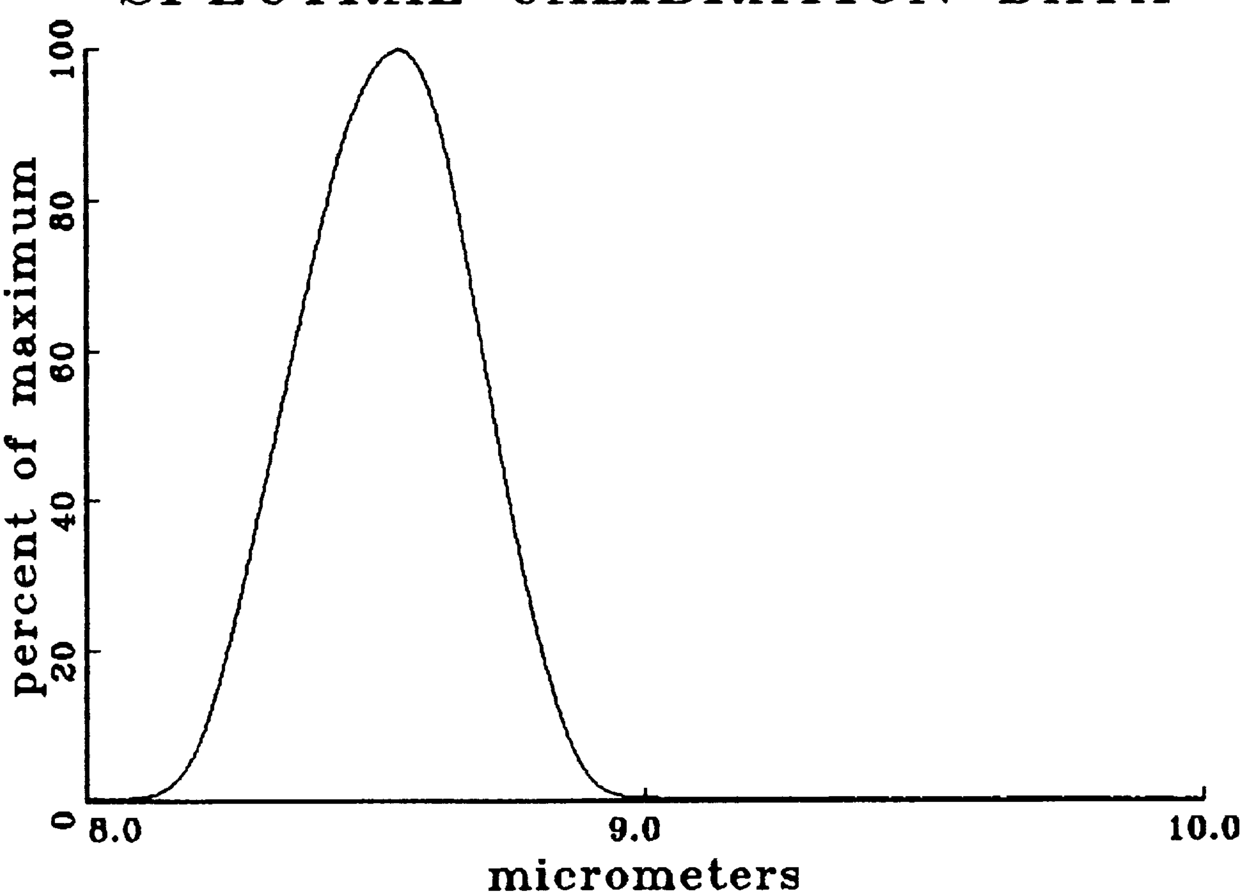
SPECTRAL CALIBRATION DATA

File: Nab184.c42 Mon May 11 08:04:05 1992 

Leader 42

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 80000 |
| Monochromator End Reading: | 100000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c42 |
| Normalization Data File | modisn.r42 |

# SPECTRAL CALIBRATION DATA




| | |
|---|---|
| LOWER HALF POWER POINT AT | 8.342 micrometers |
| UPPER HALF POWER POINT AT | 8.738 micrometers |
| PEAK POWER AT | 8.563 micrometers |

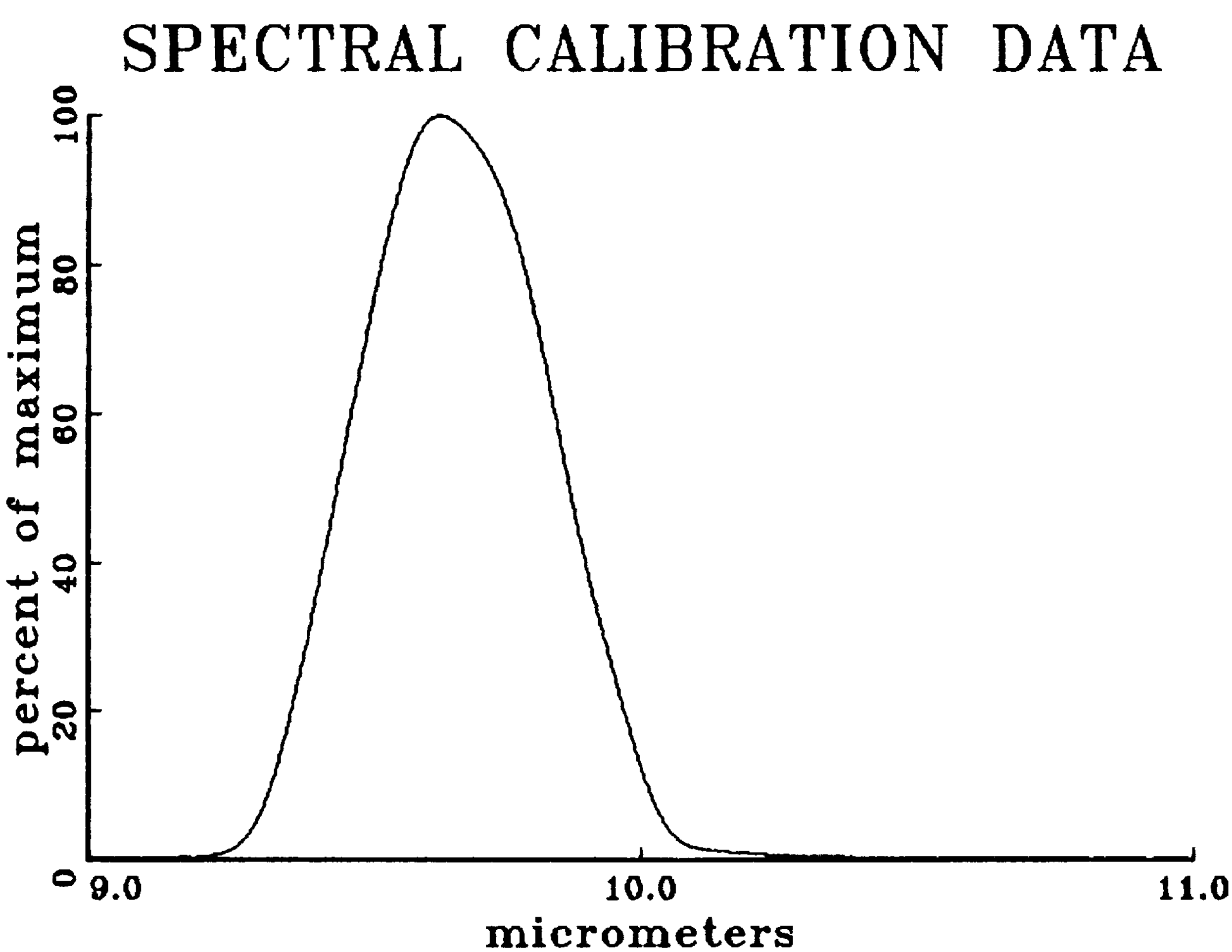
100% of the energy is between 8.121 and 8.914 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c43 Mon May 11 08:49:05 1992 Page 1

leader 43

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 90000 |
| Monochromator End Reading: | 110000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c43 |
| Normalization Data File | modisn.r43 |




LOWER HALF POWER POINT AT 9.451 micrometers
UPPER HALF POWER POINT AT 9.877 micrometers
PEAK POWER AT 9.642 micrometers

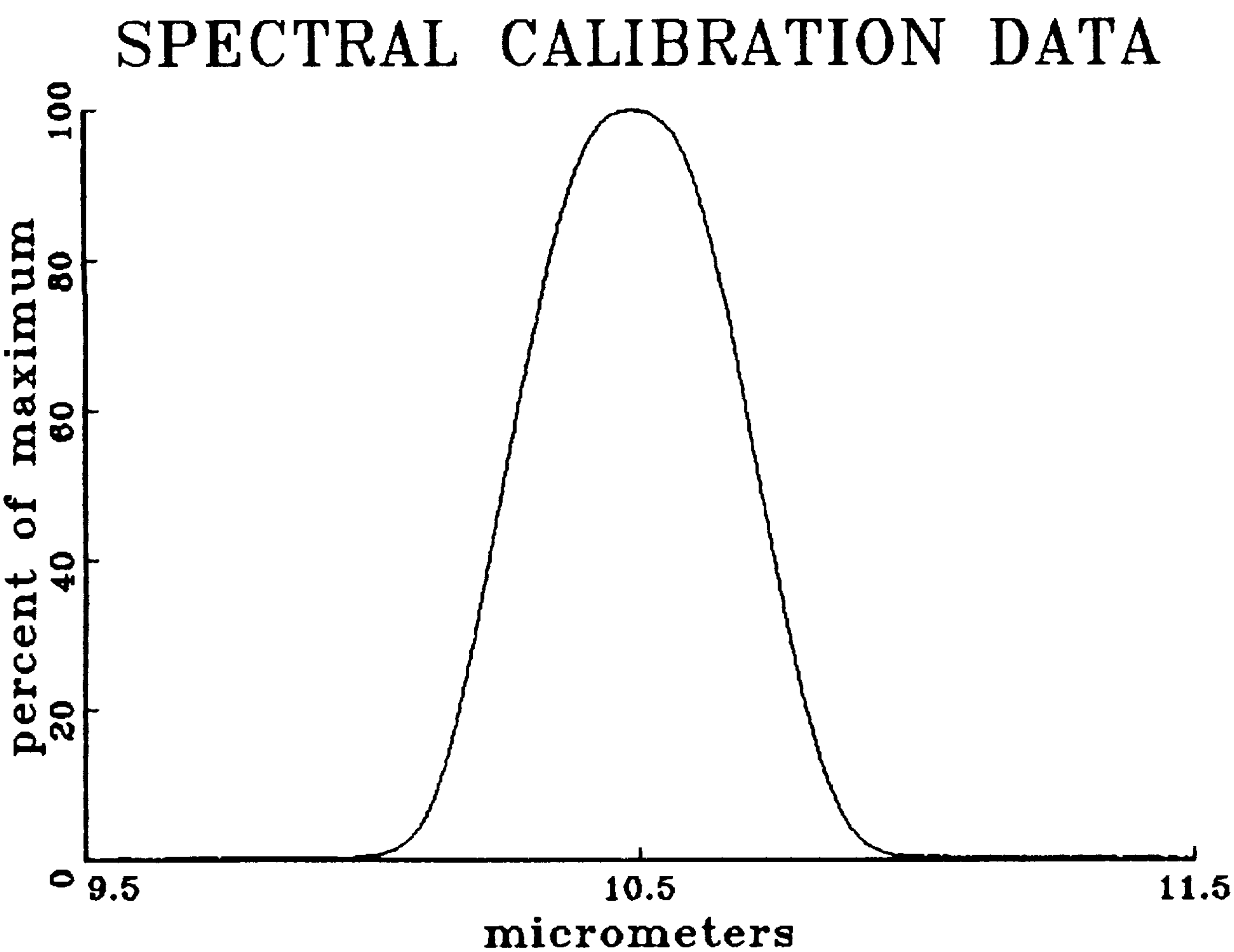
99% of the energy is between 9.260 and 10.113 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c44 Mon May 11 08:32:53 1992 

leader 44

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 95000 |
| Monochromator End Reading: | 115000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c44 |
| Normalization Data File | modisn.r44 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 10.259 micrometers |
| UPPER HALF POWER POINT AT | 10.725 micrometers |
| PEAK POWER AT | 10.498 micrometers |

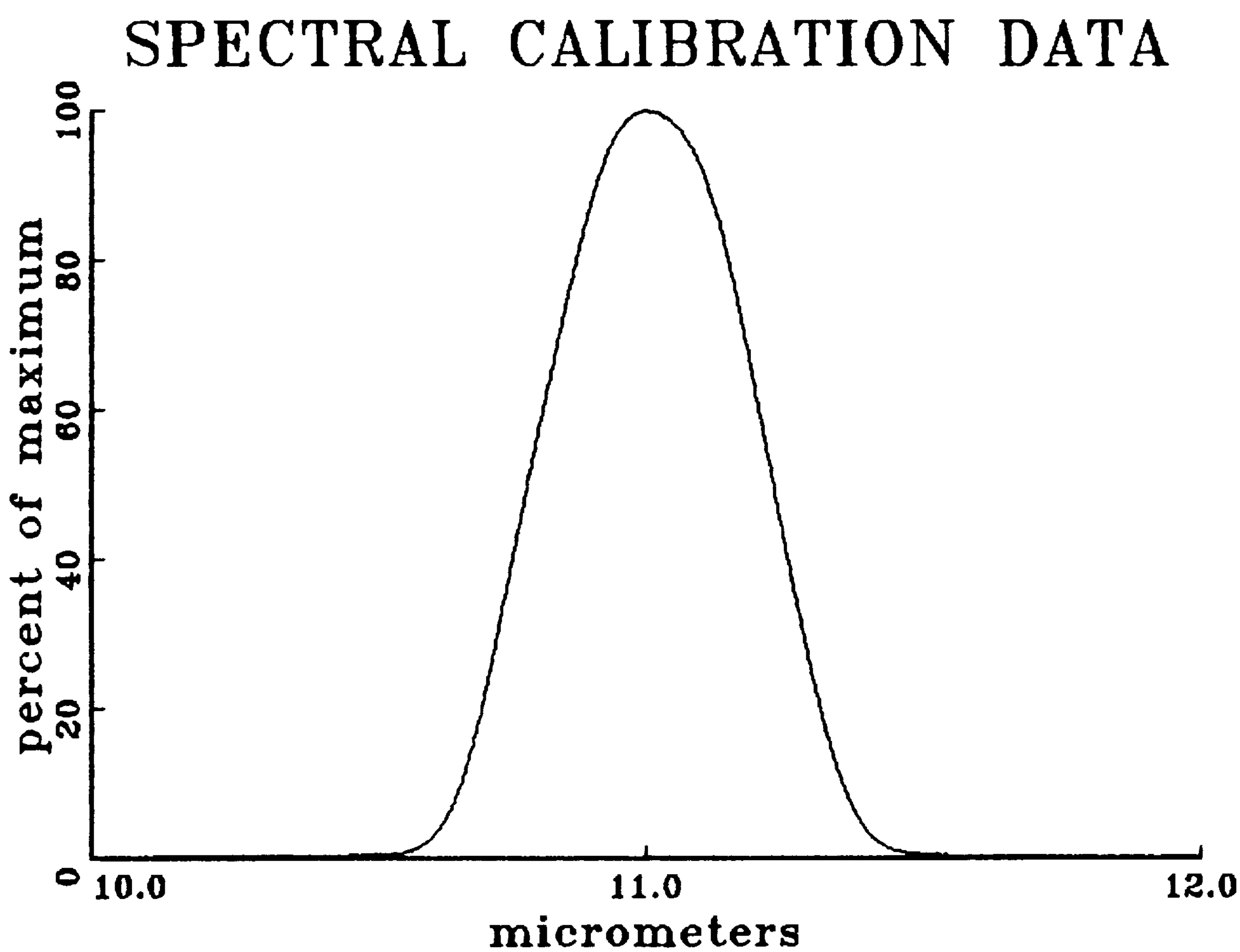
100% of the energy is between 10.019 and 10.953 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c45 Mon May 11 09:05:58 1992 Page 1

Leader 45

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 100000 |
| Monochromator End Reading: | 120000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c45 |
| Normalization Data File | modisn.r45 |




LOWER HALF POWER POINT AT 10.791 micrometers
UPPER HALF POWER POINT AT 11.239 micrometers
PEAK POWER AT 11.002 micrometers

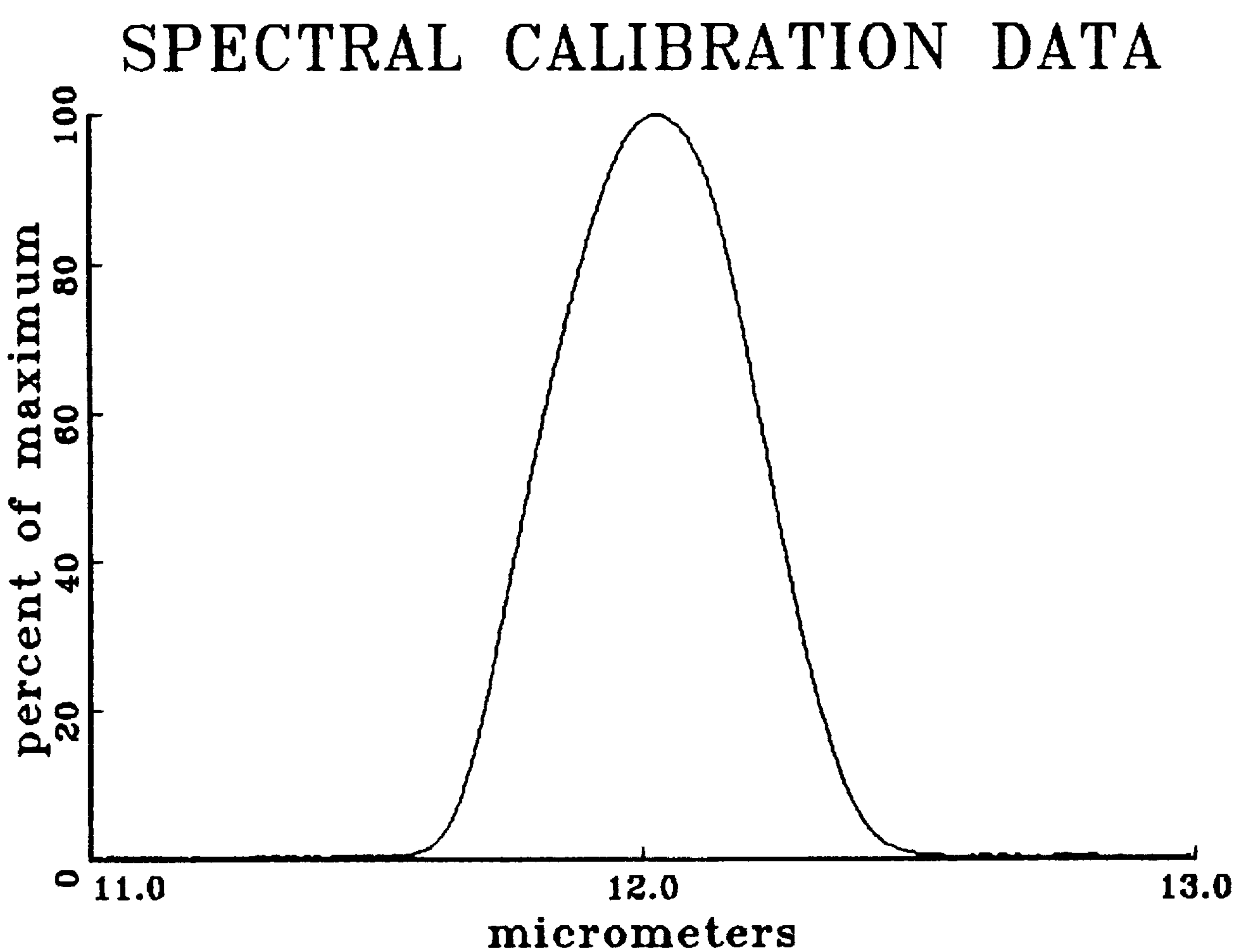
100% of the energy is between 10.580 and 11.477 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c46 Mon May 11 09:20:45 1992 

header 46

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 110000 |
| Monochromator End Reading: | 130000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c46 |
| Normalization Data File | modisn.r46 |



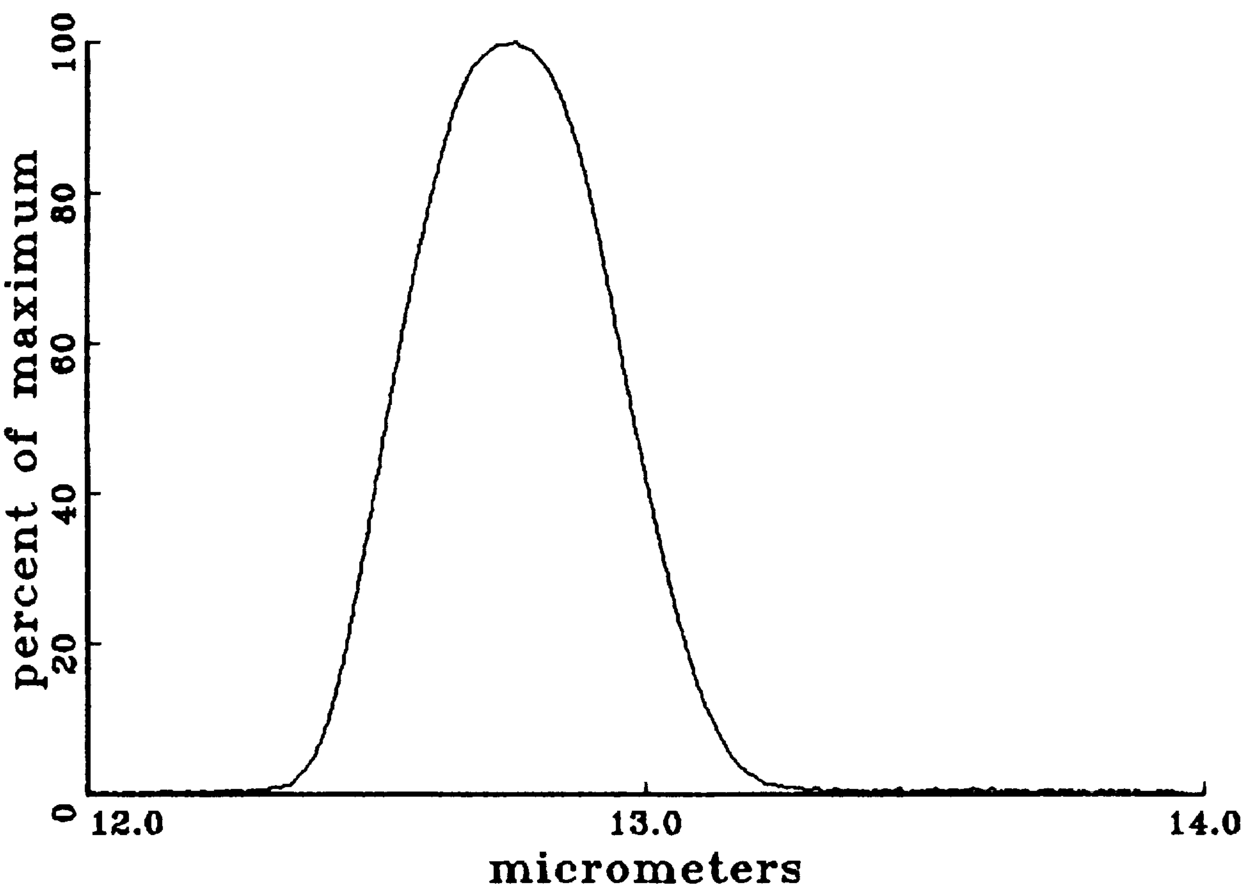

| | |
|---|---|
| LOWER HALF POWER POINT AT | 11.799 micrometers |
| UPPER HALF POWER POINT AT | 12.246 micrometers |
| PEAK POWER AT | 12.032 micrometers |

99% of the energy is between 11.565 and 12.459 nm

header 47

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 120000 |
| Monochromator End Reading: | 140000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c47 |
| Normalization Data File | modisn.r47 |

# SPECTRAL CALIBRATION DATA




LOWER HALF POWER POINT AT 12.539 micrometers
UPPER HALF POWER POINT AT 12.986 micrometers
PEAK POWER AT 12.775 micrometers

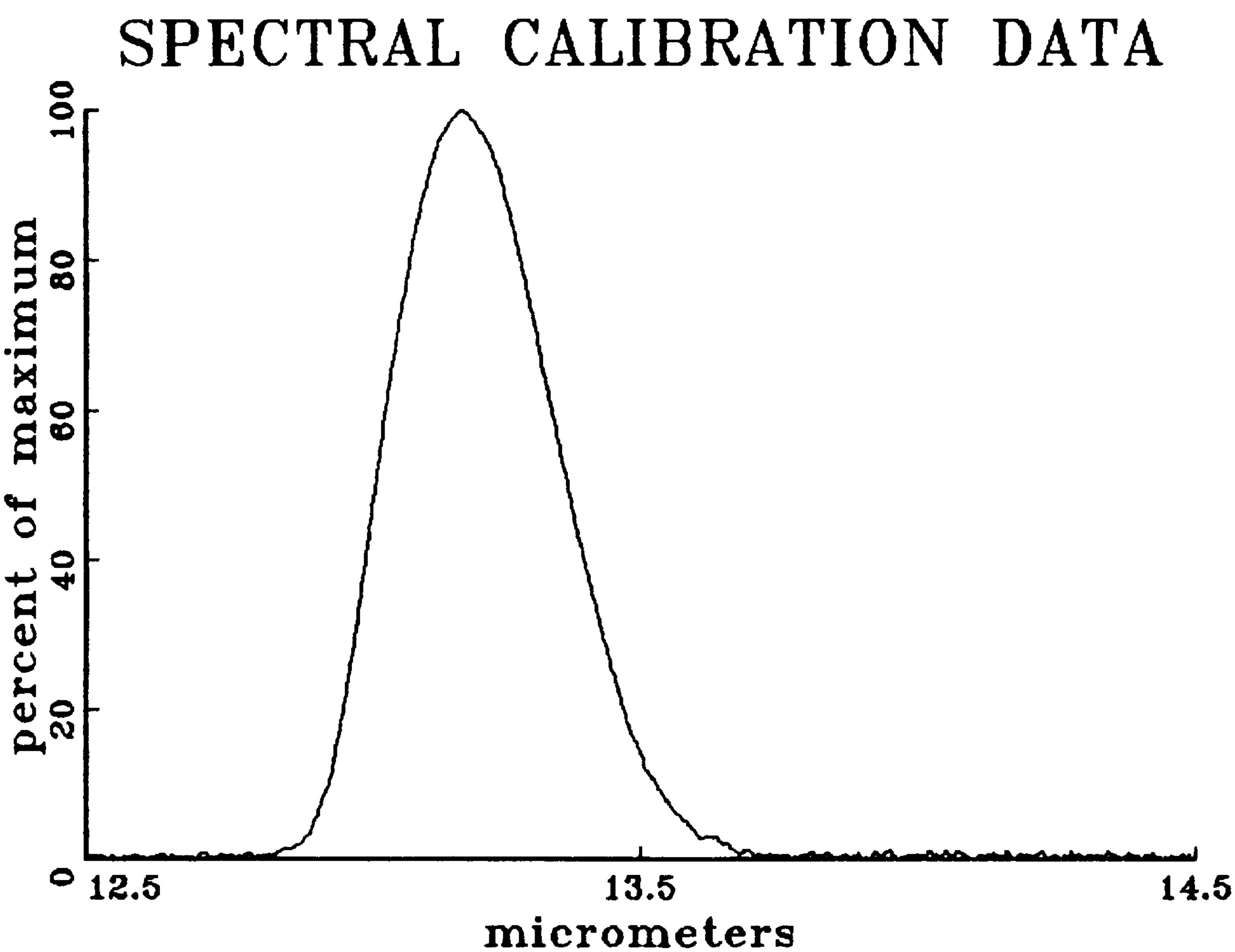
99% of the energy is between 12.304 and 13.197 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c48 Mon May 11 09:51:45 1992 

header 48

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 125000 |
| Monochromator End Reading: | 145000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c48 |
| Normalization Data File | modisn.r48 |




LOWER HALF POWER POINT AT 13.023 micrometers
UPPER HALF POWER POINT AT 13.375 micrometers
PEAK POWER AT 13.186 micrometers

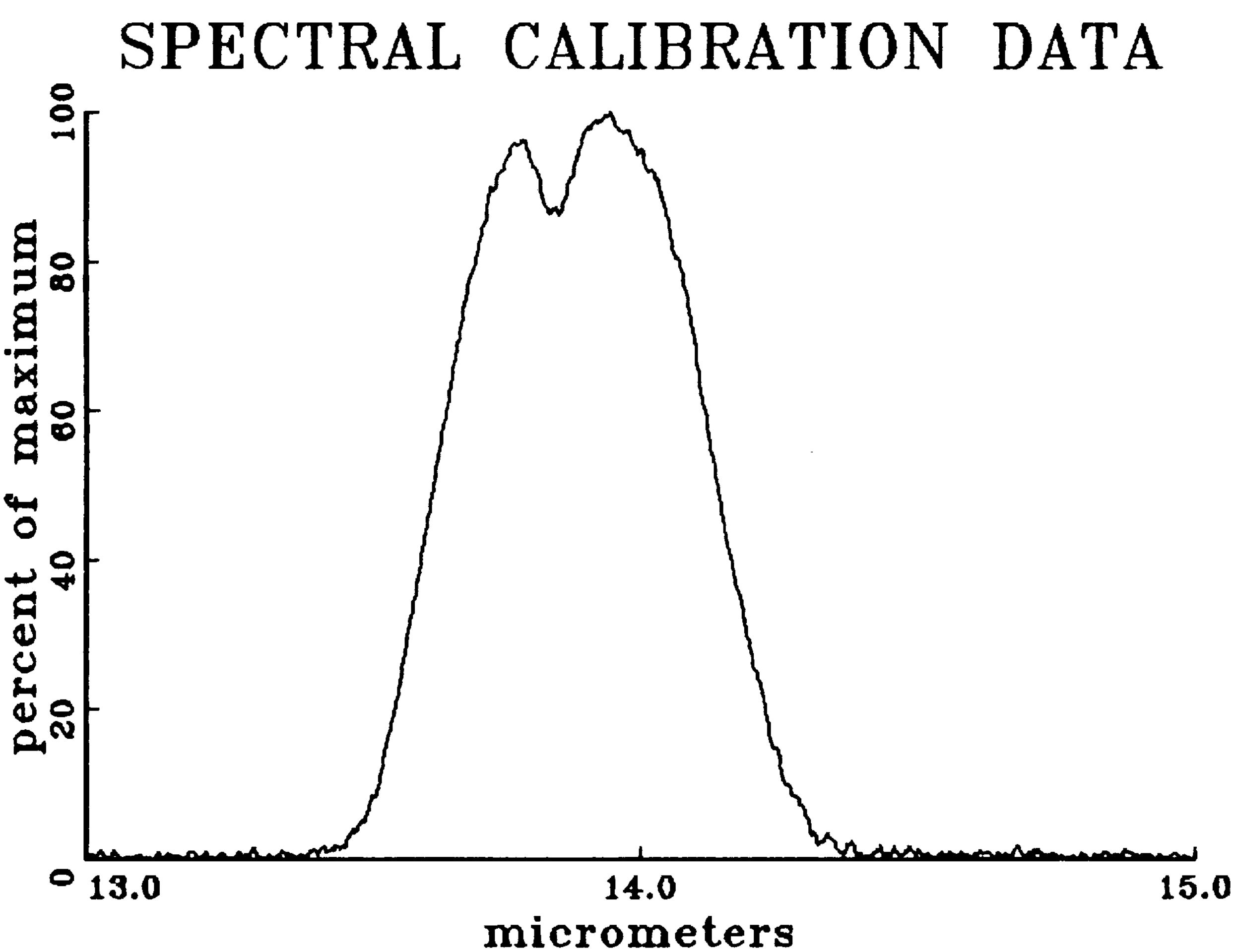
98% of the energy is between 12.860 and 13.564 nm

# SPECTRAL CALIBRATION DATA

File: Nab184.c49 Mon May 11 10:06:04 1992 

heater 49

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits,9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 130000 |
| Monochromator End Reading: | 150000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c49 |
| Normalization Data File | modisn.r49 |




| | |
|---|---|
| LOWER HALF POWER POINT AT | 13.630 micrometers |
| UPPER HALF POWER POINT AT | 14.147 micrometers |
| PEAK POWER AT | 13.952 micrometers |

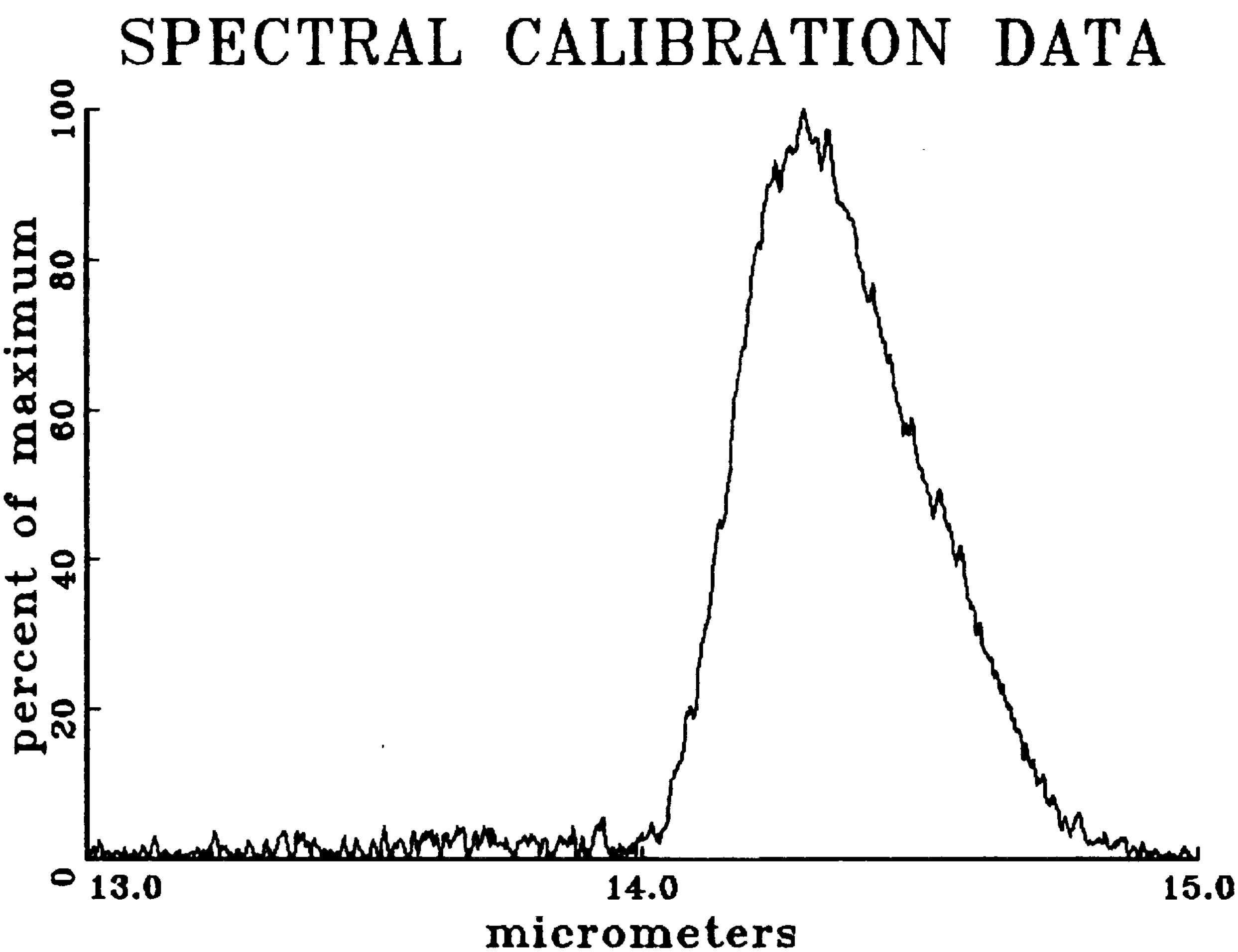
99% of the energy is between 13.308 and 14.342 nm

SPECTRAL CALIBRATION DATA

File: Nab184.c50 Mon May 11 10:23:23 1992 Page 1

header 50

| | |
|---|---|
| Operator Name: | sdc |
| Operator Comment(s): | 2mm slits, 9-15um filter |
| Operator Comment(s): | 1 sec. pre & 1 sec. post tc |
| Spectrometer Identification: | modisn |
| Detector(s) Identification: | ac18424 s/n 1 |
| Monochromator Speed: | 2000 |
| Monochromator Start Reading: | 130000 |
| Monochromator End Reading: | 150000 |
| Grating Identification: | 75 g/mm, 12um blaze |
| Source Identification: | glow bar 160 V glow bar 160 V |
| Number of Readings: | 995 |
| File Code: | 4 [4AUG86] |
| Raw Data File | ab184.c50 |
| Normalization Data File | modisn.r49 |




LOWER HALF POWER POINT AT 14.163 micrometers
UPPER HALF POWER POINT AT 14.521 micrometers
PEAK POWER AT 14.302 micrometers

95% of the energy is between 14.024 and 14.740 nm

NASA
National Aeronautics and Space Administration

# Report Documentation Page

| 1. Report No. | 2. Government Accession No. | 3. Recipient's Catalog No. |
|---|---|---|
| | | |

**4. Title and Subtitle**

FINAL REPORT MODIS-N AIRBORNE SIMUALTOR

**5. Report Date**

5-22-92

**6. Performing Organization Code**

**7. Author(s)**

STEVEN D. CECH

**8. Performing Organization Report No.**

**9. Performing Organization Name and Address**

DAEDALUS ENTERPRISES, INC.
P.O. BOX 1869
ANN ARBOR MI 48106

**10. Work Unit No.**

**11. Contract or Grant No.**

NAS5-31334

**12. Sponsoring Agency Name and Address**

NASA GODDARD SPACE FLIGHT CENTER
GREENBELT RD
GREENBELT MD 20771

**13. Type of Report and Period Covered**

FINAL
4-1-92 TO 5-1-92

**14. Sponsoring Agency Code**

**15. Supplementary Notes**

**16. Abstract**

THE MODIS-N AIRBORNE SIMULATOR HAS BEEN DEVELOPED FROM EXISTING AB184 WILDFIRE SPECTROMETER PARTS AS WELL AS NEW DETECTOR ARRAYS, OPTICAL COMPONENTS, AND ASSOCIATED MECHANICAL AND ELECTRIC HARDWARE. THE VARIOUS INSTRUMENT COMPONENTS HAVE BEEN INTEGRATED INTO AN OPERATIONAL SYSTEM WHICH HAS UNDERGONE EXTENSIVE LABORATORY CALIBRATION AND TESTING. THE INSTRUMENT HAS BEEN DELIVERED TO NASA AMES WHERE IT WILL BE INSTALLED ON THE NASA ER-2.

| 17. Key Words (Suggested by Author(s)) | 18. Distribution Statement |
|---|---|
| MODIS, SPECTROMETER, DETECTOR, ARRAYS | |

| 19. Security Classif. (of this report) | 20. Security Classif. (of this page) | 21. No. of pages | 22. Price |
|---|---|---|---|
| UNCLASSIFIED | UNCLASSIFIED | 35 | |

NASA FORM 1626 OCT 86