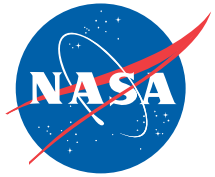


VG08-051

Transmission and Distribution of Photosynthetically Active Radiation (PAR) from Solar and Electric Light Sources for Crop Production

Takashi Nakamura, David C. Rossi and Benjamin K. Smith
Physical Sciences Inc.

Neil C. Yorio and Alan E. Drysdale
Dynamac Corporation

Raymond M Wheeler and John C Sager
NASA Kennedy Space Center

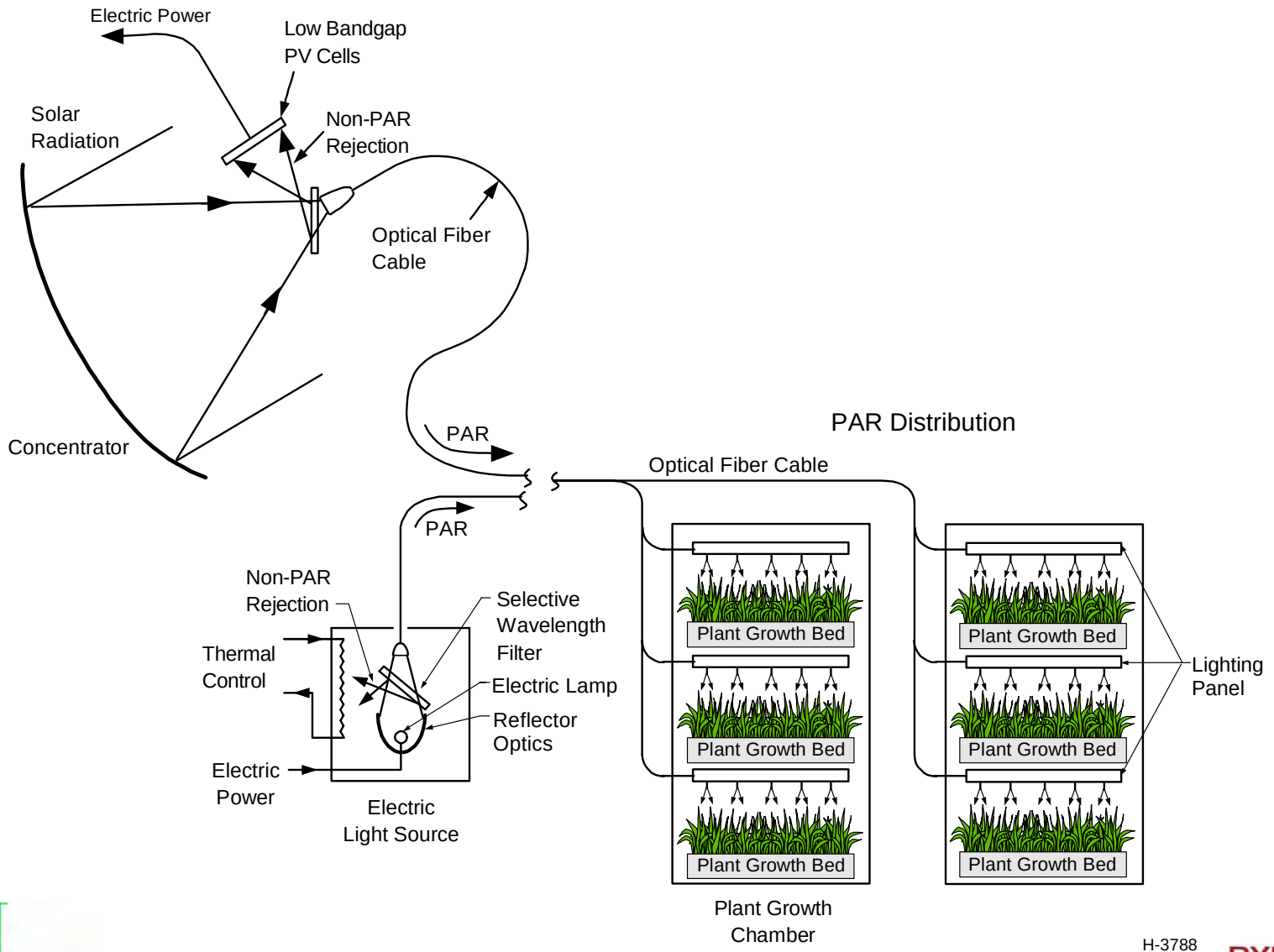
Presented at

2008 International Meeting on Controlled Environment Agriculture

March 2008

Schematic Representation of the Optical Waveguide System for Transmission and Distribution of PAR for Plant Lighting

VG08-051-1



H-3788

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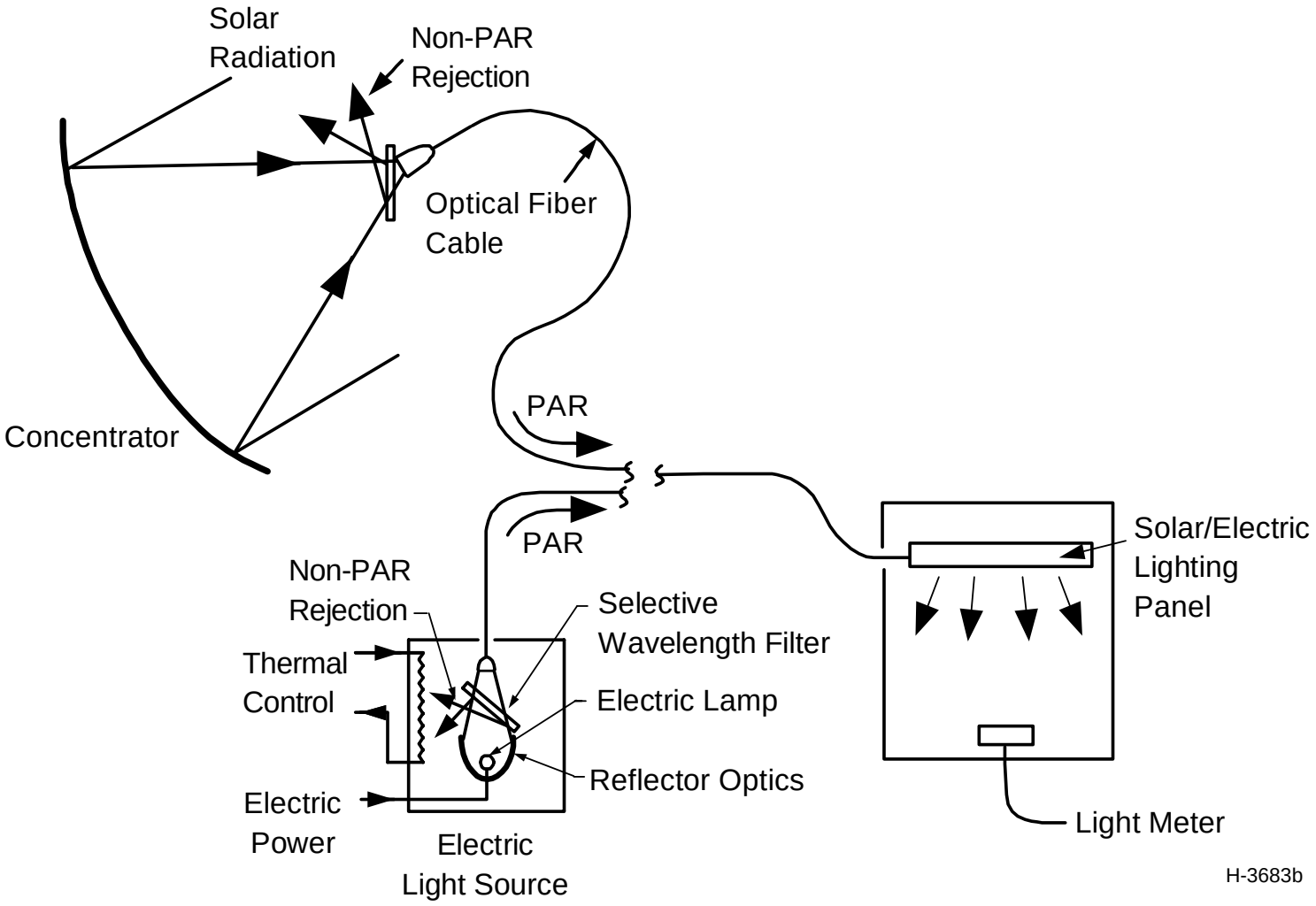
Background

- **Notion of dielectric lightguide for transport of concentrated solar radiation in 1965 (Baranov)**
  - Optiko-Mekhanicheskaya Promyshlennost, No. 6, 1965
- **First quantitative theoretical study of the application of optical fibers to solar energy transmission in 1976 (Kato and Nakamura)**
  - J. Appl. Physics, vol. 47, No. 10, 1976
- **Theoretical and experimental work on optical fiber for transmission of solar energy during 1981-1985 (University of Toulouse: Cariou et al.)**
  - Solar energy, Vol. 29, 1982
  - Solar energy, Vol. 34, 1985
- **Theoretical and experimental work on optical waveguide system for space power during 1991-1993 (Nakamura and Irvin)**
  - Air Force PL-TR-92-3006, 1993
- **Development of optical waveguide system for material processing, plant lighting and propulsion from 1994 to present**
  - NASA, AF

Laboratory Model of the Proposed System Tested In Phase I

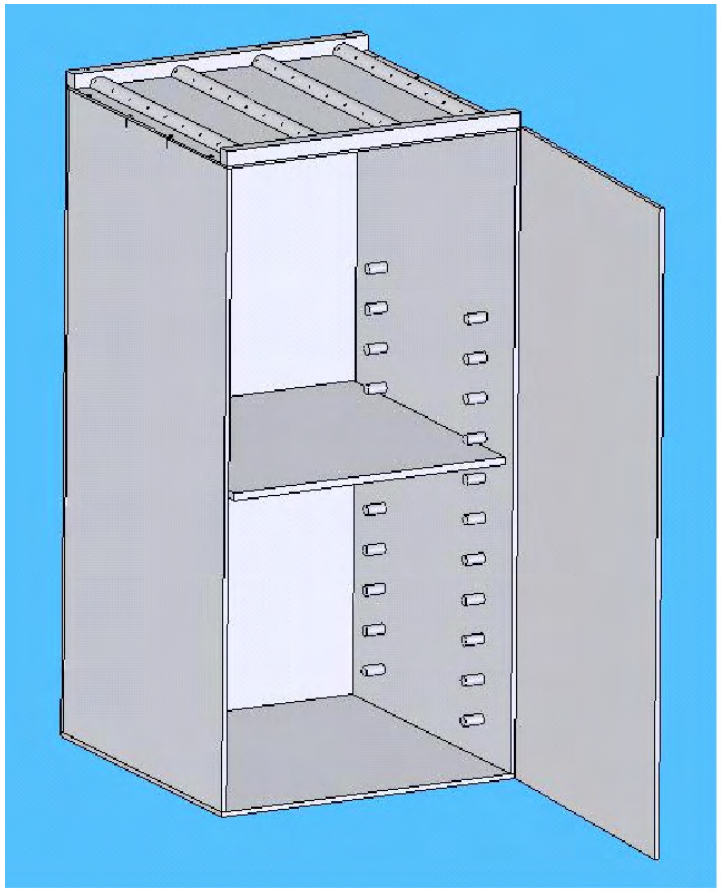
VG08-051-3



H-3683b

Plant Lighting Chamber

VG08-051-4



H-8963

16 x 16 x 32 inch

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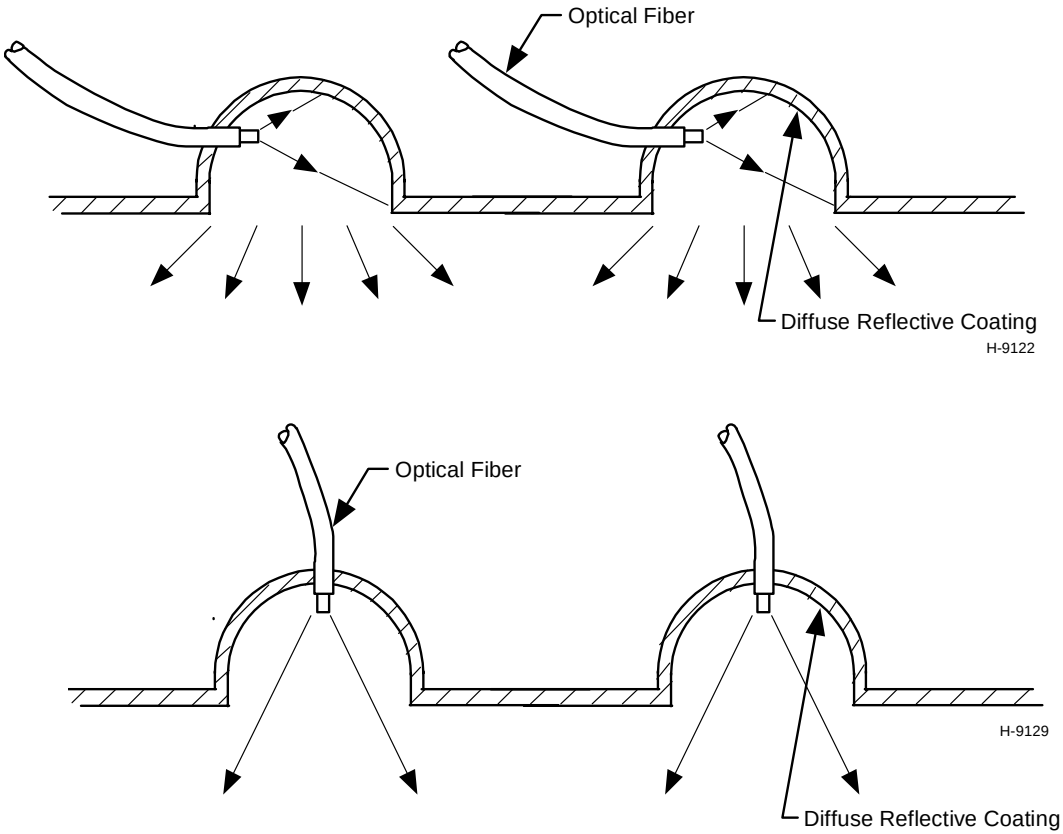
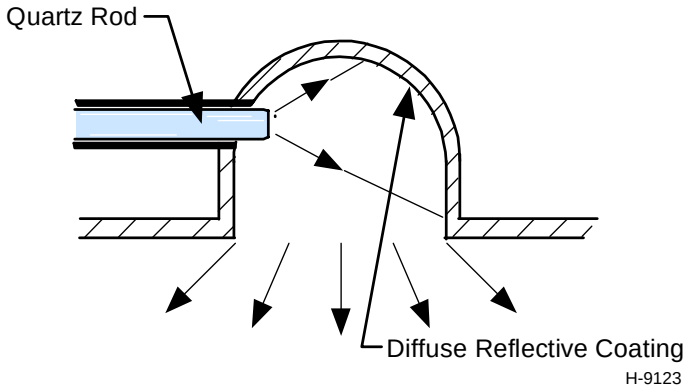
Waveguide Illuminator Integration

VG08-051-5



Flat Panel Illuminator



Single “Domed” Reflector

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Lab Model with Solar Concentrator

VG08-051-6

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Lab Model with Xe Arc Light Source

VG08-051-7

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Optical Fiber – Illuminator Panel Integration

VG08-051-8

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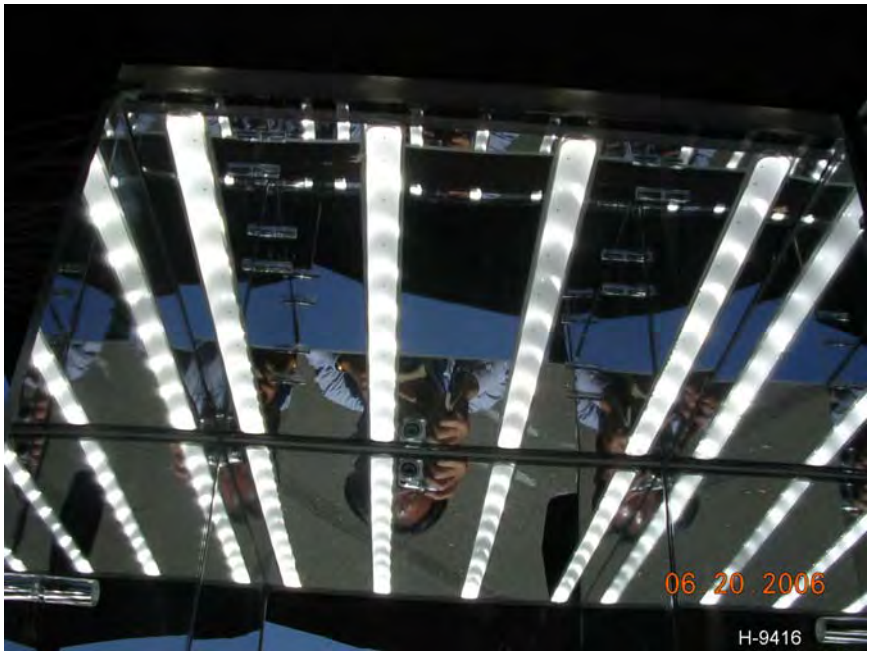
Illuminator Panels

VG08-051-9



Multiple Trough Illuminator

Single Dome-shaped Illuminator

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Instruments for Measurement

VG08-051-10

Power Measurement	Coherent FIELD MAX II Thermopile Power Meter
	Coherent 210 Power Meter
	Newport 818-150 High Power Detector
Spectral Measurement	LI-COR LI-1800 Spectroradiometer
PPF Measurement	LI-COR LI-250 Light Meter/Quantum Sensor

PPF Measurement

Spectra Measurement

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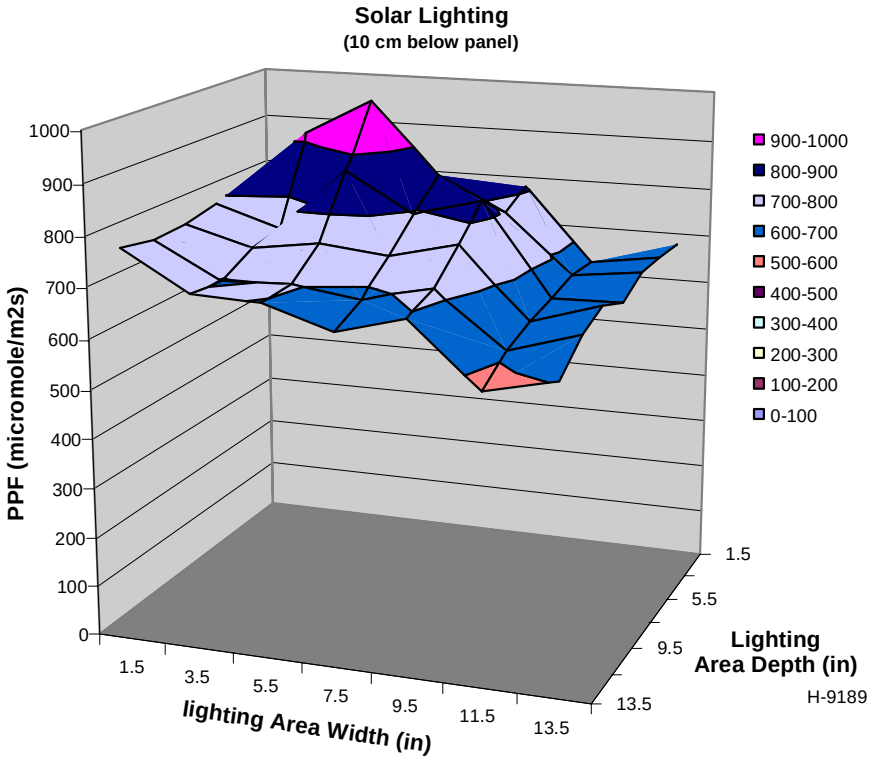
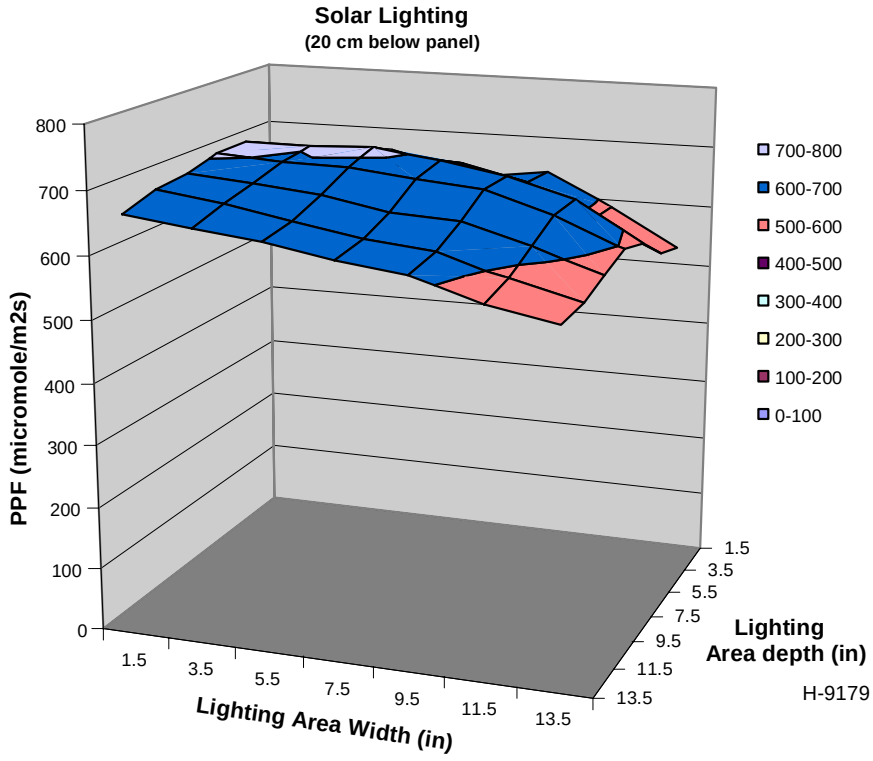
PPF Measurement (Solar): Trough Indirect

VG08-051-11





10 cm from Panel

20 cm from Panel

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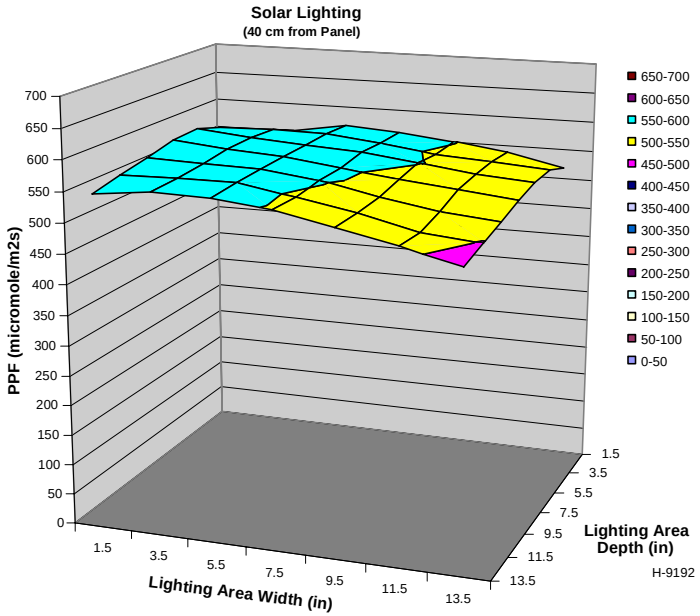
PPF Measurement (Solar): Trough Indirect

VG08-051-12



40 cm from Panel

Data Set	Distance from the Illuminator panel	Average PPF (μmol m^{-2} s^{-1})	Standard Deviation (μmol m^{-2} s^{-1})	Total PAR Flux in the Plane (μmol s^{-1})	PAR input to the lighting Chamber (μmol s^{-1})	Lighting Efficiency (%)
Solar lighting	10 cm	727	86	105	124	84.7
Solar lighting	20 cm	641	46	93	124	75.0
Solar lighting	40 cm	547	22	79	124	63.7

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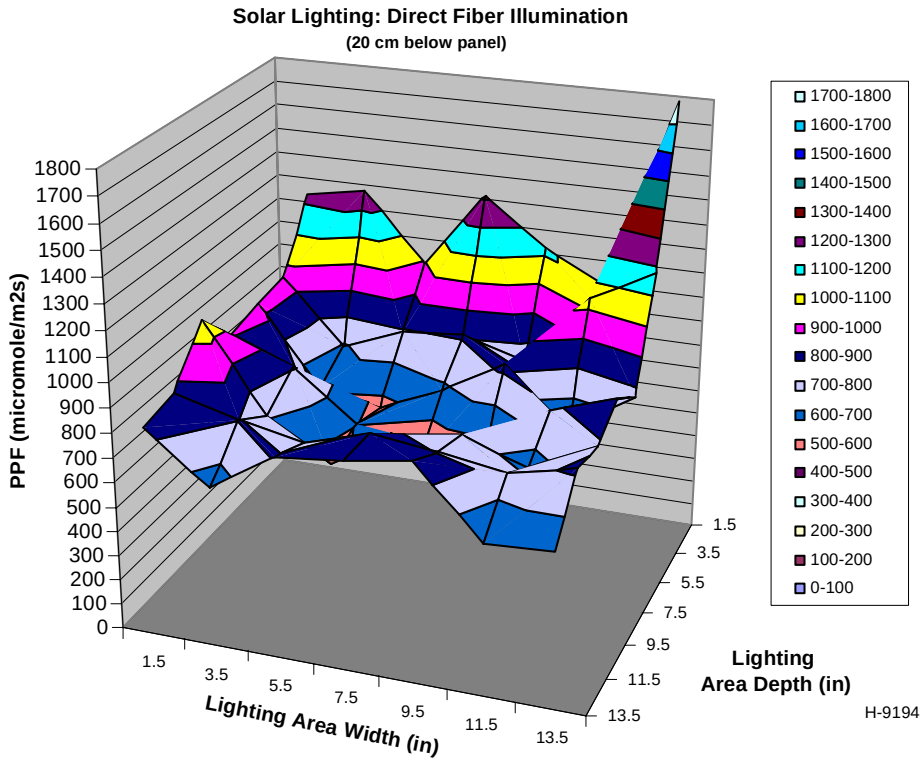
PPF Measurement (Solar): Trough Direct

VG08-051-13



Designation	Distance from the illuminator panel	Average PPF (μmol m^{-2} s^{-1})	Standard Deviation (μmol m^{-2} s^{-1})	Total PAR Flux in the plane (μmol s^{-1})	PAR input to the lighting chamber (μmol s^{-1})	Lighting Efficiency (%)
Direct fiber Illumination	20 cm	836	236	121	124	97.6

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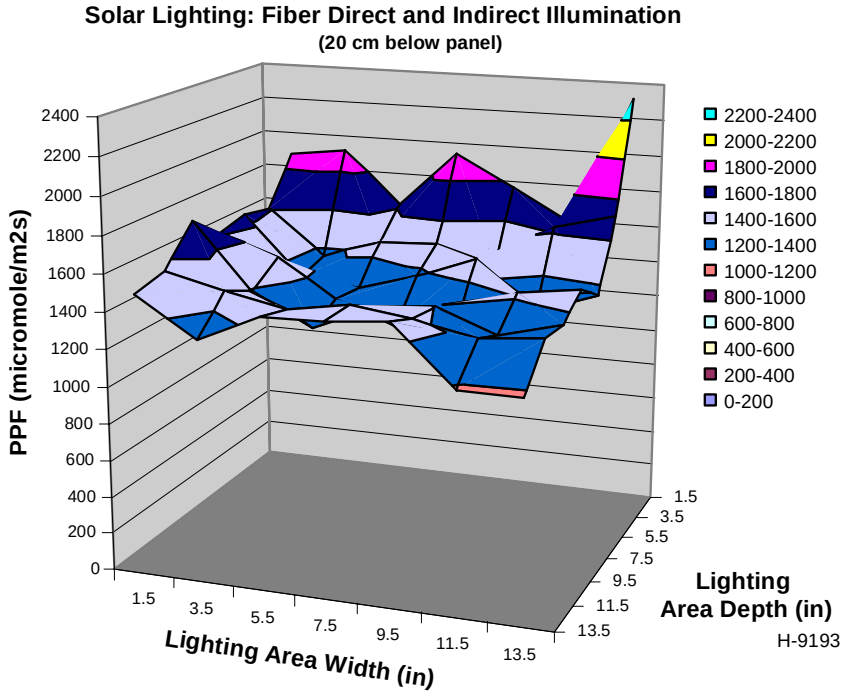
PPF Measurement (Solar): Trough Direct and Indirect

VG08-051-14



Designation	Distance from the illuminator panel	Average PPF (μmol m^{-2} s^{-1})	Standard Deviation (μmol m^{-2} s^{-1})	Total PAR Flux in the Plane (μmol s^{-1})	PAR input to the Lighting chamber (μmol s^{-1})	Lighting Efficiency (%)
Direct and indirect illumination	20 cm	1478	221	214	248	86.3

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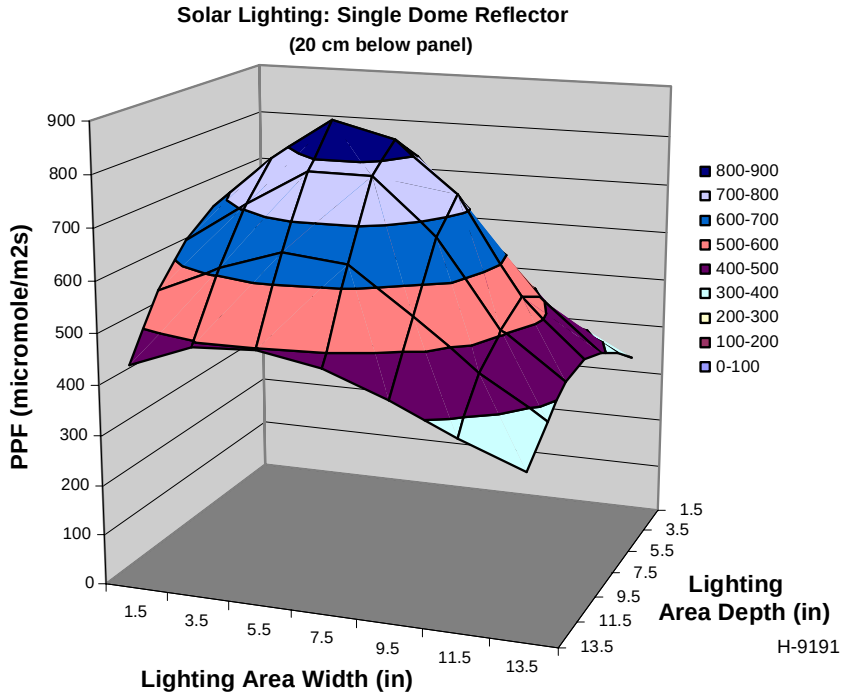
PPF Measurement (Solar): Single Dome Reflector

VG08-051-15



Designation	Distance from the illuminator panel	Average PPF (μmol m^{-2} s^{-1})	Standard Deviation (μmol m^{-2} s^{-1})	Total PAR Flux in the Plane (μmol s^{-1})	PAR input to the Lighting chamber (μmol s^{-1})	Lighting Efficiency (%)
Single Illuminator Lighting	20 cm	563	144	81.7	124	65.9

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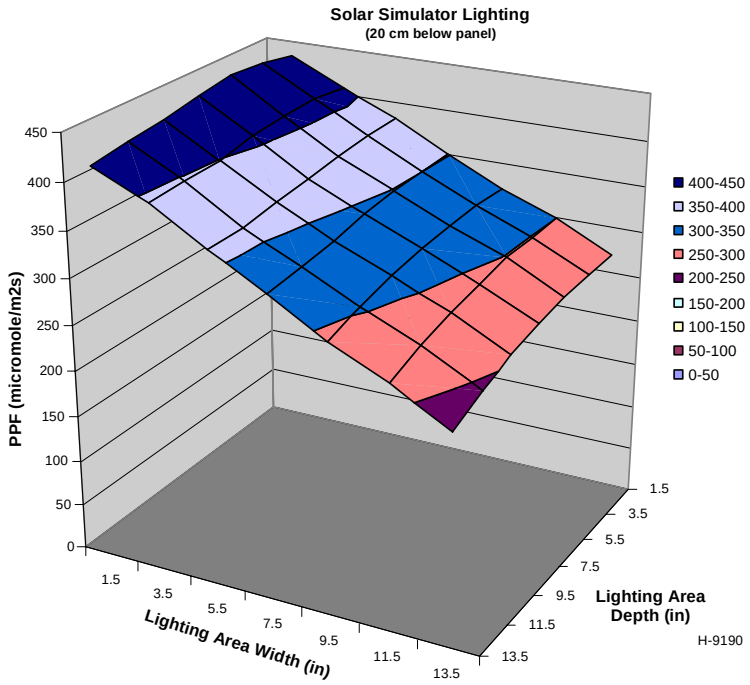
PPF Measurement (Xe Arc Lamp): Through Indirect

VG08-051-16



Designation	Distance from the Illuminator panel	Average PPF (μmol m^{-2} s^{-1})	Standard Deviation (μmol m^{-2} s^{-1})	Total PAR in the Plane (μmol s^{-1})	PAR input to the Lighting chamber (μmol s^{-1})	Lighting Efficiency (%) [note]
Xe arc lamp lighting	20 cm	344	60	50	69.3	72.1

Note: PPF input to the lighting chamber was calculated from the Xe arc lamp output from the optical fiber cable and the spectral radiometer data.

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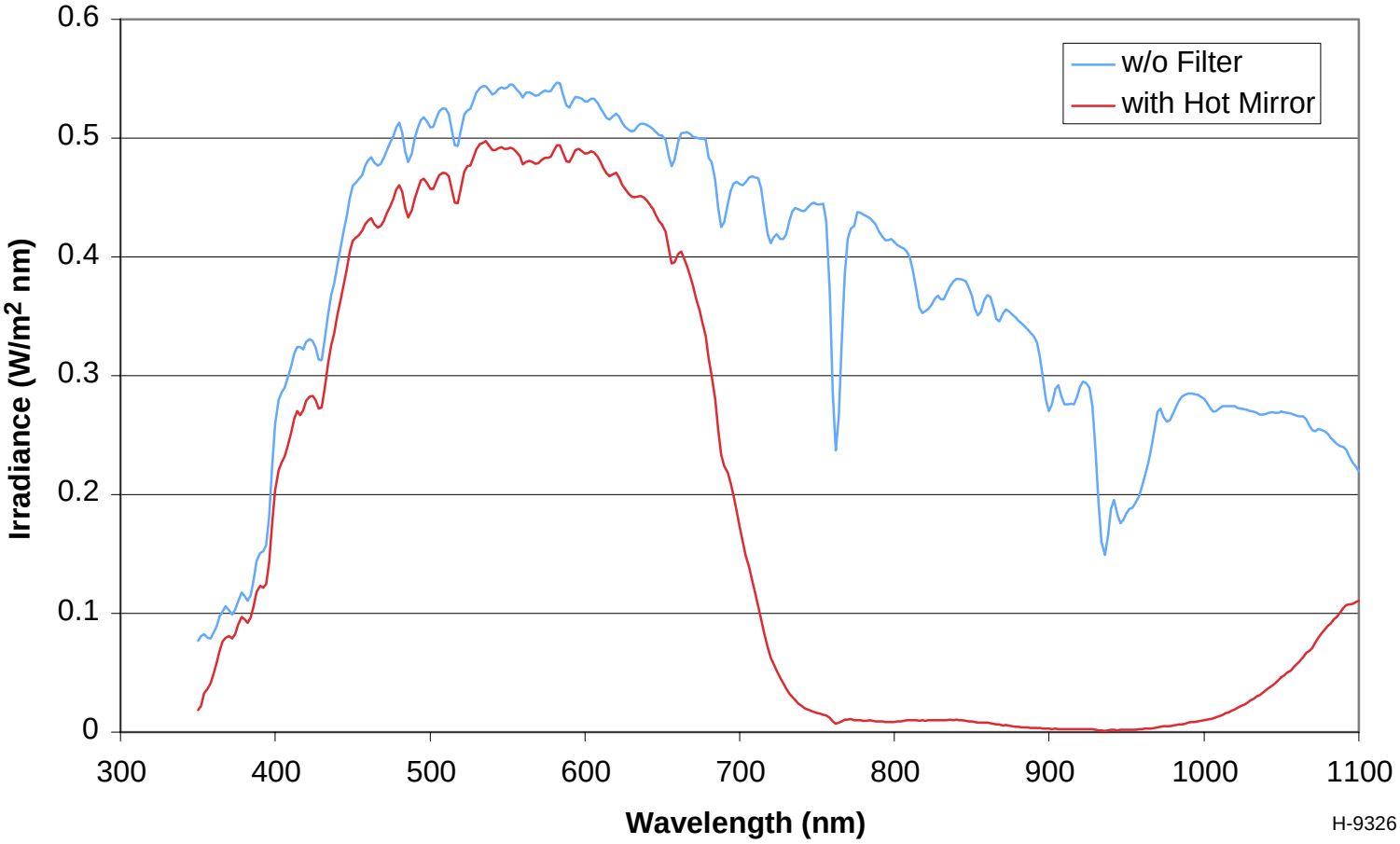
Spectra Measurement: Solar

VG08-051-17



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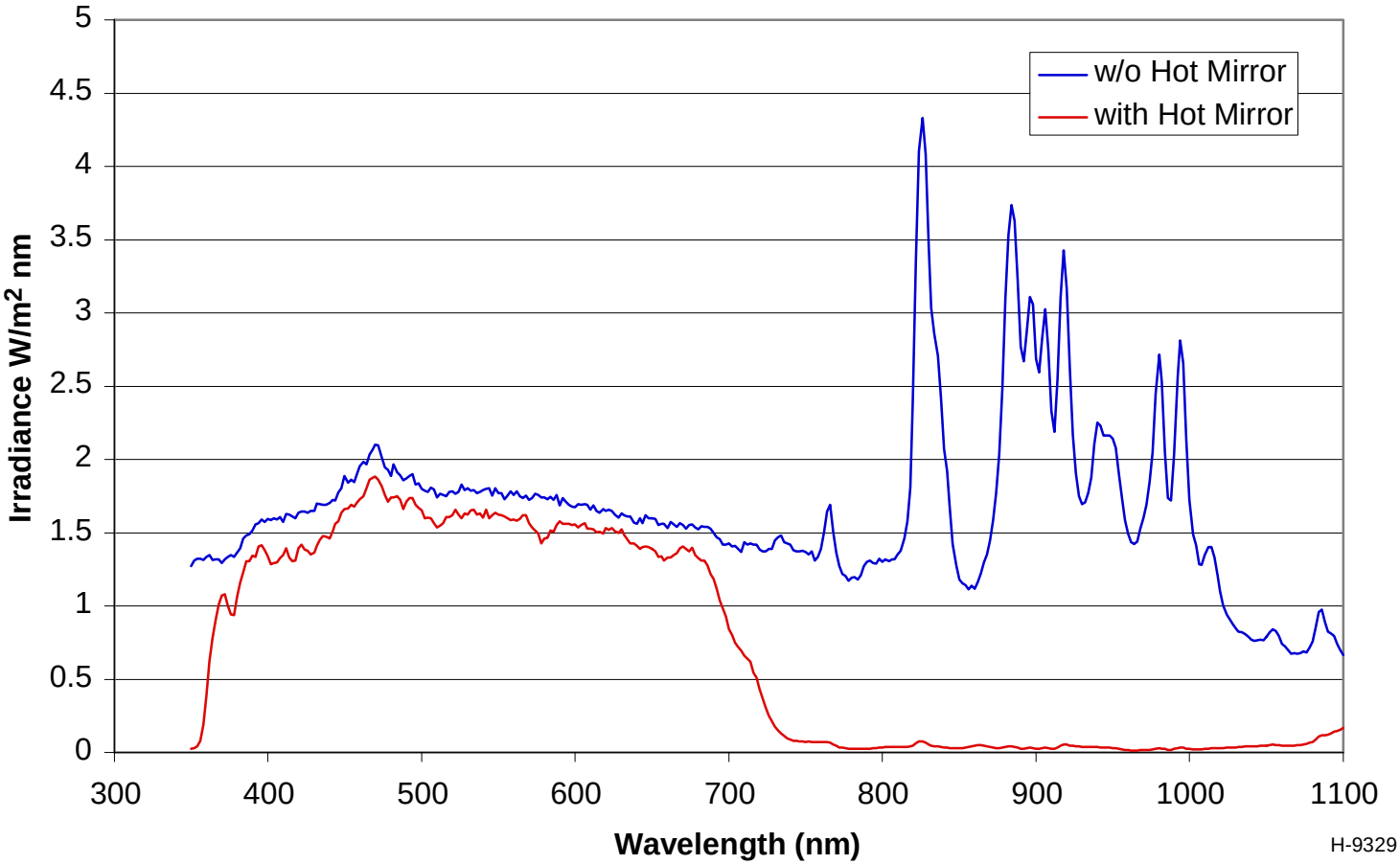
Spectra Measurement: Xe Arc

VG08-051-18



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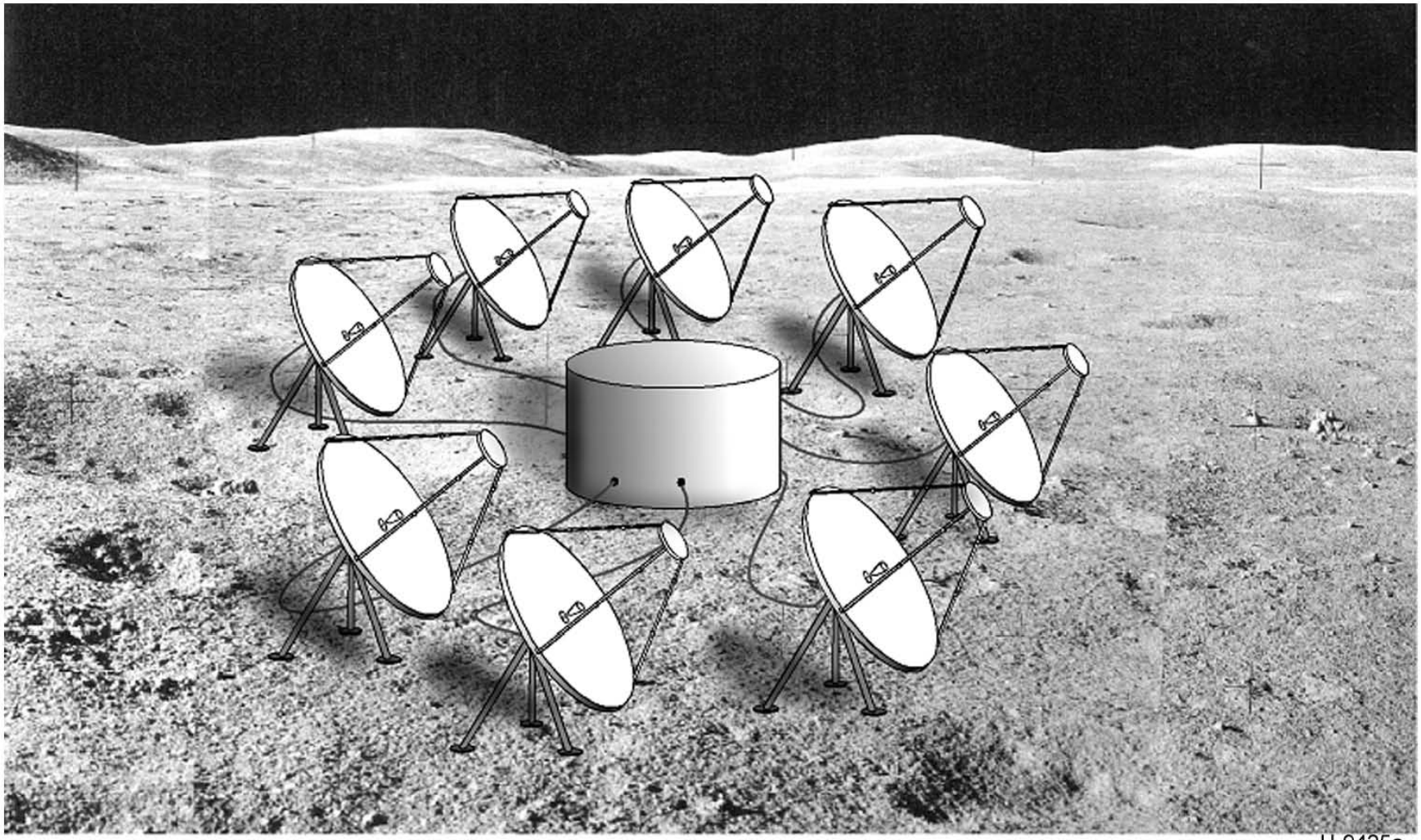
Solar Plant Lighting System for Lunar Mission

VG08-051-19



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Phase I Conclusions

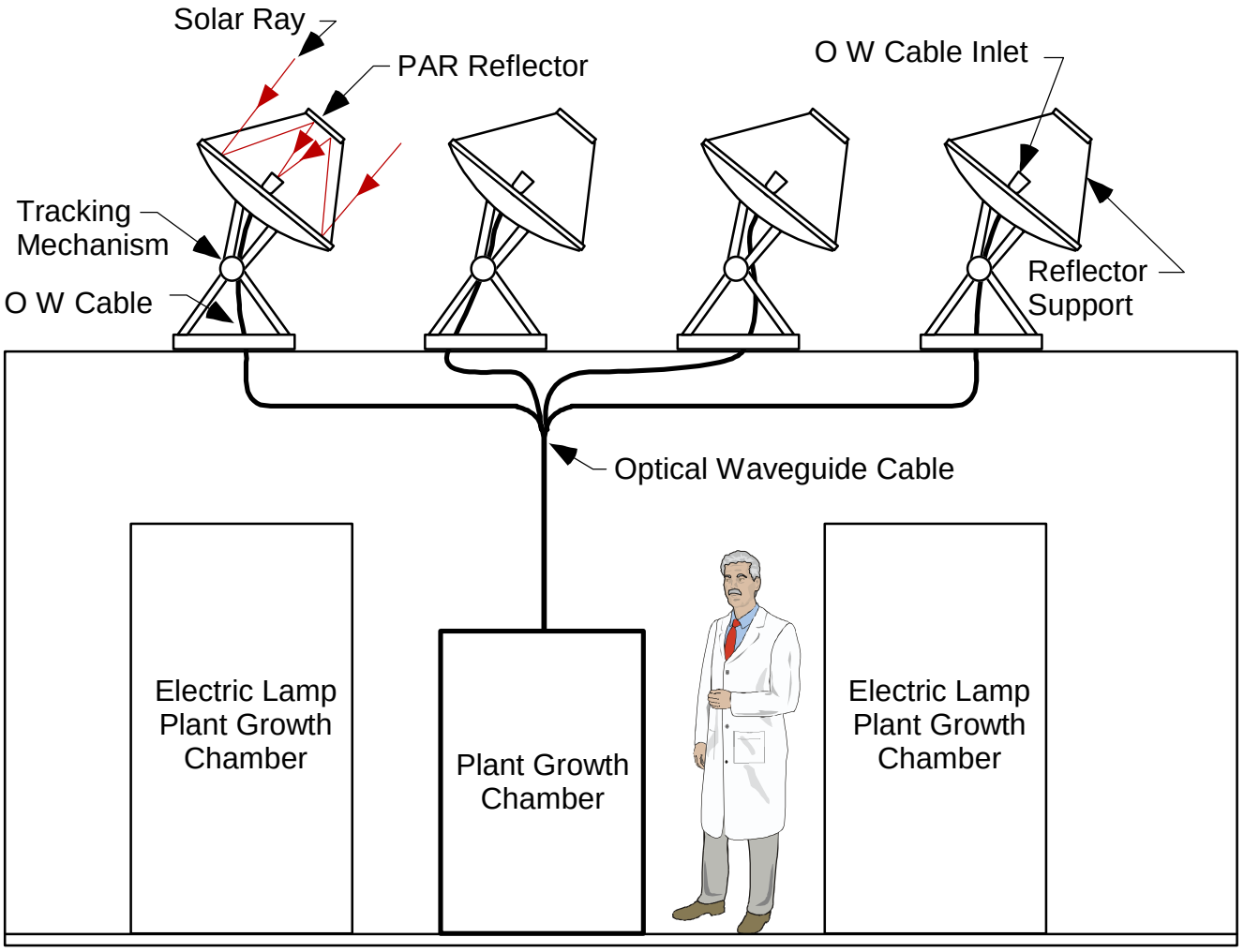
- **OW Solar Plant Lighting System is a viable and effective system concept**
- **It is one of the key enabling technologies for human exploration on long-duration missions**
- **From ESM analysis results it may be a only realistic system by which bioregenerative life support can be implemented**
- **The sound technology basis developed to date will enable us to move to engineering prototype development (TRL 6)**

Phase II Objectives

- **Build an engineering prototype of the solar plant lighting system for the Controlled Environmental Lab at NASA/KSC's Space Life Sciences Laboratory (SLS Lab) to conduct:**
  - performance evaluation
  - engineering feasibility demonstration
- **Develop a technology base for space-deployment of the proposed solar system in applications to:**
  - regenerative life support
  - in-situ resource utilization (ISRU)

Engineering Prototype of the Optical Waveguide Solar Lighting System: Schematic

VG08-051-22



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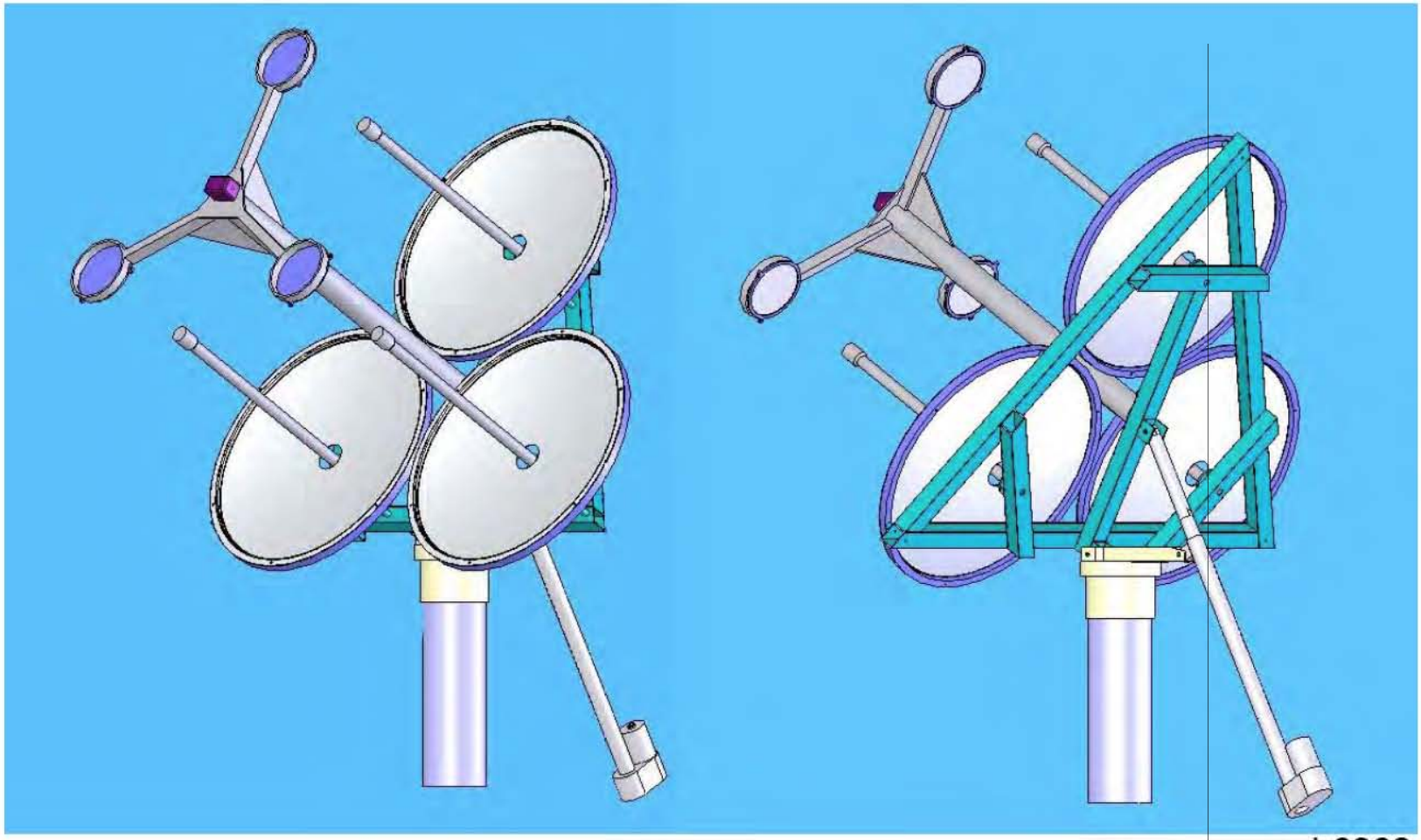
Solar Concentrator Array

VG08-051-23



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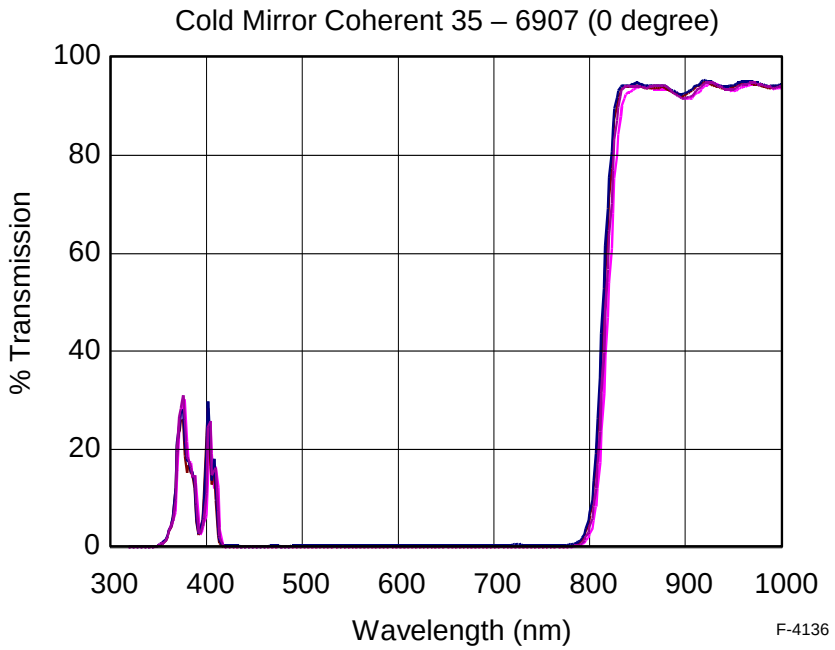
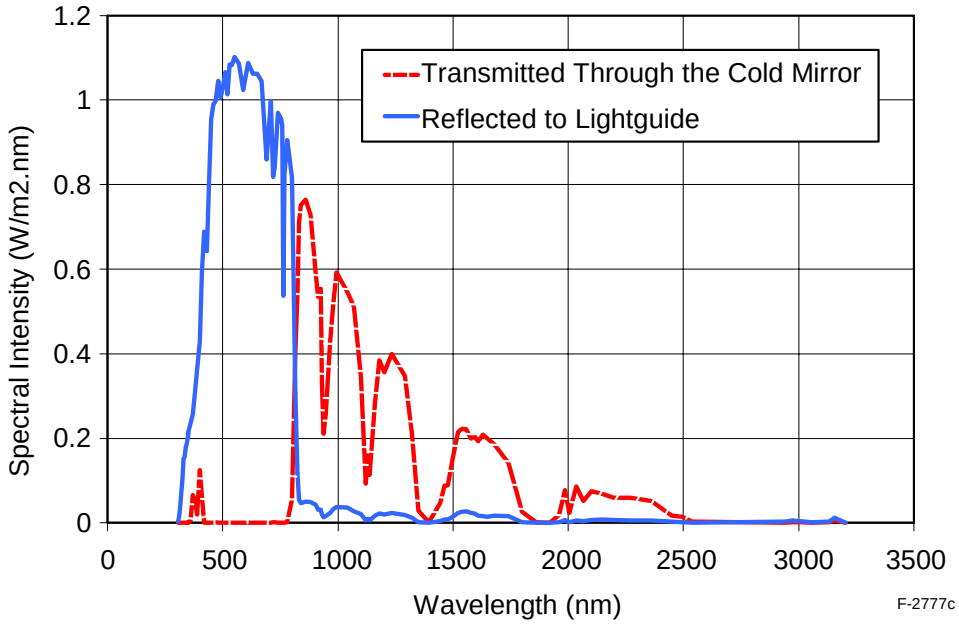
Spectral Conditioning Device

VG08-051-24





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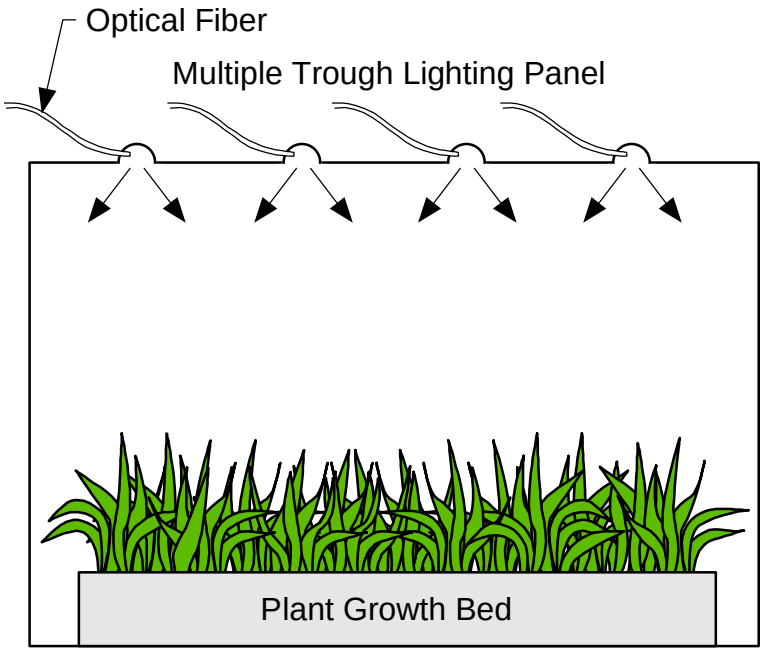
Plant Lighting Device

VG08-051-25



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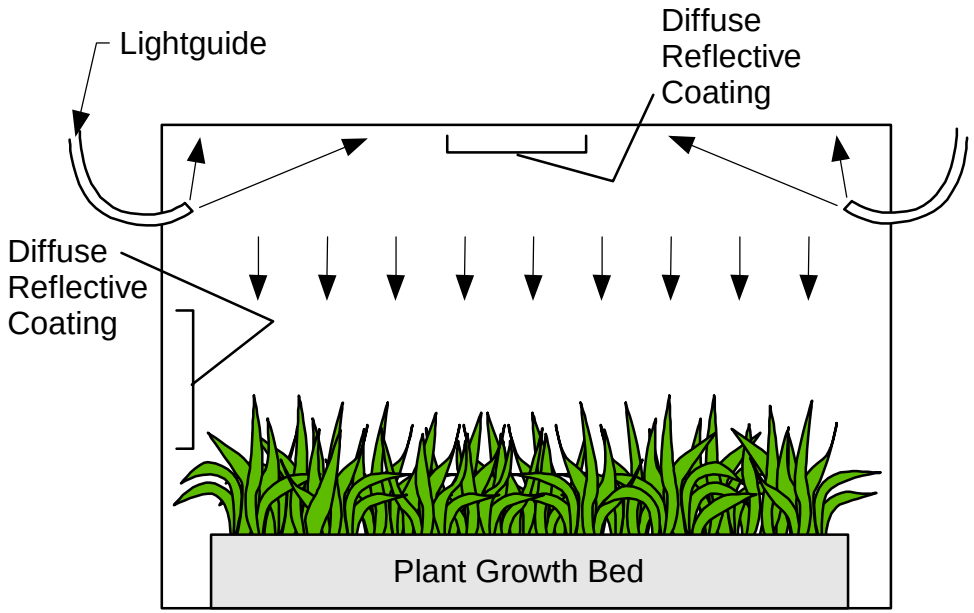

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Engineering Prototype Solar Plant Lighting System: Performance Specification

VG08-051-26

Ambient PPF at KSC:	**1800 μmol m^{-2} S^{-1} (direct)**
Ambient Solar Flux at KSC	**880 W m^{-2} (direct)**
Total Conc. Area (27 in dia. x 6)	**2.07 m^2**
Concentrator Reflectivity	**0.85**
Total PAR Collected	**3180 μmol S^{-1}**
Transmission Efficiency	**50% nominal**
Total PAR Delivered to Lighting Chamber	**1590 μmol S^{-1}**
PPF in Lighting Chamber ($2m^2$)	**795 μmol m^{-2} S^{-1}**

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Program Features

- **Innovative and significant contribution to NASA's ALS program**
- **Technology developed can be used for multiple applications in space:**
  - plant lighting
  - ISRU
  - power generation

Acknowledgement

This work was supported by NASA/KSC through contracts

SBIR Phase I: NNK06OM15C

SBIR Phase II: NNK07MA10C

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