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Solar Thermal Power System for Oxygen Production from Lunar Regolith: Engineering System Development

Takashi Nakamura[1], Benjamin K. Smith[1], and Robert J. Gustafson[2]

[1]Physical Sciences Inc.
[2]Orbital Technologies Corporation

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Multi-use Solar Thermal System: Schematic

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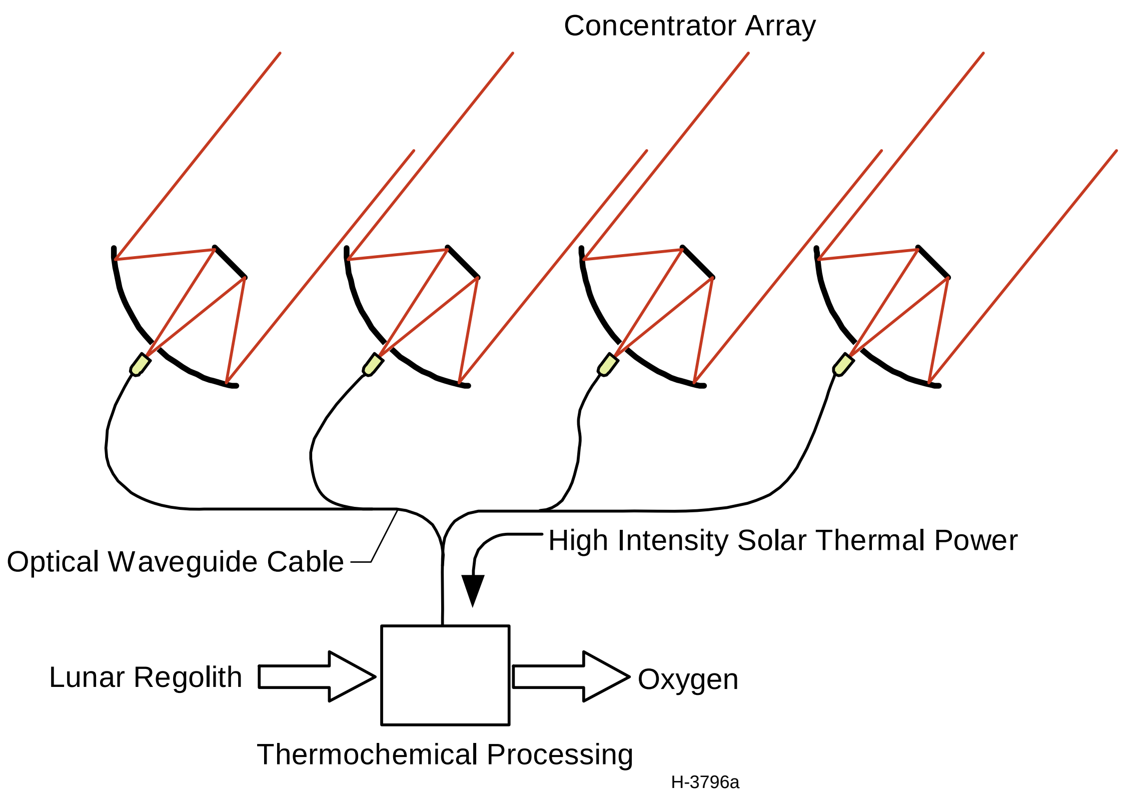

- **Transmission of high solar flux via flexible optical waveguide**
- **Scale up by incremental increase of concentrator units**
- **Transportable and deployable on the lunar surface**
- **Multi-use for a variety of oxygen production processes**

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Solar Energy for Lunar Material Processing: Previous Concept

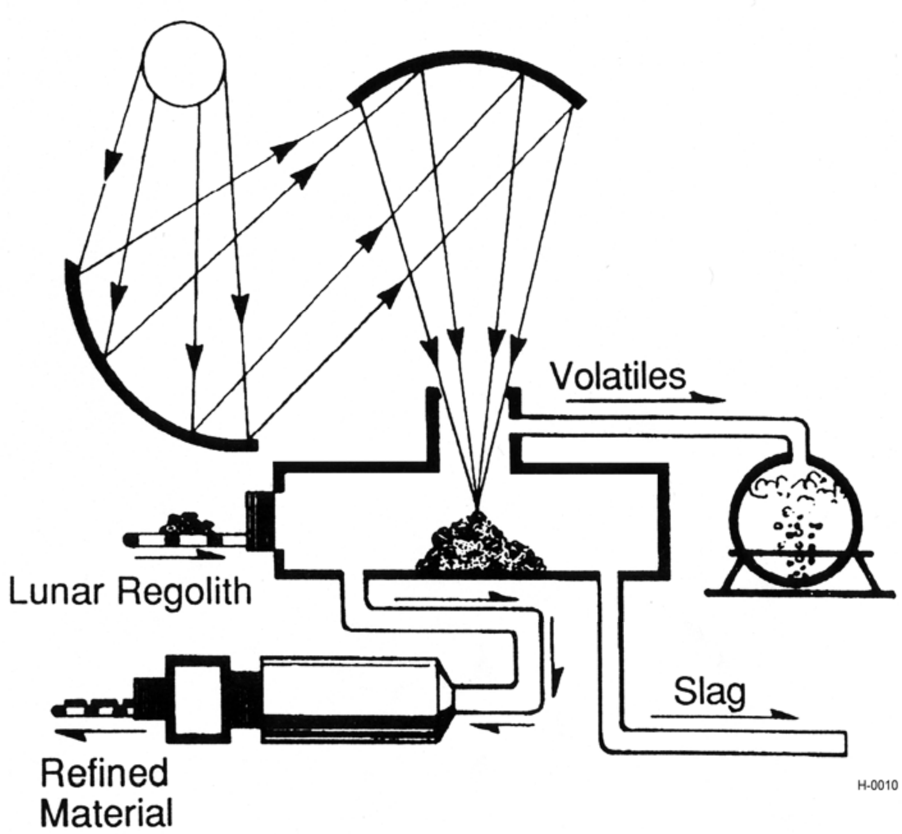

Figure by NASA/JSC (ca. 1992)

- **Difficult to achieve ideal heating of process materials**
  - uneven heating
  - uncontrolled heat flux
- **Difficult to modularize**
  - limited scaling
  - non-ideal process configuration

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The Optical Waveguide Solar Energy System Used for Hydrogen Reduction of JSC-1 and Ilmenite (1996)

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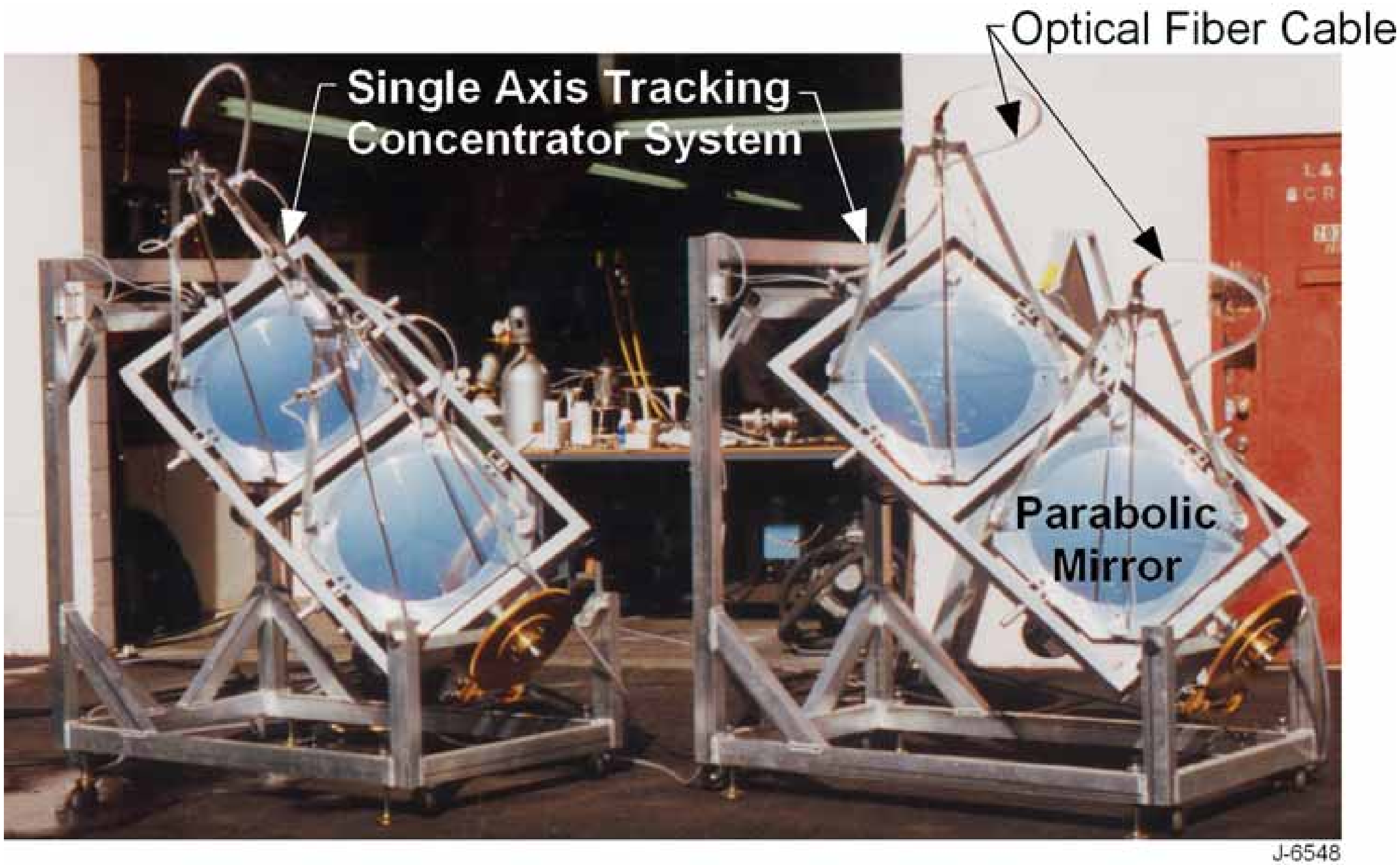

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The OW Solar System Used for Recent Solar Power Experiment

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G-5027

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Testing of Cable with New Inlet Optics (5/7/07)

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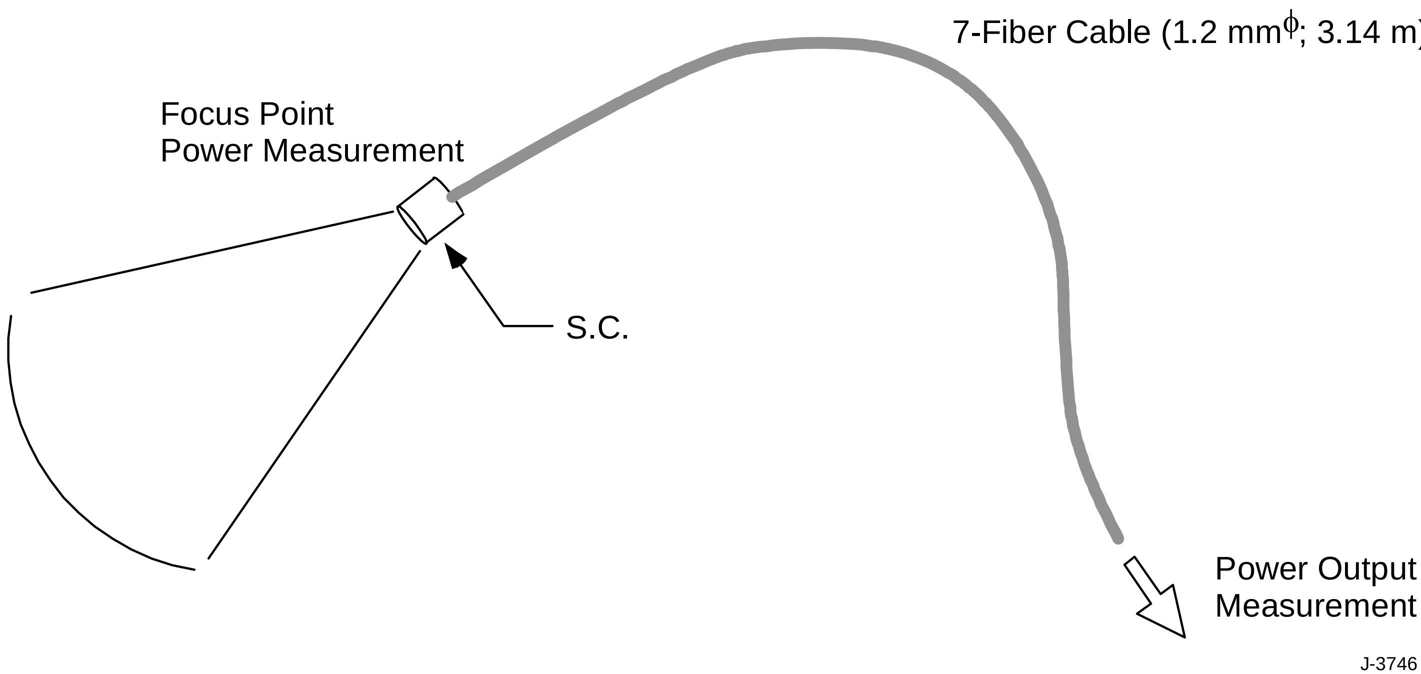

- **Focus Flux Intensity:** **167 ~182 W/cm^2**
- **Power Input to S.C.:** **31.40 W**
- **Power Output:** **21.70 W**
- **Transmission Efficiency:** **69.10% including Fresnel Loss (previous 52 ~ 55%)**

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Solar Test of Cable with New Inlet Optics

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Cable Test with PSI Concentrate

Cable Transmission (3.14 m): 69%

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Pathway for Component Efficiency Improvement

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Component	1996-2005	May 2007	Space-Based Operational System	Improvement Measures
Concentrator	**0.722**	**0.858***	**0.936**	
Reflectivity	0.82	0.975	0.975	• Protected silver coating
Intercept factor	0.88	0.88	0.96	• High slope accuracy and in the absence of atmospheric scattering
Optical Fiber Cable	**0.526**	**0.69**	**0.812**	
Front Fresnel ref	0.965	0.965	0.983	• AR coating (650~1100 m)
Fiber fill factor	0.734	1.0	1.0	
Integral fiber transmission	0.77	0.74	0.84	• Improved inlet optics and high purity fiber
Back Fresnel ref	0.965	0.965	0.983	• AR Coating (650~1100 m)
System Efficiency	**0.38**	**0.592**	**0.760**	

* Plating silver coating on the PSI concentrator surface is assumed

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Receiver Interface with Oxygen Production Process

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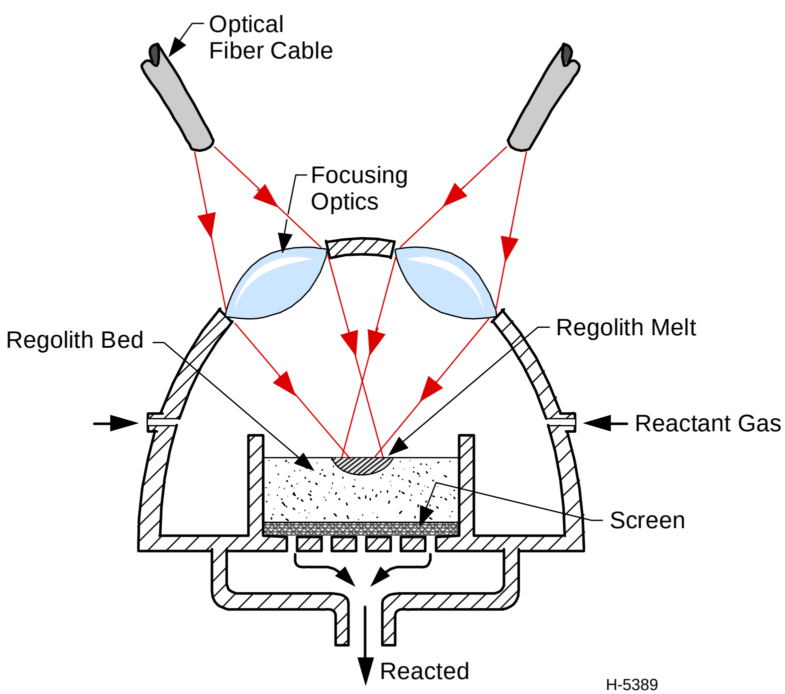
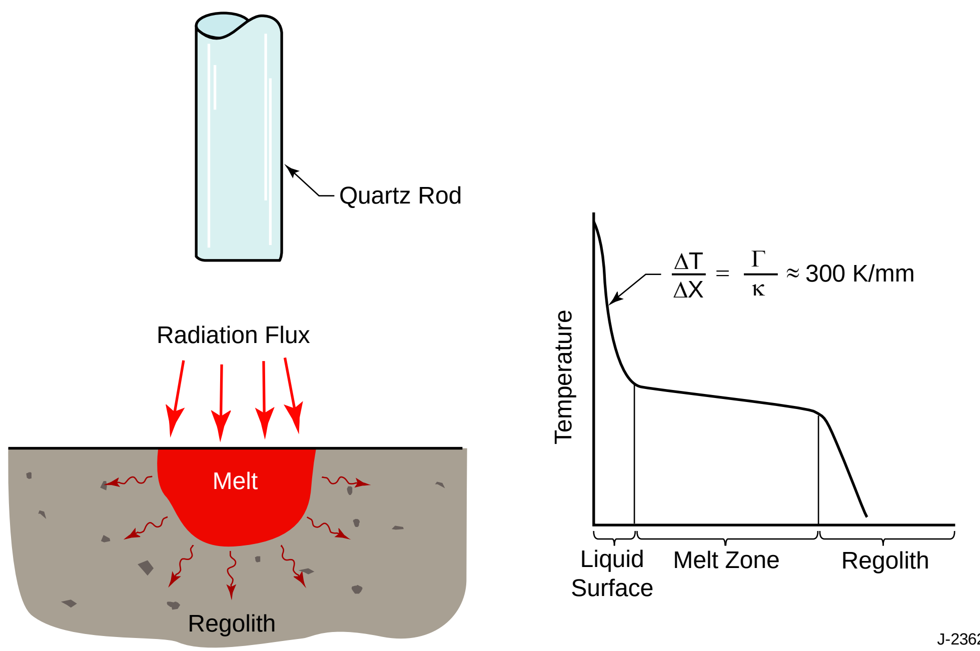
- **Hydrogen reduction of lunar regolith (850-1000C)**
  - Temperature easily attained
  - Thermochemical process demonstrated
- **Carbothermal lunar regolith processing (CLRP; 1600-1800C)**
  - High temperature requirement
  - Main focus of Phase I work



Imaging Optics



Non-imaging Optics

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Melting JSC-1 with Xe-Arc Light Source

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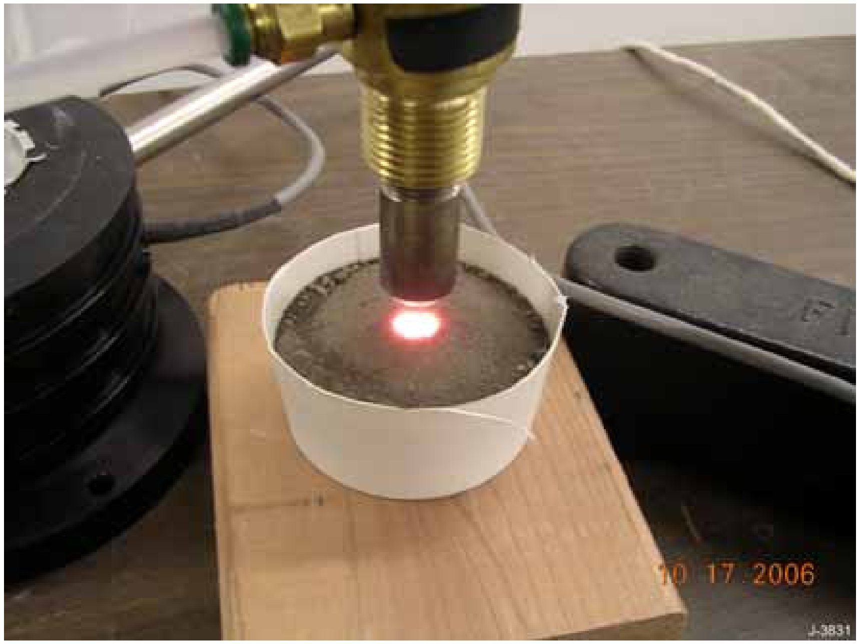
Imaging Optics



Non-imaging Optics

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Melting JSC-1 with Xe-Arc Light Source: II

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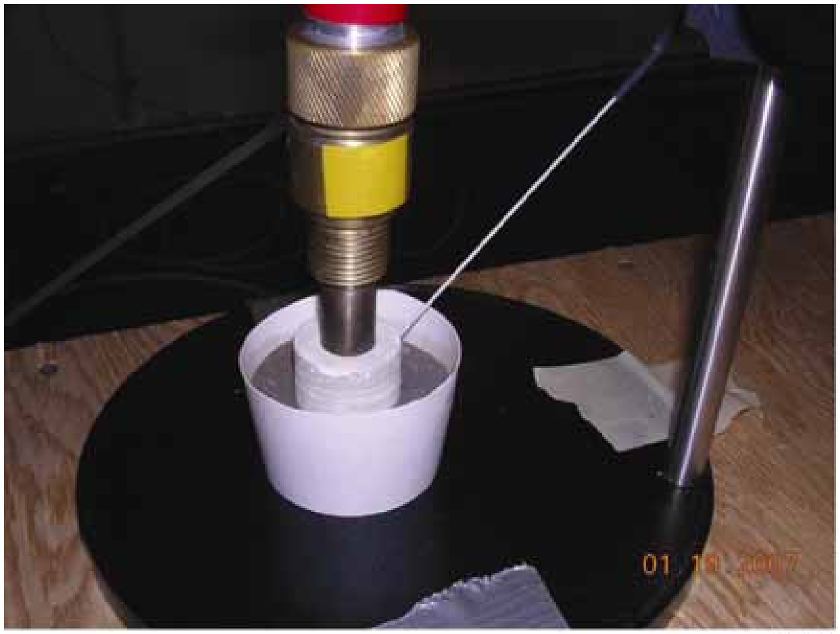

J-2390

Optical Fiber Cable
Heating JSC-1 with 60W of Power
(T = 1450 C)

J-2402

Vitrified JSC-1 Melt
(dia. = 14mm; depth = 6mm)

Source: PSI/Orbitec project, "Solar Thermal System for Carbothermal Lunar Regolith Processing System (CLRPS)"

Melting JSC-1 with Solar Heat: I

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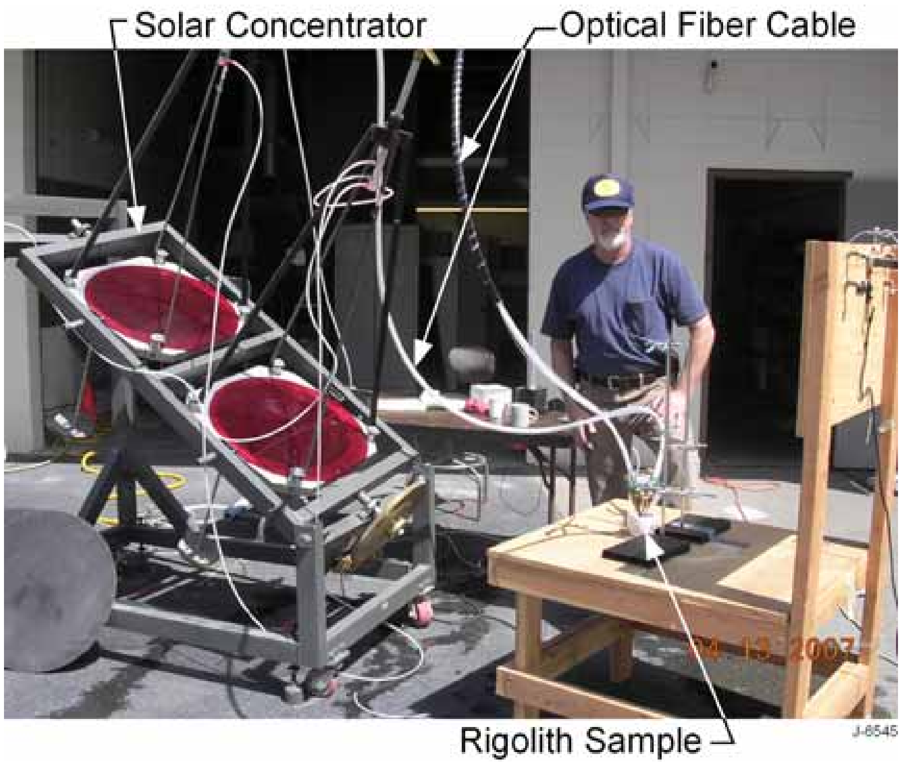

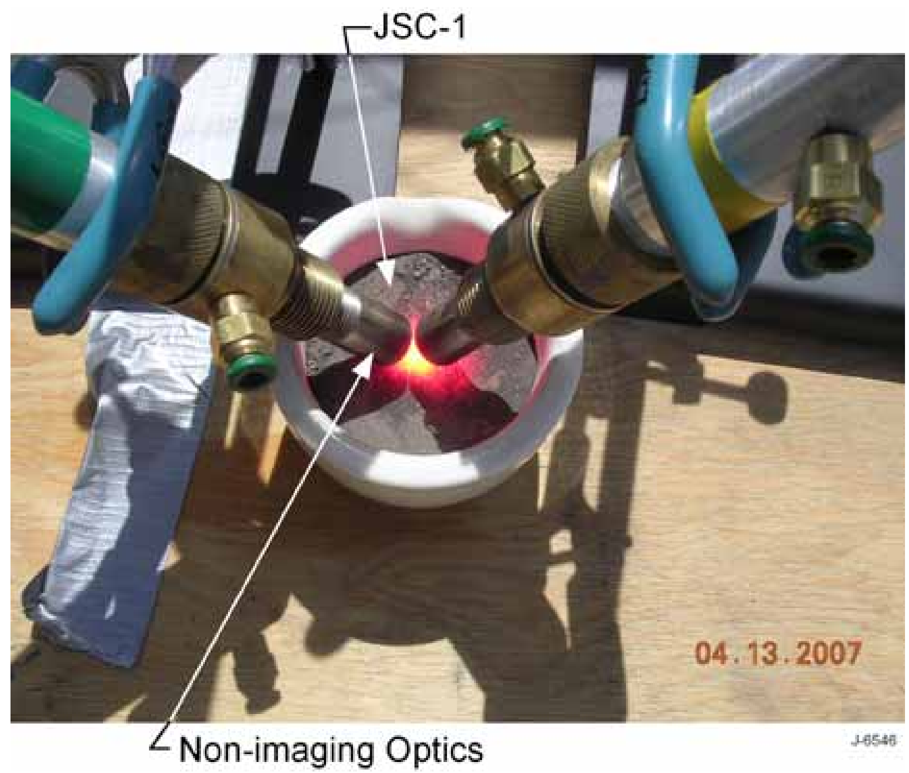

Two Cables Focused
On a Single Point

Power:	**104 W**
Peak Flux:	**84.4 W/cm^2**
Temperature:	**1556 C**

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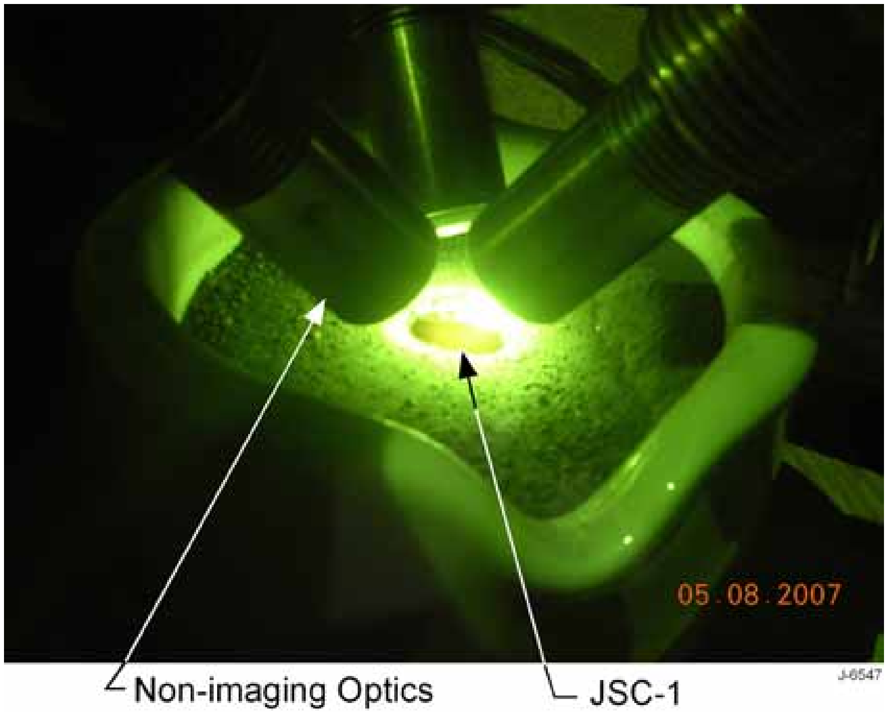
Melting JSC-1 with Solar Heat: II



Three Cables Focused On a Single Point

Power = 145 W

Peak Flux = 117.4 W/cm^2

Temperature = 1728~1800 C

Vitrified JSC-1 Melt: 14 mm dia

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Surface Temperature of JSC-1 Melt

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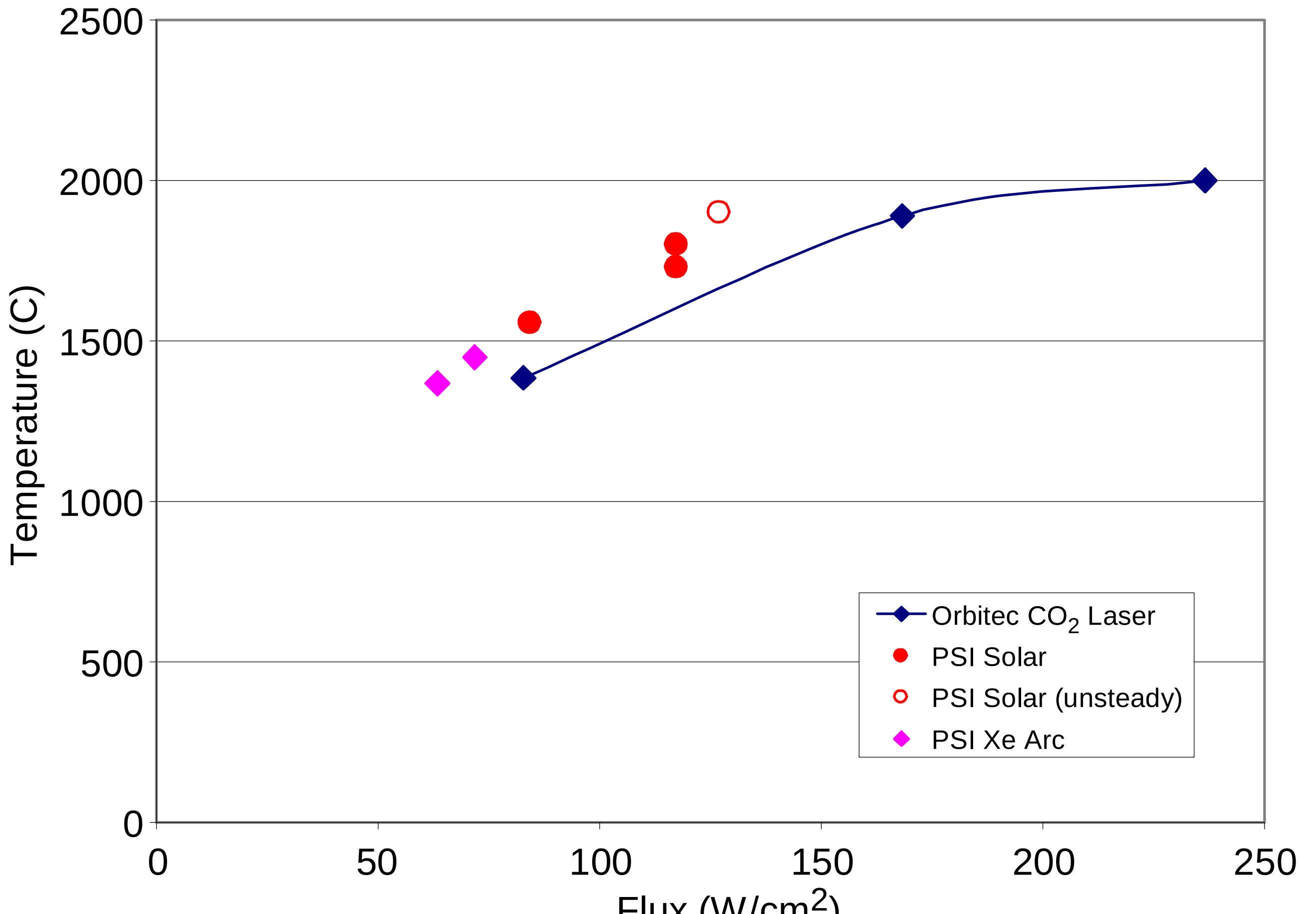

J-3836

Temperature measured by Type C (W 5% Re - W 26% Re) thermocouples

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Conceptual Design Basics

- **1 MT of oxygen/year at a lunar polar region**
- **Two oxygen production processes**
  - Hydrogen reduction process (5.6 kW)
  - Carbothermal reduction process (5.6 kW)
- **PILOT (Precursor In-Situ Lunar Oxygen Testbed) platform as the basis**

Oxygen Production Process

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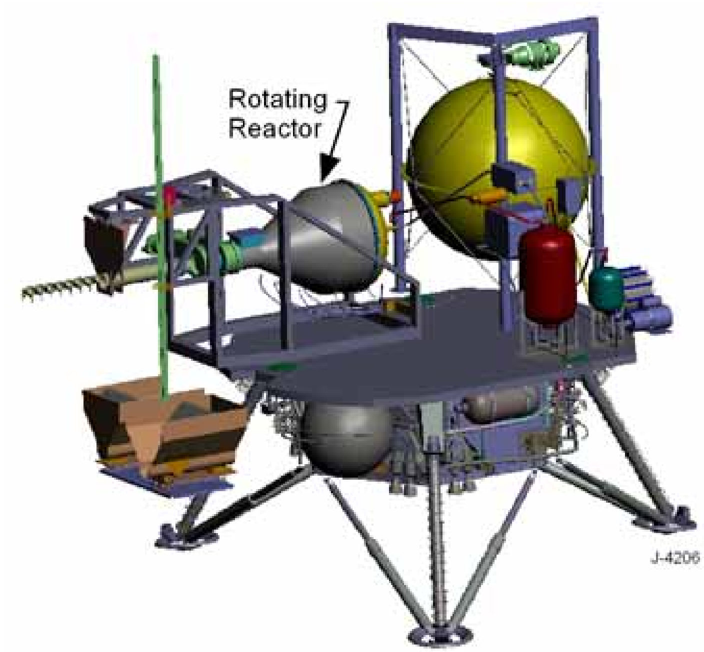

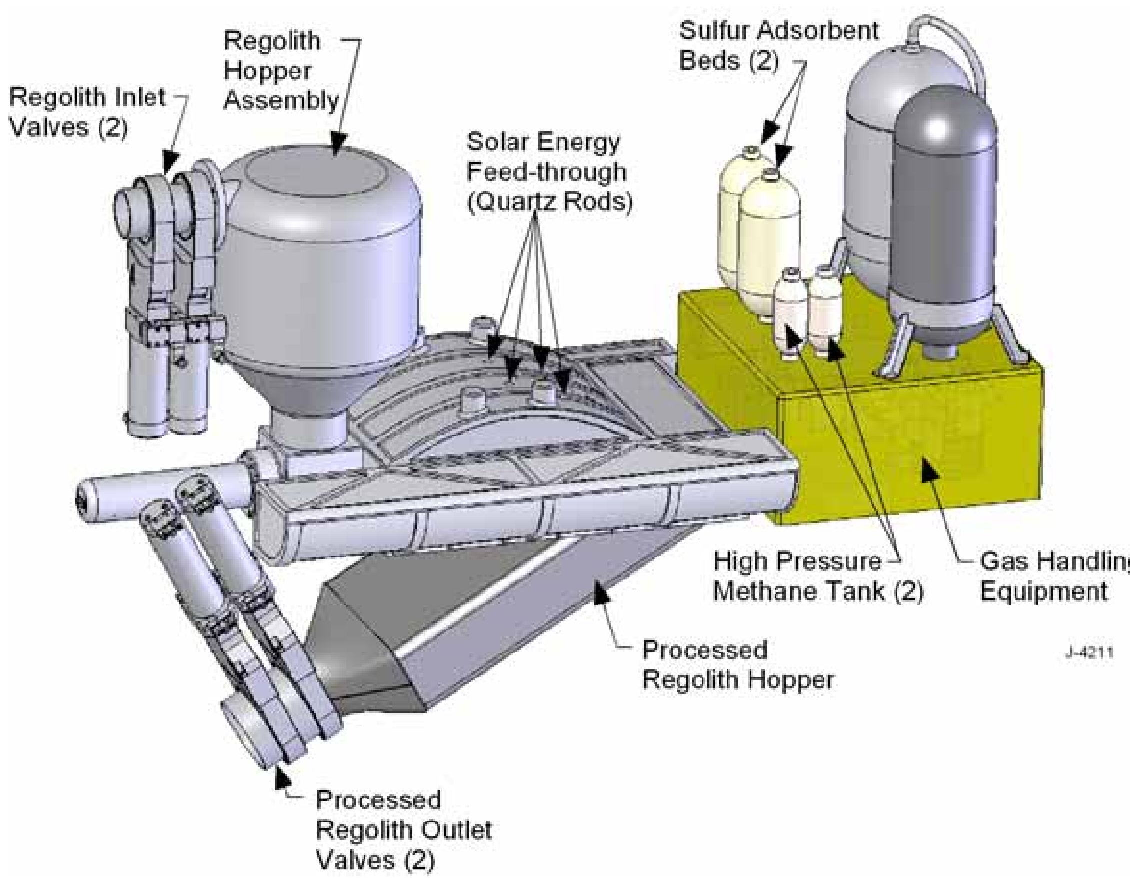

Hydrogen Reduction Process (LMSSC)

Carbothermal Reduction Process (ORBITEC)

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Carbothermal Reduction Process

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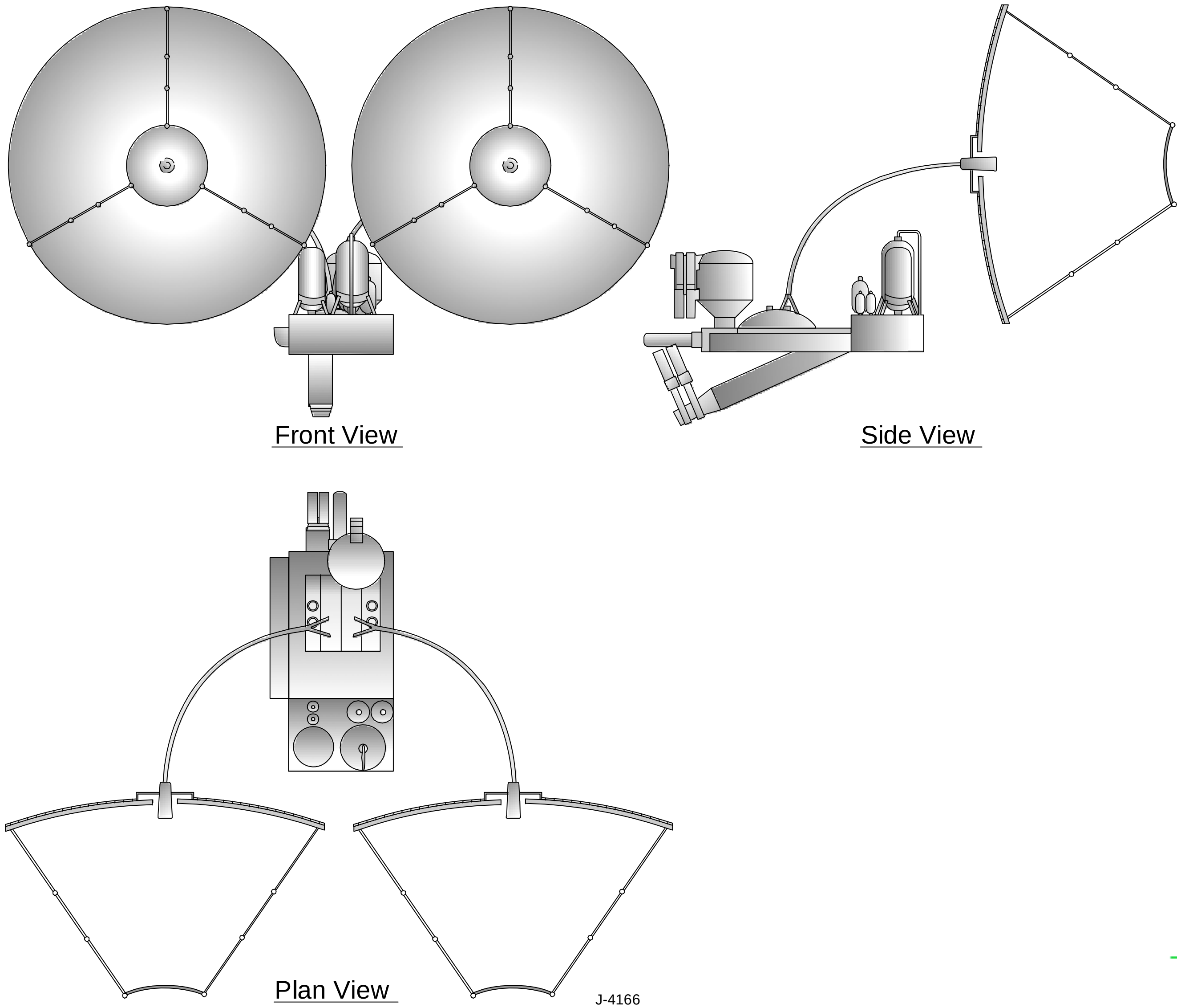

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Summary of the System Component Weight

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Concentrator System	
Concentrator	Cassegrain (parabolic primary + hyperbolic secondary)
Diameter	Primary Concentrator = 2 m , Secondary Reflector = 0.5 m
Specific Weight	3.567 kg/m^2 (RCAT: Rigid Concentrator and Tracking System, AFRL solar thermal propulsion data)
Weight per Concentrator	11.2 kg including support and tracking mechanisms
Number of Unit	2
Conc. System Weight	22.4 kg
Optical Waveguide (OW) System	
Optical Fiber	Fused Silica Core (2 mm dia.), Fluorine Doped Silica Clad (2.2 mm dia.), Polyimide Jacket (2.5 mm dia.),
Fiber Weight per meter	9.95 gram/m
Number of Fiber per Cable	169
Cable Diameter	3.8 cm (1.5 inch)
Cable Weight per meter	1.68 kg/m
Cable Length	3.5 meter
Cable Weight	5.88 kg
Number of Cable	2
OW System Weight	11.76 kg
System Weight Summary	
Concentrator System weight	22.4 kg
OW System Weight	11.76 kg
Total System Weight	**34.16 kg**
Total Supplied Power	5.905 kW
Weight per kW	**5.785 kg/kW**

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Summary and Conclusions

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- **Solar thermal system based on the optical waveguide (OW) technology is viable and effective for oxygen production from lunar regolith**

- **In this Phase I program we demonstrated a significant and dramatic increase in system efficiency**

- **We conclusively demonstrated that solar thermal power is capable of heating the lunar regolith to the temperatures necessary for oxygen production**

- **The system will be light-weight and efficient when deployed on the lunar surface**

Acknowledgement

VG08-206-19

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