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Solar Thermal Power Systems Project
Parabolic Dish Systems Development

Innovative Concentrator Requirements Definition

T.O. Thostesen

July 15, 1984

Prepared for
U.S. Department of Energy
Through an Agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
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The JPL Solar Thermal Power Systems Project is sponsored by the U.S. Department of Energy and is part of the Solar Thermal Program to develop low-cost solar thermal and electric power plants.

ABSTRACT

This report describes the requirements definition activities at the Jet Propulsion Laboratory leading to a design specification that served as an input for the preparation of the Innovative Concentrator Program Opportunity Notice (PON) issued by the Albuquerque Operations Office of the U.S. Department of Energy in January 1984.

ACKNOWLEDGMENT

The work described herein was conducted by the Jet Propulsion Laboratory, California Institute of Technology, for the U.S. Department of Energy through an agreement with the National Aeronautics and Space Administration (NASA Task RE-152, Amendment 327; DOE/ALO/NASA Interagency Agreement No. DE-AM04-80AL13137).

GLOSSARY

ABBREVIATIONS, ACRONYMS, AND INITIALISMS

DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
f/D	ratio of focal length divided by diameter
JPL	Jet Propulsion Laboratory
kWt	kilowatts of thermal energy
m^2	square meters
m/s	meters per second
mi/h	miles per hour
$\$/m^2$	installed cost per square meter of aperture area
OSHA	Occupational Safety and Health Administration
PCA	power conversion assembly (PCU + receiver)
PCU	power conversion unit
PDC-1	Parabolic Dish Concentrator No. 1
PON	Program Opportunity Notice
TBC	Test Bed Concentrator

CONTENTS

APPENDIX

Table

SECTION I

INTRODUCTION

A. BACKGROUND

This report describes the requirements definition activities at the Jet Propulsion Laboratory (JPL) leading to a design specification that served as an input for the preparation of the Innovative Concentrator Program Opportunity Notice (PON) issued by the Albuquerque Operations Office of the U.S. Department of Energy (DOE) in January 1984.

B. OBJECTIVES

This report documents the rationale used at JPL to develop a preliminary design specification for the Innovative Parabolic Dish Concentrator and to assist in preserving the continuity of the national Solar Thermal Technology Program effort, as JPL's responsibilities to the Program have been transferred to Sandia National Laboratories-Albuquerque.

C. SCOPE

This document provides an explanation for the selection of the preliminary set of requirements found in the design specification. In many instances, the selected values are based upon test experience with previous concentrators.

SECTION II

REQUIREMENTS

A. PROJECT COST AND PERFORMANCE TARGETS

Cost and performance targets of the Solar Thermal Parabolic Dish Project are listed in Table 2-1 for point-focusing solar concentrators as published in 1980. The first-generation targets were for a concentrator to be available in 1983 developed under the Low Cost Concentrator Program. The reflectance requirement ranged from 0.90 for glass to 0.78 for a reflective plastic film. A prototype parabolic dish concentrator (PDC-1), designed by General Electric, was fabricated and subsequently installed at the JPL Parabolic Dish Test Site. This design was cost analyzed, and cost projections for mass production were made. The resultant installed cost of 375 $\$/m^2$ was 2 to 3 times the 120 to 170 $\$/m^2$ first-generation cost target.

Second-generation cost and performance targets, listed for a concentrator to be available in 1987, require a significant reduction in the installed cost relative to the first-generation General Electric design. Such a reduction in cost would require innovative design.

The Project cost target in terms of $\$/m^2$ is useful as a comparative device between competitive concentrator designs only if the concentrator performances per unit area are comparable. For example, two concentrators with similar costs but with respective reflectances of 0.78 and 0.90 would not be equally cost effective. It is more indicative of relative value to compare the unit cost of the thermal energy passing through the receiver aperture in \$/kWt. Therefore, the Project cost and performance targets for a second-generation concentrator were converted to a 1983-\$/kWt basis. Assuming a reflectance of 0.92, an optical intercept factor of 0.98, an effective

Table 2-1. Preliminary Price and Performance Targets for Electric Power Generation (1980 \$)

Subsystem	Dominant Parameters	First-Generation (1983)	Second-Generation (1987)
Concentrator	Installed price[a]	120-170 $\$/m^2$	80-120 $\$/m^2$
	Surface reflectance	78-90%	92%

[a]Based on the following assumed ranges of production: first-generation — 5,000 to 25,000 units/yr; second-generation — 10,000 to 1,000,000 units/yr.

frontal area (i.e., allowance for blockage and gaps) of 0.95, an insolation level of 1 kW/m^2, and inflation factors from 1980 to 1983, the 80 to 120 $\$/m^2$ becomes 120 to 180 \$/kWt. Because a design having an installed cost under 120 \$/kWt would be perfectly acceptable, the second-generation target was then assumed to be 180 \$/kWt or less.

The concentrator was to be designed for a 30-year life with minimal maintenance and replacement costs.

B. COMPLIANCE WITH CODES

The innovative concentrator would be designed for use by industry, utilities, communities, and individuals. Therefore, the concentrator would be subject to compliance with many codes covering design, installation, operation, and personnel safety. Four codes were selected, as explained in Section III and listed in the Appendix, to cover the requirements of the innovative concentrator.

C. CONTRACT TYPE

A PON was selected as the contractual vehicle for second-generation concentrator development. It was judged that industry would not undertake such development without governmental assistance, but that the undertaking should have enough long-term sales potential that industry would be willing to invest some of its own funds under a joint cooperative agreement contract.

The name of the concentrator to be developed was changed from "second-generation" to "innovative" concentrator in order to emphasize that an innovative design would be required (1) to reduce the installed costs significantly relative to the "first-generation" General Electric concentrator and (2) to meet the Project cost and performance targets. The solar industry had also expressed concern that a "second-generation" label might result in an unfair sales advantage over other concentrators being developed outside this contract.

The PON does not require the proposer to estimate the mass-production costs for their proposed concentrator concept. Many proposers would be ill prepared to realistically predict mass-production costs, and any cost estimates would probably be based upon widely varying assumptions. It was decided to ask the proposers to provide material, weight, labor hours, and task description information for the fabrication and field erection of the proposed concentrator concept to allow the proposal evaluators to make a meaningful relative mass-production cost comparison.

SECTION III

RATIONALE FOR APPENDIX[1]

A. SECTION 1.0 - SCOPE

The concentrator is defined as an optical system installed in the field ready to operate once the power conversion assembly is installed and the concentrator control is linked to the system master controller.

B. SECTION 2.0 - APPLICABLE DOCUMENTS

Four codes were selected:

(1) Regulations of the Federal Occupational Safety and Health Administration (OSHA) would be required because concentrator operation requires a personnel interface.

(2) Regulations of the Environmental Protection Agency (EPA) are included because widespread utilization of solar concentrators would involve the dedication of significant land areas and because the potential impact on the environment would have to be understood.

(3) National Electrical Code NFPA70, National Fire Protection Association, is included because the concentrator will include electrical motors and controls.

(4) Guide for Design of Steel Transmission Towers was selected because the steel framework of a transmission tower is more like the structures found in solar concentrators than the buildings and fixed structures normally covered by the Uniform Building Code.

C. SECTION 3.0 - DESIGN OBJECTIVES

This section summarized the design objectives for the concentrator to be developed under the design specification. Design objectives were dictated by performance goals, which were based on requirements to generate power at costs that are competitive with alternatives.

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[1]The following section and paragraph numbers refer to those of the Appendix.

D. SECTION 4.0 - PERFORMANCE GOALS

1. Subsection 4.1 - Thermal

A solar incidence of 1000 W/m^2 was selected as the reference intensity for computing thermal performance because this is a nominal value representing a very clear day. Because the concentrator will be used on windy days, a wind velocity of 15 mi/h was selected as the design condition for measuring concentrator performance. This velocity was selected because the wind at a typical site exceeds this level only 5% of the time on a sunny day. A maximum receiver optical acceptance half angle of 53 deg, corresponding to an f/D of 0.5, was specified as a reasonable limit in order to be compatible with contemplated and known receiver designs.

Figure 1 in the Appendix is based upon the thermal inputs required by the thermal power conversion assemblies (PCAs) that are currently being developed under other DOE contracts and that are anticipated to be available in the 1985-87 time frame. The net engine thermal input is expected to range from 80 to 150 kWt with emphasis on the low end of the range. Temperatures could be as high as 2200°F. Because the net thermal power is a function of receiver design and temperature, Figure 1 includes an allowance for receiver losses. The thermal power output of the concentrator is plotted in terms of the concentrated energy passing through the receiver aperture. The aperture diameter starts at 6 in. as a practical lower limit and should be cut off around 15 in. as an upper limit. Figure 1 shows the additional thermal output required of a concentrator with a lower concentration ratio and a resulting larger receiver aperture. It is recognized that a lower optical quality concentrator might have sufficiently low cost per unit surface area to make the design cost effective in spite of the larger dish diameter required.

The energy incident upon the receiver lip is specified to avoid material damage due to local heating.

2. Subsection 4.2 - Solar Tracking

The concentrator should be able to look at the horizon and the zenith. It is recognized that the solar intensity is low when the sun is at the horizon and that some PCAs might not be able to operate mechanically at low elevation angles. For example, the FACC organic Rankine system could not properly operate below a 5-deg elevation angle due to fluid management.

Alaska was not included to avoid a requirement for continuous azimuth rotation (above the Arctic Circle in summer) and environmental extremes. Hawaii is included -- meaning that the gimbal lock problem of an azimuth-elevation system when the sun passes directly overhead must be addressed by the control system.

The concentrator control system involves operation of the concentrator only. It is assumed that the user's master system computer will decide when it is appropriate for the concentrator to track the sun.

The design specification does not specify solar tracking accuracy for the concentrator; that is left up to the concentrator designer. The tracking accuracy and control system have to be consistent with the maximum allowable heat flux on the receiver aperture and with the thermal performance requirements of the concentrator.

3. Subsection 4.3 - Lifetime

The typical lifetime for power company capital equipment is 30 years. This does not mean that the concentrator must last 30 years without maintenance or periodic replacement of shorter-lived parts.

E. SECTION 5.0 - INTERFACES

1. Subsection 5.1 - Mechanical

The concentrator will have a PCA mounted at its focal point. Figure 2 (Appendix) gives the envelope and weight of a typical PCA as a design point for an innovative concentrator concept. Figure 2 is based upon the organic Rankine and Brayton systems being developed. The Stirling engines generally fit this envelope except for a local alternator protrusion. As the concept evolves into a design, Figure 2 would probably evolve as PCA details become available.

Instrumentation, power, and fluid lines to the PCA will require that the PCA support truss be able to carry cables and pipes. These lines must cross the axes of rotation to the ground, and the design must accommodate the flexing and motion of these lines in those areas.

2. Subsection 5.2 - Controls

The concentrator control system will not be responsible for deciding when to start and stop operation of the complete solar power generation module. The control system will drive the concentrator off of sun track in cases of emergency in order to protect the PCA and the concentrator from overheating. Emergency situations include loss of electrical power, control system failure, loss of communication with the master system control, emergency alerts from the master system control or by an operator activated panic button. Loss of electrical power is a particularly troublesome event because failure of the concentrator drives to move while tracking the sun leads to the slow transit (walkoff) of the concentrated beam across the rim of the receiver and onto exposed areas of the PCA and the concentrator. Experience with high-performance concentrators has shown that no proven material can survive the intense energy except water-cooled metal plates and some graphites.

In addition to the walkoff heating problem, day-to-day sun acquisition and deacquisition can be a problem. The TBC (test bed concentrator) required water-cooled aluminum shutters over the receiver aperture plate while going on and off of sun track due to the slow concentrator slew speed. The PDC-1 concentrator, with a slew speed of 1.7 deg/s, moved the beam fast enough to avoid the use of water-cooled plates. Water cooling is satisfactory if it can be provided within cost constraints (including operation and maintenance) and without decreasing reliability.

A manual drive panel on the base of the concentrator to allow manual activation of the drive system has proved to be of great value.

F. SECTION 6.0 - ENVIRONMENTAL REQUIREMENTS

1. Subsection 6.1 - Operational Environment

a. Paragraph 6.1.1 - Temperature and Humidity. The temperatures are based upon extremes of the United States. The Heliostat Design Specification DOE001 stipulated temperatures from +120 to -20°F. The Appendix sets the lower limit at -15°F to allow the use of commercial electronic components.

b. Paragraph 6.1.2 - Wind. The concentrator should operate in a wind of 28 mi/h although possibly with degraded performance. The concentrator will provide rated performance in a 15-mi/h wind.

c. Paragraph 6.1.3 - Change of Insolation. Clouds will pass in front of the sun. The concentrator must be able to accommodate step function "on" and "off" sun events. This also requires that the sun sensor be sufficiently unbiased by nearby clouds to keep the beam from falling on the edge of the receiver aperture.

2. Subsection 6.2 - Survival Environment

a. Paragraph 6.2.1 - Weather. The survival wind velocity is specified by two criteria: fastest mile at 80 mi/h and a 2-second gust of 95 mi/h. The concentrator can be expected to be hit by 46-mi/h wind gusts in a 28-mi/h mean wind. A further discussion of wind loading can be found in DOE/JPL-1060-66, Wind Loading on Solar Concentrators: Some General Considerations by E.J. Roschke, (JPL Publication 83-101), May 1, 1984.

Surviving hail 3/4 in. in diameter is a standard requirement for heliostats and photovoltaic arrays although it is recognized that larger hail can be encountered. It is assumed that larger hail has a lower density.

Snow and ice requirements assume that the concentrator can be turned to dump excessive snow buildups. An ice thickness of 1/2 in. is taken from the transmission tower specification.

b. Paragraph 6.2.2 - Lightning. The concentrators will be exposed to lightning storms. The paragraph as written is probably too general. What was intended is that each concentrator not be adversely affected by nearby lightning strikes and hopefully not damaged by a direct strike. As a minimum, any lightning damage should be easily repaired.

c. Paragraph 6.2.3 - Seismic. Because the concentrator can be located anywhere in the United States, earthquakes are a concern. Seismic Zone 3 relates to moderate earthquake exposure zones.

APPENDIX

DESIGN SPECIFICATION
INNOVATIVE POINT FOCUS SOLAR CONCENTRATOR

1.0 Scope

This document covers the design requirements for the Innovative Point Focus Concentrator. The Concentrator is comprised of the optical system and supporting structure, a mounting for the receiver and power conversion unit (PCU) at the focal point, a solar tracking system (which includes the controls, software and drives) and the foundation.

2.0 Applicable Documents

The construction work, materials, equipment and completed project shall comply with the industry standards and federal specifications indicated in the technical sections of the specifications and the latest issues of the codes as listed below.

1. Regulations of the Federal Occupational Safety and Health Administration (OSHA).

2. Regulations of the Environmental Protection Agency (EPA).

3. National Electrical Code NFPA 70, National Fire Protection Association.

4. Guide for Design of Steel Transmission Towers.
   ASCE-Manuals and Reports on Engineering Practice - No. 52.
   American Society of Civil Engineers.

3.0 Design Objectives

The Concentrators to be designed and fabricated to this specification are a part of a project to develop technology for modular solar energy conversion systems. Since a large portion of the system cost is attributable to the Concentrator, the system economic feasibility is highly dependent upon both the performance and the cost to manufacture, run and maintain the Concentrator. Therefore, the concentrator must satisfy the thermal requirements of the PCU while maintaining low life cycle costs. The design must be adaptable to mass production, highly reliable, and easily maintained. The Concentrator will be designed to withstand the environmental extremes of the United States, excluding Alaska. In addition to these general considerations, the following specific objectives shall be met by the Concentrator.

4.0 Performance Goals

4.1 Thermal

The Concentrator shall direct a total energy through an aperture at the focal point per Figure 1 when illuminated by a solar flux of 1000 watts/m^2 while tracking the sun in a 15 mi/h wind at any time during the day. The maximum receiver optical acceptance half angle is 53^o, measured from the receiver axis for the cavity-type receiver.

The maximum thermal flux allowed on the lip of the aperture of the receiver during solar tracking is 100 kWt/m^2.

4.2 Solar Tracking

The Concentrator shall be capable of tracking the sun from sunrise to sunset anywhere in the United States, except Alaska. The decision for going onto and off of sun track shall be made external to this solar tracking system.

4.3 Lifetime

The goal for the operational lifetime of the Concentrator with periodic maintenance and replacement schedule is 30 years.

4.4 Environment

The Concentrator shall operate and survive the environmental limits listed in 6.0.

5.0 Interfaces

5.1 Mechanical

The Concentrator shall provide for the mounting of a receiver and PCU at the Concentrator focal point. The combined receiver and PCU weight and mechanical dimensions are shown in Figure 2.

The Concentrator structure and design shall accommodate power conversion unit power, control, fuel and instrumentation lines running from outside of the foundation to the PCU. These lines have a total weight of 10 lbs/foot length.

The Concentrator shall be designed to withstand the loads associated with shipping, erection, repair, maintenance, replacement of components and installation and removal of the receiver and PCU. The Concentrator shall be designed to facilitate maintenance and repair, including mounting and servicing of the PCU.

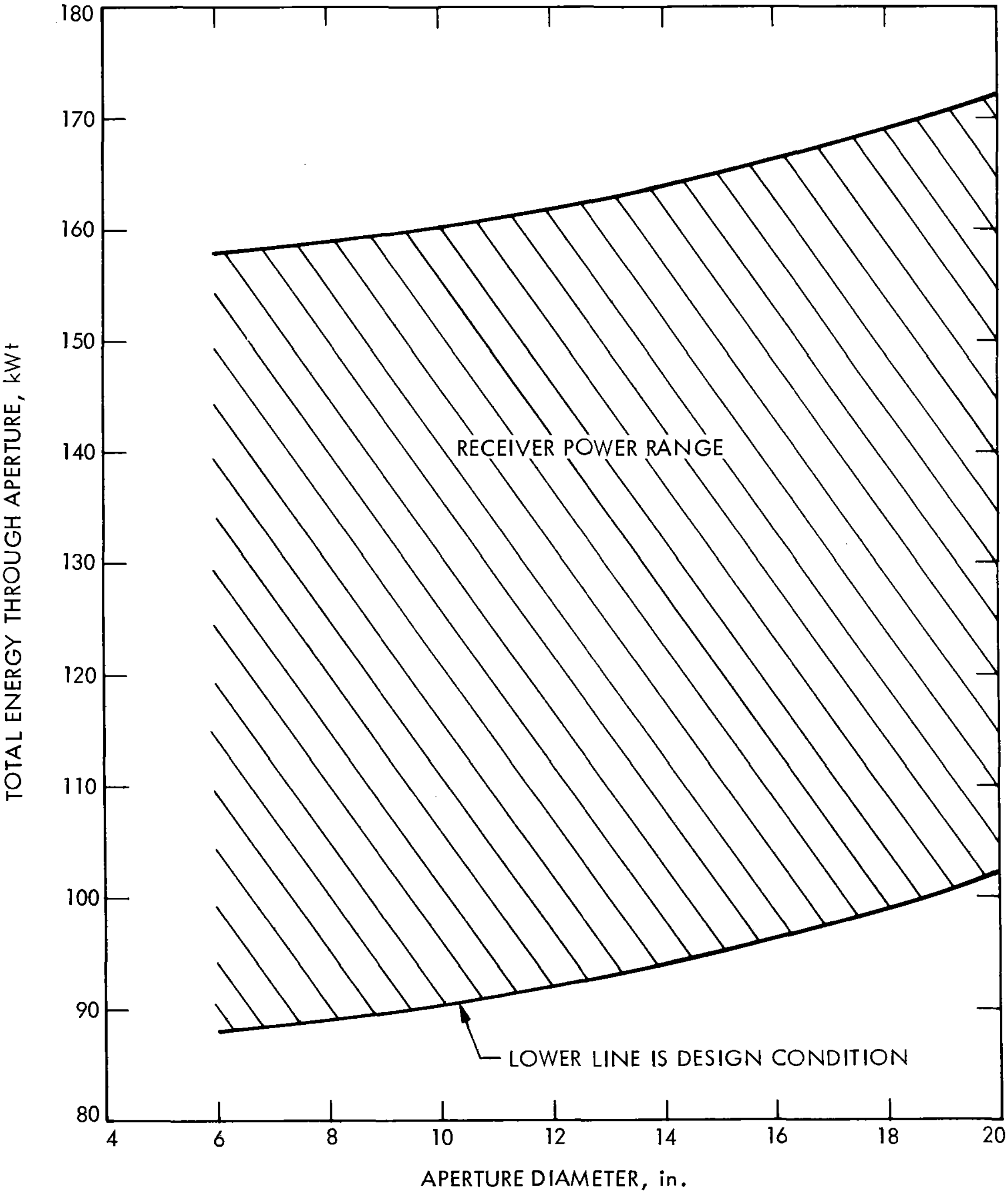
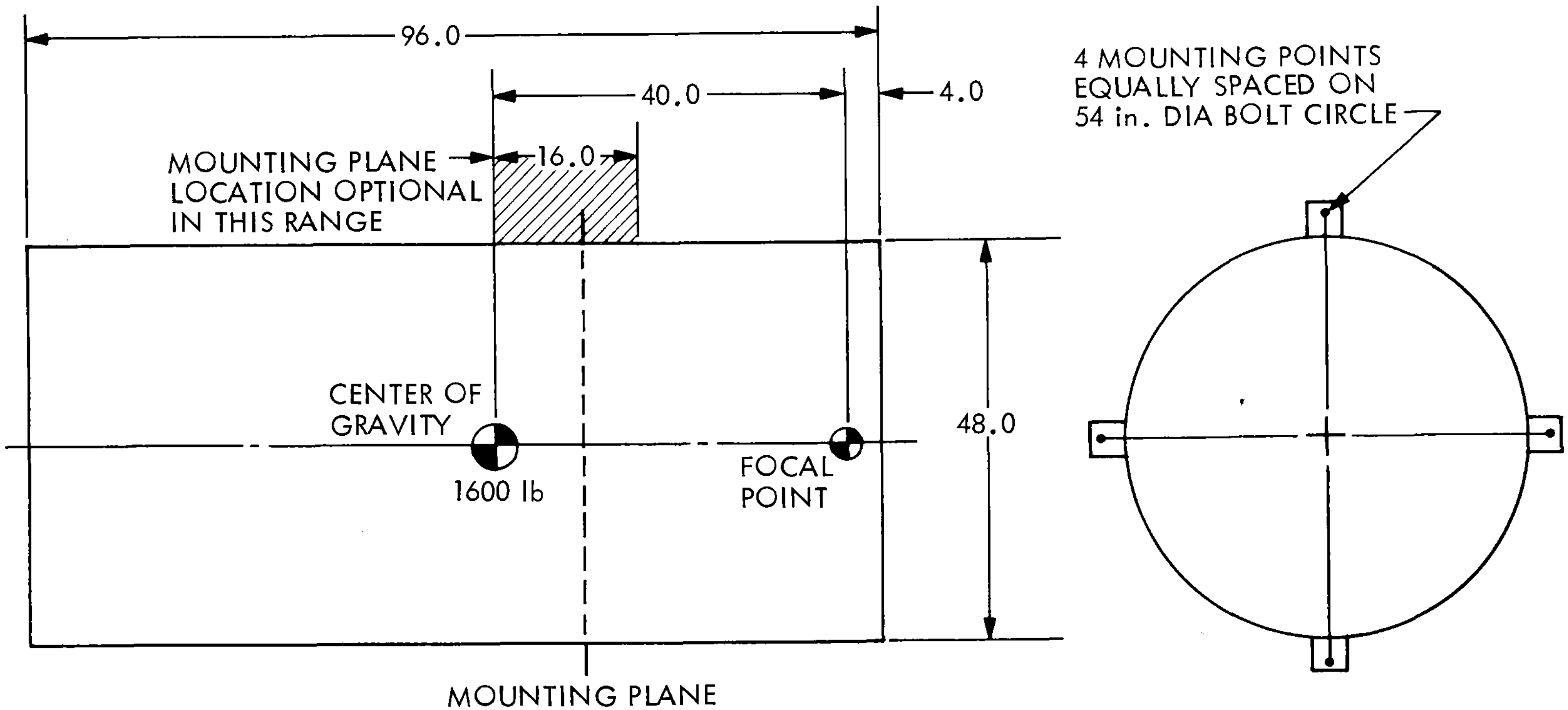


Figure 1. Concentrator Thermal Output Required for Various Receiver Apertures. (Explanation of figure as submitted: The lower limit was selected as the design point, as most of the engines are sized for an input of 80 kWt. The proposer could propose a higher performance level up to 150 kWt if he felt a larger concentrator would be more cost effective.)



DIMENSIONS IN INCHES

Figure 2. Receiver/Power Conversion Unit Envelope

5.2 Controls

The Concentrator control system, which includes the sun tracking system and drives, will receive its instructions to go on and off the sun from an external command source. The control system shall respond to emergency signals to go off the sun to remove the concentrated solar flux from the receiver aperture.

The control system shall be designed to prevent damage to the Concentrator, PCU, or personnel.

The control system shall be designed to minimize heating problems on the Concentrator structure and the PCU when acquiring or disengaging sun track or when driven off the sun in an emergency.

The concentrator shall detrack from the sun in case of control system failure or loss of electrical power.

The drive system shall have provision for a manual drive control station at the Concentrator.

6.0 Environmental Requirements

6.1 Operational Environment

6.1.1 Temperature and Humidity

The concentrator shall be able to operate continuously when conditions are within the following limits:

Ambient air temperature:
-26° to +49°C (-15° to +120°F)
(-29°C, -20°F is desired)
Relative humidity: 0 to 100%

6.1.2 Wind

The concentrator shall be able to operate continuously and provide rated output in winds of 6.7 m/s (15 mi/h). The concentrator shall be able to operate continuously and properly at mean hourly wind speeds of 12.5 m/s (28 mi/h). It shall be possible to slew the concentrators from any orientation to stowed position in such winds. These wind speeds are at a reference height of 10 m (33 ft), and in any direction.

6.1.3 Change of Insolation

The concentrator shall operate properly at rates of change of incident flux up to that resulting from the passage of a sharp-edged shadow opaque cloud at 20 m/s.

6.2 Survival Environment

6.2.1 Weather

The concentrator shall be designed to survive the following extremes of environment, and realistic combinations of these extremes, and resume normal operation after exposure, without repairs, maintenance or adjustment. The concentrators may be oriented in a protected or stowed position for these conditions except where otherwise specified.

Temperature (ambient air):

-29° to +49°C (-20 to +120°F)
(-50°C, -58°F is desired)

Wind: Fastest mile 35.6 m/s (80 mi/h); 2-second gust 42.5 m/s (95 mi/h).

Hail: 20 mm (3/4 inch), specific gravity 0.9 at 23 m/s (75 ft/s) at any concentrator orientation.

Rain: Annual average 750 m (30 inches), with maximum 24 hour rainfall 75 mm (3 inches).

Snow and Ice Accumulation: 250 pascals (5 lb/ft^2) on flat surfaces of 1/2 inch thickness on struts.

Repetitive Freezing and Thawing: Throughout the concentrator life.

Blowing Dust and Sand: Equivalent to test conditions of MIL-STD-810B, Method 510.

6.2.1.1 The concentrator shall survive, without damage, winds with 2-second gusts of 20.7 m/s (46.2 mi/h) regardless of the orientation of the concentrators.

6.2.2 Lightning

The concentrator shall be provided with lightning protection. Damage and likelihood of loss of control due to lightning shall be minimized.

6.2.3 Seismic

The concentrator shall withstand the loads specified for Seismic Zone 3 in the Uniform Building Code. The seismic spectrum presented in A.E.C. Regulator Guide 1.60 shall be used as a guide. Realignment of the collectors after a moderate earthquake is allowed.

6.3 Shock and Vibration

All components shall withstand the shock and vibration which will be encountered during fabrication, handling, transportation, hoisting, and assembly.