

# THE MOON AS A SOLAR POWER SATELLITE

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## Abstract

This paper discusses a modified version of the Satellite Solar Power System, (SPS), originally proposed in 1968 by Dr. Peter Glaser of MIT, as a series of large, photovoltaic solar collector satellites orbiting at geosynchronous (22,500 mile) altitude. The solar energy collected would be beamed to the earth surface 24 hours a day, using microwave energy (which can pass through cloud cover). This system was studied extensively by several large aerospace companies under the joint sponsorship of the D.O.E and NASA between 1977 and 1980.

The proposed modifications to this concept presented herein uses the moon as the "satellite". This allows a much larger system to be built at lower cost, because it allows the use of materials making up the lunar surface to be used to construct the solar power system, thereby eliminating the requirement for lifting them up from the earth. In addition, this approach results in a much greater ease of assembly because of the gravity of the moon.

Two configurations of such a system are described:

1. A series of photovoltaic collectors situated near the lunar poles, which can generate a net electrical energy on the earth of 60 billion Kwatt-hours per year.
2. A series of concentrating trough collectors using lunar gravity to shape a catenary cylindrical concentrator, driving Stirling Cycle electric generators, situated at the lunar equator, which can generate a net electrical energy on the earth of greater than 5.3 trillion Kwatt-hours per year.

Both systems are described in detail, and their advantages and disadvantages relative to the original geosynchronous SPS are discussed. The expected performance of these systems is analyzed based upon direct extrapolations from the analyses presented in the 1980 D.O.E. and NASA study reports, combined with recent performance measurements obtained with Stirling Cycle electric generators by NASA Lewis Research Center and others.

A method of funding this proposed project by the U.S. Government is also discussed which would cause no increase in any current U.S. taxes. Furthermore, by distributing the electrical energy generated by this system on to existing electrical power grids as a "World TVA", the receipts from electrical energy consumers at the current rate of 10 cents per Kwatt-hour could be used to retire the U.S. National Debt, and/or reduce income taxes.

Finally, the implementation of such a system, which could be accomplished within a period of than 10 years, would reduce the world emission of greenhouse gases, not to the Kyoto-desired level of 1990, but to the level of 1890.

## Introduction and Background

The Satellite Solar Power System, (SPS), was originally proposed in 1968 by Dr. Peter Glaser of MIT, as a series of large, photovoltaic solar collector satellites orbiting at geosynchronous (22,500 mile) altitude. The solar energy collected would be beamed to the earth surface 24 hours a day, using microwave energy (which can pass through cloud cover).

In this paper I propose a modified version of the Satellite Solar Power System, (SPS), using the moon as the "satellite". The original SPS was studied extensively<sup>1</sup> under the joint sponsorship of the D.O.E and NASA between 1977 and 1980.

These studies concluded positively<sup>2</sup> as to this concept's feasibility in hardware, legal, environmental, health, and societal acceptance areas. Unfortunately, in the 1980's President Reagan, proclaimed "Morning in America" but didn't see the sun.

## Description of the Lunar-Based Solar Power System

The overall advantages of a Solar Power Satellite are summarized in Table I.

Figure 1, shows the reference system configuration excerpted from 1977-1980 D.O.E. studies, consisting of a 55 km<sup>2</sup> photo-voltaic orbiting collector and a 1 km<sup>2</sup> transmitting microwave antenna. The similarly excerpted Figure 2 shows a 10 x 13 km elliptical microwave rectenna below the geostationary satellite. Figure 3 shows the energy distribution calculated in the studies as defined by the diffraction limit of the transmitting antenna from a geosynchronous altitude. (As is discussed later in this paper, in order to achieve the same pattern width the lunar transmitting antenna on the moon must be ten times larger in diameter, but this is practical because of the finite gravity on the moon.) Figure 4 shows the breakdown of the collected solar energy and the conversion efficiencies up to the output to the electrical power grid on the earth as was calculated in these studies.

I will first discuss a direct transfer of this highly defined system to a lunar platform, and will then discuss what I believe should be the ultimate lunar SPS configuration.

Figure 5 shows the reference system broken into an array of ten, 100 meter high, by 55 km long, 2/1 concentrating, Ga As collectors. Notice that the aluminized polyester concentrating mirror uses the lunar gravity and lack of wind to effectively save half the cost of the collector.

These collectors are located  $6^\circ$  from the lunar pole to account for the sun's  $\pm 5^\circ$  elevation angle variation caused by the lunar orbit's inclination to the ecliptic plane.

Table II lists the technical advantages of the lunar-based SPS compared to the Geosynchronous SPS. defined in the above-mentioned Studies, Table III lists its disadvantages, and the means of dealing with them.

As is shown in Table III, the moon does not face the same surface on the earth as does a Geosynchronous satellite in Dr. Glaser's original proposal. However, the entire earth can benefit from this electrical energy, and, as shown in Figure 6, three or four rectennas would be located  $120^\circ$  or  $90^\circ$  apart in longitude on the earth surface, and the U.S. would once again become an energy exporting nation. In order to eliminate the possibility of accidentally scanning a high power microwave beam across the earth surface while switching between ground rectennas, I propose two transmitting antennas on the moon. One of these would be aimed at one rectenna, and the second aimed at the next rectenna to which power would be switched as it comes over the earth's horizon. While it is transmitting power, each transmitting antenna, (whose diameter may have to be as large as 10 Km to achieve the required diffraction-limited microwave beam size) will be scanned around the moon's polar axis through approximately  $1^\circ$  in any 8 hour period. This can be practically accomplished by achieving the effective 10 KM diameter with an array of smaller antennas, ganged together, using the same principles as is used in large baseline radio astronomy antennas, or preferably, by increasing the ground rectenna area, or by increasing the 2.45 GHz transmitting frequency, or both.

Of course, the moon rotates relative to the sun also, so at least three such solar collectors will be required, located  $120^\circ$  apart in longitude around the lunar pole. At any time, the combined output of two collectors will be equal to or greater than the peak output of one collector directly facing the sun. The distance between the collectors is about 250 KM, a distance amenable to standard high voltage conductive transmission, microwave beamed power transmission, or superconductor transmission.

The minimum 5 Gigawatt input of this system at the power grid is equivalent to 46 Billion kilowatt hours per year, which, at the current average price of ten cents/kwhr., represents a revenue of \$4.6 Billion per year. If we complete this "necklace" around the lunar pole, the

collection area increases to  $355 \text{ km}^2$ , and the revenue increases to \$29.7 billion per year. If we use both the north and south poles of the moon the revenue increases further to \$59.4 Billion per year. Of course, once the solar cell fabrication facilities on the moon are in operation, the collection area can increase indefinitely.

However, I believe that the system shown in Figures 7 and 8 represents a more efficient and lower-cost-per-kilowatt design than the reference system defined by the DOE and NASA studies. This system, uses the attributes of the lunar platform more efficiently, and uses a higher efficiency solar-to-electrical power conversion.

Studies of Stirling cycle solar energy conversion systems, conducted at Sandia National Laboratories and at NASA Lewis Research Center<sup>3</sup> have been conducted. These have shown that end-to-end solar-to-electricity efficiencies higher than 30% are feasible, and as high as 40% if high temperatures for the gas can be reached through the use of high gain solar concentrators. This is up to 2.5 times the efficiency of the photovoltaic reference approach studied in 1977. The system shown in Figure 7, which girds the lunar equator, uses the lunar gravity and windless environment to achieve a very low cost cylindrical concentrator composed entirely of aluminized polyester film hanging in a *catenary*, (which closely approximates a parabola). This catenary focuses the sun on a series of linear pipes containing the Stirling cycle gas. This gas is heated to increase its pressure, thus driving the Stirling engines distributed along this linear concentrator, which generate the electricity. No solar tracking is required because it is an optical characteristic of a cylindrical mirror that its line focus is maintained independent of the incident angle of the incoming rays in the plane of the cylindrical axis, and the maximum  $\pm 5^\circ$  angular variation of the sun in the orthogonal plane is accommodated by the width of the black pipe collector. The availability of an unlimited heat sink less than  $100^\circ\text{K}$  on the dark side of the moon and in the shadow of the reflector, should allow even higher efficiencies than have heretofore been achieved. The use of pumped heat pipes to conduct the high temperature gases in the Stirling cycle to this unlimited heat sink should be able to achieve these high efficiencies.

The equatorial location results in 10,000 km. of collector length, with  $3,330 \text{ km}^2$  of net collecting area at any one time. As is shown in Figure 9, since the Stirling cycle efficiency is approximately twice that of the photovoltaic cell configuration, this system produces a net energy of 5.31 Trillion kwhrs per year, generating a yearly revenue of \$531 billion at 10 cents/kwhr.

In this ultimate system, the power distribution to the earth should be maintained 24 hours a day. This can be accomplished through the use of two "transponder" satellites operating at points  $120^\circ$  apart in the lunar orbit, as shown in Figure 8. These transponder satellites would consist of rectennas receiving microwave energy from the

moon, and two transmitting antennas performing the same function as the transmitting antennas to the earth from the lunar surface described above. These transponder satellites would be fabricated on the earth, assembled in lunar orbit, and located and maintained in their orbital positions using electrically driven ion engines driven from electricity received by their rectennas. It should be emphasized that these transponder satellites do not require the same large rectennas as are required on the earth because a higher microwave transmitting frequency than 2.45 GHz. can be used to beam the energy from the moon to these transponders.

### Funding and Cost Payback Considerations

Upon completion and expansion of this ultimate system, the revenues could be used to retire the U.S. National Debt and ultimately replace the income tax with an electric bill equal to what we are already paying.

Therefore, this ultimate system can be said to give the U.S. electorate what in recent years they have shown that they want, namely, a free lunch!

Now I will discuss how I propose to obtain the seed money to pay for this project. (Once the revenues from the electric power begin, these revenues can be fed back into the system to expand it, without further tax based input).

I propose to fund these initial phases of this project with, read my lips: No new taxes!

In order to accomplish this seeming feat of magic, we must first acknowledge that the "Emperor has no clothes"! By this I mean that we must finally acknowledge that for fifty years the U.S. defense budget, having a cumulative total of over \$4 trillion, has incorporated a large percentage of "make work" WPA programs for the Military Industrial Complex.

For those not familiar with "WPA", it stands for Works Progress Administration, a New Deal program initiated during the Great Depression to get the unemployed back to work on government sponsored programs. WPA paid artists to paint murals, laborers to replant forests, and contractors to build highways, such as the Merritt Parkway in Connecticut on which I drive every day. This parkway includes beautiful, artistic overpass bridges incorporating different and original artistic frescoes, which were the "S level" electrical components of the Thirties.

In fact, this useful version of WPA is alive and well today and residing in Japan. We call it "Japan Incorporated". If you harbor any remaining doubts relative to this WPA thesis, I will now dispel them with these two news items:

1. That "Superhawk", Senator Edward Kennedy, was reported to be in favor of continuing to build the unneeded Sea Wolf Submarines at Groton

Connecticut (to which some of his constituents commute every day).

2. The House and Senate Democrats passed a budget allocation continuing the fabrication of the second Sea Wolf Submarine over the objection of that "Superdove", President George Bush.

How would we transfer the funds presently going to useless defense programs to a Lunar Solar Power Satellite? We would simply convert the defense contracts covering technical disciplines similar to those in the Solar Power Satellite, with the management of these contracts being retained by the present military responsible personnel. Therefore, there should be no extensive layoffs in the Defense Establishment. If you think this is impractical, I can recall for you two precedents:

1. General Leslie Groves, successfully managed the Manhattan Project for the development of the Atomic Bomb.
2. Rockwell International stipulated that its subcontractors for the B-1 bomber must come from all 50 states, even though capable subcontractors were available locally.

For over 19 years I have written letters expounding this misappropriation of U.S. engineering talent to all U.S. Presidents, many Senators, Congressmen, journalists, Presidential candidates, and Presidents Gorbachev and Yeltsin. I have never received a single direct response to any of these letters, nor any refutation of my arguments. This indicates to me the cataclysmic lack of the "Vision Thing" in both the executive and legislative branches of our government!

In closing, I would like to read two quotations from these letters

From a letter to President Gorbachev

"When you address the "Military Industrial Complex", your attitude is that it is the incarnation of evil, intent only upon destroying the Soviet Union by military threats or application of military advantage. Since I am a member of the "Military Industrial Complex", I assure you that for me, or any one I know, this is not the case. However, when it comes to putting bread on the table, most people (including me) will justify their work in the Defense Establishment as assigned tasks that must be done properly and whose parochial justifications may even be advocated so that work accomplished on an ongoing project is not "wasted" by its cancellation. I submit to you that this insidious "work ethic" is the underlying cause of the Arms Race to a much greater extent than any military or political necessities."

From a 1986 letter to President Reagan

"It might be of interest for you to know that I am, by profession, an electro-optical engineer, whose hey-day would come with the widespread implementation of the systems in "Star Wars". However, I consider such work a prostitution of my art, which, unfortunately, I, and a majority of my professional associates, do as a matter of economic survival."

The above quotation from my letter to President Reagan proved to be a prediction of the future.

I am very proud of my conceptual design effort on the earth attitude sensor used on the Cosmic Background Explorer (COBE) spacecraft, which made a historic discovery of "wrinkles" in the Universe, and ratified the "Big Bang" Theory. I am not proud of my design stewardship of a Strategic Defense Initiative infrared scanning camera system, which was to be flown on the Space Shuttle. After \$15 million had been spent and the camera was near completion, the whole >\$200 million program was canceled due to insufficient funds, whereby this camera has now taken its place among its multi-million dollar predecessors, gathering dust in a warehouse.

## References

1. "Satellite Power System Concept System Definition Technical Assessment Report" NASA December 1980
2. "Environmental Assessment for the SPS Microwave Health and Ecological Effects" EPA November 1980
3. "Space Power Free Piston Stirling Engine Scaling Study" Mechanical Technology Inc. NASA CR-182218 October 1, 1989

## TABLE I

### OVERALL ADVANTAGES OF A SATELLITE SOLAR POWER SYSTEM

1. MAJOR REDUCTION IN THE "GREENHOUSE EFFECT" GLOBAL WARMING CAUSED BY BURNING FOSSIL FUELS
2. A TOTALLY "CLEAN" ELECTRIC POWER GENERATION WITH NO NUCLEAR OR TOXIC WASTE
3. THE APPLICABLE TECHNOLOGY IS AVAILABLE TODAY, AND REQUIRES NO SCIENTIFIC "BREAKTHROUGH" AS DOES HYDROGEN FUSION
4. APPLICATION OF U.S. ENGINEERING TALENT TO USEFUL AND CONSTRUCTIVE ENDS
5. A DEFUSING OF THE OIL-DEPENDENT POWDER KEG IN THE MIDDLE EAST
6. UNLIMITED AVAILABILITY OF CLEAN ELECTRIC POWER WORLDWIDE WILL BENEFIT DEVELOPING COUNTRIES, SAVE THE RAIN FORESTS, AND ELIMINATE ACID RAIN
7. THIS PROGRAM WILL ACCELERATE THE DEVELOPMENT OF LOWER COST EARTH-MOUNTED SOLAR PHOTOVOLTAIC CELLS DUE TO QUANTITY PRODUCTION
8. THE RECTENNAS RECEIVING THE MICROWAVE ENERGY ALLOW 80% OF THE SUNLIGHT TO PASS BY. BY MOUNTING THESE RECTENNAS ON FLOATING ISLANDS IN THE OCEAN, SIPHONING OFF SOME OF THE RECEIVED MICROWAVE ENERGY FOR USE IN DESALINIZATION OF SEAWATER, FOOD CAN BE GROWN IN ABUNDANCE TO FEED THE WORLD
9. THIS PROGRAM IS IDEAL FOR AN INTERNATIONAL CO-OPERATIVE EFFORT, WHERE EVERY NATION BENEFITS, THUS MAKING WARS AND CONFLICTS BETWEEN THE PARTICIPANTS UNLIKELY

**TABLE II**  
**TECHNICAL ADVANTAGES OF A LUNAR-BASED SPS**

1. THE MOON IS A MUCH MORE RELIABLE AND STABLE PLATFORM THAN A GEOSYNCHRONOUS SPACECRAFT.
2. THE MOON HAS UNLIMITED EXPANSION SPACE FOR ADDITIONAL SOLAR POWER CAPACITY.
3. THERE IS NO INTERFERENCE WITH VISIBLE ASTRONOMY DUE TO SUNGLINTS OFF THE SOLAR COLLECTORS, AS THERE IS WITH THE GEOSYNCHRONOUS SYSTEM.
4. RAW MATERIALS FOR INCREASED SOLAR COLLECTION CAPACITY ARE AVAILABLE DIRECTLY FROM THE MOON AND DO NOT HAVE TO BE LIFTED FROM THE EARTH.
5. COLLECTOR AND TRANSMITTING ANTENNA ASSEMBLY IS MUCH SIMPLER AND CHEAPER UNDER LUNAR GRAVITY THAN IN A ZERO G ENVIRONMENT
6. LOCATION OF THE COLLECTORS NEAR THE LUNAR POLE(S) PROVIDES:
  - THE NATURAL ARRANGEMENT FOR A CATENARY (PARABOLIC) MIRROR OPTICAL CONCENTRATOR BELOW A NEAR VERTICAL COLLECTOR.
  - THE COLD AVERAGE LUNAR SURFACE TEMPERATURE NEAR THE POLES MAKES AN EXCELLENT HEAT SINK FOR THE PHOTOVOLTAIC SOLAR ARRAYS, THUS MAKING THEM MORE EFFICIENT.

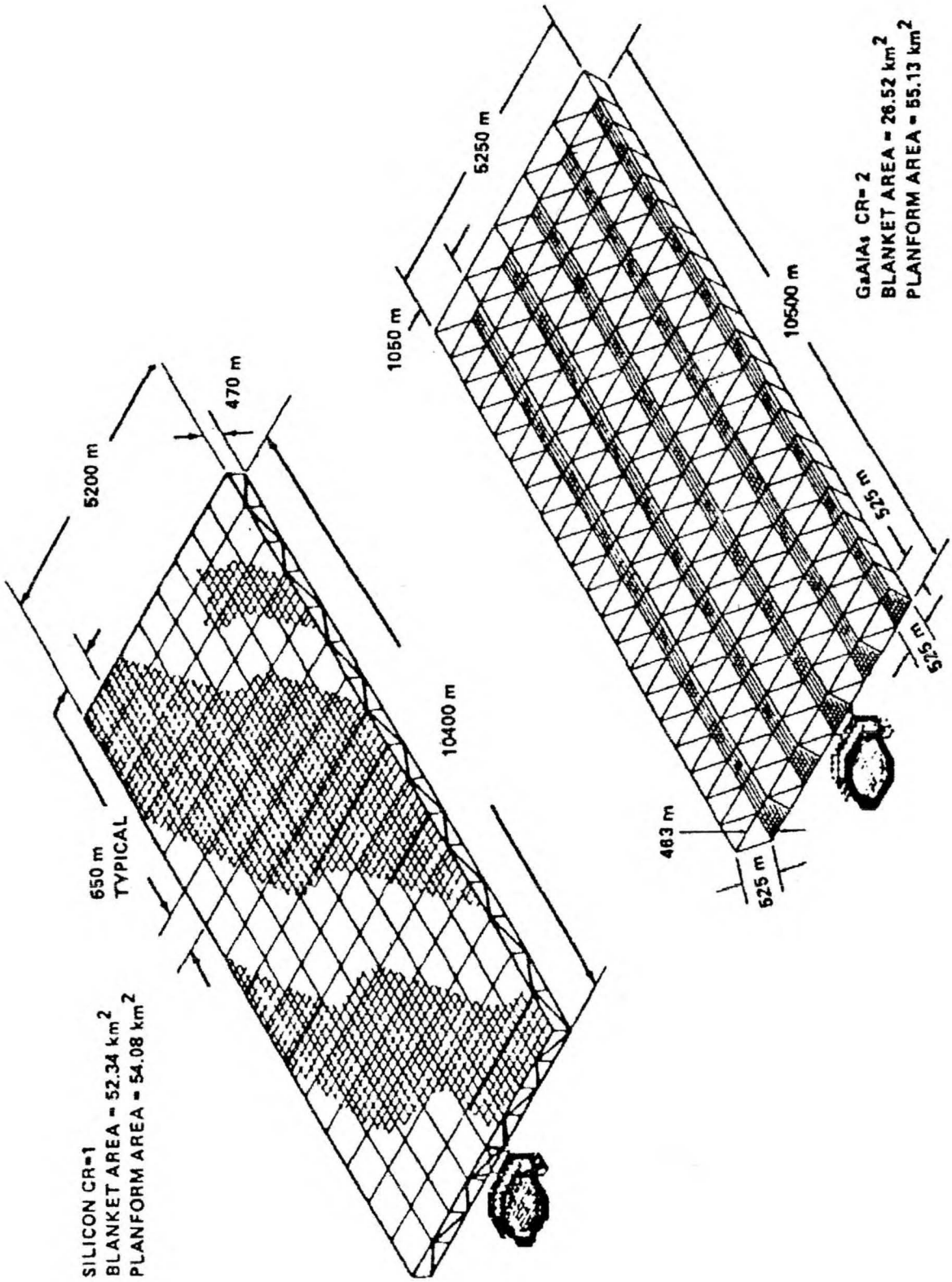
**TABLE III**

**TECHNICAL DISADVANTAGES OF A LUNAR VS. A GEOSYNCHRONOUS ALTITUDE SPS**

1. EARTH ROTATES UNDERNEATH THE TRANSMITTING ANTENNA IN A LUNAR SPS
2. THE MOON IS APPROXIMATELY 10 TIMES FARTHER FROM THE EARTH THAN GEOSYNCHRONOUS ALTITUDE, THUS REQUIRING A 10 KM. DIAMETER MICROWAVE TRANSMITTING ANTENNA FOR THE SAME DIAMETER EARTH RECTENNA DIMENSIONS
3. WITHOUT TRANSPONDING SATELLITES IN THE SOLAR POWER SYSTEM, THERE WOULD BE A DISCONTINUOUS SOLAR POWER INPUT FOR 8 HOURS OUT OF 24 HOURS FOR ANY LOCATION ON THE EARTH

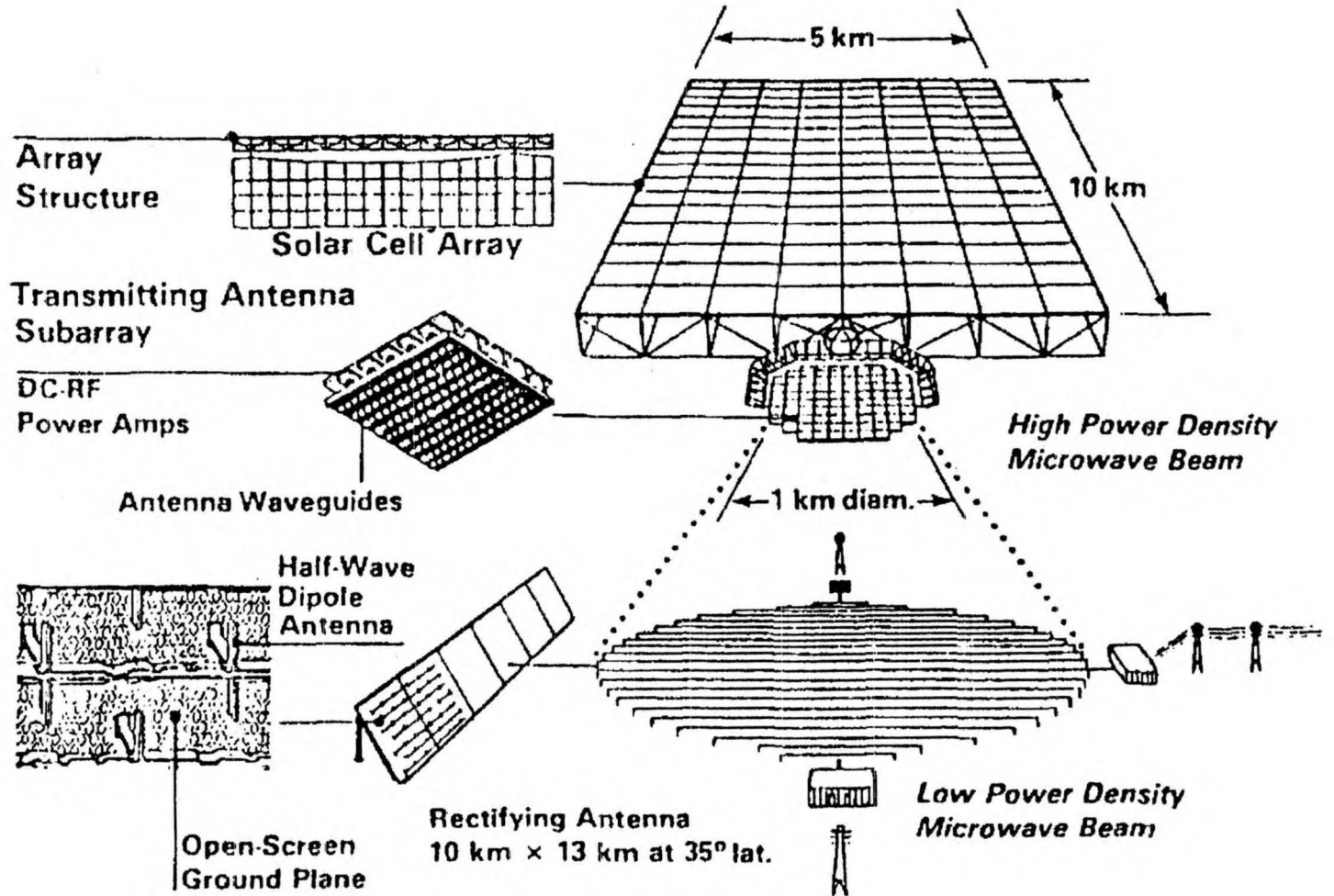
**PROPOSED SOLUTIONS**

1. LOCATE RECTENNAS AT THREE OR FOUR LONGITUDES ON THE EARTH. THIS WOULD PROVIDE SOLAR POWER TO OTHER NATIONS EXCEPT THE U.S., AND WOULD MAKE THE U.S. AN ENERGY EXPORTING NATION ONCE AGAIN
2. USE A LARGE BASELINE ARRAY OF TRANSMITTING ANTENNAS ON THE MOON (SIMILAR TO THOSE USED CURRENTLY FOR RADIO ASTRONOMY), OR INCREASE RECTENNA DIMENSIONS ON THE EARTH, OR INCREASE 2.45 GHz. MICROWAVE TRANSMITTING FREQUENCY TO >2.45 GHz. OR ALL OF THE ABOVE
3. ADD TWO TRANSPONDER SATELLITES OPERATING 120° APART IN THE LUNAR ORBIT, AND ADD TWO MORE TRANSMITTING ANTENNAS ON THE MOON. THIS ULTIMATE SYSTEM WOULD PROVIDE SOLAR POWER TO THE ENTIRE WORLD 24 HOURS/DAY.

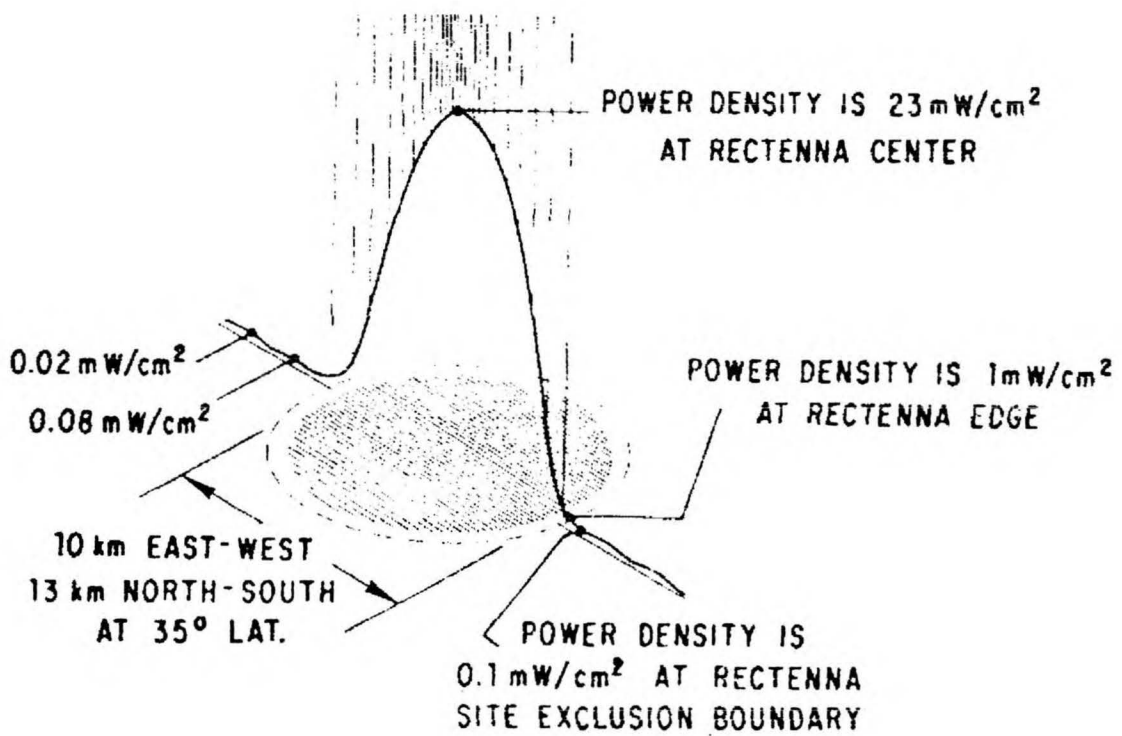


**FIGURE 1 SPACECRAFT POWER SYSTEM (FROM 1977-1980 DOE STUDIES)**

**FIGURE 2 COMPONENTS OF SPACECRAFT POWER SYSTEM  
(FROM DOE 1977-1980 DESIGN STUDIES)**

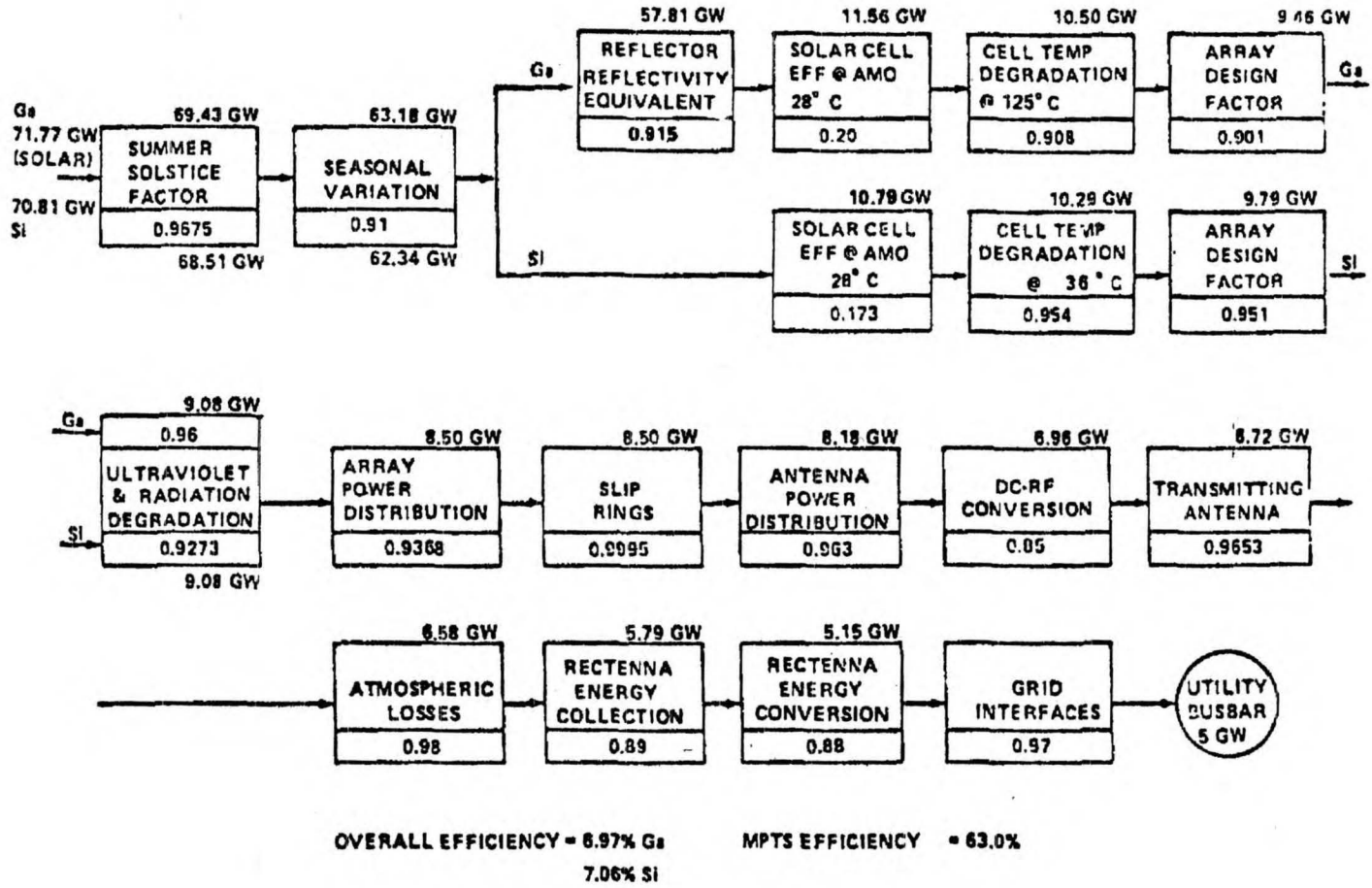






**FIGURE 3 POWER DENSITY OF MICROWAVES ON THE EARTH SURFACE  
(FROM 1977-1980 DOE STUDIES)**

FIGURE 4 SPACECRAFT POWER SYSTEM EFFICIENCIES (FROM DOE STUDIES)



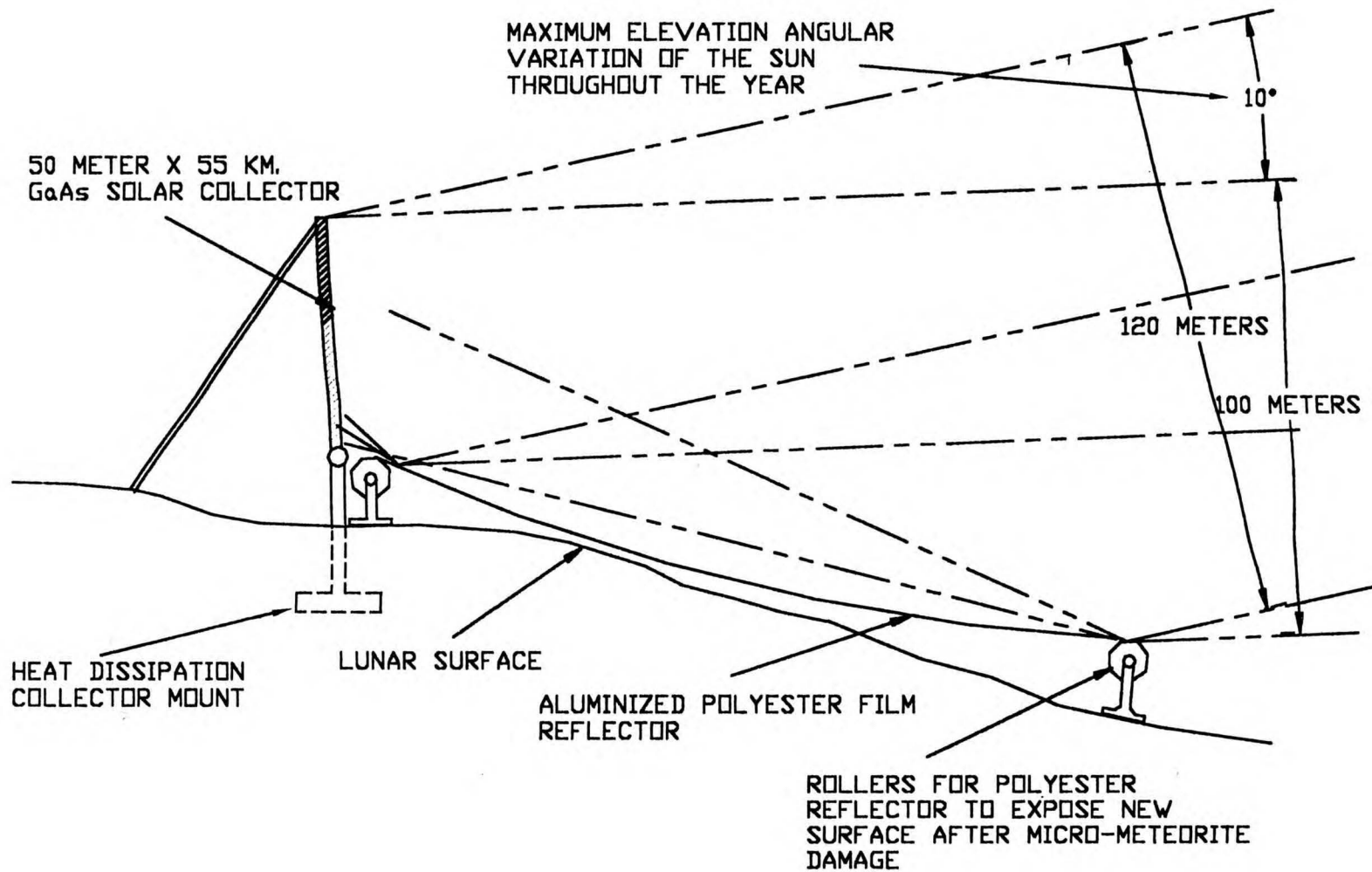
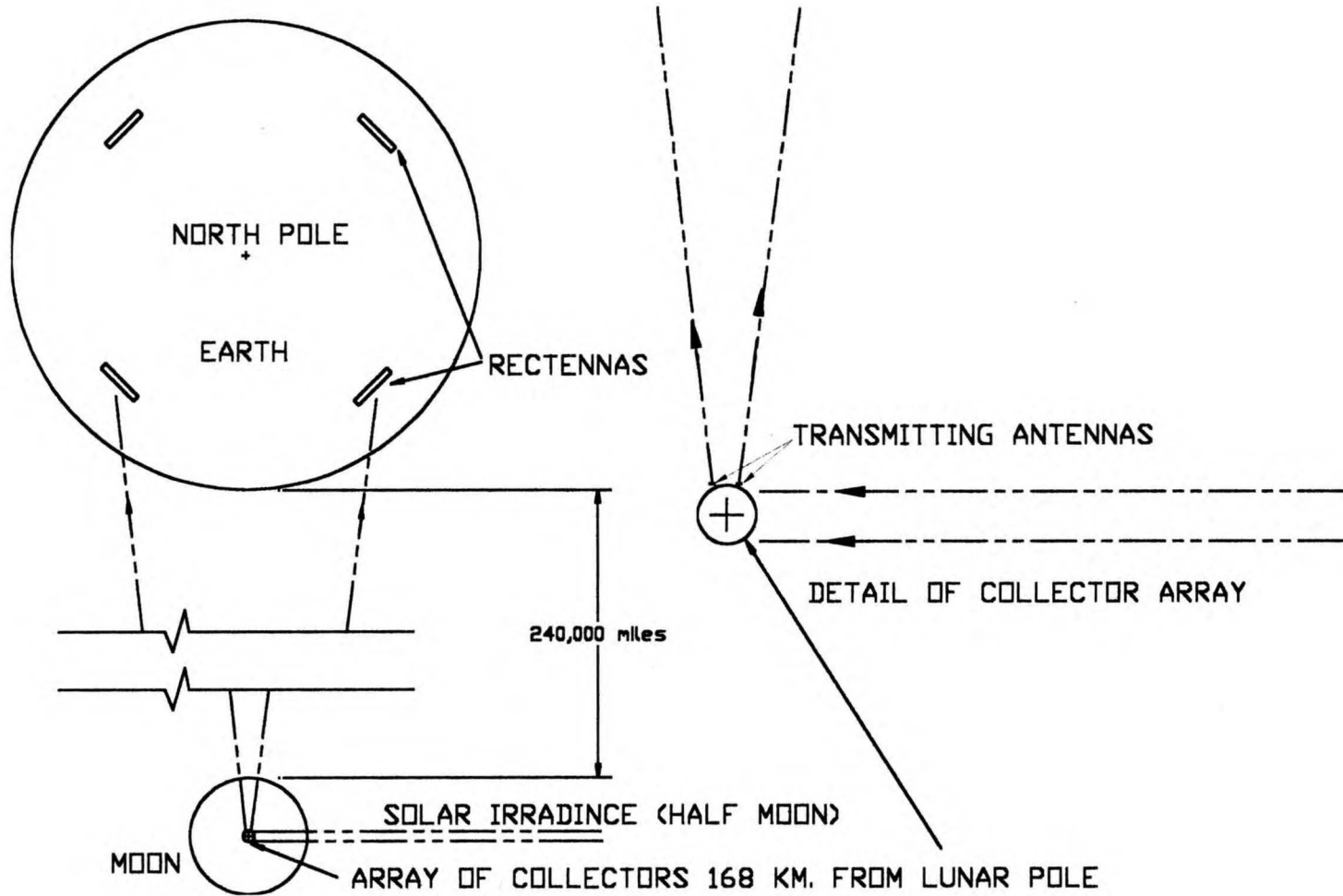
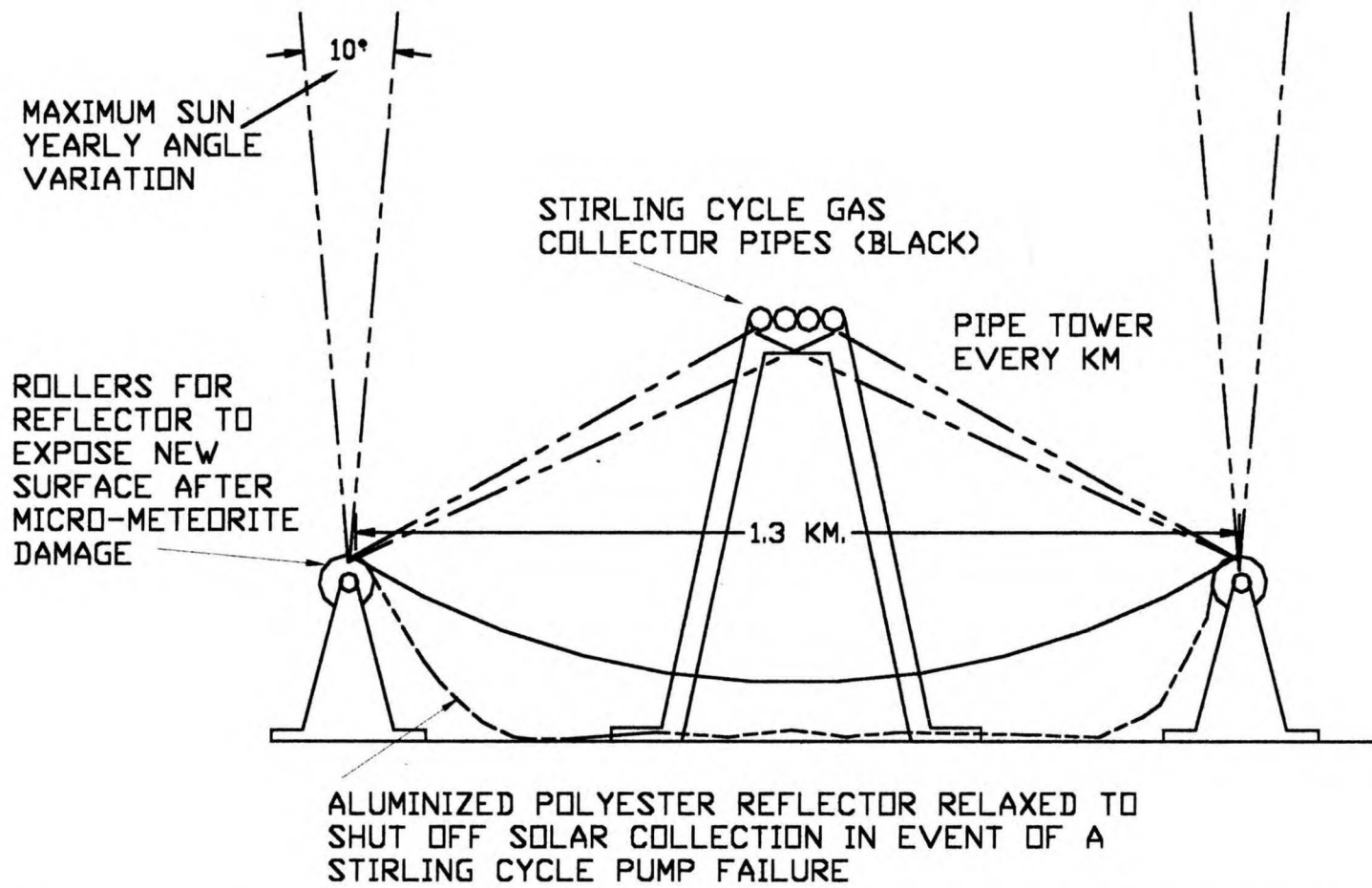


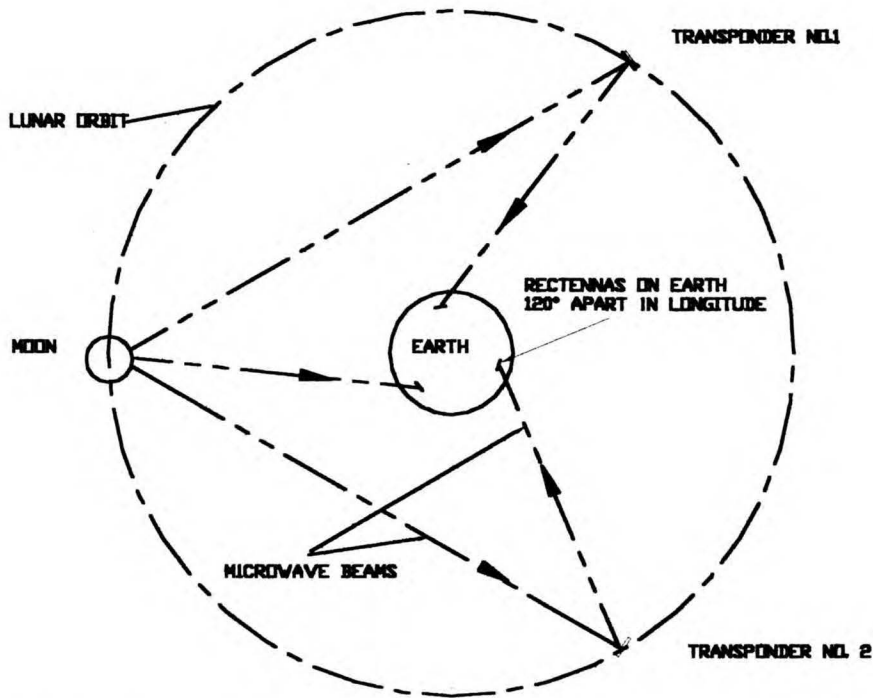
FIGURE 5 LUNAR PHOTOVOLTAIC CONCENTRATING COLLECTOR (5 COLLECTORS PER SITE)



**FIGURE 6 MICROWAVE POWER TRANSMISSION FROM MOON TO EARTH (PHOTOVOLTAIC SYSTEM)**



**FIGURE 7 OPTIMUM LUNAR CONCENTRATING SOLAR COLLECTOR USING STIRLING CYCLE ENGINES AT THE LUNAR EQUATOR**



**FIGURE 8 CONTINUOUS WORLD-WIDE POWER TRANSMISSION CONFIGURATION**

$$\frac{\text{OPTIMUM SYSTEM COLLECTOR AREA}}{\text{REFERENCE SYSTEM* COLLECTOR AREA}} \times \text{NET GWATTS OF REF.} \times \frac{\text{STIRLING EFFICIENCY}}{\text{PHOTOVOLTAIC EFFICIENCY}}$$

$$= \frac{3.330 \text{ KM}^2}{55 \text{ KM}^2} \times 5.0 \text{ GWATTS} \times \frac{2}{1}$$

= 606 GIGA-WATTS = 0.606 TRILLION WATTS

YEARLY ENERGY AVAILABLE = 0.606 TRILLION WATTS X 8750 HOURS/YEAR  
 = 5.31 TRILLION KWATT-HOURS/YEAR

**DOLLAR VALUE OF YEARLY ENERGY @ 10 CENTS/KWATT-HOUR = \$531 BILLION**

**FIGURE 9 PERFORMANCE OF OPTIMUM EQUATORIAL LUNAR SOLAR POWER SYSTEM**

\* REFERENCE SYSTEM DESCRIBED IN FIGURES 1-3 AND EXTENSIVELY ANALYZED IN IN DOE SPS STUDY PROGRAM 1977-1980