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WEIGHTLESS SOLAR ENERGY COLLECTION

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ABSTRACT

Weightless, tracking, concentrating solar collectors are described emphasizing balloon shape, balloon materials, balloon fill gas, balloon tethering, probes for collecting solar energy as heat, probes for direct conversion to electricity, probe cooling systems, tracking mounts, thin-wall conical reinforced concrete bases, lightning rods, aircraft warning lights, estimated costs and anticipated performance.

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Introduction

Weightless, tracking, concentrating solar energy collectors represent an advanced power concept which are described in terms of the technology of today. The description refers to the following items:

1. Balloon shape
2. Balloon materials
3. Balloon fill gas
4. Balloon tethering
5. Probes for collecting solar energy as heat
6. Probes for direct conversion to electricity
7. Probe cooling systems
8. Tracking mounts
9. Thin-wall reinforced concrete conical bases
10. Lightning rods and aircraft warning lights

Figure 1 shows details of balloon fabrication

Figure 2 shows details of liquid cooled heat probe at hot end

Figure 3 shows a single receiver power plant

The weightless feature is attained using bouyant fill gas to offset weight of moving parts and prevent large overturning moments at concrete bases. Fill gas pressure will prevent balloon surface flapping to 160 km/hr. Balloon tethers will prevent balloon moving and transfer all wind forces to a single pivot point. Tracking mounts will keep linear energy collecting probes aimed directly at the sun. Tracking mounts will be supported at tops of thin wall reinforced concrete bases and at a height that is one third that of the balloon diameter. Bases will contain a control room, heat exchangers for generating steam, steam turbine generator sets, condensers, condensate pumps and switchgear.

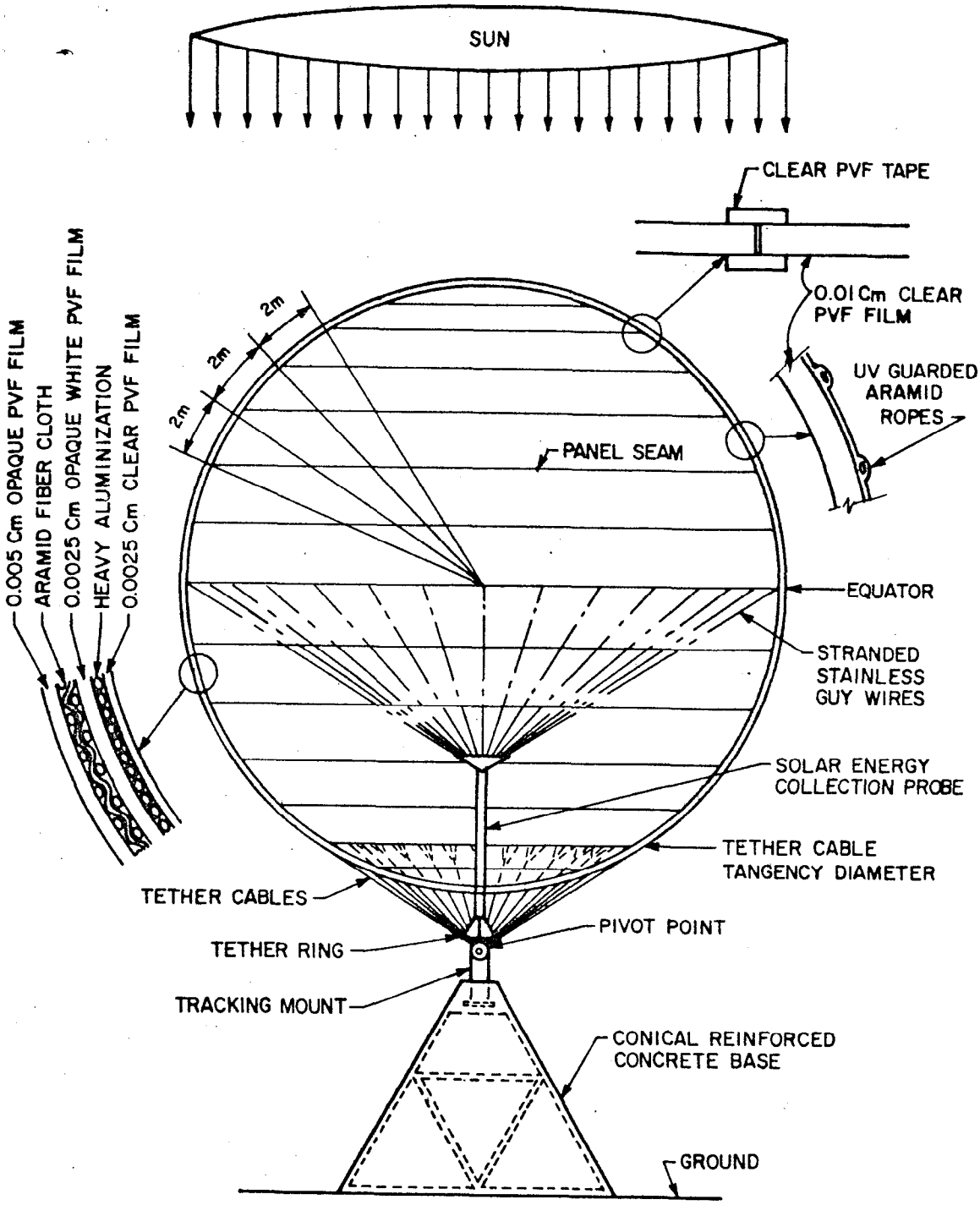
SUN
CLEAR PVF TAPE
0.01Cm CLEAR PVF FILM
UV GUARDED ARAMID ROPES
2m
2m
2m
PANEL SEAM
EQUATOR
STRANDED STAINLESS GUY WIRES
SOLAR ENERGY COLLECTION PROBE
TETHER CABLE TANGENCY DIAMETER
TETHER CABLES
PIVOT POINT
TETHER RING
TRACKING MOUNT
CONICAL REINFORCED CONCRETE BASE
GROUND
0.005 Cm OPAQUE PVF FILM
ARAMID FIBER CLOTH
0.0025 Cm OPAQUE WHITE PVF FILM
HEAVY ALUMINIZATION
0.0025 Cm CLEAR PVF FILM

FIGURE 1

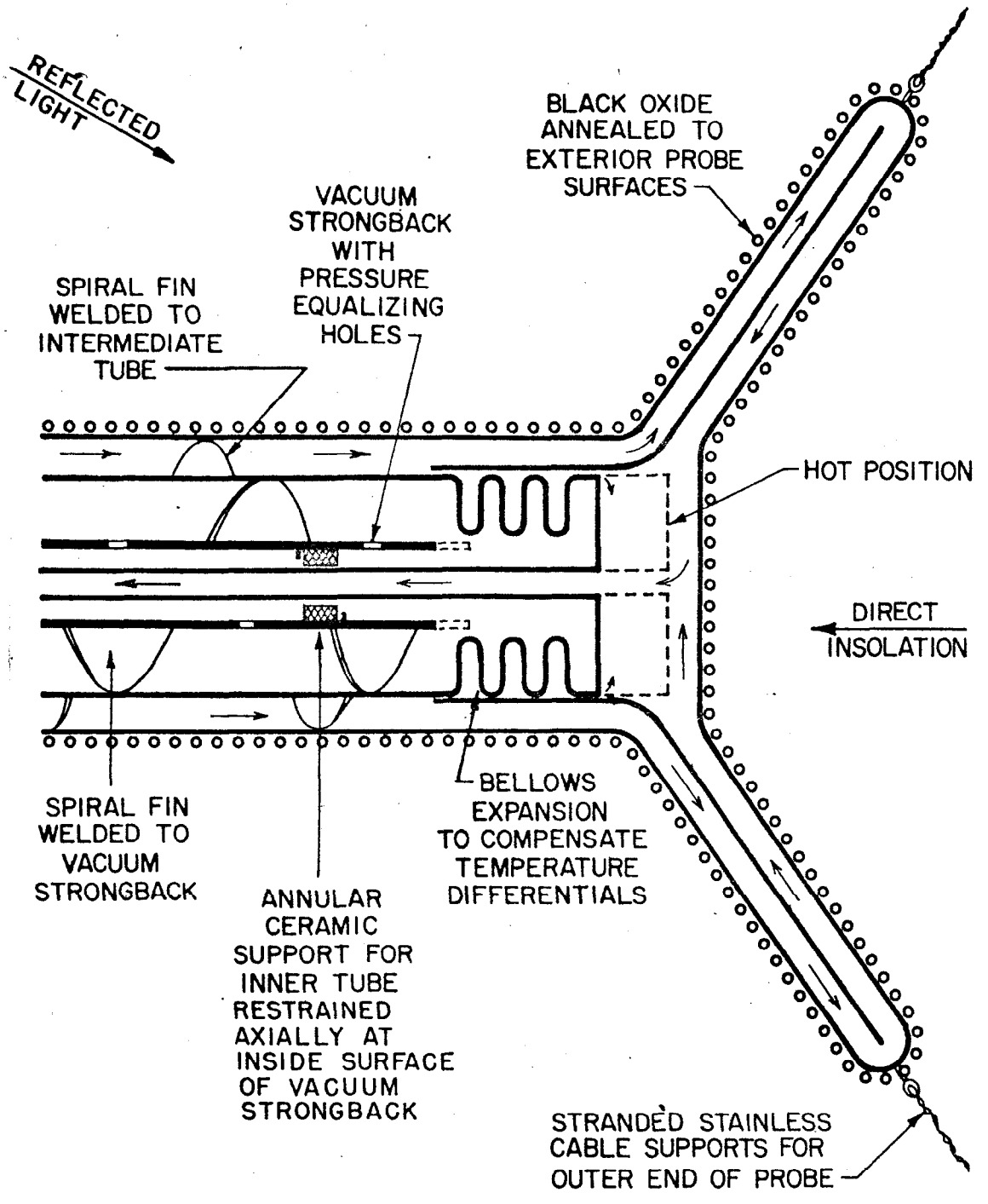
REFLECTED LIGHT
BLACK OXIDE ANNEALED TO EXTERIOR PROBE SURFACES
VACUUM STRONGBACK WITH PRESSURE EQUALIZING HOLES
SPIRAL FIN WELDED TO INTERMEDIATE TUBE
HOT POSITION
DIRECT INSOLATION
SPIRAL FIN WELDED TO VACUUM STRONGBACK
ANNULAR CERAMIC SUPPORT FOR INNER TUBE RESTRAINED AXIALLY AT INSIDE SURFACE OF VACUUM STRONGBACK
BELLOWS EXPANSION TO COMPENSATE TEMPERATURE DIFFERENTIALS
STRANDED STAINLESS CABLE SUPPORTS FOR OUTER END OF PROBE

FIGURE 2

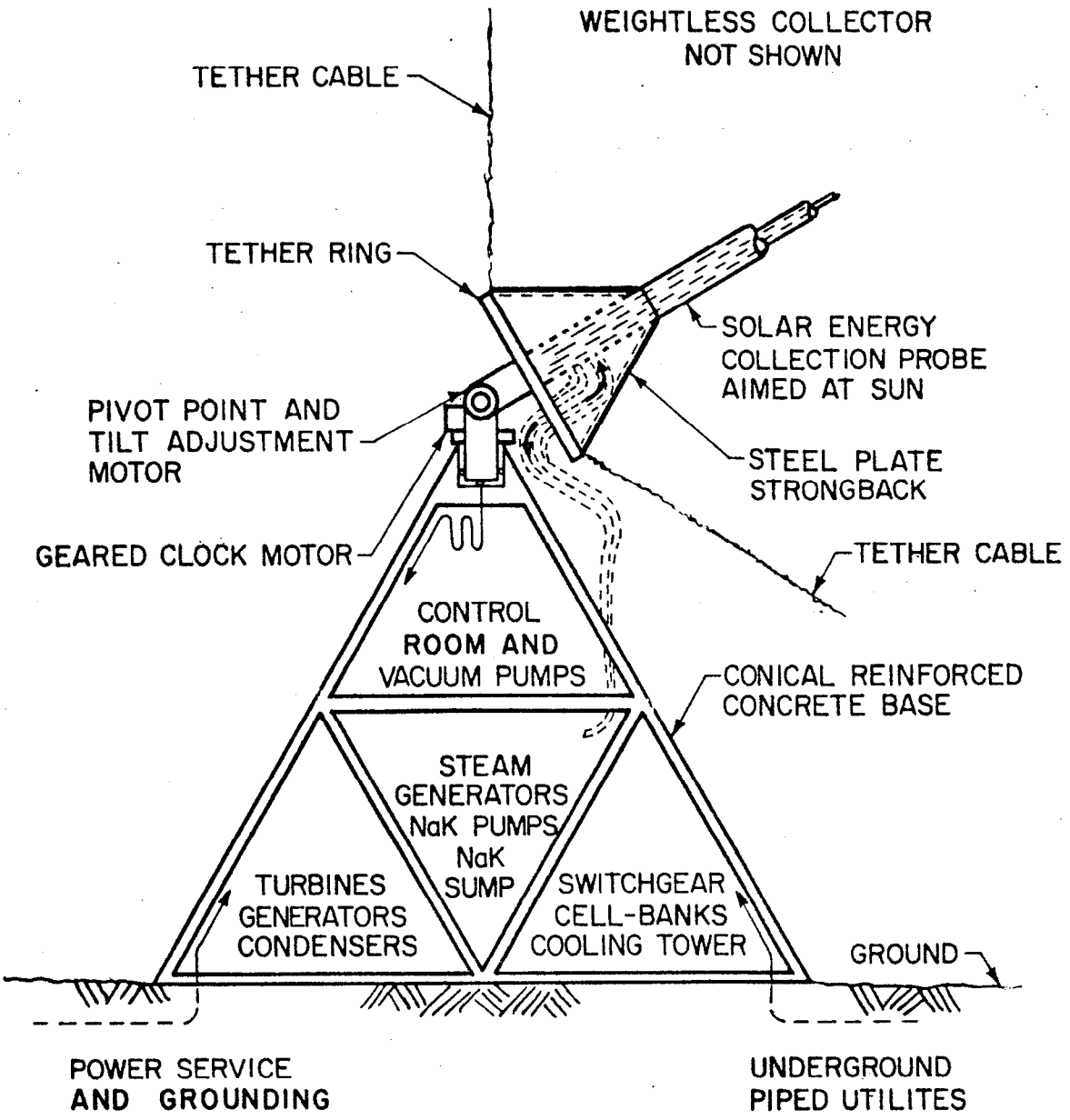
WEIGHTLESS COLLECTOR
NOT SHOWN
TETHER CABLE
TETHER RING
SOLAR ENERGY
COLLECTION PROBE
AIMED AT SUN
PIVOT POINT AND
TILT ADJUSTMENT
MOTOR
STEEL PLATE
STRONGBACK
GEARED CLOCK MOTOR
TETHER CABLE
CONTROL
ROOM AND
VACUUM PUMPS
CONICAL REINFORCED
CONCRETE BASE
STEAM
GENERATORS
NaK PUMPS
NaK
SUMP
TURBINES
GENERATORS
CONDENSERS
SWITCHGEAR
CELL-BANKS
COOLING TOWER
GROUND
POWER SERVICE
AND GROUNDING
UNDERGROUND
PIPED UTILITES

FIGURE 3

Description of Weightless Solar Energy Collector Components and Subsystems

1. Balloon Shape

Balloon shape can be spherical or might be parabaloid. Use of a parabaloid shape for equal collection of solar energy requires more balloon surface area and more rigid criteria for collection at a point receptor which cannot be attained by balloon manufacturing technology or easily by collection technology in view of the very high cost estimates of the power tower. Accordingly, the spherical balloon shape is selected which in turn requires linear collection to the extent of $\frac{1}{4}$ or less of the balloon diameter for probe length dependent on probe shape.

2. Balloon Materials

Previously most balloons have been constructed from balloon skin material which has been cut, paper doll style. Figure 1 shows this approach and indicates the high percentage of wastage. Better these balloons would be constructed using panels concentric about the heat seeking probes so that assembly material and labor are minimized. The clear hemisphere facing the sun is a 0.01 cm thick transparent polyvinylfluoride (PVF) film reinforced at from 1 m/3 to 1 m/2 centers by UV resistant sheathed aramid fiber ropes which, pound for pound, exceed the strength of steel by a factor of five. The reflective hemisphere also facing the sun is a laminate. The inner layer is 0.0025 cm thick transparent heavily aluminized on the side away from the sun. Next is a 0.0025 cm thick opaque white PVF film to improve light capture and prevent oxidation of the aluminum deposition. Next is a reinforcement cloth of aramid fiber. Outer layer is a 0.0005 cm thick opaque PVF film for protection against weather. PVF slowly ages and becomes brittle. After 12 to 14 years, it can shatter if dealt a hard blow or if subjected to fluttering. For the static service under consideration, PVF should last well beyond 13 years, but how much longer is conjectural. Other materials could be used but the consensus at present is that PVF is the best bet.

3. Balloon Fill Gas

The balloon will be filled with gas to a pressure of 0.012 atma (atmospheres absolute) to withstand null point wind pressure of 125 Kg/m^2 when wind velocity is 160 Km/hr. The fill gas density will be 1.14 kg/stere which will provide sufficient bouyancy to offset the wieght of all moving parts. The balloon fill gas will be residuals of ambient air after it has been processed through a Stirling cycle refrigerator to remove all oxygen which liquefies at $90^{o}K$ and 1 atma pressure as opposed to $77^{o}K$ for nitrogen. Essentially the balloon fill gas is nitrogen which can be provided at little cost at any site. Weightless balloons cannot impose an overturn moment against concrete bases irrespective of balloon diameter.

4. Balloon Tethering

Balloons are tethered to a tether ring mounted on the heat collection probe near its pivot point. Tethers are spread from the probe axis so that tangency with balloon surface occurs on a tangency diameter that is one half that of the balloon proper. Tether cables will be of aramid fibers sheathed by UV resistant jackets. Tether cables will be barely separated at the tether ring but will be at 2 m centers at the tangency circle. Close to the balloon surface the tethers are split into tendrils which will be attached to vang pads at 1/3 m centers. When wind forces attempt to dislocate the balloon $\frac{1}{2}$ of the tethers will go into tension and prevent this. The ultimate purpose of the tethers is to transfer all wind imposed forces to the pivot point.

5. Probes for Collecting Solar Energy as Heat

These are fabricated using thin wall boiler tubing mounted concentrically with spiral vaning used to provide structural rigidity. Figure 2 shows a typical design. For large units there is an inner tube. It is stiffened using pierced ceramic ring supports at 3 or 4 m centers. A vacuum tube is shrunk unto the ceramic ring peripheral edges and is the inner structural member of the probe. To reduce the weight of coolant an intermediate tube is loosely fitted over a spiral vane welded to the outer wall of the vacuum tube. This permits the inner tubes to slip with respect to the outer tubes but prevents sag.

A second spiral vane is welded to the intermediate tube to lengthen coolant flow path, increase coolant velocity and its heat exchange characteristic. An outer tube is shrunk unto this spiral vane to insure that the outer tube is the outer structural member of the probe. Liquid coolants spiral outward toward the probe tip and return hot via the inner tube. The two empty annular spaces are evacuated to 10^{-6} Torr to thermally isolate the hot coolant from the cooler coolant. A corrugated guided expansion joint at the tip provides for the relative expansion at start-up. The tip is restrained using stranded stainless wires connected in a similar manner as for the tether cables to equatorial pads. The tip is oversized to allow shortening of the probe while improving heat collection. Outer surface of probe has an annealed coating of black copper oxide to reduce selective solar energy reemmission by a factor of 10. Probe is also stabilized at the balloon surface and at its pivot point to reduce sag and squirm.

6. Probes for Direct Conversion to Electricity

The probes discussed under (5) above would use a liquid metal coolant and operate at the highest temperatures of interest resulting in the powering of thermal-electric cycle having a thermal efficiency of close to 43% since extraction for feedwater heating would not be necessary. It is assumed that long strips of photovoltaic cells can be developed for a spirally wound exterior surface of a probe which would result in the direct conversion at a similar thermal efficiency of close to 43%. Whenever differential costs may become close the switch to direct conversion would take place without regression since direct conversion eliminates the need for the thermal-electric cycle equipment. In this case, operational temperatures would be low, coolant would be water, probe piping would be low alloy steel rather than stainless or super stainless alloys and dc output plus voltage regulation could be fed directly to electrolytic cell-banks for generating GH_2 for storage, transmission and reuse as fuel whether in air or with LOX boil-off. In the previous case the ac power would have to be converted to dc power in order to obtain firm power convenience. It is a happy thought that the initial solar plants will be the most complex and expensive and that solid progress will reduce both of these factors.

7. Probe Cooling Systems

In the collection of solar energy as heat as discussed in (5) above there are two coolants of interest. For process heat, space heating and powering absorption type water chillers the coolant will be water. For power plant applications the coolant will be sodium-potassium (NaK) alloy at close to eutectic mix to obviate trace heating of piping. While NaK heat exchange characteristics are poorer than those of Na they are most adequate for use in linear collectors. All of the available Na technology is applicable to NaK systems and there is less complexity and no chance of freeze-ups. NaK purity is easily obtained using cold traps separated from hot piping by regenerative heat exchangers. Recirculating NaK pumps will operate at close to 500°K and pose no problem. In the direct conversion of solar energy to electricity there is only one coolant to consider. It is water. For large solar power plants this could be river water, lake water from a depth of 17 m, cooling tower water or sea water.

8. Tracking Mounts

These are typically the same two-way systems used in radar applications except they are simpler. The east-west horizontal swing with an at-night return to square one requires a geared clock motor automatically positioned by a micro-processing unit for each day of each year. Vertical tilt of sun-aimed probe will be accomplished using a pneumatic cylinder drive or a motor-driven ratchet automatically positioned by the micro-processor. In the event of coolant failure, the tilt drive would be instructed to rise to vertical or beyond as necessary to prevent burnout.

9. Thin Wall, Reinforced Concrete, Conical Bases

These are two or more equiangular cones constructed of concrete gunnited unto steel reinforcement. When wind forces at the pivot point attempt to overturn the base 50% of the reinforcement goes into tension to prevent it. Calculated thin wall thickness is 8 cm for all balloon diameters of interest. The first cone is upright. Its base area to soil friction factor is sufficient to prevent scudding. Its height is

2/3 of the radius of the balloon collector. This saves investment at dawn and dusk when solar energy collection is dubious and during days when skies are clear. In the two cone case the second cone is inverted within the first cone. The upper half of the first cone contains control consoles, crew amenities and vacuum pumps. The inverted cone contains NaK to water and steam heat exchangers, provides a sump to collect leaks and is operated in a inert nitrogen atmosphere to prevent fires or explosions. All NaK piping would be tube-in-tube with outer annular volume evacuated to provide thermal insulation and a leak pathway to the conical sumps. The lower level surrounding the inverted concrete cone is availabe for turbine-generator set(s), switchgear, station parking, condenser cooling equipment and space for underground piped and electrical utility connections. The space extraneous to these conical power houses and under the balloon collector overhang can be used for agricultural, parking or other low headroom purposes. Figure 3 shows a typical arrangement.

10. Lightning Rods and Aircraft Warning Lights

Optimum balloon diameters for power plant service are from 30 to 240 m. This makes it necessary to provide lightning rods and aircraft warning lights. Standoffs would be of ceramic or plastic.

Cost and Performance of Weightless Solar Energy Collection Systems

This type of collector will weigh less, unbouyed, than any other collection system. Accordingly its overall cost should be less than any other collection system. Diameters investigated range from 5 m to 762 m. As might be expected small diameters and large diameters are expensive. Over a wide range, however, the collector estimated cost holds very close to 50 USD per m^2. This is under 5 USD per sq. ft. The estimated cost of weightless balloon collectors at a design coolant temperature of 1506°K is under 260 USD per KW. Concentration factor is close to 400. Collection efficiency is 64% at 1506°K output. A power plant having one weightless collector with a 214 m diameter at 1506°K output and an engine efficiency of 73% will generate 6,100 KW at a thermal efficiency of 27%. A large plant having many 214 m diameter collectors could generate 7300 KW per collector at 81% engine efficiency.