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VEDA REPORT 43230-76U/Q0069

NOTES ON THE 5MWth TEST FACILITY AT ALBUQUERQUE

12 October 1976

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NOTES ON

THE 5MWth TEST FACILITY AT ALBUQUERQUE

A COMPARISON OF THE DISPERSED HELIOSTAT FIELD WITH A UNIFIED HELIOSTAT ARRAY

WITH

APPLICATION OF THE UNIFIED HELIOSTAT ARRAY TO CHEMICAL ENERGY STORAGE

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Prepared for

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COMPUTATIONS IN RESPECT TO THE 5MW(th) TEST FACILITY AT ALBUQUERQUE

BASIC DATA

1. Latitude of Albuquerque 35.08^{o}N =
2. Tower height 200' (November Semi-annual review)
3. Computations for local noon, equinox
4. Re: Black & Veatch site plans for heliostat locations
5. Heliostat size 20' x 20' = $37m^2$
6. Insolation level $800wm^{-2}$ ($977.62wm^{-2}$ normal incident energy)

DEFINITIONS

Y = north distance of heliostat row from center line of tower

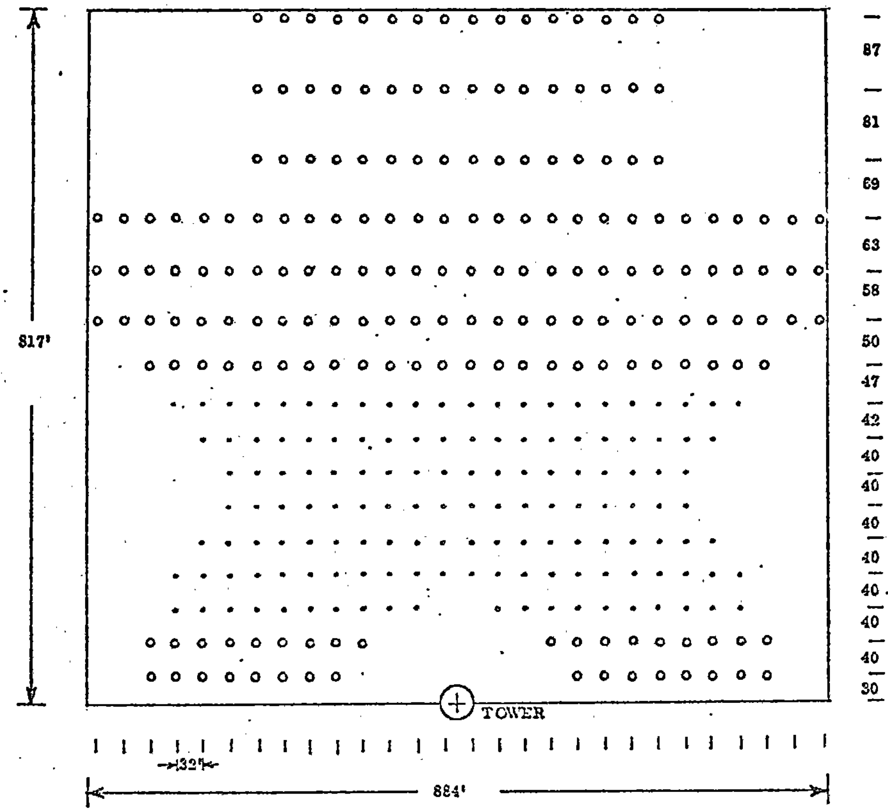
X = east/west distance of heliostat column from center line of tower

θ = angle between vertical and line from central receiver to center line of a row of heliostats

ϕ = angle between vertical and line from central receiver to center line of a column of heliostats

The effective area of a heliostat is proportional to the cosine of the angle between the normal to the heliostat and the angle to the sun. The normal bisects the angle between the sun direction and the central receiver direction. Since the directions can be expressed in north-south and east-west angles, the effective area is then proportional to the product of the cosines of their half angles. For the particular simple case chosen, this constant of proportionality is cosine$\left(\frac{\lambda-\theta}{2}\right)$ cosine $\frac{\phi}{2}$.

The heliostat field described for this project is in two phases. The resultant calculations are shown in Table I. A different heliostat system is proposed, which could be installed at this same site. The resultant calculations are shown in Table II. A comparison of the two systems is shown in Table III. A combination of the two fields is suggested, and the results shown in Table IV.



5MWth Test Facility Site Layout
Figure I

Table I

Phase I Computation Summary		162 heliostats 20' x 20'
	meter^2	feet^2
Initial Heliostat Area	5994	64800
Normal Area	5580.86	60333.6
Average of Cosine Products	0.93108	
Intercepted Energy	5,455,958 watts	
Phase II Computation Summary		190 heliostats 20' x 20'
Added Heliostat Area	7030	76000
Normal Area	6261.66	67693.6
Average of Cosine Products	0.89071	
Intercepted Energy	6,121,522 watts	
Combined Fields Summary		352 heliostats
	meter^2	feet^2
Total Heliostat Area	13024	140800
Normal Area	11642.52	128027.2
Average of Cosine Products	0.90286	
Intercepted Energy	11,577,480	
Energy Contributed by North Row Only	519,984 watts	
	Lateral	Vertical
Aperture Angle of Central Receiver	130.4^o	71^o

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PROPOSED UNIFIED HELIOSTAT ARRAY

The proposed array consists of a group of closely spaced heliostat elements mounted on a sloping south face of a single structure. The structure will be designed with mounting floors for the heliostat pedestals as shown in Figure IIIA. Details of a heliostat arrangement are shown in Figure IIIB. A conceptual drawing of the entire structure is shown in Figure IIIC. Equatorial mountings for the heliostat elements will provide a two axis tracking capability. Although each element will be set at a slightly different angle from all other elements, the drive devices may be ganged, since the units will all turn at one half the apparent sun rate, one rate about the polar axis, the other about the declination axis.

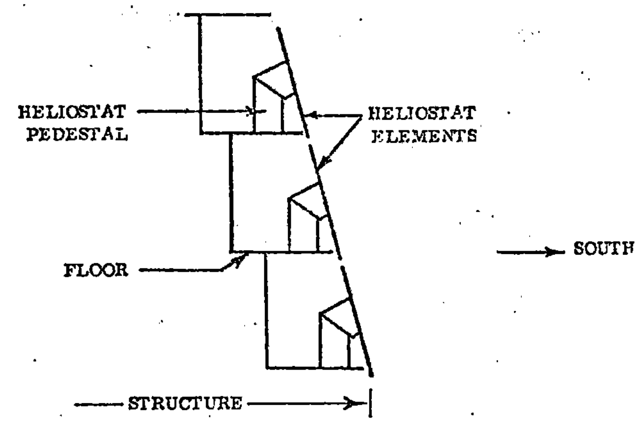
A size for heliostat elements was chosen at 6' x 10' in order to facilitate handling for installation and maintenance. A common gear box design may be used regardless of latitude. Latitude correction for a particular site, including compensating adjustments for small changes in structural accuracy, will be part of the pedestal design.

For a comparative analysis, except for the central receiver aperture angle, no computation on surface reflectivity or other system losses was made since these do not enter into the basic relative efficiency of the mounting arrangement nor field layout.

The north-south inter-heliostat shading problem requiring ground surface space separation does not exist for an array designed as in this approach. The east-west shading problem is identical except that, due to the wider lateral aperture of the central receiver required by the Black & Veatch design, it is more severe in the Black and Veatch design. In the proposed array, no east west shading exists within the range of solar noon ± 2 hours. Even at ± 4 hours, about 75% of the heliostat area is unshaded.

Table II

Proposed Array Computation Summary		2960 heliostat elements 6' x 10'
	meter^2	feet^2
Total Heliostat Area	16499.6 12,600	177600
Normal Area	14888.1	160254
Average of Cosine Products	0.90233	
Intercepted Energy	14,554,889 watts	
	Lateral	Vertical
Aperture Angle of Central Receiver	60.3	14.5^o



SECTION OF UNIFIED HELIOSTAT ARRAY SOUTH WALL

Figure IIA

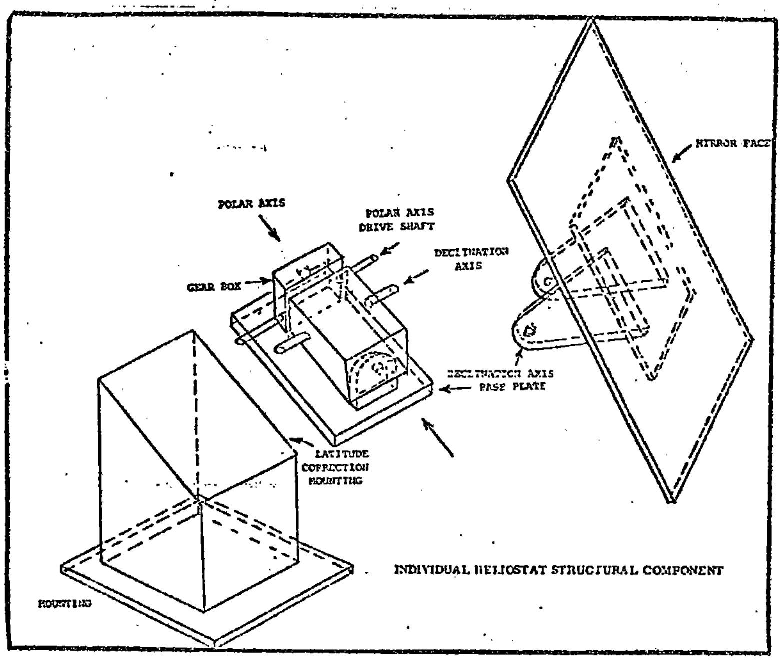


Figure IIB

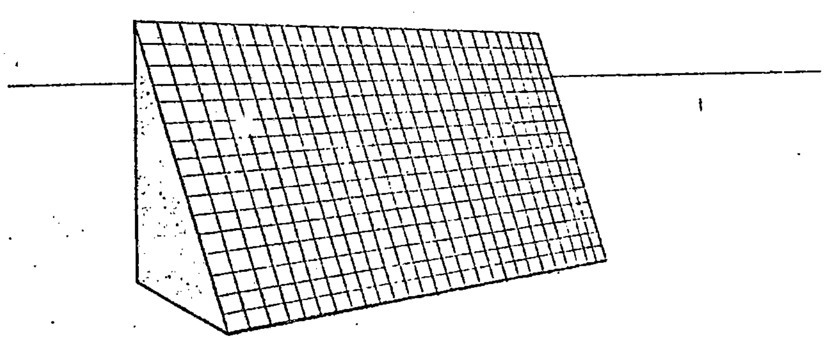


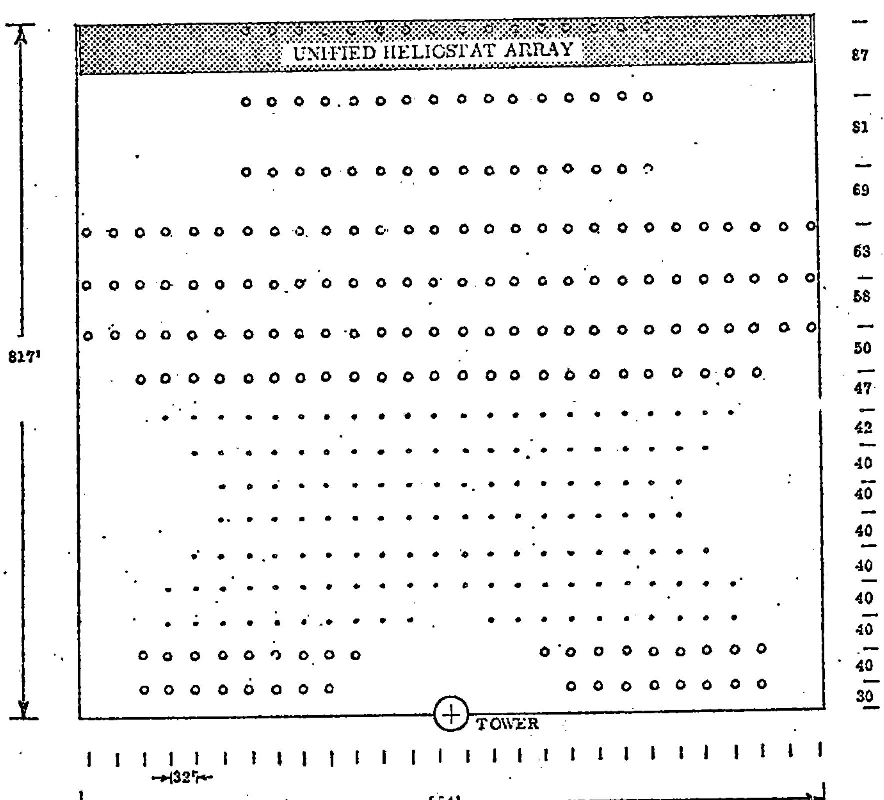
Figure IIC

COMPARISON OF THE BLACK & VEATCH DESIGN FOR ALBUQUERQUE WITH THE PROPOSED UNIFIED HELIOSTAT ARRAY

In order to evaluate the effectiveness of the two systems it would be desirable to compare them on a sameland area. Table III has made such a comparison. Although this is not an optimum arrangement for the Unified Heliostat Array, it still appears that relative production costs and land use factors will be driving factors when a commercial installation is designed.

It is suggested that, as part of the second phase of construction at the 5MWth Test Facility, a unified heliostat array should be constructed at the north line of the planned field in order to provide increased capabilities at the site and to provide a direct comparison with other devices.

A proposed additional use for this array is to provide a test capability for direct use of concentrated solar energy in chemical energy storage techniques and other industrial processes. The ability to direct this array to a variety of receivers will enable use of this demonstration unit to evaluate other devices at this same site.



5MWth Test Facility Site Layout

Figure III

Table III

Comparison of Black & Veatch with proposed array on same site land area			
	Black & Veatch	Proposed	Ratio $\frac{B \& V}{P}$
Intercepted Ratio	11,577,480 w	14,554,888 w	0.7954
Total land area assigned	74309 m^2	74309 m^2	1
Land area covered	13024 m^2	5197 m^2	2.506
Heliostat area	13024 m^2	16499.6 m^2	0.7894
Average product of cosines	0.90286	0.90233	1.0005874
Aperture angle of control receiver	130.4^o x 71^o 5.03 steradians	60.3^o x 14.5^o 0.6 steradians	8.3836

Note: The proposed array leaves 69112m^2 of land unobstructed. This is equivalent to 15.4 acres, or 93% of the total assigned land. The Black & Veatch design obstructs the entire land area.

Note: Reradiation losses from the central receiver are proportional to the aperture angle.

Table IV

Composite array -- Deletion of north row of Black & Veatch and substitute proposed array		
Energy intercepted by northernmost row of Black & Veatch design		519,984 watts
Remaining intercepted energy	11,057,496 watts	
Energy intercepted by proposed array	14,554,888 watts	
Total energy intercepted		25,612,384 w

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COMPARISON OF A CENTRAL RECEIVER WITH HORIZONTALLY DISPERSED HELIOSTAT FIELD AND A CENTRAL RECEIVER WITH A UNIFIED HELIOSTAT ARRAY

1. Total energy to the central receiver is a function of separation between the central receiver and heliostat array and receiver aperture angle. In the dispersed array arrangement the height of the central receiver may be limited, and the aperture angle being large will limit maximum useable collection area. In the system using the unified array, the aperture angle may be specified, and the horizontal separation determines total energy available.

2. Concentration ratio of a heliostat array is limited by effective focal length and apparent density of the reflective elements in the aperture angle of the receiver, The dispersed field has a very low density of heliostat elements. The unified array has a density approaching 100%.

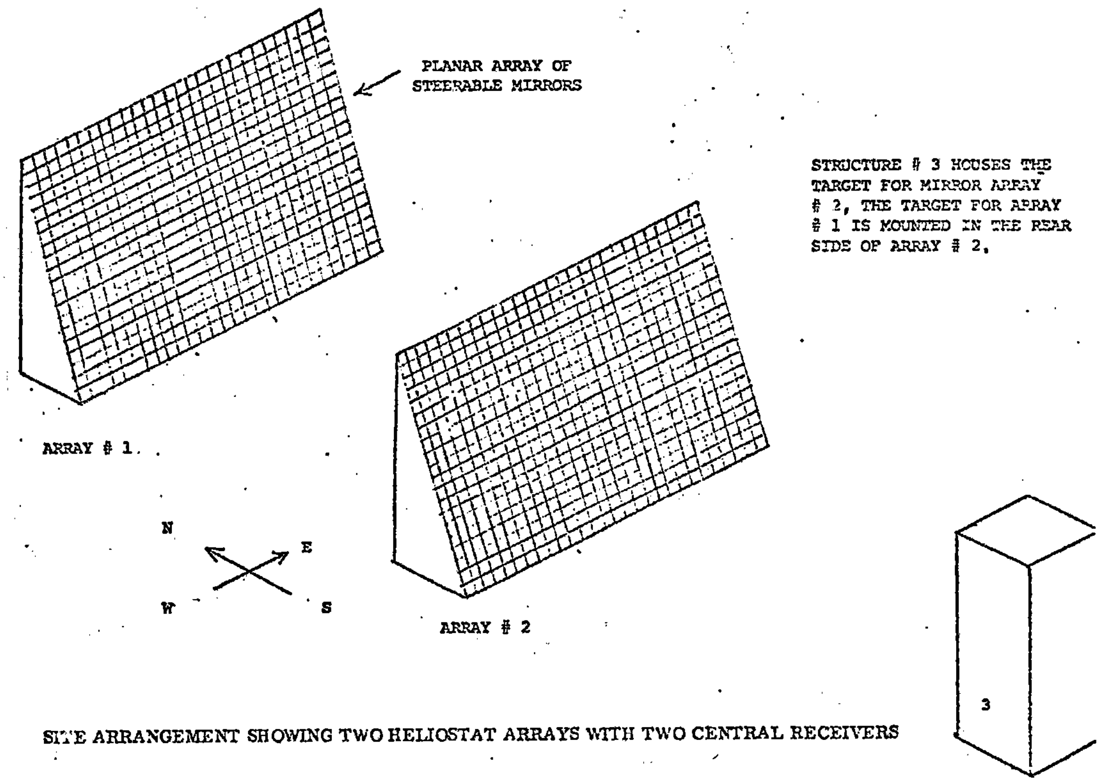
3. The dispersed field can be used with only one central receiver. Replacement of the central receiver will be a major lost time factor. The unified heliostat array may be programmed to any of many central receivers. Replacement of a central receiver need not be a lost time factor, as a spare may be installed adjacent to a primary unit at little additional cost.

4. For a given total maximum energy intercepted at a latitude greater than a few degrees, the land area required by the unified array is less than for the dispersed field. The unoccupied land is in one piece for the system using the unified array and may be used for other purposes, not so with the dispersed field.

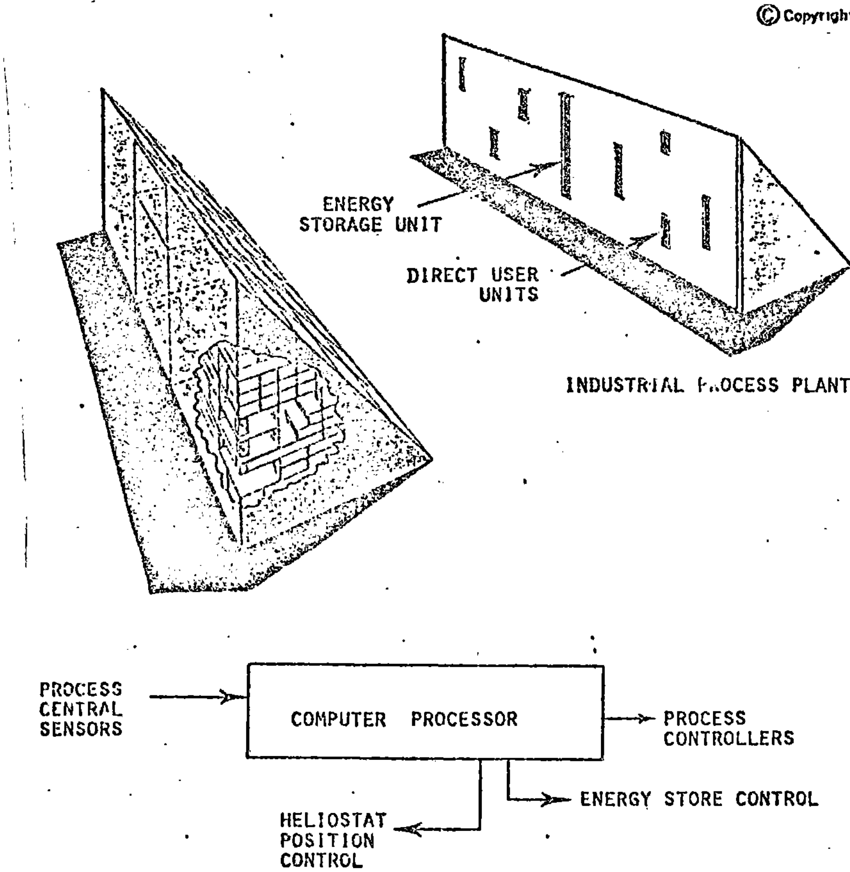
5. The structure housing the unified heliostat array may be used for many additional purposes. In a large system with multiple arrays, a site layout may be made to use the structure for one array to house the central receiver and associated equipment for a next northerly array. In the dispersed field arrangement, no such multiple use arrangement exists.

6. In a large installation of multiple units of the unified array, each array structure may be on the order of a few hundred feet tall by a few thousand feet long. Such structures can contain the entire gamut of human related facilities - homes, schools, hospitals, recreation, shopping centers, factories, etc. There is no comparable use when using the dispersed field arrangement.

7. The dispersed field, being limited to a central receiver located above the field, does not lend itself to providing energy for a variety of industrial operations. The unified field is readily adapted to a variety of industrial processes, and may be programmed to time share energy required by a variety of receivers. (E.g., one could supply varying energy levels to the different parts of a chemical processing plant.)



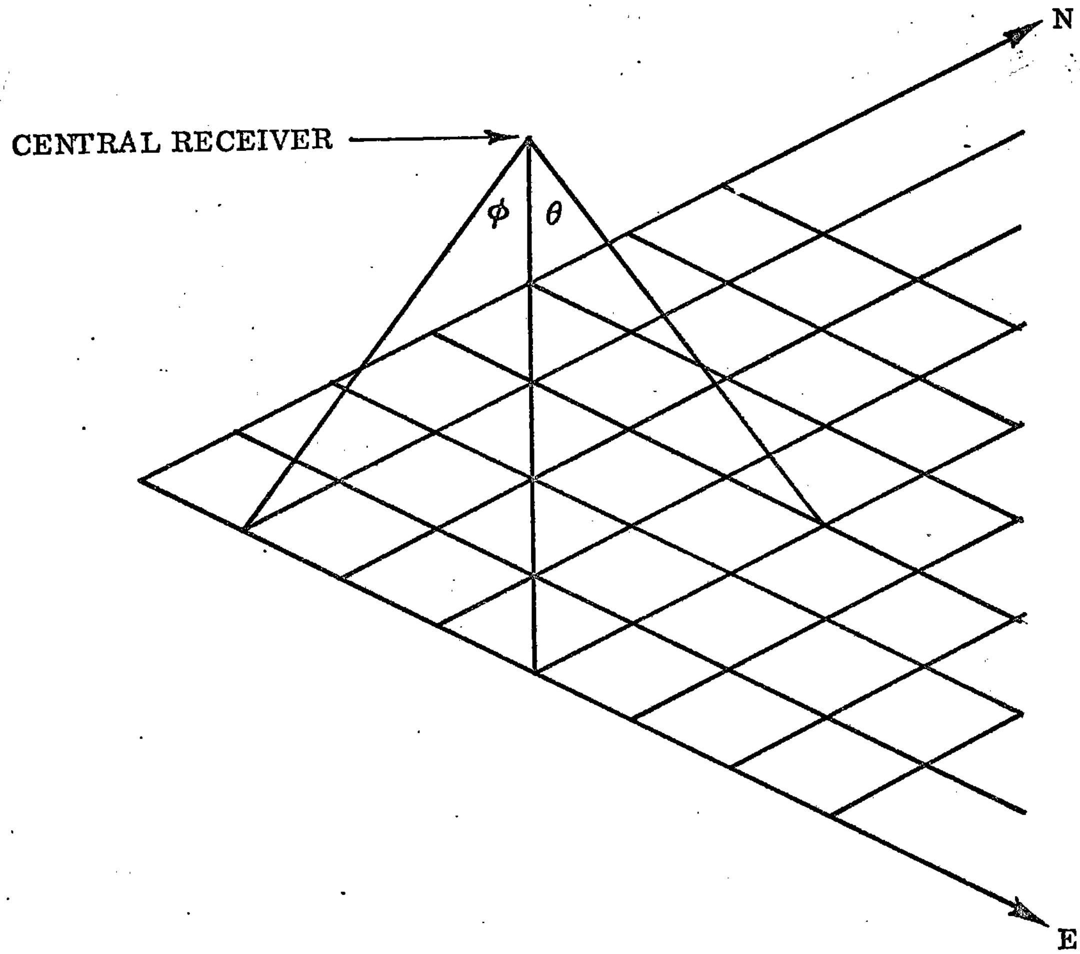
SITE ARRANGEMENT SHOWING TWO HELIOSTAT ARRAYS WITH TWO CENTRAL RECEIVERS



Industrial Process with Energy Storage Capability

Row	Y Ft	θ^{o}	$\left\lvert \frac{\lambda - \theta}{2} \right\rvert$	$\cos\left(\frac{\lambda - \theta}{2}\right)$
N-01	30	8.53	13.653	0.97174
02	70	19.29	8.273	0.98959
03	110	28.81	3.513	0.99812
04	150	36.87	0.517	0.99995
05	190	43.53	3.847	0.99714
06	230	48.99	6.577	0.99341
07	270	53.47	8.817	0.98819
08	310	57.17	10.667	0.98272
09	352	60.40	12.282	0.97711
10	399	63.38	13.772	0.97125
11	449	65.99	15.077	0.96557
12	507	68.47	16.217	0.95972
13	570	70.67	17.417	0.95415
14	639	72.62	18.392	0.94892
15	720	74.48	19.322	0.94367
16	807	76.08	20.122	0.93896

Column	X Ft	ϕ	$\cos \frac{\phi}{2}$
E-01	16	4.5739	0.99920
02	48	13.4957	0.99307
03	80	21.8014	0.98195
04	112	29.2488	0.96760
05	144	35.7539	0.95171
06	176	41.3478	0.93560
07	208	46.1233	0.92008
08	240	50.1944	0.90559
09	272	53.6732	0.89229
10	304	56.6593	0.88023
11	336	59.2373	0.86933
12	368	61.4769	0.85950
13	400	63.4349	0.85065
14	432	65.1576	0.84265



ANGLE DEFINITION FOR THE BLACK & VEATCH PLAN

Figure IV

COLUMN COSINE FACTORS FOR LOWEST ROW OF UNIFIED HELIOSTAT ARRAY

Column	X feet off Centerline	ϕ °	$\cos \frac{\phi}{2}$
1	3	0.22627	0.99999
2	9	0.67878	0.99998
3	15	1.13121	0.99995
4	21	1.5835	0.99990
5	27	2.03559	0.99984
6	33	2.48743	0.99976
7	39	2.93895	0.99967
8	45	3.39011	0.99956
9	51	3.84086	0.99943
10	57	4.29112	0.99929
11	63	4.74086	0.99914
12	69	5.19001	0.99897
13	75	5.63852	0.99879
14	81	6.08634	0.99859
15	87	6.53342	0.99837
16	93	6.97969	0.99814
17	99	7.42512	0.99790
18	105	7.86965	0.99764
19	111	8.31322	0.99737
20	117	8.7558	0.99708
21	123	9.19782	0.99678
22	129	9.63775	0.99646
23	135	10.077	0.99613
24	141	10.515	0.99579
25	147	10.952	0.99543
26	153	11.3875	0.99506
27	159	11.8217	0.99468
28	165	12.2546	0.99428
29	171	12.686	0.99387
30	177	13.116	0.99345
31	183	13.5445	0.99302
32	189	13.9714	0.99257
33	195	14.3968	0.99211
34	201	14.8206	0.99164
35	207	15.2427	0.99116
36	213	15.6631	0.99067
37	219	16.0818	0.99016
38	225	16.4987	0.98965
39	231	16.9139	0.98912
40	237	17.3272	0.98859

COLUMN COSINE FACTORS (Continued)

Column	X feet off Centerline	∅ °	$\cos \frac{\emptyset}{2}$
41	243	17.7391	0.98804
42	249	18.1482	0.98748
43	255	18.5559	0.98692
44	261	18.9617	0.98634
45	267	19.3654	0.98575
46	273	19.76722	0.98516
47	279	20.167	0.98455
48	285	20.565	0.98394
49	291	20.96	0.98332
50	297	21.354	0.98269
51	303	21.745	0.98205
52	309	22.135	0.98140
53	315	22.522	0.98074
54	321	22.907	0.98008
55	327	23.29	0.97942
56	333	23.671	0.97874
57	339	24.049	0.97806
58	345	24.425	0.97737
59	351	24.799	0.97667
60	357	25.171	0.97597
61	363	25.541	0.97526
62	369	25.908	0.97455
63	375	26.273	0.97383
64	381	26.636	0.97311
65	387	26.996	0.97238
66	393	27.354	0.97164
67	399	27.710	0.97090
68	405	28.064	0.97016
69	411	28.4151	0.96941
70	417	28.764	0.96866
71	423	29.1106	0.96790
72	429	29.4549	0.96714
73	435	29.7968	0.96638
74	441	30.1365	0.96561
Average Cosine			0.98745

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ROW COSINE FACTORS FOR UNIFIED HELIOSTAT ARRAY

Row	Y-feet from top	Δ	$\frac{\alpha - \Delta}{2}$	$\cos\left(\frac{\alpha-\Delta}{2}\right)$	Range-Feet
1	5	0.35	27.2847	0.88874	817
2	15	1.0557	26.9321	0.89154	814
3	25	1.76565	26.5777	0.89433	811
4	35	2.48032	26.21984	0.89710	808
5	45	3.19954	25.86023	0.89986	805
6	55	3.92312	25.498	0.90259	802
7	65	4.65087	25.1346	0.90531	799
8	75	5.38258	24.7687	0.90800	796
9	85	6.11805	24.401	0.91067	793
10	95	6.85707	24.03	0.91332	790
11	105	7.59941	23.66	0.91594	787
12	115	8.34485	23.288	0.91853	784
13	125	9.09314	22.913	0.92109	781
14	135	9.84405	22.538	0.92362	778
15	145	10.5973	22.1619	0.92612	775
16	155	11.3527	21.6965	0.92915	772
17	165	12.11	21.405	0.93102	769
18	175	12.8689	21.023	0.93342	766
19	185	13.6291	20.64545	0.93578	763
20	195	14.3905	20.265	0.93810	760

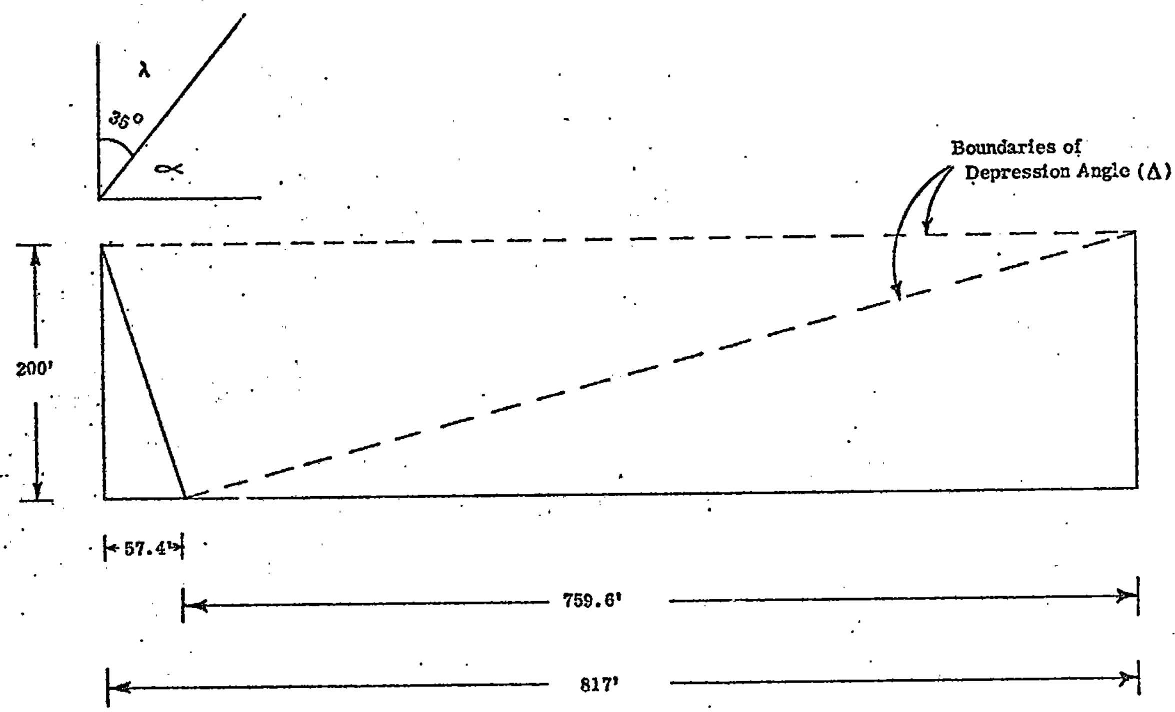
Average Cosine 0.91421

Product of Average Cosines for Array 0.90233

NOTES:

$\alpha = 90^{\circ} - \lambda$

Δ = depression angle of row viewed from central receiver



PLACEMENT OF THE UNIFIED HELIOSTAT ARRAY

Figure V

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PROPOSED WORK STATEMENT

Heliostat Study

I. Comparative Analysis of A Unified Heliostat Array and Distributed Heliostat Field

A. Efficiency

1. Computer Analysis

2. Simulator

B. Economic Analysis

1. Design Preparation by Architectural Engineering

2. Cost of Components and Construction of the Array

3. Comparative Project Costs including Multi-Purpose Array Structure (10MWe Pilot)

II. Design Augmentation Array

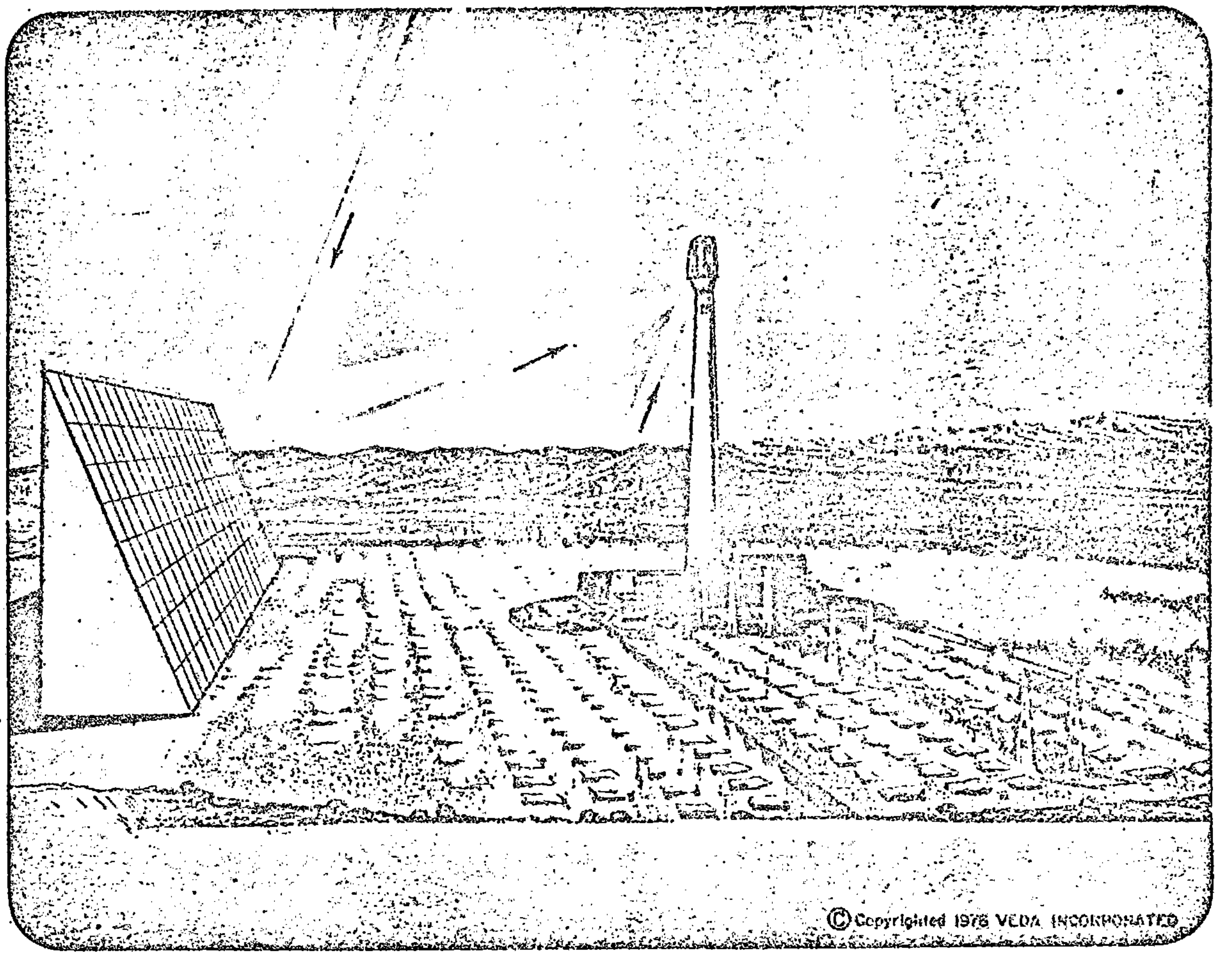
A. Albuquerque Test Facility

B. 10 MWe Pilot Plant

III. Fabricate Mirror Gear Box and Pedestal

A. Prototype Performance Tests

B. Environmental/Life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PROPOSED WORK STATEMENT

Perform a study which results in a System Design for:

The application of Solar Fueled Processor to Chemical Energy Storage. The study shall:

1. Perform the analysis of the peculiar parameters associated with the specific processes (in conjunction with process researchers like Martin Marietta and Atomics International) to optimize material and energy handling methods. Such analysis requires laboratory measurements and would utilize simulation techniques in order to properly size processor components and define the solar energy concentrator requirement in terms of cross section and flux density of the beam at the processor entry aperture.

2. Perform a comparative evaluation of the relative efficiencies of energy transfer into the storage mechanism by this method and whatever method is currently in use.

3. Prepare a Heliostat Requirements Document which will identify the heliostat components and specify the design requirements of each (e.g. latitude correcting pedestal, long life precision gear box, reflecting surface structure, mirror material and finish).

4. Prepare a System Requirements Document which will identify and evaluate the useful range of energy and material flow. This will permit a functional design for specific customer application.

R&D For The Processor Design Effort - Chemical Energy Storage

Laboratory measurements on scattering, absorption, and particle fall rate are probably best accomplished in cooperation with those organizations currently working in the chemical process. A test device can likely be fabricated by these people. The tests would provide data from which to determine optimized sizing of energy concentrator and processor. The basic tests must determine reaction rates in the radiant energy environment.

PROPOSED WORK STATEMENT

Perform a study which results in a System Design for:

The application of a Heliostat Array for Generalized Industrial Processes (e.g. chemical energy storage, coal gasification process) The Study shall:

1. Perform an analysis of the peculiar parameters associated with a specific process. This analysis will define the solar energy concentrator in terms of beam cross section(s) and flux density (ies) at the receiver entry aperture(s).

2. Perform a comparative analysis between the solar and conventionally fueled industrial process.

3. Prepare a Heliostat Requirements Document which will identify the heliostat components and specify the design requirements of each (e.g. latitude correcting pedestal, long life precision gear box, reflecting surface structure, mirror material and finish).

4. Prepare a System Requirements Document which will specify the energy concentration requirements for each segment of the heliostat array. The energy requirement of any given step in the process may require computer control of the individual heliostats. These control requirements will be included in the document.

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