342
2-3-78

Dr. 1826

SAN/1109-8

SOLAR PILOT PLANT PROJECT REVIEW NO. 9, MAY 4-5, 1977

CRDL Item 10

May 4-5, 1977

Work Performed under Contract EY-76-C-03-1109

Energy Resources Center
Honeywell, Incorporated
Minneapolis, Minnesota

MASTER

U.S. Department of Energy

Solar Energy

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SOLAR PILOT PLANT
for
United States
Energy Research and Development Administration

Project Review No. 9

May 4-5 1977

PRELIMINARY DESIGN REVIEW

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INTRODUCTION AND OVERVIEW

SOLAR PILOT PLANT PRELIMINARY DESIGN

MAY 4-5, 1977

**HONEYWELL
BLACK & VEATCH
BABCOCK & WILCOX
NORTHERN STATES POWER
RESEARCH INC.**

1-1

PROGRAM OBJECTIVE

"TO ESTABLISH THE TECHNICAL FEASIBILITY OF A SOLAR THERMAL POWER PLANT OF THE CENTRAL RECEIVER TYPE WITH SIGNIFICANT COMMERCIAL POTENTIAL AND TO OBTAIN SUFFICIENT DEVELOPMENT PRODUCTION AND OPERATING DATA TO INDICATE THE ECONOMICS OF OPERATION FOR COMMERCIAL POWER PLANTS OF SIMILAR DESIGN"

PROGRAM TEAM

PDR AGENDA
MAY 4-5, 1977
LIVERMORE, CALIFORNIA

<u>MAY 4</u>		<u>Presentation Time</u>	<u>Q&A Period</u>	<u>Speaker</u>
8:30-9:00	INTRODUCTION	25 min	5 min	J. Powell/N. Sher
9:00-9:40	Design Overview	30	10	R. Schmidt
9:40-10:10	Collector Overview	25 min	5 min	L Ball
10:10-10:50	Subsystem Analysis	30	10	G. Smith
10:50-11:30	Mechanical Design	30	10	J. Arnold
11:30-12:30	Lunch	60 min.		
12:30-1:10	Mechanical Design (Cont.)	30	10	R. Snyder
1:10-1:50	Electrical Design	30	10	R. Younskevicius
1:50-2:30	SRE Test Results	30	10	G. Brown
2:30-2:45	Break			
4-1 2:45-3:25	Tower/Housing Design	30	10	H. Smith
3:25-4:40	Steam Generator Design	60	15	W. Oberjohn
4:40-5:30	SRE Tests & Results	35	15	M. Wirth/W. Oberjohn
 <u>MAY 5</u>				
8:30-9:45	Thermal Storage	60	15	R. LeFrois
9:45-11:00	EPGS/Balance of Plant	60	15	J. Harder
11:00-11:40	Plant Controls	30	10	G. McCright
11:40-12:40	Lunch			
12:40-1:25	Transient Analysis	30	15	R. Lane
1:25-2:10	Maintenance/Safety	30	15	R. Stiles
2:10-2:25	Break			
2:25-3:45	Pilot & Commercial Plant Designs	60	20	J. Powell/E. Dowty
3:45-4:15	Summary & Recom- mendations	20	10	J. Powell

10 MW (e) SOLAR PILOT PLANT

HELIOSTAT

HELIOSTAT CONTROL

FIELD LAYOUT

HELIOSTAT AND CONTROL

It Works!

It Offers:

- High Performance
- No Technical Risk
- Simplicity
- Low Maintenance
- Built-in Safty
- High Flexibility
 - fabrication
 - transportation
 - new mirror developments

INTERNAL RECEIVER CONFIGURATION

FLUX SEPARATION

HELIOSTAT COSINE EFFECT		
	A	B
Summer	0.85	0.96
Winter	0.99	0.80
Annual	0.87	0.82

RECEIVER

It Works!

It Offers:

- Predictable Performance
- Low Development Cost
- High Reliability
- High Efficiency
- Scalability

CYCLE CHOICE

STORAGE

CONTROL HIERARCHY

PILOT PLANT PRELIMINARY DESIGN

It Will Work!

It Offers:

Low Fabrication Risk

- Low Operational Risk
- High Operational Flexibility
- Low Maintenance
- Built-in Safty

SOLAR THERMAL POWER

PILOT PLANT PRELIMINARY DESIGN

PILOT AND COMMERCIAL BASELINES

PARAMETER	PILOT PLANT	FIRST COMMERCIAL
1 Location	Barstow	TBD
2 Nameplate Capacity	15 mwe	120 MWe
3 Design Point	12/21, 2 ^{PM}	3/21, Noon
4 Design Point Net Power	10 mwe	100 MWe
5 Solar Multiple	1.23	1.7
6 Heliostat Size	40m ²	Same
7 Number of Heliostats	1598	20,220
8 Total Mirror Area	63,920 M ²	808,800 M ²
13 Total Net Annual Energy (NAE)	2.22 x 10 ⁴ MWhr(e)	2.89 x 10 ⁵ MWhr(e)
14 NAE/Total Mirror Area	0.348 MWhr(e)/M ²	0.357 MWhr(e)/M ²
9 Storage Capacity	7MWe for 3 hrs	Same
10 Turbine Cycle		Same
11 - From Receiver	10.1MPa/510 C(1450/950)	Same
12 - From Storage	3.2MPa/388 C (460/730)	Same

PHASE I DESIGN APPROACH

COLLECTOR SUBSYSTEM

COLLECTOR SUBSYSTEM PRESENTATION OBJECTIVES

0 4 7 7 - 3 8 3

- Describe four major elements
- Explain how it works
- State advantages
- Declare readiness for Phase II

SRE PROGRAM HELIOSTAT MAJOR MILESTONES

DESIGN INTERRELATIONSHIPS

REMAINDER OF PRESENTATION IS DETAILED

OVERVIEW AND SUMMARY
L. BALL

ANALYSIS
G. SMITH

MECHANICAL
JIM ARNOLD

BOB SNYDER

ELECTRICAL
BOB YOUNSKEVICIUS
(YOUNSKI)

SYSTEM
GARY BROWN

COMPUTER MODELS
G. SMITH

CONCLUSION
L. BALL

OBJECTIVES
MAJOR ELEMENTS
OVERVIEW

0477-375

FIELD EFFICIENCY
SHADING AND BLOCKING
HELIOSTAT SIZE AND TRACKING
HELIOSTAT OPTICS

MIRROR MODULES
FRAME
STRUCTURE ANALYSIS
POSTS AND FOUNDATIONS

DRIVES
ERROR BUDGET
TRADE-OFFS
ASSEMBLY

FIELD WIRING
HELIOSTAT ELECTRONICS
CALIBRATION ARRAY AND ELECTRONICS
POWER ANALYSIS

COMPUTER SUBSYSTEM
SRE TESTS AND RESULTS
ENERGY BALANCE
SAFETY

ANALYSIS VERSUS TEST

COLLECTOR SUBSYSTEM 'GOES INTO'

0 4 7 7 - 2 3 8

INSTRUMENTATION

HELIOSTAT

FIELD

COMPUTER

COLLECTOR SUBSYSTEM SCHEMATIC ARRANGEMENT

0477-68E

3 STANDBY POSITIONS OUTBOARD OF CORBELS

0477-307

HELIOSTAT DESIGN DRIVERS

0 4 7 7 - 3 8 9

<u>ITEM</u>	<u>DRIVER(S)</u>	<u>SPEC REQUIREMENT</u>
MIRROR MODULE	TORSION STIFFNESS BENDING STIFFNESS	POINTING ACCURACY FOCUSING ACCURACY
FRAME	DEFLECTION OF MM AXES MM BEARING MOMENT LOADS	POINTING ACCURACY LIFE
ACTUATOR	COLUMN LOADING	WIND LOAD AND ANGULAR RANGE
ACTUATOR MOTOR	TORQUE, SPEED	SLEW RATE: DEFOCUS, STOW, CALIBRATE
REDUCER/SPUR GEAR	BACKLASH, GEAR RATIO	POINTING ACCURACY
TIE RODS	LATERAL DEFLECTION	POINTING ACCURACY
CRANK ARMS	BENDING STIFFNESS, TORSION STIFFNESS	POINTING ACCURACY
MM BEARINGS	MM SHAFT DIA MOMENT LOADING	POINTING ACCURACY LIFE
MM SPACING	SHADING, BLOCKING	95 PERCENT OF REDIRECTED ENERGY INTO CAVITY
FOUNDATION	SOIL BEARING PRESSURE, OVERTURNING MOMENTS	SURVIVAL
POSTS	BENDING STIFFNESS	POINTING ACCURACY

SIMPLE HELIOSTAT CONTAINS FEW ASSEMBLIES

A7701-40

MOST STIFFNESS FOR DOLLARS SPENT

0477-324

HELIOSTAT EVOLUTION SHOWS SIMPLIFICATION

0576-851

COLLECTOR FIELD LAYOUT IS MODULAR

$$R_1 = 274\text{m}$$

$$A = 137\text{m}$$

$$R_2 = 50\text{m}$$

PILOT PLANT AND MODULE DETAILS

$$H_1 = 129.8\text{m}$$

$$L_1 = 153.6\text{m}$$

$$L_2 = 192.6\text{m}$$

$$L_3 = 418\text{m}$$

PILOT PLANT AND COMMERCIAL PLANT MODULE COLLECTOR FIELD

0 477-148

COLLECTOR USES COMMERCIAL COMPUTER

0477-415

- Only new thing for SRE is small panel
- Software resident was tracking, data acquisition plus executive
- Data recorded on magnetic tape and reduced off-line
- Preliminary design is more modern design
- Software algorithms directly usable

INSTRUMENTATION IS VITAL TO PRELIMINARY DESIGN

PHOTO DETECTORS ARE
AT 1 FT GRID INTERVALS

- CALIBRATION ARRAY HAS 224 SENSORS
- ORIGINALLY DESIGNED FOR CENTROID DATA
LATER USED FOR ENERGY COMPUTATIONS
- SRE UNIT WAS NOT BUILT FOR LONG LIFE
- EFFECTIVE MEANS OF TEST
- NOT PROPER HEIGHT
- ALL 224 SENSORS INPUT TO COMPUTER

SRE PROVEN HARDWARE DIRECTLY APPLIES TO PILOT PLANT

0 477-390

SRE

- HELIOSTAT
 - SUB AND FULL SCALE TESTS
 - PP CONFIGURATION
 - SMALL FOUNDATION
 - HAND BUILT PROCESSES
 - 339m FOCAL LENGTH
- FIELD
 - PP ASSEMBLY TECHNIQUES AND TOOLS
 - 4 H/S 90 DEGREES APART
 - 1 H/S PER LINE POWER AND SIGNAL
 - 314m MAXIMUM DISTANCE
 - 148m MINIMUM DISTANCE
- CONTROL COMPUTER
 - DDP-516 MINICOMPUTER
 - 1 μ SEC
 - FORTRAN/ASSEMBLY LANGUAGE
 - ALGORITHMS FOR CORRECTION
 - 4 H/S PP DATA RATE
- CALIBRATION ARRAY
 - 1 ARRAY 4.3 x 4.9m
 - 1 FOOT CENTERS
 - PVC PACKAGE
 - 224 SENSORS
 - 240 MUX CHANNELS/UNIT
 - 1 MUX UNIT

PILOT PLANT PRELIMINARY DESIGN

- ONLY FULL SCALE UNITS
- MINOR DESIGN CHANGES
- SITE DEPENDENT CHANGES
- PRODUCTION PROCESSES
- 418m FOCAL LENGTH
- LARGER CREW AND BETTER TOOLS
- CLOSER PACKING
- 94 H/S PER SIGNAL LINE 200 PER POWER LINE
- 418m MAXIMUM DISTANCE
- 154m MINIMUM DISTANCE
- L 6/43
- 0.3 μ SEC
- FORTRAN/ASSEMBLY LANGUAGE
- SAME ALGORITHMS
- UP TO 25,000 H/S
- 8 ARRAYS 8.5 x 7.3m
- OPTIMAL CENTERS
- WEATHER PROOF PACKAGE
- 224-700 SENSORS
- 768 MUX CHANNELS/UNIT
- 8 MUX UNITS

VENDOR LOCATIONS

HELIOSTAT SUBSYSTEM ANALYSIS TOPICS

- FIELD EFFICIENCY
- SHADING AND BLOCKING
- HELIOSTAT SIZE & TRACKING ERROR
- HELIOSTAT OPTICS

RAY TRACE ENERGY PATH

FIELD EFFICIENCY – COSINE EFFECT

COSINE ONLY TRACKING EFFICIENCY

WINTER SOLSTICE, NOON

SUMMER SOLSTICE, NOON

COSINE ONLY ANNUAL TRACKING EFFICIENCY

● CLEAR AIR MODEL at 33° N' Latitude

● No Reflectance Loss

Axes show distance from tower location in tower heights

ANNUAL COSINE PERFORMANCE FOR VARIOUS FIELDS

SHADING AND BLOCKING

NO FACET-TO-FACET BLOCKING CAN OCCUR

ANNUAL SHADING & BLOCKING ENERGY LOSSES vs FIELD POSITION

ANNUAL SHADING & BLOCKING ENERGY LOSSES vs RADIAL DISTANCE FOR THE NORTH FIELD

GROUND COVER SELECTION

Issues

Closer heliostat spacing

Advantages

- Shorter Optical Path
- Smaller Aperture
- Shorter Tower

Disadvantage

- Increased shading & Blocking Losses

Cost

Heliostats are several times more expensive than the tower and receiver combined

Answer

Minimize shading and blocking losses

MAXIMUM GROUND COVER RATIO vs FIELD POSITION

GROUND COVER RATIO FOR PRELIMINARY DESIGN

HELIOSTAT SIZE & TRACKING ERROR ISSUES

HELIOSTAT SIZE VERSUS PERFORMANCE

0.9 mr tracking error budget

TOWER CENTERED FIELD
UNIFORM GROUND COVER

Aperture Geometry

IMPACT OF TRACKING ERROR ON PERFORMANCE

COST OPTIMAL HELIOSTAT SELECTION

HELIOSTAT OPTICS

OPTICAL ISSUES

RAY TRACE CODE ANALYSIS

- FOCUSsing

Focal Length = Slant Rnge	Power into Aperture 42.3 MW
Focal Length = Max Slant Range	42.3 MW

(Toe-in set individually each H/S)

- TOE-IN

Toe-In Angles Same All Heliostats	Power into Aperture 39.6 MW
Toe-in Angle Set Individually	42.3 MW

(Focal Length = Slant Range)

TOE-IN ISSUE

ON AXIS TOE-IN STRATEGY

TOE-IN OFF AXIS STRATEGY
(EQUINOX MOON TOE-IN)

SINGLE HELIOSTAT FLUX DENSITY COMPARISON

IMAGES FOR SUMMER SOLSTICE NOON SUN POSITION

● PERFECT TOE-IN

● EQUINOX NOON TOE-IN

CONCLUSIONS

- Field Layout
 - Has high cosine efficiency
 - Provides separation of Boiler/Superheater functions
 - Minimizes Shading and Blocking
- Heliostat Configuration
 - Heliostat size & tracking error budget are optimal
 - All Mirror Modules have same radius of curvature
 - Small facets, Outer-axis normal to LOS with toe-in optimizes optical performance

PROVEN STRUCTURAL ELEMENTS DESCRIBED

0477-414

- Mirror module assembly
- Frame assembly
- Support post assemblies
- Structural analysis and test results
- Thermal analysis and test results

MIRROR MODULE DESIGN REQUIREMENTS

0477-376

● FOCAL LENGTH

ANALYSIS SHOWS SINGLE FIXED FOCUS AT MAXIMUM DISTANCE

- DEVELOPMENT UNITS - 339m
- PILOT PLANT - 418m
- COMMERCIAL PLANT - 748m

● CONTOUR TOLERANCE

- FABRICATION - 1 mr MAXIMUM SLOPE ERROR
- LOADS - 1 mr MAXIMUM SLOPE ERROR
- MAXIMUM TOLERANCE ACCUMULATION - 1.6 mm (1/16 IN.)

● DESIGN LOADS - 9.77 kg/m²

● TORSIONAL DEFLECTION - 1 mm - 86.4 kg-m

● SIZE - 10 m²

● REFLECTIVE SURFACE - 3 mm SECOND SURFACE SILVERED GLASS

● LIFE - 30 YEARS IN OUTDOOR ENVIRONMENT

● BALANCE COMPENSATION FOR INNER DRIVE

● WEIGHT - 226.8 kg MAXIMUM

MIRROR MODULE DESIGN

0477-374

● PRELIMINARY DESIGNS

- PLYWOOD
- VARIABLE FOCUS (STEEL FRAME)
- URETHANE FOAM CORE
- ALUMINUM HONEYCOMB CORE

● SELECTED ALUMINUM HONEYCOMB CORE

● SIZE

- ENGINEERING MODEL - 3.17m x 3.17m (10 m²)
- SOLAR RESEARCH EXPERIMENT - 3.05m x 3.05m (9.3 m²)
- PILOT AND COMMERCIAL PLANTS - 3.05m x 3.30m (10 m²)

● CONSTRUCTION OF ALUMINUM HONEYCOMB MODEL

- CENTER TORQUE TUBE WITH ALUMINUM HONEYCOMB CORE 22.8 cm SQUARE
- ALUMINUM CLAD STEEP SKINS - 0.55 mm
- ALUMINUM HONEYCOMB CORE - 32 kg/m³
- FOAM FILLED ALUMINUM HONEYCOMB CONTOUR LAYER - 7.62 mm THICK
- 3 mm FLOAT GLASS MIRRORS - 9 PIECES
- BUILT IN TOOLING POINTS

ALUMINUM HONEYCOMB 120 BY 120 INCH MIRROR MODULE (14 PROCURED)

0277-066

MIRROR MODULE ASSEMBLY DETAILS

0477-66B

MIRROR MODULE TEST RESULTS

0477-177

- Contour
 - Tooling points provide measurement reference
 - Initial contour well within specification
 - Contour not significantly affected by loads
- Torsional deflection - 0.8 mr
- Mirror reflectivity
 - Standard float glass - 88 percent
 - Low iron (water white) glass - 91 percent
- Optical beam quality excellent
- Weight - 318 kg

TYPICAL MIRROR CONTOUR DATA

1076-257

FRAME ASSEMBLY REQUIREMENTS

0 477 - 393

- Provide outer gimbal of heliostat
- Support four mirror modules
- Attachment for outer axis actuator
- Operating load
 - Meet performance at 13.5 m/sec wind
 - Operate only at 25 m/sec wind
 - Survive in stowed position at 40 m/sec wind with 10 degree angle of attack

FRAME ASSEMBLY DESIGN

0 477 - 381

- DESIGN TRADE-OFF
 - BARJOIST TYPE STRUCTURE - ADEQUATE BUT HIGHER COST
 - WIDE FLANGE AND I-BEAM STRUCTURE
 - REQUIRES TORSIONAL STIFFNESS AUGMENTATION
 - LOWER COST
 - DESIGN USING STRUCTURAL SHAPES SELECTED
 - AUGMENTED BY BRACES AND STIFFNERS AT SELECTED POINTS
 - MAJOR STRUCTURAL ELEMENT, 25.4 cm - 37.2 kg/m WIDE FLANGE
- LENGTH - 15.5m
- WIDTH - 3.38m
- WEIGHT - 1806 kg
- BEAMS SIZED BY DEFLECTION
 - MINIMUM STRESS MARGIN OF SAFETY OF 2.0

HELIOSTAT FRAME ASSEMBLY

0576-90

2-56

POST AND FOUNDATION REQUIREMENTS

0477-416

- Support gimbaled weight - 3447 kg
- Meet deflection requirements under operating wind loads
 - Meet requirements at 13.5 m/sec
 - Operate at 25 m/sec
- Survive for 40 m/sec wind with 10 degree angle of attack on heliostat
- Provide mounting for outer gimbal actuator
- Allow 105 degrees of frame rotation

POST AND FOUNDATION DESIGN

- Foundation at Florida

1.1m x 1.7m x 0.3m reinforced concrete

- Foundation at pilot plant site

1.8m x 3.0m x 0.4m reinforced concrete

- Post - - two 25.4 cm - 12.5 kg/m

- Support braces for added strength

2-60

STRUCTURAL ANALYSIS

0 4 7 7 - 2 8 0

- Mirror module analysis by supplier
- Complete heliostat used STARDYNE program
 - Divided complete heliostat into small elements
- Static analysis as follows
 - 1g load in stowed and frame at 75 degrees
 - 1g load and 30 mph wind at 75 degrees
- Dynamic analysis in stowed position
- Survivability analysis

STRUCTURAL ANALYSIS RESULTS

0477-281

STATIC

MIRROR MODULE

- DESIGN LIMIT WAS TORSION - PREDICTED 0.7 mr
- STRESS LEVELS VERY LOW - MARGIN >> 2
- MIRROR BOND LINE HAS INSIGNIFICANT LOAD

HELIOSTAT ASSEMBLY

- MAXIMUM FRAME DEFLECTIONS WITHIN LIMITS
- STRESS LEVELS VERY LOW - MARGIN >> 2

DYNAMIC

NATURAL FREQUENCIES - 2.71 TO 1555 Hz

FIRST MODE - MIRROR MODULE TORSION - 2.71 Hz

MAJOR FRAME BENDING MODE - 4.25 Hz

SURVIVABILITY ANALYSIS

- VORTEX SHEDDING - 40 PERCENT FREE STREAM VELOCITY
- 400 EQUALLY SPACED POINTS - 0 TO 5 SEC
- RESULTS PROVED ADEQUATE DESIGN - MARGIN = 0.3

DEFORMED PLOT - HELIOSTAT HORIZONTAL - FIRST MODE

0876-35

FREQUENCY - 2.71 HZ

MRI/STARDYNE FINITE ELEMENT MODEL PROJECTION ON X2-X3 PLANE

DEFORMED PLOT - HELIOSTAT HORIZONTAL - 4TH MODE

THIRD FRAME MODE DISPLACEMENT CASE 4

FREQUENCY - 4.25 HZ

0876-36

MRI/STARDYNE FINITE ELEMENT MODEL PROJECTION ON X2-X3 PLANE

THERMAL DESIGN

0477-282

- Exposed components painted white to reduce solar load
- Frame expansion
 - 5.1 mm in 10.1m dimension for ΔT of 50°C
- Dynamic temperature changes
 - Tests have shown 4°C maximum
 ΔT between components resulting from shading
- Electronics
 - Maximum component ambient
64°C compared to 70°C allowable
 - Package must be protected from direct solar radiation
 - Motor temperature
122°C compared to 155°C allowable

CONCLUSIONS

0477-419

PERFORMANCE VALIDATED BY TESTS

- MIRROR MODULE

- ADEQUATE STRUCTURE FOR LOADS
 - EXCELLENT CONTOUR CONTROL
 - INSIGNIFICANT STRESS ON MIRROR BOND

- FRAME

- USES STANDARD AISC STRUCTURAL ELEMENTS
 - FABRICATED TO INDUSTRY TOLERANCES
 - STABILITY INSURED BY WELDED ASSEMBLY

- FOUNDATION AND SUPPORT POSTS

- HELIOSTAT DESIGN PERMITS SMALL FOUNDATIONS
 - STANDARD AISC STRUCTURAL ELEMENTS
 - STABILITY INSURED BY WELDED ASSEMBLY

ANALYSIS CONFIRMED BY TESTS

- STRUCTURAL ANALYSIS

- STATIC AND DYNAMIC DEFLECTIONS ARE WITHIN TOLERANCE
 - SURVIVABILITY ANALYSIS SHOWS AMPLE MARGIN

- THERMAL DESIGN

- WHITE PAINT ADEQUATE FOR MECHANICAL COMPONENTS
 - SUN SHADE ADEQUATE FOR ELECTRONICS TEMPERATURE CONTROL
 - MOTORS WITHIN OPERATING LIMITS

DRIVES, ASSEMBLY AND POINTING ACCURACY

0 4 7 7 - 3 9 5

- Inner axis gear drive assembly
- Inner axis linkage assembly
- Frame drive assembly
- Bearings
- Heliostat assembly/alignment
- Pointing accuracy analysis

0876-142

2-70

INNER AXIS GEAR DRIVE ASSEMBLY

0 477 - 373

REQUIREMENTS

- REDUCER RATIO :16000:1
- SELF-LOCKING
- BACKLASH 0.15 MR MAX
- TORQUE OUTPUT 9236 Kg-CM
AT 0.005 RADIAN/SECOND
- MINIMUM LIFE CYCLE COST
- SPRING RATE
7.7 E6 Kg-CM/RADIAN

HOW SATISFIED

- 2-STAGE REDUCER 1600:1
SPUR GEAR SET 10.1:1
- 2-STAGE HELICON GEAR SET
- SPRING PRELOAD
SHIMS
- DC TORQUE MOTOR
2.57 Kg-CM AT 84 RADIAN/SECOND
- ENVIRONMENTAL RESISTANCE
SEALS, COVERS
SELF-ALIGNING SPUR GEARS
TOOTH HARDNESS
MODULARITY
- PIVOT LOCATED ON TANGENT
STRUCTURE AND COMPONENT DESIGN

INNER DRIVE COVER AND SEALS

0477-98

INNER AXIS LINKAGE ASSEMBLY

0477-401

REQUIREMENTS	HOW SATISFIED
● SPRING RATE	CRANK ARM STIFFNESS TIE ROD LATERAL AND AXIAL STIFFNESS BEARING RADIAL STIFFNESS
● BACKLASH	ROD END FIT MM BEARING FIT TAPER LOCKS
● FACE DOWN STOWAGE	360° ROTATION 90° CRANKARM OFFSET TIE-ROD LENGTH ADJUSTMENT
● THERMAL STABILITY	REFLECTIVE PAINT ALL-STEEL CONSTRUCTION
● TOE-IN ADJUSTMENT	TAPER-LOCKS
● "g" INSENSITIVITY	TUBULAR TIE-ROD BALANCED SYSTEM

TAPER LOCK/CRANK ARM

1076-298

STRESS RATIO VERSUS INNER AXIS WIND LOADING

0 4 7 7 - 4 2 0

	BASELINE 13.5 M/S OPER 45 M/S SURV & 0.20 PROFILE EXP., LOAD ONE MM ONLY	OPER 0.15 EXP	OPER 25 M/S WCADA	SURV 40 M/S 10° AOA	SURV 40 M/S 10° AOA 4 MM
RATIO BY WHICH MOMENT LOADS INCREASE	1	1.15	3.43	5.35	15.9
MOMENT (IN-LBS)	3300	3795	11319	17655	52470
MM STUB SHAFT	54.5	47	15.9	10.2	3.4
MM BRG LOAD	10.7	9.3	3.1	2.0	0.67
CRANK ARM STRESS	11.9	10.3	3.5	2.2	0.74
TAPER LOCK SHEAR STRESS	16.23	14.1	4.7	3.0	1.0
TIE ROD COLUMN LOAD	7.16	6.23	2.1	1.3	0.45
SPUR GEAR TOOTH STRESS	12.11	10.5	3.5	2.3	0.76
MOTOR TORQUE	9.1	7.9	2.7	N/A	N/A

NOTE: RATIO OF 1.0 OR LESS = STRUCTURAL FAILURE

0876-143

2-78

FRAME DRIVE ASSEMBLY

0477-378

REQUIREMENTS

- REDUCTION RATIO
- BACKLASH 0.25 mm
- SELF-LOCKING
- ACTUATOR SPRING RATE
- ANGULAR RANGE 105 DEG
(+75 DEG TO -30 DEG)
- POWER OUTPUT
364 Kg AXIAL FORCE
0.45 CM/SEC
- POINTING ACCURACY

HOW SATISFIED

- WORM RATIO 40:1
SCREW LEAD 12 mm
PIVOT GEOMETRY
- STANDARD SAGINAW
BALLSCREW ACTUATOR
CATALOG BEARINGS, ROD ENDS
- 40:1 WORM RATIO
- ACTUATOR HOUSING AND
SCREW STIFFNESS
- PIVOT GEOMETRY
ACTUATOR TRAVEL
- COLUMN STRENGTH OF SCREW
DC TORQUE MOTOR
- PIVOT GEOMETRY ALIGNMENT
SCREW LEAD CALIBRATION
ACTUATOR LOT CONTROL
CONTROL OF BEARING RADIAL PLAY

FRAME DRIVE ASSEMBLY (Continued)

0 4 7 7 - 4 0 0

REQUIREMENTS

- FRAME TWIST CONTROL
- "g" INSENSITIVITY
- THERMAL STABILITY
- ENVIRONMENTAL RESISTANCE
- MAINTAINABILITY
- LIMIT SWITCHES

HOW SATISFIED

- SYNCHRONIZED ACTUATOR PAIR
- BALANCED GIMBAL ASSEMBLY
BALL SCREW INSENSITIVITY TO SIDE LOAD
- REFLECTIVE PAINT
ALL STEEL CONSTRUCTION
BALL SCREW INSENSITIVITY TO SIDE LOADS
SELECTIVE COMPLIANCE ACTUATOR MOUNTING
- COVER TUBE
- PROTECTIVE BOOT
- SEALED MOTOR INTERFACE
- FIELD REPLACEABLE ACTUATOR/
MOTOR ASSEMBLY
BOLT-ON MOTOR
- MECHANICAL STOPS; THERMOSTATS
IN MOTORS

BEARING SELECTION

0 4 7 * - 3 9 9

- Low stiction torques
- Low radial play and runout
- Proven sealing
- Dimensional stability under load
- Predictable life
- Lubrication limited only by shelf life
- High volume production base
- Cost reduction potential
- Actuator and gear box efficiency

HELIOSTAT ASSEMBLY/ALIGNMENT

0 477 - 338

- Alignment is built into assembly process
- Special tools minimize labor costs
- No time-of-day restrictions
- Once through operation
- 52 man-hours per heliostat

ASSEMBLY / ALIGNMENT SEQUENCE

0 4 7 7 - 3 9 7

(T1) AZIMUTH MEASURING TOOL

(T2) ACTUATOR PIVOT BRACKET ALIGNMENT TOOL

0477-1400

(T3) ACTUATOR PIVOT AXIS ALIGNMENT TOOL

0477-458

(T4) FIXED LENGTH TRAMMEL TOOL

0 477-1418

(T5) MIRROR MODULE CLAMPING TOOL

0477-1396

(T6) PRECISION BEAM LEVEL

0-77-1438

(T7) TOOLING PIN

0477-1428

HELIOSTAT ACCURACY ANALYSIS

0477-396

- Predicts performance
- Provides accounting tool (>100 elements)
- Identifies sensitivities
- Sets design requirements
- Provides technical understanding
- Updated per SRE test data
- Shows margin for new elements
- Provides basis for cost reduction

HELIOSTAT ACCURACY ANALYSIS SUMMARY

0477-380

<div>Subtotal</div> <div>Source</div>	Deviations (milliradians)			
	Outer Axis 3σ	Inner Axis 3σ	Outer Axis 1σ	Inner Axis 1σ
Wind	0.39	0.99	0.39	0.99
Temperature	0.20	0.15	0.20	0.15
Gravity	0.25	0.09	0.25	0.09
Independent	1.04	0.97	0.35	0.325
RSS/Axis	1.16	1.40	0.61	1.06
Total RSS	1.82		1.22	

DESIGN GOAL 2 MILLIRADIANS (1σ)

HELIOSTAT CONTROL SYSTEM

0477-434

- Incremental
- Open Loop

SRE HELIOSTAT ELECTRONICS

INNER AXIS CONTROL ELECTRONICS DIAGRAM

0477-4258

PILOT PLANT HELIOSTAT ELECTRONICS DIAGRAM

POWER SEQUENCING MECHANIZATION

0 4 7 7 - 4 7 8

ANALYSES

0 4 7 7 - 4 0 4

- Gimbal motor calculations
- Heliostat operating power

SUMMARY OF CALCULATIONS, HELIOSTAT GIMBAL MOTOR ANALYSIS

J 477 - 403

INNER AXIS MOTOR CALCULATIONS							
T_L FT-LBS	T_{FG} FT-LBS	$\dot{\theta}_L$ DEG/SEC	W_M WATTS	W_L WATTS	EFF %	ΔT RISE, °C	REMARKS
0	0.021	0.43	7.3	3.4	47	25	0 WIND AND UNBALANCE
119	0.070	0.36	21.6	14.7	68	75	1/2 WIND AND UNBALANCE
238	0.112	0.28	37.9	20.6	54	132	FULL WIND AT 13.5 M/S
476	0.22	0.12	70	16.7	24	245	2X WIND AND UNBALANCE
660	0.30	0	95	0	0	332	T_L AT STALL, $\dot{\theta}_L \rightarrow 0$

OUTER AXIS MOTOR CALCULATIONS							
T_L FT-LBS	T_{FG} FT-LBS	$\dot{\theta}_L$ DEG/SEC	W_M WATTS	W_L WATTS	EFF %	ΔT RISE, °C	REMARKS
0	0.26	0.22	33	21.7	66	115.5	0 WIND AND UNBALANCE
258	0.26	0.20	41	24.6	60	141	1/2 WIND AND UNBALANCE
517	0.26	0.18	49	26.5	54	171	FULL WIND AT 13.5 M/S
1034	0.26	0.15	53	28.4	45	220	2X WIND AND UNBALANCE
3014	0.26	0	120	0	0	320	T_L AT STALL, $\dot{\theta}_L \rightarrow 0$

HELIOSTAT OPERATING POWER SUMMARY

0.477-379

	AC/DC EFF	LINE POWER REQUIREMENTS	OP HRS OR DEG PER DAY	TOTAL POWER WATT HRS/DAY
FIXED POWER	0.25	39.67 WATTS	14 HRS	555.38
INNER MOTOR, TRACK	0.50	0.1268 WATT HRS/DEG	90 DEG	11.21
INNER MOTOR, SLEW	0.50	0.0396 WATT HRS/DEG	450 DEG	17.82
OUTER MOTORS, TRACK	0.50	0.2921 WATT HRS/DEG	90 DEG	26.29
OUTER MOTORS, SLEW	0.50	0.2461 WATT HRS/DEG	180 DEG	44.33
TOTAL				655.03

$$\text{AVERAGE POWER} = \frac{655.03 \text{ WATT HR/DAY}}{14 \text{ HR/DAY}}$$

$$= 46.7 \text{ WATTS}$$

$$\frac{\text{POWER CONSUMED}}{\text{POWER GENERATED}} (\%) = \frac{46.7 \text{ WATTS/HELIO}}{10,000,000 \text{ WATTS/1598 HELIOS}} \times 100$$

$$= 0.74 \text{ PERCENT}$$

2-102

CALIBRATION SYSTEM DIAGRAM

0 4 7 7 - 4 0 2

CAL ARRAY ELECTRONICS AND MULTIPLEXER SWITCHING DIAGRAMS

0576-368

PHOTODETECTOR CIRCUIT

OPTICAL CALORIMETER DIAGRAM

0 477 -5 1

THREE TIERED MULTIPLEXER WITH 756 CHANNEL CAPACITY

0 4 7 7 - 4 3 8

NOTE: ALL BOXES ARE 16 CHANNEL
ANALOG MULTIPLEXER CHIPS

RECEIVER AND CALIBRATION ARRAY

ELECTRONIC PARTS

0 477 -39 1

- Costs to achieve operational status after assembly
- Failure rate

AQL LEVELS ON FUNCTIONALITY VERSUS BOARD REWORK RATES

0 477 -7 5

RELATIVE FAILURE RATE VERSUS TIME

SCREENING REQUIREMENTS FOR LOGIC

0 4 7 7 - 4 1 0

- Visual check
- Stabilization bake; 6 hrs at 150°C
- Temperature cycle; 0 to 100°C, 3 cycles
- DC functional test; 100% at 25°C
- Continuity test; 100%
- Burn-in; 168 hrs at 125°C
- Cost: 5 to 15 cents per element

BASIC ELECTRONICS PART TYPES USED IN HELIOSTAT

0477-409

Logic: Vendor screened

Transistors and Diodes: JAN types

Resistors: RLR07

Capacitors: M39014/05

LIGHTNING PROTECTION

0 4 7 7 - 4 0 8

- Transient suppression on communications lines
- Grounding

HELIOSTAT COMMUNICATIONS INTERFACE DIAGRAM

0477-718

HELIOSTAT POWER AND GROUNDING DIAGRAM

037-180

POWER AND GROUNDING DIAGRAM HELIOSTAT CONTROL COMPUTER COMPLEX

POWER AND GROUNDING DIAGRAM CAL ARRAY, TYPICAL OF 8

0377-170

FIELD WIRING

0477-407

- Power distribution
- Signal distribution
- Data collection

FIELD LAYOUT SHOWING VOLTAGE FEED

POWER DISTRIBUTION SYSTEM WIRE SUMMARY

0 4 7 7 - 4 0 6

Total Length: 20575 M (67500 ft)

Wire sizes: 110 volt system, AWG 000-14
220 volt system, AWG 4-20

HELIOSTAT COMMUNICATIONS INTERCONNECT AND WIRING SUMMATION

E 377-191

COMM LINE NO.	NO. OF HELIOS	ROUTE LENGTH L1(M)	TOTAL LENGTH L1+3N(M)
1	100	887	1192
2	96	985	1277
3	104	1770	2088
4	93	1737	2020
5	91	853	1130
6	82	789	1039
7	90	1278	1553
8	90	1048	1323
9	103	1169	1513
9	849	10549 M	13137 M
X2	X2		
18	1698	21098 M	26274 M

WHOLE
FIELD
TOTALS

PILOT PLANT COLLECTOR SUBSYSTEM FIELD INSTRUMENTATION INTERCONNECT DIAGRAM

TOPICS TO BE PRESENTED

0 4 7 7 - 4 1 2

- Control subsystem
- Computer selection
- Safety
- SRE test results
- Energy balance
- Wind tunnel tests

PILOT PLANT COLLECTOR SUBSYSTEM DIAGRAM

COMPUTER INTERFACES

SERIAL DIGITAL I/O

0 877-440

MEGABUS

0477-199B

RACK MOUNTED COMPUTER AND PERIPHERALS

TABLETOP CARD READER

TABLETOP CRT (TTY) AND KEYBOARD

CAB90003 60 INCH RACK MOUNTED
CABINETS WITH ALL PANELS AND DOORS

TABLETOP KSR33 120 CPS
KEYBOARD TYPEWRITER CONSOLE

FREESTANDING LINE PRINTER

0477-67

WHY IS LEVEL 6 A GOOD CHOICE?

0477-285

<u>FUNCTION</u>	<u>L6</u>	<u>CLOSE COMPETITOR</u>	<u>REMARKS</u>
INTERRUPT	64	60	HP IS CLOSE 21 MX MACHINE
BUS BANDWIDTH	6.5×10^6	6×10^6	TI IS CLOSE 990/10 MACHINE
NUMBER OF BUSES	1	1	TI IS CLOSE 990/4 MACHINE
MEMORY ADDRESSES	16×10^6	2×10^6	TI IS CLOSEST 990/10 MACHINE
NUMBER OF CONTROL- LERS AND DEVICE ADDRESSES	1024	1024	TI IS CLOSE 990/10 MACHINE

LOW COST
COMMERCIALLY AVAILABLE
EXPANSION CAPABILITY
SIMPLE SERIAL DIGITAL INTERFACES

COLLECTOR SUBSYSTEM OPERATOR CONTROL CONSOLE

047-442

COLLECTOR SUBSYSTEM SEMIAUTOMATIC CONTROL

0 477 - 286

DESCRIPTION OF CONTROL FUNCTION	HOW INITIATED	
	OPERATOR CONTROL	SOFTWARE CONTROL
1. NORMAL PRIMARY TARGET TRACKING		X
2. TO CALIBRATE SELECTED HELIOSTATS BASED ON:		
ROUTINE OPERATIONS (ONCE/WEEK)	X	X
CONTROL OF TIME BEAM ON CALIBRATION ARRAY		X
SPECIAL TROUBLESHOOTING	X	
CONTROL OF TIME BEAM ON ARRAY	X	
UPDATE SITE PARAMETERS	X	X
3. TRACK SECONDARY (OR STANDBY TARGET)		
DURING START-UP (ALL HELIOSTATS)		X
SPECIAL REASONS (E.G., EXPERIMENTATION, RECEIVER EVALUATION, ETC.) (INDIVIDUAL HELIOSTATS)	X	
DURING STANDBY AFTER UNEXPECTED EVENT (RECEIVER PROBLEM, AFTER PECULIAR ENVIRON- MENTAL CONDITION, ETC.)	X	

COLLECTOR SUBSYSTEM SEMIAUTOMATIC CONTROL (Continued)

0 477 - 436

DESCRIPTION OF CONTROL FUNCTION	HOW INITIATED	
	OPERATOR CONTROL	SOFTWARE CONTROL
4. SAFING		
BEAM CONTROL DURING ROUTINE STARTUP - SHUTDOWN	X	X
BEAM CONTROL DURING EMERGENCY DEFOCUS (3 TO 4 DEGREES OFFSET)	X	X
HELIOSTAT FIELD SECTOR EMERGENCY DEFOCUS	X	
INITIATE EMERGENCY DEFOCUS (RECEIVER THERMAL STRESS, INSOLATION GRADIENTS DUE TO PARTIAL CLOUD COVERAGE, ETC.)	X	X
EQUIPMENT SAFING (GO TO STOW DUE TO WIND OR HAIL CONDITIONS)	X	X
BEAM CONTROL DURING EMERGENCY STOW		X
5. INITIALIZE (I.E., GO TO INITIALIZE)	X	
SELECTED HELIOSTATS	X	
DURING STARTUP SEQUENCE - ALL HELIOSTATS	X	X
6. STOW (END OF DAY, OR AMPLE WEATHER WARNING)		
SELECTED HELIOSTATS	X	
ENTIRE FIELD OF HELIOSTATS	X	X
7. POINT MIRROR NORMAL IN GIVEN DIRECTION (NO TRACKING)	X	

COLLECTOR SUBSYSTEM SEMIAUTOMATIC CONTROL (Continued)

0 4 7 7 - 4 3 9

DESCRIPTION OF CONTROL FUNCTION	HOW INITIATED	
	OPERATOR CONTROL	SOFTWARE CONTROL
8. CONTROL OF RATE TO REACH A GIVEN POSITION OR TARGET		X
9. TESTING		
WRAPAROUND COMMO CHECK (NORMAL OPERATION)		X
WRAPAROUND COMMO CHECK (SPECIAL REQUEST)	X	
SELF-TEST OF CONTROL SUBSYSTEM	X	
LAMP TEST, ETC.	X	
10. DATA OUTPUT		
NORMAL OPERATION		
DISK		X
DISPLAYS	X	X
SPECIAL REQUESTS	X	
11. CONTROL INTERFACE WITH MASTER PLANT CONTROLLER	X	X
12. DISPLAY FIELD AC POWER MONITORS		X
13. COMPARE RESOLVER DATA OF 18 INSTRUMENTED HELIO- STATS WITH CALCULATED GIMBAL POSITION		
ROUTINE		X
SPECIAL REQUEST FOR DISPLAY	X	

COLLECTOR SUBSYSTEM SEMIAUTOMATIC CONTROL

(Continued)

0 4 7 7 - 2 8 3

DESCRIPTION OF CONTROL FUNCTION	HOW INITIATED	
	OPERATOR CONTROL	SOFTWARE CONTROL
14. UPDATE TIME		X
15. SWITCH OR UPDATE OPERATIONAL PROGRAM	X	
16. DISPLAY PARTICULAR METEOROLOGICAL DATA		
ROUTINE		X
SPECIAL REQUESTS	X	

CONTROL ARRANGEMENT FOR SAFING

0477-421

Control during normal operation

- Start up and shutdown sequence
- Daily monitoring, checks and control
- Calibration

Control to protect power plant personnel and equipment

- 15 heliostats coincident at a point 2X focal length beyond tower to produce 1000 watts m^{-2}

Passive measures

- SOP
- Barriers
- Reflective materials

Active

- Software control
- Start up - shutdown timing
- Operator intervention

SRE TEST RESULTS SUMMARY

INSERT WILL BE FURNISHED

SRE TEST RESULTS SUMMARY (Continued)

0 477 - 437

Result highlights

- Aluminum honeycomb mirror modules meet all structural and focal requirements
- The 2 mr open loop daily tracking accuracy requirements can be met
- Wind loading is largest heliostat build cost driver - with regard to structural rigidity and inner drive torsion/lash requirements
- Emergency slew rates can be met
- Calibration method established
One week or longer interval
- All operational modes of operation were demonstrated
- Data provided input for iterative design concepts applicable to pilot plant preliminary design
- Energy balance method developed

IMAGE HORIZONTAL CENTROID DRIFT, SOUTH SIDE, FIRST DAY OF OPERATION

0477-239

HORIZONTAL
DISPLACEMENT

SOUTH HELIOSTAT
LOS - 1031 FT
26 OCTOBER 1976

IMAGE CENTROID VARIATION WITH WIND - EAST SITE

1901.57
28 DEC 1976

SENSOR BANDWIDTH VERSUS COST

TIL99 PHOTOTRANSISTOR GAIN CALIBRATION

0477-422

Quantity - 294

Light Source - Sun

Date - 27 February 1976

Reference Sample Data (10:30 AM to 12:15 PM)

No. 1	± 2.6 percent	} Insolation Variation
No. 2	± 3.2 percent	
No. 3	± 2.2 percent	

Calibration Accuracy - ± 5 percent

PHOTOSENSOR DIRECTIONAL SENSITIVITY

0477-308

TYPICAL LEVEL OF RESIDUAL CALIBRATION ARRAY READOUT WITH NO REDIRECTED INSOLATION

0477-284

DAYS RADGYR PRESS	HOURS PAX2MOM TEMP1	MINS SAX2MOM TAMB	DELVER PAXANG TEMP3	DELHOR GOF TDELTA	WINDSPD ANGSVN PYNOR	WINDDIR RADGLOBAL	CALMAX RATIO	CALSUMG ENERGY	BACKAVG
1	1	0	1	1	0	1	1	1	1
1	1	1	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	1	0
1	1	0	1	0	1	1	1	1	1
1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	0
1	1	1	0	1	1	1	0	0	1
1	1	1	0	1	1	1	1	1	1
1	1	1	1	0	1	1	1	1	2
1	1	1	0	1	1	1	1	1	0
1	1	1	1	0	1	1	1	1	1
1	1	1	1	1	0	1	1	1	1
0	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	206	1	5	151
98.00	19.00	2.000	-0.1450	0.1050	0.6708	11.84	0.7843E-01	200.0	0.7843E-01
5.111	16.16	21.19	-85.37	0.7150	27.44				
915.3	0.0000	-33.61	0.0000	0.0000	897.6	950.7	0.7850	-75.11	

ENERGY BALANCE CALCULATION FROM CALIBRATION ARRAY DATA

$$\text{Energy Indicated} = \frac{\begin{array}{c} \text{Area} \\ \text{of Array} \\ \downarrow \\ [20.82 \text{ m}^2] \end{array} \begin{array}{c} \text{Direct Normal Insolation} \\ \text{(DNI)} \\ \downarrow \\ [\text{Pyreheliometer (watt m}^{-2}\text{)} \\ \text{Reading}] \end{array} \begin{array}{c} \text{Unitless} \\ \text{Scale} \\ \text{Factor} \\ \downarrow \\ [8.43] \times \end{array} \left[\frac{\text{Cal Array Sum-Residual}}{224} \right] \left[\frac{1}{\text{Tracking Photocell Reading}} \right]}{\text{Cos (Off Array Normal Angle)}}$$

INSOLATION ATTENUATION LOSSES

2-148

ENERGY BALANCE COMPARISON

0 4 7 7 - 4 3 5

<u>GMT</u>	<u>SITE (METERS)</u>	<u>EXPECTED ENERGY (WATTS)</u>	<u>MEASURED ENERGY WATTS</u>	<u>PERCENT DIFFERENCE</u>	<u>REMARKS</u>
1905	80.8	5864	5938	+1.3	ONE MIRROR MODULE, 29 MARCH 1977
1913	144	5556	5551	-0.8	ONE MIRROR MODULE, 29 MARCH 1977
1928	220	5385	5395	+0.2	ONE MIRROR MODULE, 29 MARCH 1977
1945	269	5232	5256	+0.5	ONE MIRROR MODULE, 29 MARCH 1977
2009	323.5	5057	4994	-1.2	ONE MIRROR MODULE, 29 MARCH 1977
1944	148	22816	22716	-0.43	NORTH HELIOSTAT, 7 APRIL 1977

ENERGY LOSSES

0477-314

ENERGY LOSSES

LINE OF SIGHT = 80.8M (265) FT

SINGLE MIRROR MODULE (9.3 M²)

29 MARCH 1977, TOD = 1905 HRS

INSOLATION = 842.9 WATT M⁻²

CALIBRATION ARRAY
MEASURED 5938 WATTS
= 1.3% DIFFERENCE

2-L50

ENERGY LOSSES

ENERGY LOSSES

0477-319

ENERGY LOSSES

LINE OF SIGHT = 220'M (722) FT
SINGLE MIRROR MODULE (9.3 M²)
29 MARCH 1977, TOD = 1928 HRS
INSOLATION = 837.3 WATT/M²

CALIBRATION ARRAY
MEASURED 5395 WATTS
= 0.2% DIFFERENCE

TYPICAL SINGLE 9.3M² MIRROR MODULE FLUX MAP

TOD = MARCH 29, 1928 HOURS

DAYS RADGYR PRESS	HOURS PAX2MOM TEMP1	MIN SAX2MOM TAMB	DELVER PAXANG TEMP3	DELHOR GOF TDELTA	WINDSPD ANGSVN PYNOR	WINDDIR RADGLOBAL	CALMAX RATIO	CALSUMG ENERGY	BACKAVG
1	1	0	1	5	0	1	0	1	1
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	2	2	3	2	3
1	1	0	1	1	3	5	9	13	12
1	1	1	2	2	6	8	21	25	26
1	1	1	2	3	9	19	30	36	40
1	1	1	13	4	13	25	35	45	52
1	1	1	1	3	13	21	36	50	57
1	1	1	1	0	9	18	32	46	54
1	1	1	0	2	4	13	22	32	37
1	1	1	1	0	2	5	8	15	21
1	1	1	1	1	0	3	4	6	8
1	1	1	1	1	1	1	1	1	2
0	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	1	201	1	6
88.00	19.00	28.00	-0.2406	1.338	0.5769	14.21	2.235	1781.	0.7843E-01
3.470	5.098	6.946	-74.63	0.9635	33.12				
915.3	0.0000	-33.61	0.0000	0.0000	831.0	849.2	0.7448	5050.	

ENERGY LOSSES

ENERGY LOSSES

ENERGY LOSSES

LINE OF SIGHT = 323.5M (1061) FT

SINGLE MIRROR MODULE (9.3 M²)

29 MARCH 1977, TOD = 2009 HRS

INSOLATION = 803.7 WATT/M²

0477-315

WIND TUNNEL TEST

(APRIL 4 - APRIL 23, 1977)

0 477 - 438

- 1/10 scale model (SRE) - fully instrumented
- $(V/V_{\infty})^{0.15}$ boundary layer profile
- Direct moment readings
- With interference model upstream -
2 distances
- Pressure coefficients
- Vented module evaluation -
3 aspect ratio configurations

2-158

2-160

SPECIFICATION VELOCITY PROFILE

0477-441

PRELIMINARY RESULTS

0 4 7 7 - 2 8 7

- Max worse case moment coefficient = 0.105
- Reduced 90 mph, -13 degree angle of attack from $c_m = 0.18$ to 0.067
- Interference of one heliostat
 - Reduce largest drag loads to $< 1/2$
 - Reduce all large moment coefficients by differing amounts from 30 percent to 50 percent
 - Increased moments in a few cases - low moment coefficients
- Vented mirror modules reduce drag ~ solidity ratio
 - Moment coefficients reduced at mid-range angle of attacks
 - Not much difference at shallow angles
 - Aspect ratio effect very apparent

OPTICAL MODEL PREDICTED FLUX DENSITY

RUN: 3:00 p.m. Solar Time, 4/7/77

NORTH SITE

FLUX DENSITY MEASURED ON THE CALIBRATION ARRAY

PREDICTED AND MEASURED LOSSES VERSUS RANGE

APRIL 7, 1977 TEST DATA

ATTENUATION
LOSS MODEL
CONDITIONS

RELATIVE HUMIDITY 55%
TEMPERATURE 21° C
VISIBILITY 16 km.

CONCLUSION: OUR UNIQUE HELIOSTAT IS READY FOR PILOT PLANT

0 4 7 7 - 3 8 4

- Collector subsystem has unique features
- Collector subsystem warrants high confidence
- Collector subsystem is ready for detail design
- Collector subsystem is moderate cost

COLLECTOR SUBSYSTEM HAS UNIQUE FEATURES

0 4 7 7 - 3 8 5

- Tilt-Tilt
- Low Profile
- Double supports
- Unloaded mirrors
- Simple electronics

THE COLLECTOR SUBSYSTEM WARRANTS HIGH CONFIDENCE

0 4 7 7 - 3 8 6

- Proven through analysis and test
- Highly flexible and adaptable
- Commercial components
- No risk
- Modular design
- Simple

COLLECTOR SUBSYSTEM IS READY FOR PHASE II

0 4 7 7 - 3 8 7

- Capability established
- Tasks known and scoped
- Improvement areas identified
- Lead times defined

ADDITIONAL COLLECTOR SUBSYSTEM EFFORTS ASSURE LOWER PILOT PLANT AND COMMERCIAL COSTS

0477-388

- Design is conservative to reduce risk at increased cost
- Design improvements are defined and cost goals are set
- Designing costs out is an iterative process

RECEIVER SUBSYSTEM

SOLAR RECEIVER STRUCTURE SYSTEM

- RECEIVER TOWER FOUNDATION
- RECEIVER TOWER
- TOWER AUXILIARY EQUIPMENT
- SOLAR STEAM GENERATOR HOUSING

RECEIVER TOWER ELEVATION AND SECTION

RECEIVER STRUCTURE DESIGN CRITERIA

- FUNCTIONAL REQUIREMENTS
 - HELIOSTAT CONFIGURATION
 - TOWER HEIGHT
 - RECEIVER APERTURE GEOMETRY
 - ACCESS AND MAINTENANCE
- LOADS
 - SITE DEPENDENT
 - EQUIPMENT ARRANGEMENT
- STATE-OF-THE-ART TECHNOLOGY

RECEIVER FOUNDATION PLAN AND SECTION

STEAM GENERATOR HOUSING

CORBEL SECTIONAL PLANS

TYPICAL CORBEL CONNECTION

ROOF FRAMING AND BOILER SUPPORT STEEL

STEAM GENERATOR SUPPORT TRUSS

TYPICAL TRUSS HANGER

TYPICAL CORBEL RADIATION SHIELD DETAILS

SOLAR RECEIVER STRUCTURE LOADS

- STATIC LOADS
 - EQUIPMENT
 - STRUCTURE DEAD LOADS
 - SERVICE LIVE LOADS
 - IMPACT LOADS
- WIND LOADING
 - STATIC
 - RADIAL
 - LATERAL SWAYING AND OVALING
- SEISMIC LOADING
 - ACCELERATIONS
 - DISPLACEMENTS
 - SHEARS
 - MOMENTS

SOLAR RECEIVER STRUCTURE
LOAD SUMMARY

	<u>10³ KILOGRAMS</u>	<u>10³ LBS</u>
● STATIC LOADS		
EQUIPMENT	295	650
STRUCTURE DEAD LOADS		
RECEIVER HOUSING	499	1100
CORBELS	109	241
TOWER	4989	11,000
FOUNDATION	7846	17,300
SERVICE LIVE LOADS	79	175

SOLAR RECEIVER STRUCTURE

LOAD SUMMARY (CONT'D)

● WIND LOADS

STATIC (TOWER BASE)

SHEAR	243×10^3 KILOGRAMS	536×10^3 LBS
MOMENT	$21,160 \times 10^6$ GRAM-METERS	$153,000 \times 10^3$ LB-FT

RADIAL

RECEIVER HOUSING	NOT GOVERNING	NOT GOVERNING
TOWER (MOMENT-INSIDE TENSION)	279×10^3 GRAM-METERS	2016 LB-FT
TOWER (MOMENT-OUTSIDE TENSION)	242×10^3 GRAM-METERS	1747 LB-FT

LATERAL SWAYING AND OVALING

INSIGNIFICANT	INSIGNIFICANT
---------------	---------------

SOLAR RECEIVER STRUCTURE

SEISMIC LOADING - STATIC ANALYSIS

- METHODOLOGY

USE FORMULAS DEVELOPED FOR CONVENTIONAL
STRUCTURES AS PROVIDED IN STANDARD
CODES

EQUATIONS CONSIDERED WERE FROM UBC,
SEAOC AND ACI BUILDING CODES

- BASIC RESULTS

MOMENTS AND SHEARS AT THE RECEIVER
TOWER BASE

- LIMITATIONS

CODE EQUATIONS USED ARE NOT DIRECTLY
APPLICABLE TO PROBLEM
ACCELERATIONS AND FORCES WITHIN THE
RECEIVER HOUSING CANNOT BE CALCULATED

SCLAR RECEIVER STRUCTURE
SEISMIC LOADING-ELASTIC/DYNAMIC ANALYSIS

- METHODOLOGY

USED RESPONSE SPECTRA AND TIME HISTORY ANALYSIS TO
VERIFY CODE EQUATIONS, OBTAIN ACCELERATIONS AND
FORCES, AND DETERMINE EFFECTS OF INCREASED HEIGHT

DEVELOPED STICK MODEL WITH PROPERTY CHARACTERISTICS
OF RECEIVER TOWER

USED NRC REGULATORY GUIDE 1.60 RESPONSE SPECTRA
NORMALIZED TO 0.25g

ASSUMED DAMPING TO BE 2% OF CRITICAL DAMPING

LATERAL VIBRATION MODE

SOLAR RECEIVER STRUCTURE
SEISMIC LOADING-ELASTIC/DYNAMIC ANALYSIS (CONT'D)

- BASIC RESULTS

ACCELERATIONS, DISPLACEMENTS, SHEARS, AND MOMENTS
ARE CALCULATED

DISPLACEMENTS ARE LINEARLY RELATED TO TOWER HEIGHT

ACCELERATIONS ARE INDEPENDENT OF TOWER HEIGHT

SOLAR RECEIVER STRUCTURE
LOAD SUMMARY (CONT'D)

● SEISMIC LOADS

STATIC

BASE SHEAR-ACI 307	825×10^3 KG	1820×10^3 LBS
BASE SHEAR-UBC 1976	449×10^3 KG	990×10^3 LBS
BASE MOMENT-ACI 307	$51,862 \times 10^6$ GRAM-METERS	$375,000 \times 10^3$ LB-FT

ELASTIC, DYNAMIC

BASE SHEAR	1242×10^3 KG	2740×10^3 LBS
BASE MOMENT	$66,937 \times 10^6$ GRAM-METERS	$484,000 \times 10^3$ LB-FT

MAXIMUM ACCELERATION AND DISPLACEMENTS AS A FUNCTION OF SUPPORT TOWER

SOLAR RECEIVER STRUCTURE
SEISMIC LOADING-ELASTIC/DYNAMIC ANALYSIS (CONT'D)

- CONCLUSIONS

DYNAMIC ANALYSIS SHOULD BE PERFORMED USING RESPONSE SPECTRUM OR TIME HISTORY ANALYSIS

RECEIVER TOWER SHOULD BE ELASTICALLY AND DYNAMICALLY ANALYZED THEN DESIGNED IN ACCORDANCE WITH ACI 318

STEEL COMPONENTS DESIGNED ACCORDING TO THE ELASTIC, DYNAMIC ANALYSIS, AND THE AISC CODE

SOLAR RECEIVER STRUCTURE SUMMARY

- SUPPORT TOWER/FOUNDATION
 - REINFORCED CONCRETE CIRCULAR RAFT FOUNDATION
 - REINFORCED CONCRETE SLIP-FORM CHIMNEY STRUCTURE
 - ADEQUATE ACCESS EQUIPMENT
- RADIATION SHIELDING AND VENTILATION
- SOLAR-STEAM GENERATOR HOUSING
 - BOX BEAM COREELS
 - GENERATOR SUPPORT TRUSS LEVELS
 - ACCESS AND MAINTENANCE PLATFORMS
 - CAVITY BARRIER
 - CONVENTIONAL WALL PANEL AND GIRT SYSTEM
- STRUCTURAL DESIGN ACCOMMODATES
 - STRUCTURAL EQUIPMENT DEAD AND LIVE LOADS
 - STATIC AND DYNAMIC WIND LOADS
 - EARTHQUAKE LOADS

DESIGN DIMENSIONS

- REQUIREMENTS
- DESIGN METHODOLOGY
- DESIGN DESCRIPTION
- PERFORMANCE CHARACTERISTICS
- COMPONENTS
- FUNCTIONAL PERFORMANCE
- STRESS ANALYSIS
- MATERIAL SELECTION
- SRE RESULTS
- SUMMARY

REQUIREMENTS

- FUNCTIONAL

Supply 516°C steam at 10.1 MPa to turbine while accepting all available energy

Design Steam Flow (12/21/2 PVI) 827 kg/min (104300 lb/hr)

Maximum Steam Flow (3/21/12 AM) 1017 kg/min (134 400 lb/hr)

Low Steam Flow (3/21/7AM) 237 kg/min (31300 lb/hr)

Rapid and Stable Startup 390° C/hr (700° F/hr)

Cloud Shadowing

Steam to Thermal Storage

- PHYSICAL

- HEAT ABSORPTION

- STRUCTURAL

DESIGN METHODOLOGY

- USE STATE-OF-THE-ART FOSSIL BOILER TECHNOLOGY
- INCORPORATE SRE DESIGN FEATURES AND
APPLY SRE BUILD AND TEST EXPERIENCE
- INCLUDE DESIGN MARGINS TO ALLOW FOR
OFF-DESIGN OPERATION

RECEIVER GEOMETRY

INTERNAL RECEIVER CONFIGURATION

CAVITY WALL INCIDENT FLUX AZIMUTHAL MAP FOR 12:00, 3/21

AVERAGE ABSORBED POWER DENSITY VERTICAL DISTRIBUTION

ABSORBED POWER DENSITY AZIMUTHAL DISTRIBUTION AT PRIMARY/ SECONDARY SUPERHEATER INTERFACE

FLOW CIRCUIT STEAM CONDITIONS FOR 12:00 PM, March 21

Figure 3-4. Steam Generator Flow Circuit

Location	P MP (PSIA)	T °C °C °F	W kg6mm Kg/min 2 (#/hr)
① Feedwater	—	179 (353)	928 (122600)
② Pump Inlet	11.78 (1709)	315 (597)	10280 (1358000)
③ Pump Discharge	12.12 (1759)	315 (597)	10280 (1358000)
④ Drum Discharge	11.64 (1690)	322 (613)	928 (122600)
⑤ Primary Outlet	11.33 (1645)	461 (863)	928 (122600)
⑥ Attenuator Spray		179 (353)	102 (13500)
⑦ Secondary Inlet	11.30 (1640)	378 (712)	1030 (136100)
⑧ Secondary Outlet	11.02 (1600)	515 (960)	1030 (136100)

BOILER SECTION FLOW CIRCUITS

BOILER SECTION DETAIL

SPECIFICATIONS:

TUBE:

O.D. 2.223 cm (.875 IN.)
 MIN. WALL 0.376 cm (0.148 IN.)
 MAT'L. SA 210 GRADE A1CF

* 7.62cm (3.0 INCH) ON NORTH WALL

WEB:

THICKNESS $.635\text{cm}$ (0.25 IN.)
 MAT'L. CARBON STEEL (C1015 C.F.)

SUPERHEATER MODULE SPECIFICATION

SPECIFICATIONS

TUBES:

OD	2.54cm (1.0 IN.)
MIN WALL	0.419cm (0.135 IN.)
MAT'L	SA 213 T22
NO TUBES	126 PRIMARY
	189 SECONDARY

HEADERS:

OD	16.8cm (6.675 IN.)
MIN WALL	3.27cm (1.286 IN.)
MAT'L	SA 335 P22

SUPERHEATER FLOW SCHEMATIC

SUPERHEATER HANGER SPECIFICATION

SUPERHEATER LATERAL TIES DETAIL

RECIRCULATING PUMP

ATTEMPERATOR

SUPPORT TRUSS CONFIGURATION

FUNCTIONAL PERFORMANCE CONSIDERATIONS

- BALANCE FLOW AND HEAT ABSORPTION

BOILER

SUPERHEATER

- ENERGY LOSSES

CONDUCTION

CONVECTION

RADIATION

BOILER TUBE FLOW REQUIREMENTS

- PREVENT FILM BOILING
- PREVENT DOWNFLOW IN COLD CIRCUITS AND TUBES
- PREVENT UNDESIRABLE FLOW PATTERNS (SLUG)

BOILER FLOW CIRCUIT PERFORMANCE CHARACTERISTICS AT 12:00, 3/21

<u>Circuit</u>	<u>Flow Kg/min (lb/hr)</u>	<u>Valve ΔP KPa (psi)</u>	<u>No. Of Tubes</u>	<u>Average Flow Per Tube kg/min (lb/hr)</u>	<u>Average Absorption Per Tube KW (1000 BTU/HR)</u>	<u>Average % SBW @ Outlet</u>
N	1231 (162600)	7.3 (1.06)	173	7.1 (940)	2.6 (8.93)	-2.8
EN	891 (117700)	20.7 (3.0)	138	6.4 (853)	10.1 (34.4)	3.4
ES	1670 (220600)	30.0 (4.35)	138	12.1 (1599)	44.2 (150.9)	14.1
SE	1664 (219800)	30.0 (4.35)	138	12.0 (1593)	48.4 (165.1)	16.0
S	628 (82900)	12.8 (1.86)	69	9.1 (1202)	40.4 (138.0)	18.4
SW	1670 (220600)	30.0 (4.35)	138	12.1 (1598)	47.6 (162.4)	15.6
WS	1660 (219300)	30.0 (4.35)	138	12.0 (1589)	39.9 (136.2)	12.5
WN	866 (114400)	20.3 (2.95)	138	6.3 (829)	10.0 (34.1)	3.53
Total	10280 (1.358 x 10 ⁶)	-----	1070	9.6 (1269)	28.7 (98.1)	10.7

FLOW AND ENTHALPY VARIATION' **BOILER CIRCUIT NE AT 12:00 PM, 3/21**

<u>Tube Orientation</u>	<u>Flow Per Tube kg/min (lbs/hr)</u>	<u>Absorption KW (KETU/HR)</u>	<u>Enthalpy @ Outlet cal/gm (BTU/LB)</u>	<u>% SBW @ Outlet</u>
50°	6.1 (800)	1.96 (6.67)	.352 (633)	-3.0
60°	5.9 (785)	4.98 (17.0)	.359 (646.3)	-0.4
70°	6.2 (825)	7.5 (25.65)	.365 (656.4)	1.6
80°	7.0 (921)	15.2 (51.84)	.379 (681.9)	6.7
90°	7.7 (1015)	28.6 (97.54)	.401 (720.6)	14.43

PRESSURE DROP VERSUS RECIRCULATION RATIO

STATIC STABILITY, EN BOILER CIRCUIT AT 12:00 PM, 3/21

PRIMARY SUPERHEATER STEAM TEMPERATURE AND HEAT FLUX VERSUS AZIMUTH ANGLE AT 12:00 PM, 3/21

SUPERHEATER METAL TEMPERATURES

TIME	LOCATION	UPSET STEAM TEMP.		UPSET ABSORPTION RATE		DESIGN METAL TEMPERATURE	
		°C	(°F)	KW/M ²	(BTU/HR - FT ²)	°C	(°F)
3/21/12PM	1	386	(726)	154	(43±10 ³)	438	(820)
3/21/12PM	2	444	(832)	114	(35±10 ³)	488	(910)
3/21/12PM	3	474	(885)	91	(29±10 ³)	510	(950)
3/21/12PM	4	443	(829)	66	(21±10 ³)	474	(885)
3/21/12PM	5	499	(930)	66	(21±10 ³)	531	(988)
3/21/12PM	6	535	(995)	46	(14.5±10 ³)	559	(1039)
12/2/12PM	3	468	(875)	74	(23.5±10 ³)	500	(932)
12/2/12PM	6	538	(1000)	38	(12±10 ³)	563	(1045)
3/21/7AM	3	510	(950)	22	(7±10 ³)	529	(985)
3/21/7AM	6	518	(965)	2.3	(0.8±10 ³)	521	(970)
6/21/12PM	3	450	(815)	86	(27.4±10 ³)	524	(975)
6/21/12PM	6	528	(982)	53	(13.8±10 ³)	554	(1030)

SUPERHEATER CIRCUIT PERFORMANCE AT 12:00 PM, 3/21

	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>	<u>E</u>	<u>F</u>
Absorption, KW (KBTU/hr)	3178 (10837)	2932 (10000)	2582 (8805)	2474 (8435)	2277 (7766)	2330 (7947)
Flow, kg/min (lb/hr)	327 (43200)	315 (41600)	286 (37800)	331 (43690)	353 (46620)	352 (46460)
Average Outlet Temp, °C (°F)	465 (870)	456 (854)	458 (858)	530 (986)	502 (936)	510 (950)

RANGE OF OPERATION WITH CLOUD SHADOWING

<u>Case</u>	<u>Description</u>	<u>Reduction in Boiler Absorption</u>	<u>Reduction in Superheater Absorption</u>	<u>Reduction in Total Absorption</u>	<u>Limit</u>
1	Cloud shadows boiler section	20%	0	13%	Metal Temperature
2	Cloud shadows top of super- heater	0%	25%	8.75%	Metal Temperature
3	Cloud shadows part of all surfaces	23%	23%	23%	Metal Temperature

ATTEMPERATOR SPRAY FLOW REQUIRED TO CONTROL STEAM TEMPERATURE

<u>Case</u>	<u>Description</u>	<u>Feedwater Temperature C, (F)</u>	<u>Spray Flow kg/s (lb/hr)</u>	<u>Steam Flow kg/s (lb/hr)</u>	<u>Absorbed Energy Mw</u>
4	Operation with high pressure feedwater heater out of service	111* (232)	124.6 (16450)	939 (124060)	45.3
5	Feedwater temperature based on revised turbine heat balance data	215 (419)	86.5 (11430)	1098 (145070)	45.3
6a	Steam to thermal storage alone, maximum absorbed energy	140* (285)	8.2 (1085)	966 (127600)	45.3
6b	Steam to thermal storage alone, low absorbed energy	140* (285)	120.7 (15950)	235 (31000)	11.0

*Preliminary turbine heat balance.

CONVECTION LOSSES

CONDUCTION LOSSES

<u>Component</u>	<u>Conduction Loss, KW (KBTU/HR)</u>	
	<u>SRE</u>	<u>Pilot Plant</u>
Boiler Section	17.9 (61.0)	283 (966)
Superheater	23.6 (80.4)	394 (1343)
Ceiling	5.7 (19.3)	104 (356)
Total	47.1 (160.7)	781 (2666)
% of Maximum Absorbed Energy	0.94%	1.72%

CAVITY EFFICIENCY VERSUS THERMAL RADIATION COEFFICIENT AT 12:00 PM, 3/21

OVERNIGHT COOLDOWN RATE

MATERIAL SELECTION

THE SELECTED MATERIALS WHICH ARE COMMONLY USED
IN SIMILAR FOSSIL BOILER APPLICATIONS

- BOILER SECTION
- CARBON STEEL
- SUPERHEATER
- CROLOY 2¼

TYPICAL CROLOY 2-1/4 TUBE APPLICATIONS

Unit	Startup Date	P _{steam} MPa (psig)	T _{steam} °C (°F)	Tube OD cm (in)	Wall Thickness cm (in)	ID Temp. °C (°F)	OD Temp. °C (°F)	Cycles
RB-100	1951	10.2 (1475)	533 (990)	5.1 (2.0)	0.711 (0.280)	562 (1043)	578 (1071)	--
RB-101	1951	10.2 (1475)	533 (990)	5.1 (2.0)	0.711 (0.280)	562 (1043)	578 (1071)	~1000-2000
RB-148	1953	10.2 (1475)	538 (1000)	5.7 (2.25)	0.711 (0.280)	560 (1040)	572 (1060)	--
RB-471 Superheater	1972	15.3 (2225)	526 (979)	5.1 (2.0)	0.889 (0.350)	--	586 (1086)	Daily Cycling
RB-471 Reheater		--	546 (1015)	6.4 (2.5)	0.419 (0.165)	--	587 (1088)	Daily Cycling
RB-472 Superheater	1972	15.3 (2225)	538 (999)	5.1 (2.0)	0.881 (0.347)	--	589 (1091)	--
RB-472 Reheater		--	542 (1007)	5.7 (2.25)	0.376 (0.148)	--	575 (1067)	--

STRESS ANALYSIS

BOILER SECTION

SUPERHEATER TUBE

PERMISSIBLE RATE OF TEMPERATURE CHANGE

SUPERHEATER TUBE GEOMETRY

SUPERHEATER TUBE CROSS SECTION AND TEMPERATURE GRADIENT

SUPERHEATER TUBE CROSS-SECTION

ASSUMED TEMPERATURE GRADIENT

PRIMARY SUPERHEATER TUBE STRESSES

NODE 1, POINT A, 12 PM, 3/21

$$\phi = 80.8 \text{ kw/m}^2 \quad T = 468^\circ \text{ C (873}^\circ \text{F)}$$

	σ_ϕ	σ_l	σ_r
Pressure	3.1 ksi	1.5	0
Mechanical	1.5	0	0
Thermal	0	7.6	0
Total	4.6	-6.1	0

Comparison to Elastic Analysis Criteria
--- Of Code Case 1592

- Load Controlled Stresses Are Acceptable
- Steam Units to Prevent Ratcheting and Creep Enhancement Due To Thermal Cycling Are satisfied
- The Accumulated Creep-Fatigue Damage is Acceptable

$T_m < 950^\circ \text{F}$ Elastic Analysis Criteria Are Met

$T_m \leq 950^\circ \text{F}$ Inelastic Analysis is Required

BOILER CIRCUIT TRANSIENT THERMAL STRESSES

SUPERHEATER TRANSIENT THERMAL STRESS

SUMMARY

PILOT PLANT STEAM GENERATOR DESIGN WILL MEET THE PERFORMANCE REQUIREMENTS:

Supply 516^o C steam at 10.1 MPa to the turbine

without defocusing heliostats approximately one hour after startup is initiated

Supply steam to the turbine and/or thermal storage without defocusing heliostats

Operate with partial cloud shadowing without defocusing heliostats
or reducing steam temperature

SRE STEAM GENERATOR TEST ARRANGEMENT

CONTROL VALVES

STEAM OUTLET VALVES

TRANSDUCER STATION

STEAM GENERATOR

RADIANT ARRAY IN OPERATION

STEAM GENERATOR IN OPERATION

CONTROL CONSOLE

SRE TEST RESULTS

OBJECTIVES

- **VERIFY DESIGN METHODS**
 - STEADY STATE**
 - TRANSIENT**
- **DEMONSTRATE THAT STEAM GENERATOR IS**
 - RELIABLE**
 - CONTROLLABLE**
 - RESPONSIVE**
- **DEMONSTRATE VALIDITY OF INCIDENT AND
ABSORBED HEAT FLUX MEASUREMENTS**

STEADY STATE PERFORMANCE

VERIFY DESIGN METHODS WITH AXISYMMETRIC FLUX DISTRIBUTION

- **BOILER SECTION METAL TEMPERATURES**
- **SUPERHEATER METAL TEMPERATURES**
- **SUPERHEATER FLOW AND HEAT INPUT
BALANCE**
- **SUPERHEATER PRESSURE DROP**

ABSORBED HEAT FLUX MEASUREMENTS

- **BOILER SECTION**
- **SUPERHEATER**

ASYMMETRIC FLUX DISTRIBUTION

SRE STEADY STATE DATA APRIL 13, 1977 11:37 AM

INCIDENT ENERGY	3.2 MW
ENERGY LOSS	0.18 MW
ABSORBED ENERGY	3.0 MW
BOILER	2.1 MW
PRIMARY SUPERHEATER	0.67 MW
SECONDARY SUPERHEATER	0.22 MW

	MEASURED			PREDICTED
LOCATION	FLOW (LBM/HR)	TEMPERATURE (°F)	PRESSURE (PSIA)	PRESSURE (PSIA)
FEEDWATER	9924	469	1915	—
BOILER INLET	86900	603	—	—
BOILER OUTLET	86900	610	—	—
DRUM	10136	610	1670	1670
PRIMARY SH OUT	10136	843	1641	1642
SECONDARY SH OUT	10136	958	1601	1594

SUPERHEATER FLUID TEMPERATURE PROFILE

HEAT FLUX PROFILES

SUPERHEATER HEAT TRANSFER

STEAM GENERATOR TEMPERATURE

TRANSIENT PERFORMANCE

OBJECTIVES:

- **VALIDATE STEAM GENERATOR
TRANSIENT MODEL**
- **EVALUATE STEAM GENERATOR CONTROLS**
- **EVALUATE STEAM GENERATOR PERFORMANCE
DURING TRIP SIMULATIONS**

OPEN LOOP CONTROL TESTS

- **STEAM FLOW STEP**
- **ATTEMPERATOR SPRAY FLOW STEP**
- **INCIDENT FLUX STEP**

CLOSED LOOP CONTROL TESTS

- **9%/MIN POWER RAMP**
- **BOILER SECTION INCIDENT FLUX STEP**
- **TOTAL INCIDENT FLUX STEP**

TRIP SIMULATIONS

- **HELIOSTAT TRIP AND RESTART**
- **RECIRCULATION PUMP**
- **FEEDWATER PUMP**

STEAM CONTROL VALVE STEP

INITIAL CONDITIONS

VARIABLE	PREDICTIONS	ACTUAL TESTS
FEEDWATER TEMPERATURE	400°F	475°F
POWER LEVEL (ABSORBED)	4.2 MW (100%)	3.02 MW (72%)
FLUX DISTRIBUTION	70% – BOILER 24.3% – FSH 5.7% – SSH	69.8% – BOILER 22.8% – FSH 7.4% – SSH
ATTEMPERATION FLOW	400. LBM/HR	0 LBM/HR

MAIN STEAM FLOW (STEAM CONTROL VALVE STEP CHANGE)

MAIN STEAM PRESSURE (STEAM CONTROL VALVE STEP CHANGE)

PRIMARY S. H. OUTLET TEMPERATURE (STEAM CONTROL VALVE STEP CHANGE)

MAIN STEAM TEMPERATURE (STEAM CONTROL VALVE STEP CHANGE)

CLOUD TRANSIENT

CLOUD TRANSIENT

CLOUD TRANSIENT

CLOUD TRANSIENT

CLOUD TRANSIENT

CLOUD TRANSIENT

SUMMARY

THE SRE STEAM GENERATOR PERFORMANCE IS

- **RELIABLE**
- **PREDICTABLE**
- **CONTROLLABLE**
- **RESPONSIVE**

**FOSSIL BOILER TECHNOLOGY CAN FORM THE
BASIS FOR A SUCCESSFUL SOLAR STEAM GENERATOR**

PDR - THERMAL STORAGE SUBSYSTEM - AGENDA

Description

Tradeoffs

Performance

Operation

**THERMAL STORAGE SUBSYSTEM
PRELIMINARY DESIGN - ARTIST CONCEPT**

THERMAL STORAGE SUBSYSTEM - 100 MW (e) PLANT SITE PLAN

THERMAL STORAGE SUBSYSTEM - 100 MW(e) PLANT

SITE PLAN

■ 10 MW(e)

THERMAL STORAGE SUBSYSTEM SCHEMATIC

THERMAL STORAGE CHARGING CYCLE

TO BE IDENTIFIED

THERMAL STORAGE DISCHARGE CYCLE

THERMAL STORAGE DISCHARGING CONFIGURATION

TO BE IDENTIFIED

MOLTEN SALT STORAGE VAULT

SUPERHEATER STORAGE - DESIGN FEATURES

- **MOLTEN HITEC SALT**
 - LONG INDUSTRIAL USAGE
 - LOW VAPOR PRESSURE
 - MINIMAL CORROSION PROBLEMS

- **BELOW GRADE STORAGE**
 - LOW COST APPROACH TO TANK INSULATION
 - MINIMUM EARTHQUAKE HAZARD
 - GRAVITY DRAIN OF SALT

- **SYSTEM DESIGN**
 - TRACE HEATING TO PREVENT FREEZING
 - ATTEMPERATION FOR SALT TEMPERATURE LIMIT
 - NITROGEN ATMOSPHERE FOR MINIMAL SALT OXIDATION
 - LUBRITE PADS FOR TANK THERMAL GROWTH

TO BE IDENTIFIED

OIL/ROCK STORAGE TANK

STORAGE TANK MANIFOLD PLAN AND DETAILS

ROCK AND OIL STORAGE - DESIGN FEATURES

OIL AND ROCK

HIGH FIRE AND FLASH POINTS

REASONABLE LIFE CYCLE REPLACEMENT COSTS

ROCK IS INEXPENSIVE

ABOVE GRADE CONSTRUCTION

ALLOWS FOR THERMAL BREATHING

ECONOMICAL CONTAINMENT OF OIL LEAKAGE

SYSTEM DESIGN

SINGLE STRATIFIED TANK

REPEATED COOL DOWN TO AMBIENT

SLOPED BOTTOM AND SUMP FOR DRAINAGE

EARTHQUAKE-ZONE 3

HEAT EXCHANGERS

TO BE IDENTIFIED

STORAGE INSTRUMENTATION

TANK INSTRUMENTATION - THERMOCOUPLE LOCATIONS

TRADEOFFS

- MAIN STORAGE
- SUPERHEATER STORAGE
- NUMBER OF STAGES
- HEAT EXCHANGER SIZING
- TANK CONFIGURATION
- FINAL OIL TEMPERATURE
- ROCK SIZE

MAIN STORAGE DESIGN POINT SELECTION

THERMAL ENERGY STORAGE

COST COMPARISON FOR THREE ALTERNATIVE NEAR TERM SENSIBLE HEAT STORAGE SYSTEM FOR SOLAR PILOT PLANT APPLICATION

SUPERHEATER STORAGE DESIGN POINT SELECTION

TEMPERATURE ENTHALPY DIAGRAM

• HEAT EXCHANGER SIZING:

APPROACH TEMP
(PINCH PT.)

• STORAGE MATERIAL QUANTITY:

STORAGE TEMPS.

• THERMAL STORAGE CAPACITY:

DISCHARGE
PRESSURE
(PRESSURE RATIO)

THERMAL STORAGE HEAT EXCHANGER PINCH POINT TRADE-OFF

T.S. SUBSYSTEM TRADE-OFF STUDIES FOR FINAL FLUID TEMPERATURE OUT

BED PRESSURE DROP AND UTILIZATION FACTOR vs PARTICLE SIZE

PARTICLE SIZE TRADE-OFF

THERMOCLINE PRINCIPLE (HEAT TRANSFER ZONE)

THERMAL STORAGE PERFORMANCE SUMMARY

<u>CHARACTERISTIC</u>	<u>PILOT</u>	<u>COMMERCIAL</u>
NET ELECTRICAL OUTPUT, MW(e)	7.0	70.0
DURATION OF OUTPUT, HOURS	3	3
HOLD PRIOR TO OUTPUT, HOURS	20	20
SEALING AND TRACING STEAM DURATION, HOURS	20	20
MAXIMUM DISCHARGE RATE MW _{9t}) MW(t)	31.6	284.5
MAXIMUM CHARGE RATE EFFICIENCY, %	31.6	247.3
GROSS THERMAL EFFICIENCY, AT 100%, 50% and 25% F FLOW	0.285/0.235 /0.158	0.318/0.262 /0.176
HEAT LOSS RATE % CAPACITY/DAY	5	5
OPERATIONAL AVAILABILITY	98%	98%
CHARGE RATE EFFICIENCY, %	84	84

THERMAL STORAGE DESIGN SUMMARY

<u>PARAMETER</u>	<u>PILOT PLANT</u>	<u>COMMERCIAL PLANT</u>
Storage Capacity, MWH(t)	133	961
Main Storage, MWH(t)	116	831
SH Storage, MWH(t)	17	130
Main Storage Media	Caloria Oil/Rocks	Caloria Oil/Rocks
SH Storage Medium	Hitec Salt	Hitec Salt
Main Storage Tankage-Quantity	One	Two
Diameter, Meters	18.3	34.8
Wall Height, Meters	14.6	14.6
SH Storage Tankage	Two Cylindrical Tanks With Dished Heads - Below Ground	
Diameter, Meters	6.1	12.2
Wall Height, Meters	4.9	9.8
Heat Loss Rate, % Capacity/day	5	5

THERMAL STORAGE DESIGN SUMMARY (concluded)

<u>PARAMETER</u>	<u>PILOT PLANT</u>	<u>COMMERCIAL PLANT</u>
Operating Temperatures		
Main Storage, °C	303 249	303 249
Min. Oil temperature when charged, °C	300 290	300 290
discharged, °C		
SH Storage, C	454 299	454 299
Sealing & Tracing Steam, % of Capacity	6.0	2.3
Oil Maintenance Unit		
Type	Distillation Column	Distillation Column
Capacity, bpd	200	800
Fired	electric/oil	electric/oil
Boiler Load, kw	184	750 kw
Operation	Continuous	Continuous
Oil/Hitec Usage Unit		
Gas	Nitrogen	Nitrogen
Storage Type	Liquid	Liquid
Vaporizer	2 Stage/ambient Air	2 Stage/ambient Air
Liquid Capacity, Liters	6400	37,200
Standard Cubic Meters, SCM	3542	23,456
Fire Protection		
Type	Light Water Foam	Lightwater Foam
Detectors	Ultra-Violet	Ultra-Violet
Operation	Automatic	Automatic
Rate, Liters/Min	2000	16,000
Capacity, Liters	130,000	960,000

THERMAL STORAGE SUMMARY

FEATURE	BENEFIT
<ul style="list-style-type: none">• MODULAR EQUIPMENT• ROCK AND OIL STORAGE<ul style="list-style-type: none">• INORGANIC SALT FOR SUPERHEAT• TURBINE ADMISSION MARCHING• SIMULTANEOUS CHARGE AND DISCHARGE• BELOW GROUND SUPERHEATER STORAGE• STANDARD EQUIPMENT AND MATERIALS• READY ACCESS TO ALL STORAGE ELEMENTS• OPERATIONAL SIMPLICITY	<ul style="list-style-type: none">• DESIGN CONTINUITY FOR COMMERCIAL PLANT• LOW CAPITAL AND OPERATING COST• SUPERIOR SWITCHING PERFORMANCE• FLEXIBLE OPERATING STRATEGIES• LONG SERVICE LIFE AND SAFE OPERATIONS• LOW DEVELOPMENT RISK• EASE OF MAINTENANCE• USE EXISTING UTILITY SKILLS WITH MINIMAL SPECIAL TRAINING

EPGS / BALANCE OF PLANT

ELECTRICAL POWER GENERATION SUBSYSTEM OVERVIEW

- REQUIREMENTS
- CYCLE CONSIDERATIONS
- MAJOR MECHANICAL SYSTEMS
- MINOR MECHANICAL AND CHEMICAL SYSTEMS
- ELECTRICAL SYSTEMS
- OPERATING MODES

ELECTRICAL POWER GENERATION SUBSYSTEM PERFORMANCE REQUIREMENTS

- 10 MW NET BUSBAR ELECTRICITY AT 2 PM ON WINTER SOLSTICE USING SUPERHEATED STEAM SUPPLIED FROM RECEIVER SUBSYSTEM.
- 7 MW NET BUSBAR ELECTRICITY FOR 3 HOURS USING SUPER-HEATED STEAM SUPPLIED FROM THERMAL STORAGE SUBSYSTEM.
- 7 MW NET BUSBAR ELECTRICITY USING STEAM FROM RECEIVER AND THERMAL STORAGE SUBSYSTEMS SIMULTANEOUSLY.
- OPERATE SAFELY AND RELIABLY AT MAXIMUM STEAM FLOW GENERATED BY RECEIVER SUBSYSTEM.

PILOT PLANT PRIMARY OPERATING MODES

SUBSYSTEM	MODE A	MODE B	MODE C	MODE D
COLLECTOR	FOCUSED	DEFOCUSED	FOCUSED	FOCUSED
RECEIVER	GENERATING STEAM	SEALED	GENERATING STEAM	GENERATING STEAM
THERMAL STORAGE	HOLDING	DISCHARGING	DISCHARGING	CHARGING
EPGS/BOP	GENERATING ELECTRICITY	GENERATING ELECTRICITY	GENERATING ELECTRICITY	SEALED

ADVANTAGES OF AN AUTOMATIC ADMISSION TYPE TURBINE

- ALLOWS BOTH RECEIVER AND THERMAL STORAGE SUBSYSTEM STEAM TO BE USED SIMULTANEOUSLY.
- TRANSFER OF STEAM SOURCES CAN OCCUR MORE EFFICIENTLY, WITH GREATER SPEED AND SMOOTHNESS OF TRANSITION.
- THERMAL SHOCK TO TURBINE, PIPING AND VALVES IS GREATLY REDUCED DURING STEAM SOURCE TRANSFER.
- TURBINE NEED NOT BE OVERRATED TO MEET 7 MW NET GENERATION REQUIREMENT USING THERMAL STORAGE STEAM.

TURBINE STEAM CONDITION SELECTION

<u>PARAMETER</u>	<u>OBJECTIVE</u>	<u>CONSTRAINT</u>	<u>SELECTION</u>
THROTTLE PRESSURE	LOW VOLUMETRIC STEAM FLOW	TURBINE DOUBLE SHELL LIMIT	10,101 kPa (1465 PSIA)
THROTTLE TEMPERATURE	HIGH SYSTEM EFFICIENCY	CYCLIC THERMAL CRACKING	510°C (950°F)
ADMISSION PRESSURE	EQUAL THROTTLE AND ADMISSION FLOWS	THERMAL STORAGE COST TRADEOFF	3275 kPa (475 PSIA)
ADMISSION TEMPERATURE	MINIMAL STEAM SOURCE TRANSFER TIME	THERMAL STORAGE	388°C (730°F)

MAJOR MECHANICAL SYSTEMS

<u>SYSTEM</u>	<u>FUNCTION</u>
TURBINE GENERATOR	CONVERT THERMAL ENERGY TO ELECTRICAL ENERGY
HIGH PRESSURE STEAM	TRANSPORT STEAM BETWEEN RECEIVER, THERMAL STORAGE AND TURBINE
EXTRACTION STEAM AND HEATER DRAIN	TRANSPORT EXTRACTION STEAM TO FEEDWATER HEATERS AND DEAERATOR
FEEDWATER	PUMP FEEDWATER AND ATTEMPERATOR WATER TO RECEIVER AND THERMAL STORAGE
CONDENSATE	CONDENSE TURBINE EXHAUST STEAM
CIRCULATING WATER	REMOVE CONDENSER WASTE HEAT

AUTOMATIC ADMISSION TURBINE SCHEMATIC

GENERATOR OUTPUT VS. STEAM MASS FLOW FOR THREE STAGES OF FEEDWATER HEATING

THROTTLE - 10101 kPa (1465 PSIA), 510°C (950°F)

ADMISSION - 3275 kPa (475 PSIA), 388°C (730°F)

EXHAUST - 6.8 kPa (2 IN HG)

GROSS TURBINE EFFICIENCY
VS.
THROTTLE PLUS ADMISSION STEAM FLOW

TURBINE CHOKING BACKPRESSURE VS. THROTTLE STEAM FLOW

TYPICAL CYCLIC LIFE CURVES FOR TURBINES WITH .46 M (18") DIAMETER ROTORS

TYPICAL COOL DOWN CURVE FOR SINGLE SHELL TURBINE

TURBINE SEAL STEAM ALTERNATIVES

<u>ALTERNATIVE</u>	<u>PRESSURE</u>	<u>TEMPERATURE</u>	<u>MASS FLOW</u>
	kPa (PSIA)	C (F)	KG/HR (LB/HR)
1	10,101 (1465)	510 (950)	454 (1000)
2	3275 (475)	388 (730)	454 (1000)
3	138 (20)	121 (250)	590 (1300)

FEEDWATER PUMPING CONSIDERATIONS

- PUMP TYPE

- MULTI-STAGE CENTRIFUGAL

- HIGH SPEED CENTRIFUGAL

- POSITIVE DISPLACEMENT PUMP

- PUMP ARRANGEMENT

- SINGLE PUMP

- BOOSTER AND MAIN PUMP

- PUMP CAPACITY

- FULL CAPACITY

- HALF CAPACITY

- AUXILIARY FEEDWATER PUMP

SELECTED FEEDWATER PUMPING CONCEPT

FEEDWATER TEMPERATURE VS. FEEDWATER FLOW

STEAM SURFACE CONDENSER WITH WET COOLING TOWER

CONDENSER PRESSURE VS. WET BULB TEMPERATURE AT VARIOUS THROTTLE STEAM FLOWS

MINOR MECHANICAL AND CHEMICAL SYSTEMS

- AUXILIARY COOLING WATER
- CHEMICAL CLEANING
- CHEMICAL FEED
- CIRCULATING WATER MAKEUP AND BLOWDOWN
- CONDENSATE POLISHING
- CONDENSATE STORAGE
- CONDENSER AIR REMOVAL
- DEMINERALIZED WATER STORAGE
- DEMINERALIZED WATER SUPPLY
- FIRE PROTECTION
- HEATER VENTS AND DRAINS
- MISCELLANEOUS VENTS AND DRAINS
- SERVICE AIR AND COMPRESSED AIR
- SERVICE WATER
- SHUTDOWN CORROSION PROTECTION
- SPACE CONDITIONING
- TURBINE LUBRICATING OIL
- TURBINE SEAL STEAM AND DRAINS
- WASTE TREATMENT
- WATER QUALITY CONTROL

ELECTRICAL SYSTEMS

<u>SYSTEM</u>	<u>FUNCTION</u>
MAIN ELECTRIC	GENERATE GROSS ELECTRICAL POWER DELIVER NET BUSBAR POWER
AUXILIARY ELECTRIC	SUPPLY ELECTRICAL POWER TO PLANT AUXILIARIES
ESSENTIAL SERVICE POWER	PROVIDE RELIABLE ELECTRICAL POWER FOR MAJOR PLANT EQUIPMENT PROTECTION
MISCELLANEOUS ELECTRICAL	PROVIDE MISCELLANEOUS PLANT ELECTRICAL POWER

PILOT PLANT AUXILIARY POWER REQUIREMENTS* FOR EPGS/BOP COMPONENT INPUTS

<u>COMPONENT</u>	RECEIVER DRIVING <u>TURBINE</u>	STORAGE DRIVING <u>TURBINE</u>	REC/STO DRIVING <u>TURBINE</u>	RECEIVER CHARGING <u>STORAGE</u>	STORAGE SEALING <u>TURBINE</u>
COOLING TOWER EQUIPMENT	448	448	448	448	197
MAIN FW PUMP	409	0	155	409	0
BOOSTER FW PUMP	148	148	148	148	0
MISCELLANEOUS EQUIPMENT	562	548	562	567	572
TOTAL	1567	1144	1313	1572	769

*KWE

PILOT PLANT AUXILIARY POWER REQUIREMENTS* AT GENERATOR TERMINALS

<u>SUBSYSTEM</u>	RECEIVER DRIVING <u>TURBINE</u>	STORAGE DRIVING <u>TURBINE</u>	REC/STO DRIVING <u>TURBINE</u>	RECEIVER CHARGING <u>STORAGE</u>	STORAGE SEALING <u>TURBINE</u>
COLLECTOR	78	0	78	78	0
RECEIVER	124	0	124	124	0
THERMAL STORAGE	44	207	207	370	98
EPGS/BOP	1741	1271	1459	1747	854
TOTAL	1987	1478	1868	2319	952

*KWE

ELECTRICAL POWER GENERATION SUBSYSTEM MODE A-RECEIVER DRIVING TURBINE, THERMAL STORAGE HOLDING

ELECTRICAL POWER GENERATION SUBSYSTEM
MODE B-THERMAL STORAGE DRIVING TURBINE,
RECEIVER OFF

ELECTRICAL POWER GENERATION SUBSYSTEM
MODE C-RECEIVER AND THERMAL STORAGE
DRIVING TURBINE SIMULTANEOUSLY

ELECTRICAL POWER GENERATION SUBSYSTEM

MODE D-RECEIVER CHARGING THERMAL STORAGE, TURBINE OFF

ELECTRICAL POWER GENERATION SUBSYSTEM SUMMARY

- MEETS ALL PERFORMANCE REQUIREMENTS
- UTILIZES A GENERAL ELECTRIC CO. AUTOMATIC
ADMISSION TURBINE
- USES A WET COOLING TOWER WITH THREE STAGES OF
FEEDWATER HEATING
- PROVIDES ALL REQUIRED MECHANICAL AND CHEMICAL
SUPPORT SYSTEMS
- DELIVERS REQUIRED NET ELECTRICAL POWER AND
SUPPLIES ELECTRICAL POWER TO ALL PLANT AUXILIARIES
- OPERATES IN ALL PLANT MODES AND MODE TRANSITIONS

PLANT CONTROLS / TRANSIENT ANALYSIS

MASTER CONTROL SUBSYSTEM - INTRODUCTION

- CONTROL AND INSTRUMENTATION DESIGN CONSIDERATIONS
 - SYSTEM REQUIREMENTS/CAPABILITIES
 - PLANT OPERATING MODES
 - CONTROL DESIGN STRATEGY
- PLANT CONTROL SYSTEMS
 - PLANT OVERALL CONTROL
 - PLANT PROTECTIVE SYSTEM
 - LOCAL LOOP CONTROLS
- PLANT OPERATIONAL SEQUENCES
 - STARTUP
 - SHUTDOWN
 - TYPICAL DAY'S OPERATION
- PLANT CONTROL & INFORMATION EQUIPMENT
- SUMMARY

SYSTEM REQUIREMENTS/CAPABILITIES

- RELIABLY MAINTAIN PLANT OPERATION AND PERFORMANCE
- PERMIT FLEXIBILITY IN PLANT OPERATING STRATEGY TO MATCH VARYING SOLAR CONDITIONS
- COLLECT, DISPLAY AND RECORD PLANT OPERATING PARAMETERS FOR OPERATIONAL MONITORING AND EXPERIMENTAL OBJECTIVES
- PROTECT PLANT EQUIPMENT FROM CATASTROPHIC FAILURE AND DAMAGE

PILOT PLANT PRIMARY OPERATING MODES

SUBSYSTEM	MODE A	MODE B	MODE C	MODE D
COLLECTOR	FOCUSED	DEFOCUSED	FOCUSED	FOCUSED
RECEIVER	GENERATING STEAM	SEALED	GENERATING STEAM	GENERATING STEAM
THERMAL STORAGE	HOLDING	DISCHARGING	DISCHARGING	CHARGING
EPGS/BOP	GENERATING ELECTRICITY	GENERATING ELECTRICITY	GENERATING ELECTRICITY	SEALED

CONTROL DESIGN STRATEGY

- UTILIZE ALL AVAILABLE SOLAR ENERGY (DIRECT TO TURBINE OR STORAGE)

- FOLLOW ENERGY APPORTIONMENT POLICY

FIRST PRIORITY OF DIRECT SOLAR ENERGY TO LOAD DEMAND SATISFACTION

SURPLUS SOLAR ENERGY USED TO CHARGE STORAGE SUBSYSTEM

SUPPLEMENT DIRECT SOLAR WITH STORAGE STEAM TO MEET LOAD DEMAND IF NECESSARY

- PROTECT PLANT EQUIPMENT
- SATISFY DEMANDED GENERATION
- MAINTAIN CONSTANT THROTTLE STEAM PRESSURE

PLANT CONTROL SYSTEMS

- PLANT OVERALL CONTROL
 - COORDINATED MASTER CONTROL
 - STORAGE IN CONTROL
 - STORAGE OUT CONTROL
 - TURBINE-GENERATOR CONTROL
 - RECEIVER CONTROL
 - LOCAL LOOP CONTROLS

- PLANT PROTECTIVE CONTROL
 - GENERATOR TRIP
 - TURBINE TRIP
 - RECEIVER/COLLECTOR TRIP
 - STORAGE SYSTEM TRIP

COORDINATED MASTER CONTROL

THERMAL ENERGY STORAGE SYSTEM

STORAGE-IN CONTROL

STORAGE-OUT CONTROL

RECEIVER STEAM GENERATOR CONTROL

RECEIVER CONTROL

LOCAL LOOP CONTROLS

NORMAL CONTROL SYSTEM

BACKUP

● CONDENSATE HOTWELL LEVEL	LOCAL MANUAL
● CONDENSATE FLOW	DEAERATOR OVERFLOW,
LOCAL MANUAL
● CONDENSATE PUMP RECIRCULATION	LOCAL MANUAL
● CONDENSATE POLISHER BYPASS	LOCAL MANUAL
● DEAERATOR MINIMUM PRESSURE	LOCAL MANUAL
● HP & LP HEATER LEVEL	EMERGENCY HEATER LEVEL
● FEEDWATER PUMP RECIRCULATION	PUMP TRIP
● TURBINE LUBE OIL TEMPERATURE	LOCAL MANUAL
● TURBINE E H FLUID TEMPERATURE	LOCAL MANUAL

PLANT PROTECTIVE SYSTEM - TURBINE/GENERATOR

GENERATOR TRIP

- REVERSE CURRENT RELAY
- DIFFERENTIAL RELAY
- LOSS OF EXCITATION

TURBINE TRIP

- OVERSPEED
- LOW VACUUM
- HIGH THRUST BEARING VIBRATION

PLANT PROTECTIVE SYSTEM - RECEIVER/COLLECTOR/STORAGE

COLLECTOR FIELD TRIP

- LOW RECEIVER BOILER DRUM LEVEL
- LOSS OF RECEIVER BOILER CIRCULATING PUMP
- STEAM TEMPERATURE OUT OF LIMITS
- HELIOSTAT TRACKING MALFUNCTION
- SIGNIFICANT WEATHER EVENTS
- AUXILIARY POWER FAILURE

STORAGE OUT TRIP (IF OPERATING)

- STEAM TEMPERATURE OUT OF LIMITS
- AUXILIARY POWER FAILURE

PLANT OPERATIONAL SEQUENCES

STARTUP SEQUENCES

- COLD
- DIURNAL
- STORAGE CHARGE
- STORAGE DISCHARGE

SHUTDOWN SEQUENCES

- DIURNAL
- EXTENDED
- EMERGENCY

COLD STARTUP SEQUENCE

1. ENERGIZE PLANT AUXILIARY ELECTRICAL SYSTEM
2. ENERGIZE STEAM LINE ELECTRIC HEATERS (15 HOURS BEFORE SUNRISE)
3. START CIRCULATING WATER, AUXILIARY COOLING WATER AND COMPRESSED AIR SYSTEMS
4. START BOILER FEED PUMPS - ESTABLISH BOILER DRUM LEVEL
5. START RECEIVER BOILER CIRCULATING PUMP
6. EXPOSE RECEIVER BOILER HEATING SURFACE
7. INITIATE HEATING THE BOILER BY SELECTIVE USE OF HELIOSTATS
8. OPEN STEAM LINE AND TURBINE STOP VALVE DRAIN VALVES WHEN STEAM BECOMES AVAILABLE

COLD STARTUP SEQUENCE (CONT'D)

9. START STEAM SUPPLY TO DEAERATOR WHEN STEAM PRESSURE REACHES 345 kPa (50 psi)
10. START ONE MAIN CIRCULATING PUMP
11. START STEAM SUPPLY TO TURBINE STEAM SEALS
12. START CONDENSER VACUUM PUMPS
13. START SUPERHEATING STEAM BY SELECTIVE USE OF HELIOSTATS
14. ROLL TURBINE OFF TURNING GEAR WHEN PRESSURE REACHES 1380 kPa (200 psi) AND ACCELERATE TO SYNCHRONOUS SPEED, SYNCHRONIZE GENERATOR
15. PROCEED WITH GENERATION RAMP WHEN DRUM IS AT OPERATING PRESSURE. CONTINUE AS PERMITTED BY AVAILABLE SOLAR ENERGY
16. WHEN STEAM PRESSURE AND TEMPERATURE REACH RATED VALUES, PLACE COORDINATED MASTER CONTROL IN OPERATION

COLD STARTUP PRESSURE RAMP AND LOADING

OVERNIGHT OPERATED SYSTEMS

1. AUXILIARY ELECTRIC SYSTEM
2. AUXILIARY COOLING WATER SYSTEM
3. CONTROL AIR SYSTEM
4. SERVICE AIR SYSTEM
5. CONDENSATE SYSTEM*
6. CONDENSER VACUUM SYSTEM
7. STEAM LINE ELECTRIC HEAT SYSTEM
8. STORAGE DISCHARGE SYSTEM*
9. CIRCULATING WATER SYSTEM*
10. TURBINE SEAL STEAM SYSTEM
11. FEEDWATER SYSTEM*

*OPERATION AT REDUCED CAPACITY PERMISSIBLE

TYPICAL DAY'S OPERATION

NORMAL FLANT SHUTDOWN

DIURNAL SHUTDOWN SEQUENCE

1. REDUCE TURBINE LOAD DURING FINAL 30 MINUTES OF OPERATION
2. TRIP THE TURBINE-GENERATOR, LEAVING AT LEAST 3000 MWTH (10 MILLION BTU) IN THERMAL STORAGE INVENTORY
3. SUPPLY THERMAL STORAGE STEAM TO THE TURBINE SEAL SYSTEM
4. SHUTDOWN RECEIVER BOILER FEED PUMP AND CIRCULATION PUMP, ISOLATE RECEIVER CAVITY
5. PLACE TURBINE ON TURNING GEAR AFTER DECELERATION
6. OPERATE STORAGE DISCHARGE, FEEDWATER, CONDENSATE, AND CIRCULATING WATER SYSTEMS OVERNIGHT AT MINIMUM CAPACITY
7. CONTINUE TURBINE SEAL SYSTEM, CONDENSER VACUUM SYSTEM OPERATION

PLANT CONTROL AND INFORMATION EQUIPMENT

PLANT COMPUTERS

- DDC
- DATA ACQUISITION
MONITORING INFORMATION
TEST PROGRAM DATA

ANNUNCIATION EQUIPMENT

- VISUAL
- RECORDING

FIELD MOUNTED INSTRUMENTATION

- THERMOCOUPLES (ISA TYPE K, CHROMEL-CONSTANTAN)
- TRANSMITTERS (4-20 mA_{DC})

FLOW

PRESSURE

LEVEL

TEMPERATURE

6-22

SUMMARY

- CONTROL SYSTEM DESIGN REQUIREMENTS MET THROUGH USE OF COORDINATED MASTER CONTROL CONCEPT AND DDC
- PLANT AND PERSONNEL PROTECTION REQUIREMENTS MET THROUGH PROVISION OF A PLANT PROTECTION SYSTEM
- MONITORING AND RECORDING OF PLANT PARAMETERS PROVIDED BY DAS
- STUDY OF VARIOUS STARTUP, SHUTDOWN STRATEGIES, AND TYPICAL DAY'S OPERATION INDICATES THAT THE PLANT CAN BE APPROPRIATELY CONTROLLED

SOLAR PILOT PLANT/TRANSIENT ANALYSIS STUDIES

PDR PRESENTATION

4 – 5 MAY 1977

DISCUSSION TOPICS/TRANSIENT ANALYSIS STUDIES

- STUDY OBJECTIVES
- STUDY ISSUES
- MODEL DESCRIPTION
- TECHNICAL STUDY APPROACH
- STUDY RESULTS
 - MORNING PLANT STARTUP
 - CLOUD PASSAGE
 - LOAD DEMAND CHANGE
 - EQUIPMENT FAILURES
- CONCLUSIONS

STUDY OBJECTIVES/TRANSIENT ANALYSIS STUDIES

**PROVE THE PILOT PLANT WILL
PERFORM UNDER EXPECTED
OPERATING CONDITIONS**

STUDY ISSUES/TRANSIENT ANALYSIS STUDIES

MORNING STARTUP

- **HOW LONG TO REACH DESIRED LOAD DEMAND?**
- **HOW MUCH NET BUSBAR ENERGY CAN BE GENERATED?**

CLOUD TRANSIENTS

- **DO CLOUD PASSAGES CREATE STEAM GENERATOR POWER IMBALANCE PROBLEMS?**
- **CAN LOAD DEMAND BE CONTINUOUSLY SATISFIED?**

STUDY ISSUES / TRANSIENT ANALYSIS STUDIES

LOAD DEMAND CHANGES

- Is Plant Responsive to Changes in Load Demand?

FAILURE EFFECTS

- Will Plant be Damaged by Equipment Failures?

TECHNICAL STUDY APPROACH/TRANSIENT ANALYSIS STUDIES

- **DEVELOP TIME-DEPENDENT MATH MODELS
FOR ALL SYSTEM ELEMENTS**
- **IMPLEMENT MODELS INTO COMPUTER
SIMULATION**
- **EXERCISE SIMULATION FOR RESULTS**

TIME DEPENDENT PERFORMANCE FACTORS/TRANSIENT ANALYSIS STUDIES

PILOT PLANT DYNAMIC SIMULATION MODEL / TRANSIENT ANALYSIS VS STUDIES

EXAMPLE OF DYNAMIC SIMULATION LEVEL OF DETAIL / TRANSIENT ANALYSIS STUDIES

PLANT STARTUP SCENARIO/TRANSIENT ANALYSIS STUDIES

TIME SUNRISE

CONDITIONS

STEAM GENERATOR	1379 kPa/193°C (200 PSIA/380°F)
TURBINE	371°C (TURNING GEAR) (700°F)
STEAM PIPING TO TURBINE	371°C (700°F)
THERMAL STORAGE	HOLDING (SEALING STEAM)

OBJECTIVE

**SATISFY DAY'S LOAD DEMAND SETTING AS
QUICKLY AS POSSIBLE**

PLANT STARTUP TIMELINE/TRANSIENT ANALYSIS STUDIES

PLANT STARTUP RESULTS FOR FIRST 200 MINUTES OF JUNE 10
TRANSIENT ANALYSIS STUDIES

CLOUD TRANSIENT EFFECTS ON SOLAR POWER TRANSIENT ANALYSIS STUDIES

CLOUD TRANSIENTS/TRANSIENT ANALYSIS STUDIES

TIME

MIDDAY

CONDITIONS

LOAD DEMAND	— 7 MWe
STEAM GENERATOR	— RATED PRES./TEMP.
THERMAL STORAGE	— CHARGING
DIRECT NORMAL INTENSITY	— 0.98 KW/M^2

OBJECTIVE

DETERMINE ABILITY OF PILOT PLANT TO SUPPLY CONTINUOUS
LOAD DEMAND WITH CLOUD PASSAGES.

CLOUD SCENARIO/TRANSIENT ANALYSIS STUDIES

CLOUD

DIRECTION: W → E

SPEED: 11.4 km/HR (7.1 MFH)

LENGTH: 1.8 km (5900 FT)

COVERAGE: NORTH ½

CLOUD TRANSIENT PARAMETERS VARIED/ TRANSIENT ANALYSIS STUDIES

<u>APPROACH DIRECTION</u>	<u>CLOUD SPEED</u> <u>KM/HR (MPH)</u>	<u>CLOUD LENGTH</u> <u>KM (MI)</u>
WEST	11.4 (7.1)	0.67 (0.42)
NORTH	21.9 (13.6)	1.8 (1.12)
SOUTH	32.9 (20.4)	

CLOUD TRANSIENT EFFECTS ON SOLAR POWER/TRANSIENT ANALYSIS STUDIES

CLOUD TRANSIENT EFFECTS ON RECEIVER

PLANT PERFORMANCE ON CLOUDY SOUTHWESTERN U.S. DAY/ TRANSIENT ANALYSIS STUDIES

INSOLATION DATA FOR CLOUDY SOUTHWESTERN U.S. DAY/ TRANSIENT ANALYSIS STUDIES

LOAD DEMAND CHANGES

EFFECTS OF SIMULATED RECIRCULATING PUMP FAILURE / TRANSIENT ANALYSIS STUDIES

HELIOSTAT FIELD LOCATION - EFFECTS UPON STEAM GENERATOR / TRANSIENT ANALYSIS STUDIES

SUMMARY OF COMPUTER RUNS/TRANSIENT ANALYSIS STUDIES

<u>RUNS</u>	<u>RUN DESCRIPTION</u>
1	PLANT STARTUP VARIABLE PRESSURE MORNING STARTUP
11	CLOUD TRANSIENTS VARIATIONS OF: <ul style="list-style-type: none">● CLOUD SPEED● CLOUD LENGTH● APPROACH DIRECTION● FIELD COVERAGE
1	LOAD DEMAND CHANGES INCREASE, DECREASE OF DEMAND
3	FAILURE EFFECTS RECIRCULATING PUMP, HEATER, COLLECTORS

CONCLUSIONS / TRANSIENT ANALYSIS STUDIES

- PLANT WILL BE RESPONSIVE, STABLE, CONTROLLABLE WITH OUR DESIGN
- VARIABLE PRESSURE STARTUP WILL OPTIMIZE PLANT EFFICIENCY FOR ENERGY UTILIZATION
- CLOUDS WILL NOT BE A PROBLEM WITH OUR DESIGN
- THERMAL STORAGE WILL OPTIMIZE EFFICIENCY OF ENERGY USAGE:
 - STORES EXCESS OF THERMAL ENERGY PRODUCED
 - PRODUCES STEAM POWER ON DEMAND
- EQUIPMENT FAILURES WILL NOT BE DETRIMENTAL TO PLANT OPERATION

AVAILABILITY AND SAFETY

SYSTEM AVAILABILITY GROUND RULES

- SYSTEM IS AVAILABLE WHEN CAPABLE OF 98% OUTPUT AT A GIVEN SOLAR INPUT
- SUBSYSTEM AVAILABILITY = $\frac{\text{MEAN TIME BETWEEN FAILURES}}{\text{MEAN TIME BETWEEN FAILURES} + \text{MEAN TIME TO REPAIR}}$
- SYSTEM AVAILABILITY IS CALCULATED AS PRODUCT OF SUBSYSTEM
- AVAILABILITIES AND SCHEDULED MAINTENANCE AVAILABILITY

AVAILABILITY CONSIDERATIONS IN DESIGN

- Compliance With Code Requirements
- Redundancy
- Ease Of Maintenance
- Operator/Maintenance Skill Levels

OPERATIONAL STRATEGY FOR AVAILABILITY CALCULATIONS

FREE TIME MAINTENANCE

COLLECTOR	12 hours
RECEIVER	12 hours
EPGS	10 hours
STORAGE	17.5/19.5/0 hours

SOURCES OF DATA

- Edison Electric Institute
- Mechanical Design & Systems Handbook-Rothbart
- Honeywell Reliability Department

SYSTEM AVAILABILITY SUMMARY

PILOT PLANT AVAILABILITY (APP) =

(A COLLECTOR) (A STORAGE) (A EPGS & RECEIVER)

(A CONTROL) (A PLANNED OUTAGE)

APP = (.997) (.985) (.992) (.997) (.962)

APP = .934

COLLECTOR SUBSYSTEM MTTR AND MTBF PREDICTIONS

<u>Unit</u>	<u>Failure Rate / 10⁶ hrs (λ)</u>	<u>Qty</u>	<u>Contribution of Total Failures</u>	<u>Repair Time (Rp) (Hrs)</u>	<u>$\Sigma (\lambda Rp)$</u>
Heliostat					
Frame	0.01	1598	16	24	384
Mirror	0.1	6392	639	72	46,008
Inner Dr Gear Box	15	1598	23,970	4	95,880
Inner Dr Linkage	40	1598	63,960	8	511,680
Inner Dr Motor	10	1598	15,980	4	63,920
Outer Drive Motor	10	3196	31,960	4	127,840
Actuator	10	3196	31,960	4	127,840
Heliostat Elec.	4	3196	6,384	10	63,840
Central Processor					
Central Processor	40	4	160	4	640
Peripheral Equipment	67	4	268	4	1,072
*Cal Array	72	8	576	24	13,824
P/S Batteries	2	1598	3,196	2	6,400
Field XMFR	10	8	80	10	800

$$\begin{aligned}
 \Sigma \lambda &= 179,153 & \Sigma \lambda R_p &= 1,060,128 \\
 \text{MTTR} &= \frac{\Sigma \lambda R_p}{\Sigma \lambda} = \frac{1,060,128}{179,153} = 5.92 \text{ hours} & \text{MTBF} &= \frac{10^6}{\Sigma \lambda} = 5.582
 \end{aligned}$$

$$\begin{aligned}
 \text{Failures} &= \frac{1 \text{ Solar Pilot Plant} \times 360 \text{ hrs/mo} \times 1 \text{ mo/30 days}}{5.582 \text{ hours/failure}} = 2.15 \text{ Failures Day}
 \end{aligned}$$

* Loss considered non-impacting during a 24 hour cycle.

COLLECTOR SUBSYSTEM AVAILABILITY

COLLECTOR SUBSYSTEM AVAILABILITY = .997

SYSTEM AVAILABILITY STORAGE SUBSYSTEM

DAILY USE	24 hrs.	6.5 hrs.	4.5 hrs.
MTBF	1094 hrs.	1342 hrs.	1945 hrs.
MTTR	14.8 hrs.	2.3 hrs.	1.1 hrs.

STORAGE SUBSYSTEM AVAILABILITY = .985

RECEIVER & EPGS AVAILABILITY

- CONSIDERED ONE SUBSYSTEM TO PERMIT USE OF EDISON ELECTRIC INSTITUTE (EE1) AVAILABILITY DATA
- EE1 DATA USED EXCLUSIVE OF FUEL RELATED AVAILABILITIES
- EE1 PLANT REPAIR TIMES FACTORED FOR FREE TIME MAINTENANCE
- MEAN TIME TO REPAIR - 10.9 HRS.
- MEAN TIME BETWEEN FAILURES - 1397 HRS.
- EPGS & RECEIVER AVAILABILITY - .992

SAFETY ASSURANCE DESIGN FEATURES

- Design Complies with OSHA & Design Codes
- Safe Control Rules For Collector Operation
- Protection For Ground & Airborne Observers
- Weather Protection

COLLECTOR FIELD OPERATIONAL MODES

- NORMAL

- Heliostats Tracking the Sun
- Sequenced Heliostat Calibration
- Heliostat Beam Directed Into Aperature

- STANDBY

- Heliostats Tracking the Sun
- Heliostat Beam Directed at Standby Point

- TRANSIENT

- Heliostats Not Tracking the Sun
- Heliostats Aiming Between Stow & Standby
- Heliostats May or May Not Be Under Control

NORMAL OPERATION CAVITY RERADIATION

WHISTLE THROUGH
& HOUSING/CORBEL
RERADIATION
IS NEGLIGIBLE
(~20% of Cavity Reradiation)

STANDBY OPERATION INTENSITY ZONE

WORST CASE CONDITIONS ASSUMED

- NO COSINE EFFECT
- PERFECT OPTICS
- TOWER CENTERED (FIELD RADIUS - 401m)
- HEIGHT OF ZONE - 2 FACET FOCAL LENGTHS
- ALL HELIOSTATS ON STANDBY AIM POINTS
- 1000 W/m² SOLAR INSOLATION

CONVERGING HELIOSTAT INTENSITY

NUMBER OF
CONVERGING
HELIOSTAT
BEAMS TO
PRODUCE
1KW/M2
INTENSITY

INTENSITY LEVEL PROBABILITY

● **INTENSITY PROBABILITY** = $(a/A)^n \cdot 1598! / (1598-n)!$

Where: a = Single heliostat beam area at distance x
A = Surface area of a hemisphere with radius
X = Distance from heliostat to point of convergence
n = Number of converging heliostats

- ALL HELIOSTATS NEAR CENTER OF HEMISPHERE
- RANDOM AIMING
- 1 KW/M2 SOLAR INSOLATION
- NO COSINE EFFECT
- NO SHADING & BLOCKING
- PROBABILITY INTENSITY

INTENSITY LEVEL PROBABILITY

TRANSIENT OPERATION INTENSITY ZONE

- RANDOM PROBABILITY OF OCCURENCE IS 1.6×10^{-4}
- 3 CONVERGING HELIOSTATS

GROUND SAFETY BARRIERS

RECOMMENDED AIRCRAFT RESTRICTED ZONE (HELICOPTERS & LIGHTER THAN AIR)

FIXED WING TRANSIT TIME
23 to 100 sec. (285 mph to 70 mph)

ENVIRONMENTAL SAFETY

- Weather
 - Wind
 - Hail
 - Rain
 - Lightning
 - Sandstorm
 - Freezing
 - Snow & Ice
- Earthquake
 - Receiver Tower
 - Oil Storage

PILOT & COMMERCIAL PLANT DESIGNS

PILOT AND FIRST COMMERCIAL PLANT DESIGN

A G E N D A

- **COMMERCIAL PLANT CONFIGURATION STUDY**
- **PILOT AND COMMERCIAL PLANT LAYOUTS**
- **PILOT AND COMMERCIAL SUBSYSTEMS COMPARED**
- **PERFORMANCE ESTIMATES**
- **COST ESTIMATES**

FIRST COMMERCIAL PLANT DESIGN REQUIREMENTS

- 100 MWe PEAK NET OUTPUT - RECEIVER ONLY
- DESIGN CONDITIONS
 - 23° C WET BULB TEMPERATURE
 - 28° C DRY BULB TEMPERATURE
 - 3.5 M/S AT 10M REFERENCE HEIGHT
 - 950 W/M² DIRECT NORMAL INTENSITY AT
 - Noon, March 21
 - Wet Cooling
- 1.7 SOLAR MULTIPLE
- 3 HOURS AT 70 MWe NET SENSIBLE STORAGE CAPACITY
- SEISMIC ZONE 3

FIRST COMMERCIAL PLANT CONFIGURATION TRADEOFF

DERIVED REQUIREMENTS

- TILT-TILT / 4 FACET HELIOSTAT
- NON UNIFORM FIELD / TOWER 1/2 RADIUS SOUTH
- ASYMETRIC BOTTOM OPENING APERTURE RECEIVER
- TURBINE STEAM CONDITIONS
 - THROTTLE 10.1 MPa / 510 C (1465 psia / 950 F)
 - ADMISSION 8.3 MPa / 388 C (475 psia / 730 F)
- SINGLE EPGS / BALANCE OF PLANT / STORAGE

DETERMINE

- PRACTICAL NUMBER OF TOWERS / FIELD TO MEET DESIGN REQUIREMENTS

COMMERCIAL CONFIGURATION

- TRADE STUDY SCOPE -

- OPTIMAL APERTURE DESIGN FOR
 - RERADIATION
 - CONDUCTION
 - CONVECTION
 - SPILLAGE
- MIRROR FIELD PERFORMANCE
- INTER-FIELD PIPING PERFORMANCE / COST
- AUXILLARY POWER REQUIREMENTS
- TOWER / RECEIVER HEIGHT / COST

FIRST COMMERCIAL PLANT - CONFIGURATION COMPARISON -

PERFORMANCE (MW(t))

<u>CONFIGURATION</u>	<u>POWER AVAILABLE</u>	<u>MIRROR POWER</u>	<u>REDIRECTED POWER</u>	<u>CAVITY POWER</u>	<u>ABSORBED POWER</u>
1 TOWER	704	654	572	555	488
4 TOWERS	706	656	574	557	490
12 TOWERS	720	699	585	569	495

CHARACTERISTICS

<u>CONFIGURATION</u>	<u>NO' OF HELIOSTATS</u>	<u>TOWER HEIGHT</u>	<u>FIELD OD</u>	<u>FIELD ID</u>
1 TOWER	18,519	431 m	1823 m	343 m
4 TOWERS	18,568	215.5	912	171
12 TOWERS	18,960	132	533	100

COMMERCIAL PLANT SCALE COMPARISONS

FIRST COMMERCIAL PLANT CONFIGURATION vs COST RESULTS

COMMERCIAL CONFIGURATION SELECTION

CLEAR ECONOMIC JUSTIFICATION FOR SINGLE TALL TOWER
IN ZONES 1 & 2

DETAILED DESIGN REQUIRED FOR ZONE 3 SINGLE TOWER
TO OBTAIN ACCURATE COST ESTIMATES

TOWER/HOUSING STRUCTURAL REQUIREMENTS IN
SEISMIC ZONES 1 & 2 SET BY WIND LOADING'

ZONE 3 REQUIREMENTS SET BY NRC GUIDE 1.60

SOLAR "COMMUNITY" DIVIDED OVER "TALL" TOWER
ACCEPTABILITY

750 FT TOWER SELECTED AS PRUDENT COMPROMISE

FIRST COMMERCIAL PLANT DESIGN SUMMARY

NAME PLATE CAPACITY	100 MWe
SOLAR MULTIPLE	1.7
TOWER / FIELDS	4
TOWER HEIGHT	226 (740 ft)
FIELD OD	951 m (3120 ft)
FIELD ID	180 m (590 ft)
NUMBER OF HELIOSTATS	5055 / FIELD
TOTAL PLANT MIRROR AREA	808,800 m ²

COMMERCIAL PLANT SITE PLAN

100 MW(e) MAIN STEAM LINES

COMMERCIAL PLANT CONCEPTUAL DESIGN

PRELIMINARY DESIGN SPECIFICATIONS

	<u>PILOT PLANT</u>	<u>COMMERCIAL</u>
LOCATION	BARSTOW	— — —
NAME PLATE CAPACITY	15 MW(e)	112 MW(e)
DESIGN POINT NET POWER	10 MW(e) - 12/21, 2 PM	100 MW(e) - 3/21 NOON
TOWER HEIGHT	126.5 M (415 FT)	225.6 M (740 FT), 4 TOWERS
HELIOSTAT SIZE	40 M ²	SAME
SOLAR MULTIPLE	1.23	1.7
NUMBER OF HELIOSTATS	1598	20,220
TOTAL MIRROR AREA	63,920 M ²	808,800 M ²
STORAGE TYPE	SENSIBLE	SAME
STORAGE CAPACITY	7 MW(e) FOR 3 HOURS (115.2 MW HR(t))	SAME (908.6 MW HR(t))
RECEIVER PEAK FLUX	300 KW/M ²	SAME
APERTURE AREA	118.4 M ² (1274 FT ²)	738 M ² (7944 FT ²)/TOWER
RECEIVER PEAK/AVERAGE	92.7/91.1	SAME
TURBINE CYCLE (FROM RCVR)	10.1 MPA/510°C (1450/950)	SAME
TURBINE CYCLE (FROM STORAGE)	3.2 MPA/388°C (460/730)	SAME
DESIGN POINT NET EFFICIENCY (FROM RECEIVER)	25.9	29.3
DESIGN POINT NET EFFICIENCY (FROM STORAGE)	22.1	26.3
TOTAL NET ANNUAL ENERGY (NAE)	2.22 X 10 ⁴ MW HR(e)	2.89 X 10 ⁵ MW HR(e)
NAE/TOTAL MIRROR AREA	0.348 MW HR(e)/M ²	0.357 MW HR(e)/M ²

10 MW (e) SOLAR PILOT PLANT

PILOT PLANT SITE PLAN

PILOT PLANT CENTRAL COMPLEX

PILOT PLANT GROUND FLOOR

PILOT PLANT OPERATING FLOOR

PILOT PLANT SECTIONAL ELEVATION

COLLECTOR SUBSYSTEM CHARACTERISTICS

Tracking Accuracy

-- 1 mr, 1 optics

- 2 mr, 1 /axis

Reflectivity 0.9 clean

Heliostat Area 40 m²

PILOT
PLANT

FIRST COMMERCIAL PLANT

FIELD 03

FIELD ID

GROUND COVER

SOLAR MULTIPLE

NC' Heliostats

NET ANNUAL ENERGY

Per Unit Mirror Area

535 m

101 m

29% Avg

1.23

1598

1.60 mwhr,t)/m²

951m/FIELD

180m/FIELD

Same

1.7

5055/FIELD , 20,220 Total

RECEIVER SUBSYSTEM CHARACTERISTICS

PARAMETER	PILOT PLANT	FIRST COMMERCIAL
TOWER HEIGHT	126.5m (415 ft)	228.6m (750 ft)
CAVITY DIAMETER	14.9m (49ft)	26.1m (86 ft)
CAVITY HEIGHT (Major)	16.6m (54 ft)	28.3m (93ft)
(Minor)	14.6m (48 ft)	25.3m (83 ft)
ANNULUS APERTURE AREA	218 m2	651m2
PEAK ABSORBED POWER	43 mw (t)	510 mw(t)
PEAK INCIDENT WALL FLUX	300 kw/m2	same
RCVR PEAK/AVE EFFICIENCY	87.2/84.1	87.5/84.4

THERMAL STORAGE SUBSYSTEM CHARACTERISTICS

ELECTRICAL POWER GENERATION SUBSYSTEM

PARAMETER	PILOT PLANT	FIRST COMMERCIAL
Turbine Type	Automatic Admission	Same
Name Plate Capacity	15 MWe	120 MWe
Cycle Conditions		
-Throttle	10.2MPa/510 C (1450/950)	Same
-Admission	3.2 MPa/388 C (460/730)	Same
Number of Extractions	3	5
Heat Rejection Type	Wet Cooling	Same
Net Plant Efficiency		
—Receiver Design Point	34.5%	38.5%
-Storage Design Point	28.5%	31.8%

PILOT PLANT - DESIGN POINT PERFORMANCE

PILOT PLANT NET ANNUAL ENERGY - RECEIVER ONLY -

PILOT PLANT NET ANNUAL ENERGY - DIURNAL STORAGE CHARGE/DISCHARGE -

PRELIMINARY COST ESTIMATES

	<u>PILOT PLANT</u>	<u>FIRST COMMERCIAL</u>
ESTIMATED PLANT PERFORMANCE		
AVG. NET OUTPUT OVER 4000 HOURS	5.55 MWe	72.3 MWe
NET ANNUAL ENERGY PRODUCTION	2.22×10^4 MWe hr	2.89×10^5 MWe hr
ESTIMATED DIRECT COST (MILLIONS OF DOLLARS)		
COLLECTOR SUBSYSTEM	\$ 27.9 M	\$ 152.7 M
STEAM GENERATOR UNIT	8.8	52.2
BLANCE OF RECEIVER SUBSYSTEM	5.3	45.0
THERMAL STORAGE SUBSYSTEM	8.3	28.7
EPGS/BALANCE OF PLANT	9.6	31.0
SPARES (1%)	0.6	3.1
CONTINGENCY (15%)	9.1	46.9
TOTAL DIRECT COSTS	69.6	359.6
GENERAL INDIRECT COSTS (12%)	8.4	43.2
TOTAL CAPITAL COSTS	\$ 78.0 M	\$ 402.8 M
UNIT CAPACITY COST (\$ PER)		
KILOWATT OF AVG. OUTPUT	\$ 14,000/KWe	5,570/KWe
CONTRIBUTION OF CAPITAL INVESTMENT		
TO ENERGY COST (16%FCR)	562mills/KWe	223mills/KWe

ENERGY COST VS. HELIOSTAT COST

COLLECTOR SUBSYSTEM FEATURES

- LOW PROFILE/WIDE STANCE/WIND RESISTANT
- MINIMAL FOUNDATION REQUIREMENTS
- USES ONLY STANDARD COMMERCIAL COMPONENTS
- MODULAR DESIGN PROVIDES EASY FIELD ASSEMBLY
- DEMONSTRATED ENVIRONMENTAL PERFORMANCE
- SIMPLE COMMAND & CONTROL AND POWER DISTRIBUTION
- SIMPLE ELECTRONIC ALIGNMENT APPROACH
- FIELD DESIGN MINIMIZES SHADOWING/BLOCKING
- 360° FIELD YIELDS SUPERHEATER THERMAL AVERAGING AND HIGH TRACKING EFFICIENCY

COLLECTOR DESIGN BENEFITS

- NO PHASE II RISK BECAUSE IT HAS BEEN
VALIDATED BY BOTH ANALYSIS AND BY
TEST
- ACHIEVES HIGH PERFORMANCE AT MODERATE
COST WITH EXCELLENT LOW COST POTENTIAL

RECEIVER DESIGN FEATURES

- TOWER UTILIZED PROVEN DESIGN/CONSTRUCTION METHODS
 - SLIP FORM POURED CONCRETE
 - APERTURE OPTIMALLY MATCHED WITH HELIOSTAT FIELD

- STEAM GENERATOR DESIGN USES
 - STANDARD ASME CODE PRACTICE
 - FORCED CIRCULATION DRUM SEPARATION
 - HIGH TURNDOWN RATIO
 - LOW PEAK FLUXES
 - SUPERHEAT THERMAL AVERAGING
 - STANDARD MEMBRANE WALL BOILER
 - SPRAY DOWN STEAM CONTROL
 - CLOUD TRANSIENT BLANCE CONTROL

RECEIVER DESIGN BENEFITS

- LOW PHASE II RISK BECAUSE:
 - USES STANDARD FOSSIL TECHNOLOGY
 - MINIMAL CONFIGURATION CHANGE FROM SRE TO PILOT PLANT
 - INDEPENDENT BOILER/SUPERHEATER CONTROL MINIMIZES STARTUP PROBLEMS
 - THE DESIGN METHODOLOGY HAS BEEN VALIDATED BY SRE TEST
 - THE SRE RESULTS INDICATE HIGHLY RELIABLE OPERATION

- HIGH PERFORMANCE OPTIMALLY MATCHED WITH HELIOSTAT FIELD ECONOMICS

THERMAL STORAGE DESIGN FEATURES

- SUPERHEAT FOR EXPANSION LINE MATCHING
- COST OPTIMAL ADMISSION PORT PRESSURE
- UTILIZES "BEST" FEATURES OF ALTERNATIVE DESIGNS
 - HITEC HOT & COLD TANKS
 - OIL & ROCK MAIN STORAGE
- STEAM GENERATION TIME CONSTANT LESS THAN RECEIVER-TURBINE T/C

STORAGE DESIGN BENEFITS

- LOW PHASE II RISK BECAUSE:
 - TURBINE THERMAL SHOCK MINIMIZED
 - DESIGN UTILIZES PROVEN TECHNOLOGY
 - STEADY POWER OUTPUT DURING CLOUD TRANSITION
- LOWER CAPITAL AND BUSBAR COST

EPGS FEATURES

- AUTOMATIC ADMISSION TURBINE
- SIMULTANEOUS STEAM SOURCE OPERATION
- HIGH CYCLE EFFICIENCY
- AMERICAN MADE TURBINE/COMMERCIALLY AVAILABLE
- DDC MASTER CONTROL

EPGS DESIGN BENEFITS

- LOW PHASE II RISK BECAUSE OF PROVEN TECHNOLOGY
- LOW CAPITAL COST

SUMMARY AND RECOMMENDATIONS

SUMMARY OF PHASE I FINDINGS

- PRELIMINARY DESIGN FEASIBILITY ESTABLISHED
- NO ADVANCED TECHNOLOGY REQUIRED
- COMMERCIAL PLANT ECONOMICS HIGHLY DEPENDENT ON
ULTIMATE HEILOSTAT AND STORAGE COSTS
- PHASE II OBJECTIVES CAN BE ACCOMPLISHED AT
LOW RISK AND MODERATE COST

RECOMMENDATIONS

- PROCEED IMMEDIATELY TO PHASE II
- ESTABLISH WELL FUNDED, FLEXIBLE, ON-GOING HELIO-STAT DEVELOPMENT PROGRAM AIMED AT LOW COST
- ESTABLISH WELL FUNDED, FLEXIBLE, ON-GOING THERMAL STORAGE DEVELOPMENT PROGRAM AIMED AT LOW COST
- PROCEED WITH SUNLIGHT RECEIVER TESTS
- PROCEED WITH LATENT HEAT STORAGE TESTS
- PROVIDE FOR ADDITIONAL SRE TESTS