1010

FIRST QUARTERLY REVIEW MEETING

SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY

PREPARED FOR
SANDIA NATIONAL LABORATORIES
LIVERMORE, CALIFORNIA

JULY 10, 1985

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

12 Peach Tree Hill Road, Livingston, New Jersey 07039

FOSTER WHEELER

SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY

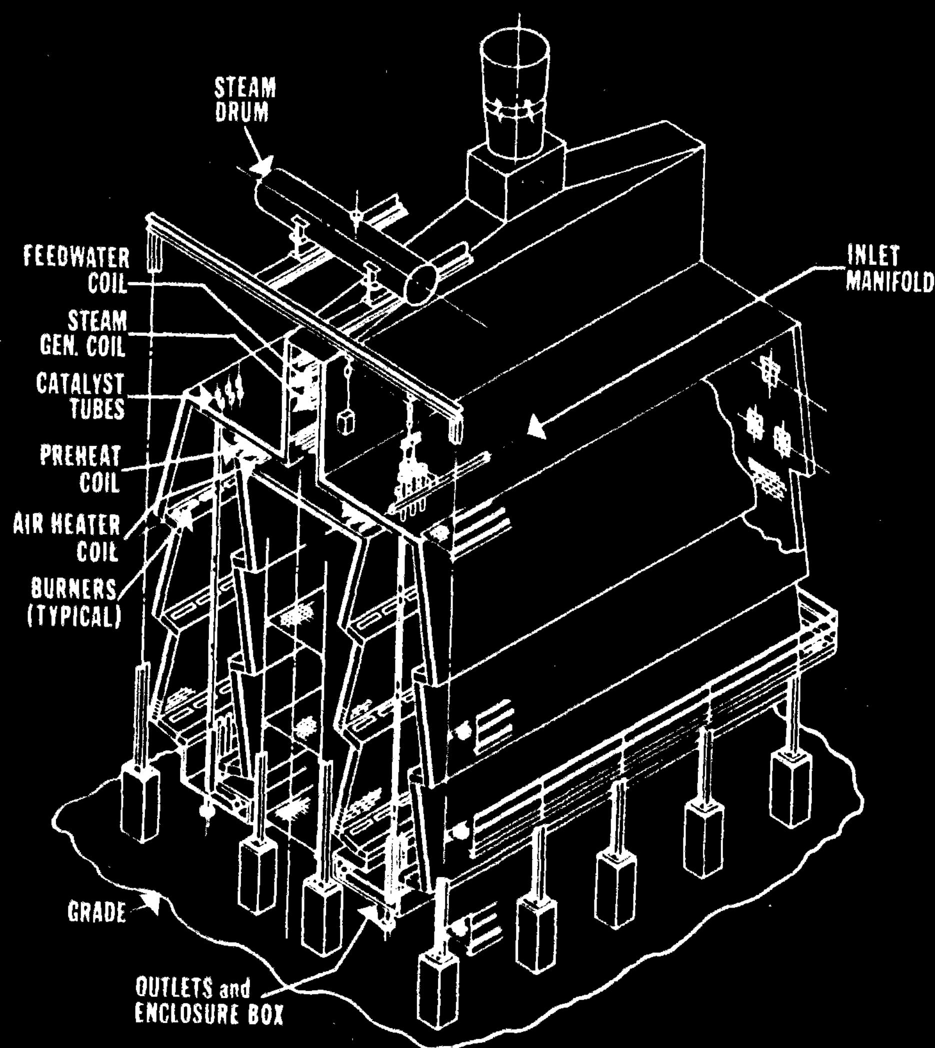
FIRST QUARTERLY REVIEW

JULY 10, 1985 SNLL LIVERMORE, CA

AGENDA

8:30	Introduction	Betty Carrell, SNLL
8:40	Project Summary and Agenda	S. F. Wu, FW
	Task 1 -- Project Management	
9:10	Schedule, Manhours and Costs	S. F. Wu, FW
	Task 2 -- Process Optimization	
9:20	Selection of Heat-Transfer Medium	S. F. Wu, FW
9:40	Heliostat Field/Receiver Performance Data	S. F. Wu, FW
10:00	---- BREAK ----	
10:15	Process Studies and Selection - Plant Capacities and Operating Conditions - Design Basis and Process Requirements - Process Flow Diagram - Preliminary Heat and Mass Balances - Design Data for Reformer and Ammonia Burner	Bob McCallister, FW
11:10	Process Simulation - Simulation Model - Operating Strategy - Results of Parametric Study	David Allen, FW
12:00	---- LUNCH ----	
1:00	Product Mix and Plant Size Selection	S. F. Wu, FW

TERRACE WALL STEAM METHANE REFORMING FURNACE



FOSTER WHEELER 80-3

AGENDA (Continued)

Task 3 -- Facility Design

1:20	System Design and Performance	S. F. Wu, FW
1:40	Component/Subsystem Designs	Gio Carli, FW
2:20	---- BREAK ----	
2:30	Discussion and Action Items	Betty Carrell, SNLL S. F. Wu, FW
3:10	Adjourn	
3:20 to 3:50	SNLL Cost Data Management System (CDMS) Mini Workshop	Betty Carrell, SNLL

PROJECT SUMMARY

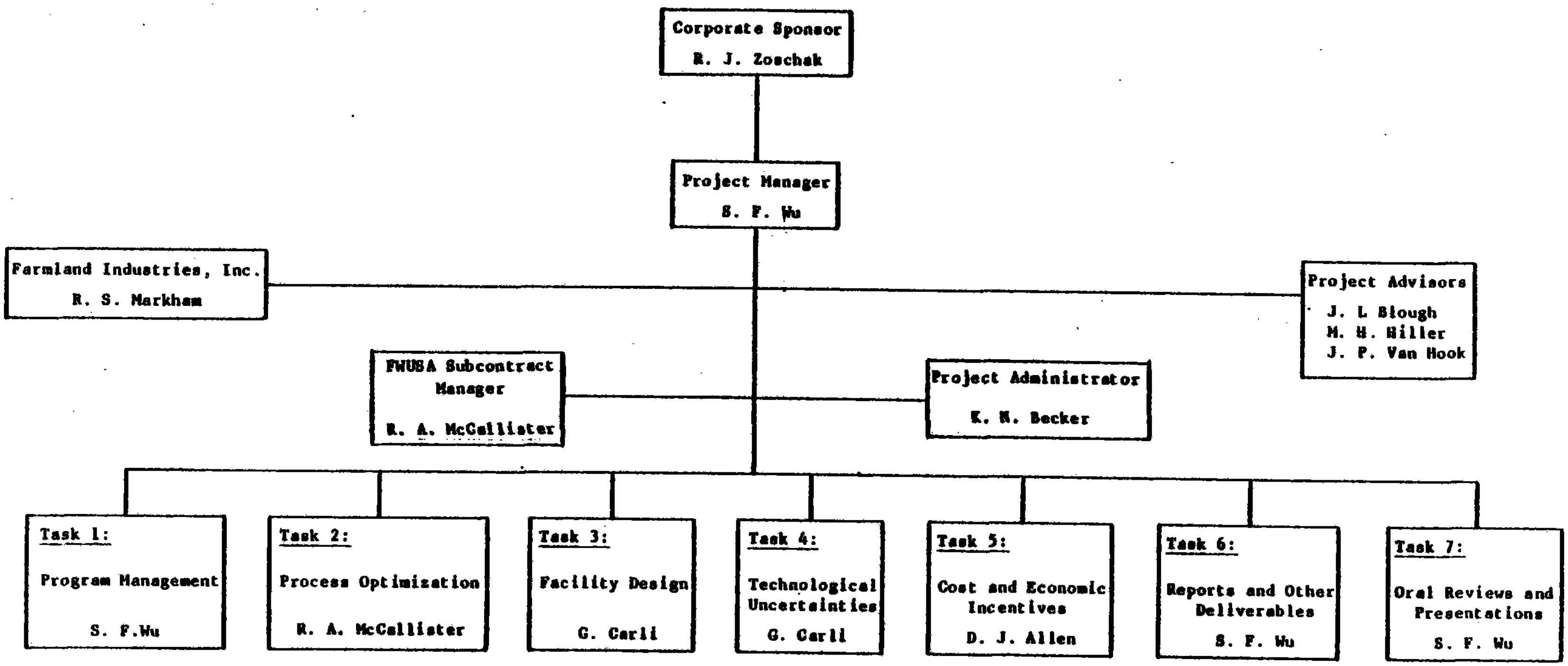
TITLE:	SOLAR FUELS AND CHEMICALS SYSTEM DESIGN STUDY
CLIENT:	SANDIA NATIONAL LABORATORIES
CONTRACT NO.:	9-91-4648 A
TOTAL COST:	$408,284
PERIOD OF PERFORMANCE:	MARCH 3 TO DECEMBER 31, 1985
PRIME CONTRACTOR:	FOSTER WHEELER SOLAR DEVELOPMENT CORP.
SUBCONTRACTORS:	FOSTER WHEELER, USA CORP. FARMLAND INDUSTRIES, INC.

PROJECT OBJECTIVES

TO DETERMINE THE TECHNICAL AND ECONOMIC FEASIBILITY OF A FACILITY TO PRODUCE AMMONIA AND NITRIC ACID USING SOLAR ENERGY AS THE SOURCE OF PROCESS HEAT BY:

- PERFORMING PROCESS EVALUATION AND SELECTION
- DEVELOPING FACILITY AND COMPONENTS CONCEPTUAL DESIGN
- CONDUCTING COST ESTIMATES AND ECONOMIC EVALUATION
- IDENTIFYING TECHNICAL UNCERTAINTIES AND DEVELOPMENT REQUIREMENTS

PROJECT ORGANIZATION CHART



PROPOSED SYSTEM CONCEPT

- USE SOLAR ENERGY TO PRODUCE AMMONIA AND NITRIC ACID WITH METHANE AS THE PRIMARY FEEDSTOCK

- SOLAR-FUELED CHEMICAL PLANT CONSISTS OF:

  SOLAR CENTRAL RECEIVER

  PRIMARY METHANE REFORMER (ENDOTHERMIC PROCESS)

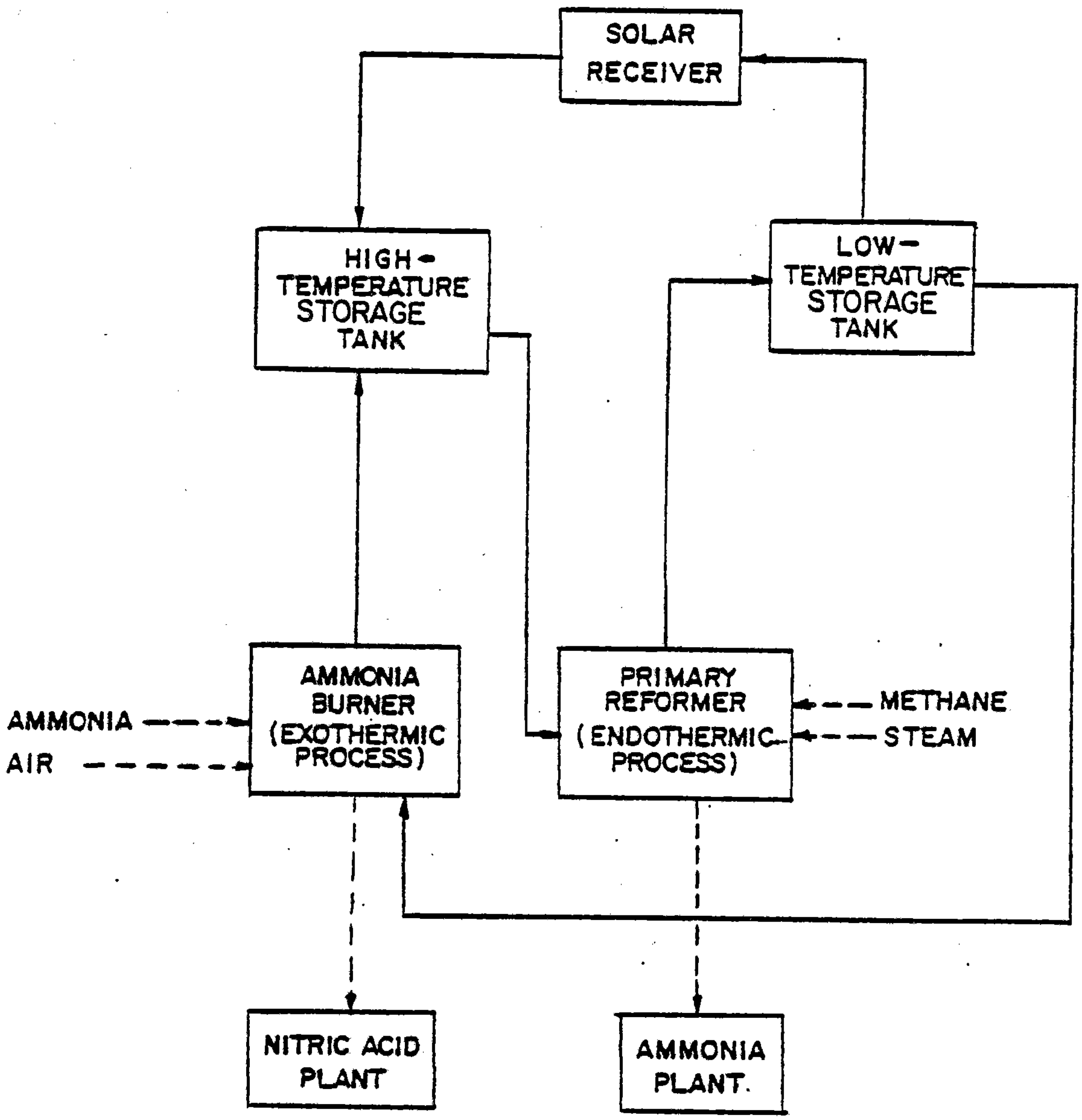
  AMMONIA BURNER (EXOTHERMIC PROCESS)

  HEAT TRANSPORT LOOP AND STORAGE

  AMMONIA PLANT

  NITRIC ACID PLANT

SIMPLIFIED BLOCK DIAGRAM OF THE SYSTEM CONCEPT



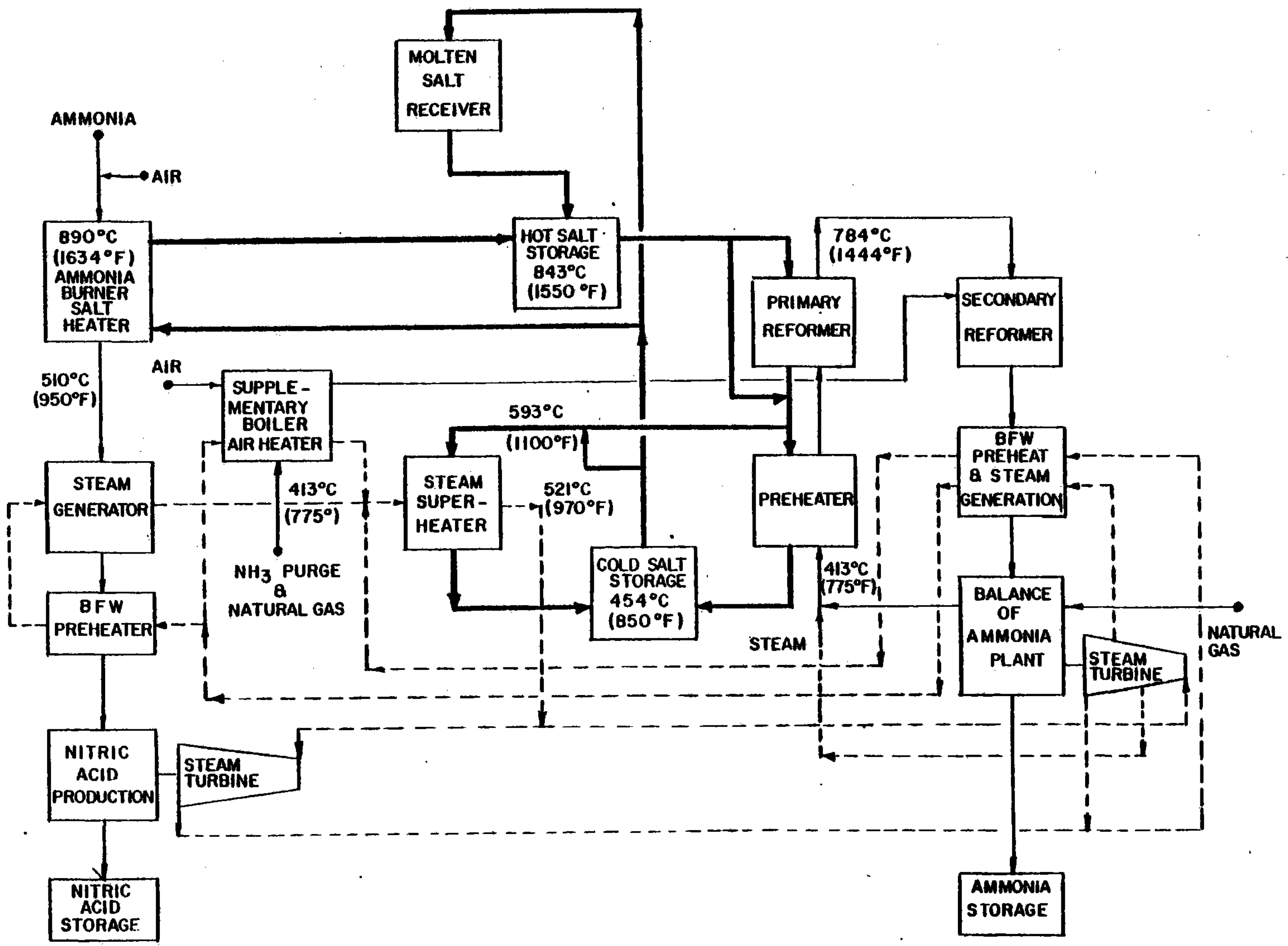
DESIRABLE FEATURES OF THE PROPOSED CONCEPT

- COMPLEMENTARY ENDOTHERMIC/EXOTHERMIC REACTION
- ENERGY INTENSIVE PROCESS AND ECONOMICALLY ATTRACTIVE PRODUCTS
- CONSTANT TEMPERATURE HEAT SOURCE TO THE REFORMER
- HIGH PLANT AVAILABILITY WITH THERMAL (MOLTEN SALT) AND CHEMICAL (AMMONIA) STORAGES
- HIGH SOLAR CONTRIBUTION TO PLANT ENERGY REQUIREMENT

SUMMARY OF THE SELECTED OVERALL SYSTEM

- MOLTEN CARBONATE-SALT CHOSEN AS THE HEAT-TRANSFER AND THERMAL STORAGE MEDIUM
- DIRECT ABSORPTION RECEIVER
- HOT AND COLD MOLTEN SALT STORAGE TANKS
- PRIMARY REFORMER AND AMMONIA PLANT AT CONTINUOUS, CONSTANT LOAD
- AMMONIA BURNER/SALT HEATER AND NITRIC ACID PLANT AT CONTINUOUS OPERATION WITH A 5 TO 1 TURN-DOWN RATIO
- MOLTEN SALT HEATED STEAM SUPERHEATER
- SUPPLEMENTARY FIRED STEAM GENERATOR AND AIR HEATER

PROCESS SCHEMATIC OF THE OVERALL SYSTEM



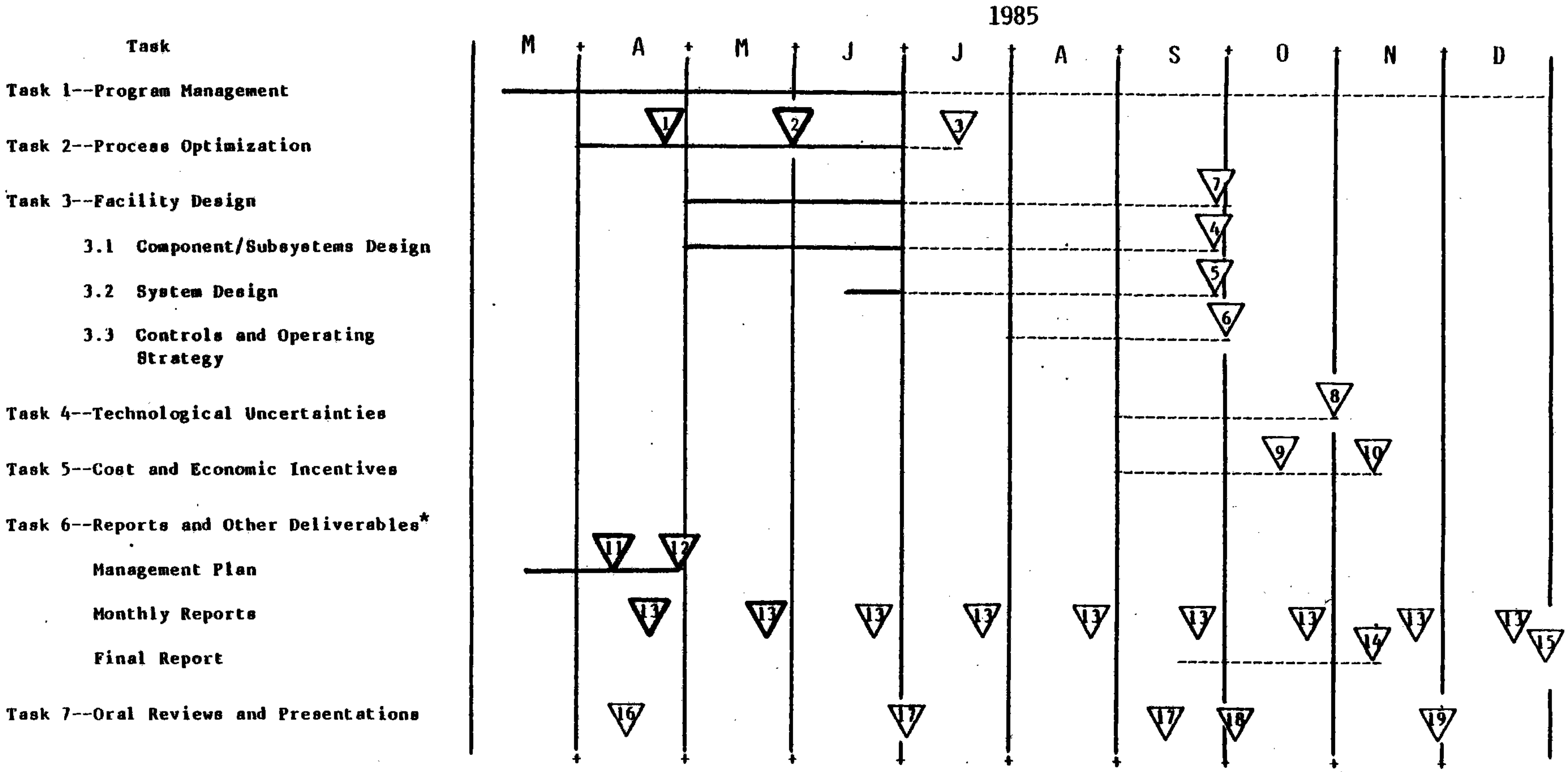
TASK 1 -- PROJECT MANAGEMENT

- PROJECT SCHEDULE AND MILESTONES

- MANPOWER STATUS

- COST STATUS

PROJECT SCHEDULE AND MILESTONES



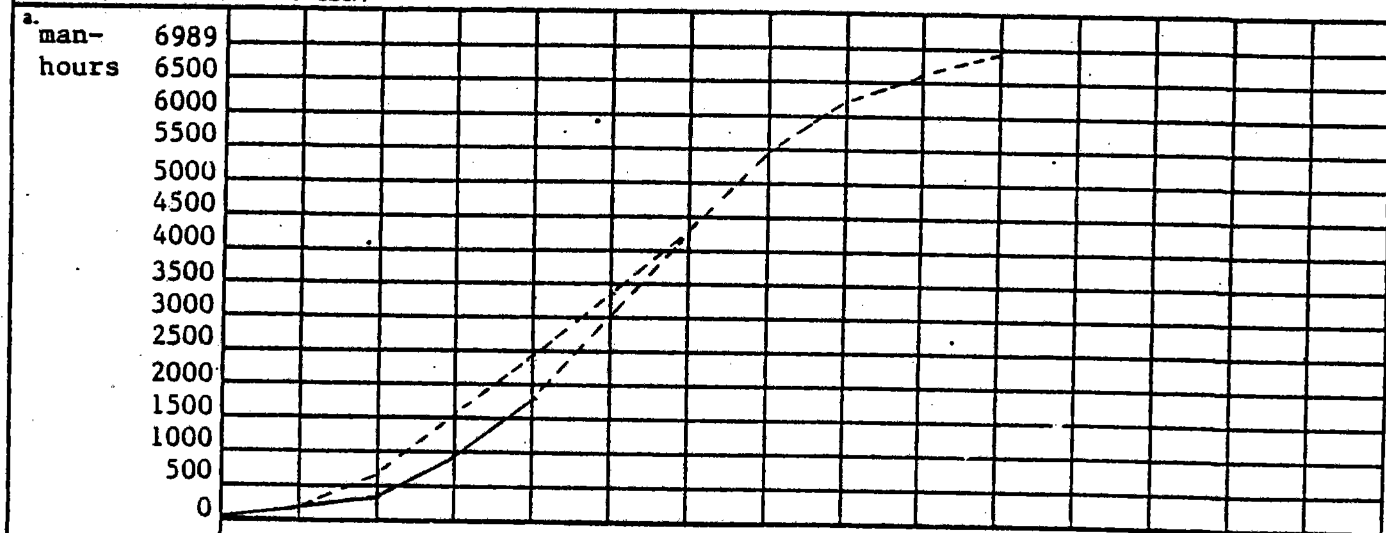
1. Heat-transport fluid selected
2. Optimized process selected
3. Conceptual process design completed
4. Component sizing completed
5. System integration and design point efficiencies calculated
6. Control and operation defined annual solar contribution projected
7. Facility design completed
8. Technological uncertainties and development activities identified
9. Component cost estimates completed
10. Product cost projection and economics incentives study completed
11. Management Plan (draft) submitted
12. Management Plan (final) submitted
13. Monthly Reports submitted
14. Final Report (draft) submitted
15. Final Report (final) submitted
16. Kick-Off Meeting
17. Quarterly Reviews
18. DOE Annual Review
19. Final Project Review

MANPOWER STATUS

7. Months	M	A	M	J	J	A	S	O	N	D						8. FY 1985

10. Manpower Status (Direct Labor)

a.



Man-power																
b. Planned	87	630	795	942	960	904	1191	724	371	385						
c. Actual	87	278	587	783												
d. Variance		352	208	159												

e. Manpower Plan Date 4/5/85

f. Planned Manpower Prior FYs

g. Actual Manpower Prior FYs

h. Total Estimated Manpower for Contract 6,989

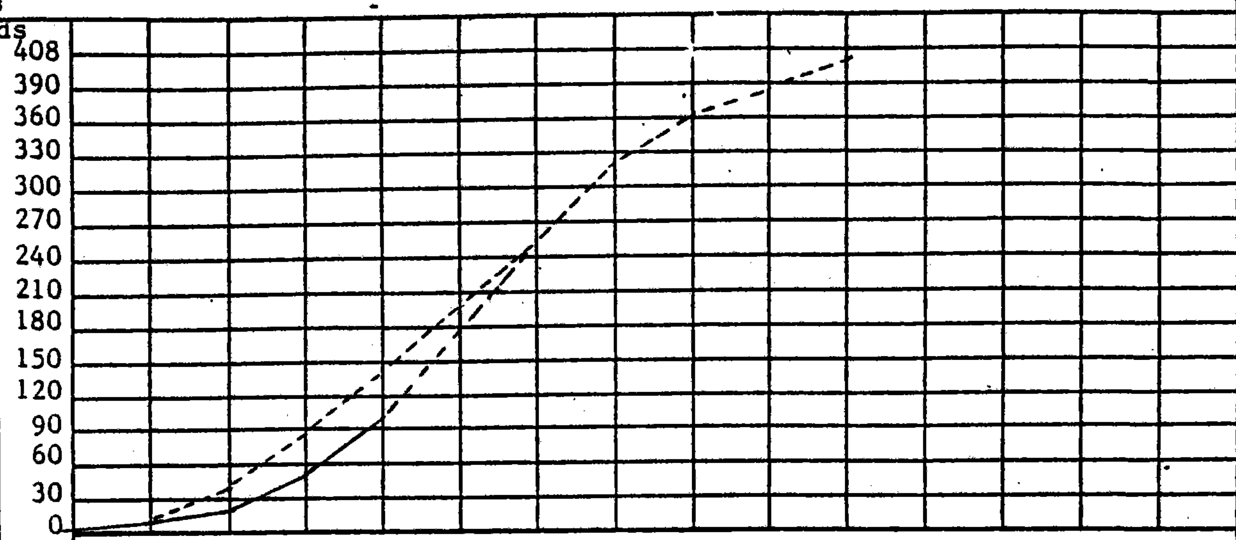
i. Total Contract Manpower 6,989

COST STATUS

7. Months	M	A	M	J	J	A	S	O	N	D						8. FY 1985

9. Cost Status

a. thousands



b. B&R Numbers

Accrued Costs		M	A	M	J	J	A	S	O	N	D					
	c. Planned	5.1	36.7	46.4	55	56.1	52.8	69.5	42.4	21.8	22.4					
	d. Actual	5.1	16.9	33.8	45.6											
	e. Variance		19.8	12.6	9.4											
	f. Cum. Variance		19.8	32.4	41.8											

g. Cost Plan Date: 4/5/85

h. Planned Costs Prior FYs

i. Actual Costs Prior FYs

j. Total Estimated Costs for Contract: 408.2

k. Total Contract Value: 408.2

l. Unfilled Orders Outstanding

m. Estimate for Subsequent Reporting Period: 75.4

TASK 2 -- PROCESS OPTIMIZATION

- SELECTION OF HEAT-TRANSFER MEDIUM
- HELIOSTAT FIELD/RECEIVER PERFORMANCE DATA
- PROCESS STUDIES AND SELECTION
- PROCESS SIMULATION
- PRODUCT MIX AND PLANT SIZE SELECTION

HEAT TRANSFER MEDIA CONSIDERED

- MOLTEN TERNARY CARBONATE SALT
- SOLID PARTICLES
- PRESSURIZED GAS

ROLES OF THE HEAT TRANSFER MEDIUM

- RECEIVER AND STORAGE MEDIUM

- HEATING MEDIUM FOR THE REFORMER AND STEAM SUPERHEATER

- COOLANT FOR AMMONIA BURNER

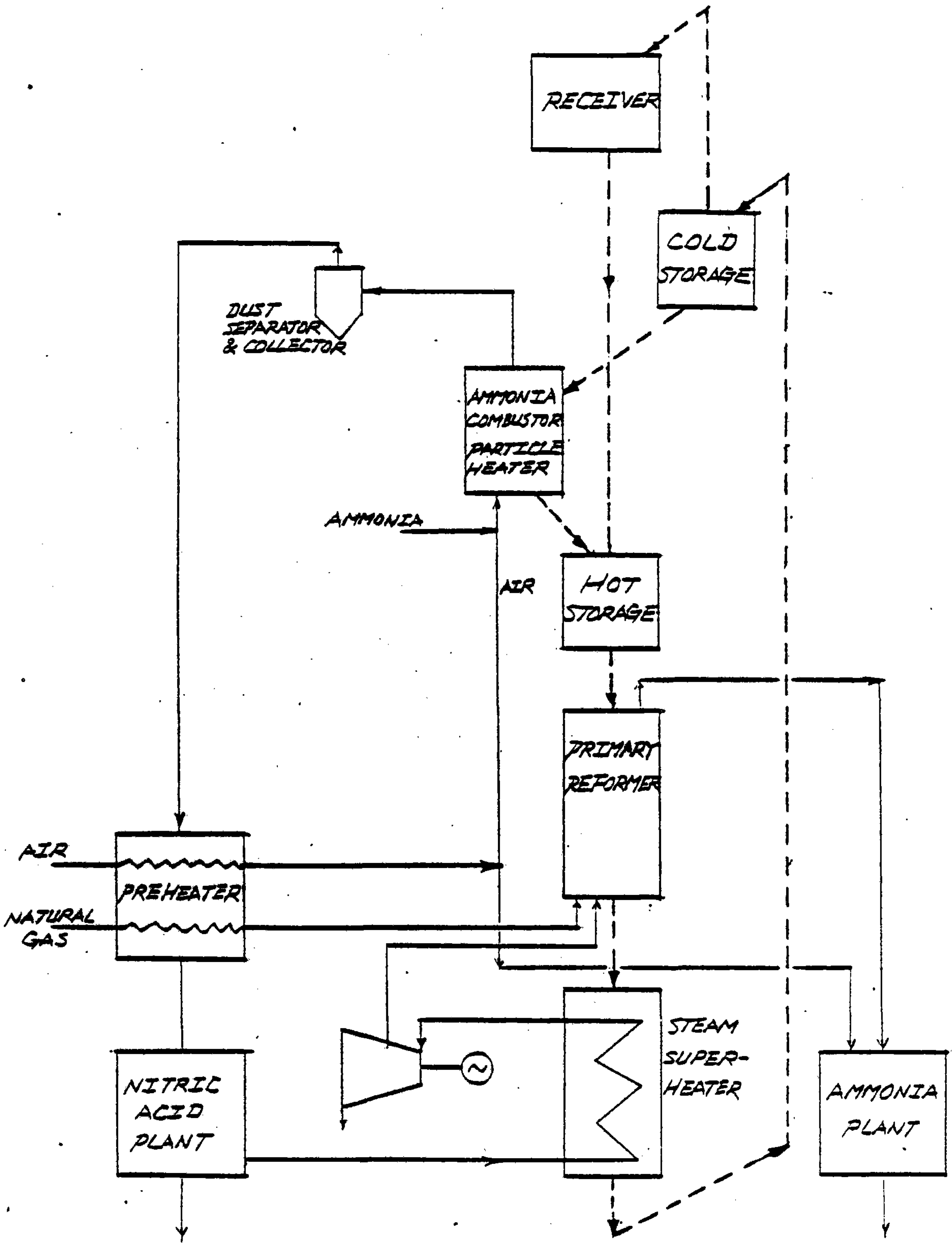
SELECTION CRITERIA

- SUITABLITY FOR THE OVERALL PROCESS
- TECHNOLOGICAL MATURITY OF COMPONENTS
- HEAT TRANSFER AND FLOW CHARACTERISTICS
- MATERIAL COMPATIBILITY
- DESIGN LIMITATION
- ECONOMIC ATTRACTIVENESS

REASONS NOT TO SELECT PRESSURIZED GAS

- RECEIVER FLUX LIMITATION
- DESIGN AND FABRICATION SOPHISTICATION OF CERAMIC MATERIAL
- POOR HEAT TRANSFER CHARACTERISTICS
- NOT COST EFFECTIVE FOR A LARGE THERMAL STORAGE

CONCEPTUAL SCHEMATIC OF A SOLID PARTICLE SYSTEM



COMPARISON OF MOLTEN SALT AND SOLID PARTICLES

- RECEIVER AND THERMAL STORAGE - SIMILAR TECHNICAL ADVANTAGES AND SAME LEVEL OF DEVELOPMENT MATURITY
- MOLTEN SALT HAS BETTER HEAT TRANSFER AND FLOW CHARACTERISTICS
- REFORMER DESIGN - MOLTEN SALT OFFERS LESS COMPLEX AND MORE CONVENTIONAL ARRANGEMENT
- AMMONIA - COMBUSTOR/PARTICLE - HEATER REPRESENTS A SUBSTANTIAL DEVIATION FROM A CONVENTIONAL AMMONIA BURNER
- MATERIAL COMPATIBILITY - LESS CONCERN FOR SOLID PARTICLES

OUR SELECTION -- MOLTEN CARBONATE SALT

- BETTER SUITED TO THE OVERALL PROCESS

- SIMPLER, MORE COMPACT AND LESS COSTLY PROCESS COMPONENT DESIGNS

- CLOSER TO CONVENTIONAL PRACTICE

MATERIAL COMPATIBILITY OF CARBONATE SALT

- INCONEL 600, THE MOST PROMISING ALLOY
- AT 900 C (1652°F), SERI TEST DATA SUGGESTED A CORROSION RATE OF 1 MM/YR FOR INCONEL 600
- LOWER OPERATING TEMPERATURE (E.G., 800 C) WILL REDUCE CORROSION RATE SUBSTANTIALLY
- MORE TESTS (LONG-TERM EXPOSURES, THERMAL CYCLING, AND MORE TEMPERATURE POINTS) AND DETAILED STUDIES ARE NEEDED

DESIGN APPROACHES

- LIMIT THE UPPER SALT TEMPERATURE TO 850°C

- INCLUDE SUFFICIENT CORROSION ALLOWANCE AND REPLACEMENT PROVISIONS IN THE COMPONENT DESIGN

HELIOSTAT FIELD/RECEIVER PERFORMANCE DATA

- BASED ON DAR (DIRECT ABSORPTION RECEIVER) SYSTEM STUDY CONDUCTED BY SERI
- METHODOLOGY -- USE DELSOL2, RADSOLVER AND SHAPEFACTOR COMPUTER CODES TO DETERMINE A MAXIMUM IN PERFORMANCE FOR A GIVEN SET OF SYSTEM PARAMETERS

  REF: DIRECT ABSORPTION RECEIVER SYSTEM STUDY
  SERI/SP-253-2592

- DELSOL2 COMPUTER OUTPUTS FOR RECEIVER SIZES OF 75 AND 225 MWT WERE OBTAINED FROM SERI

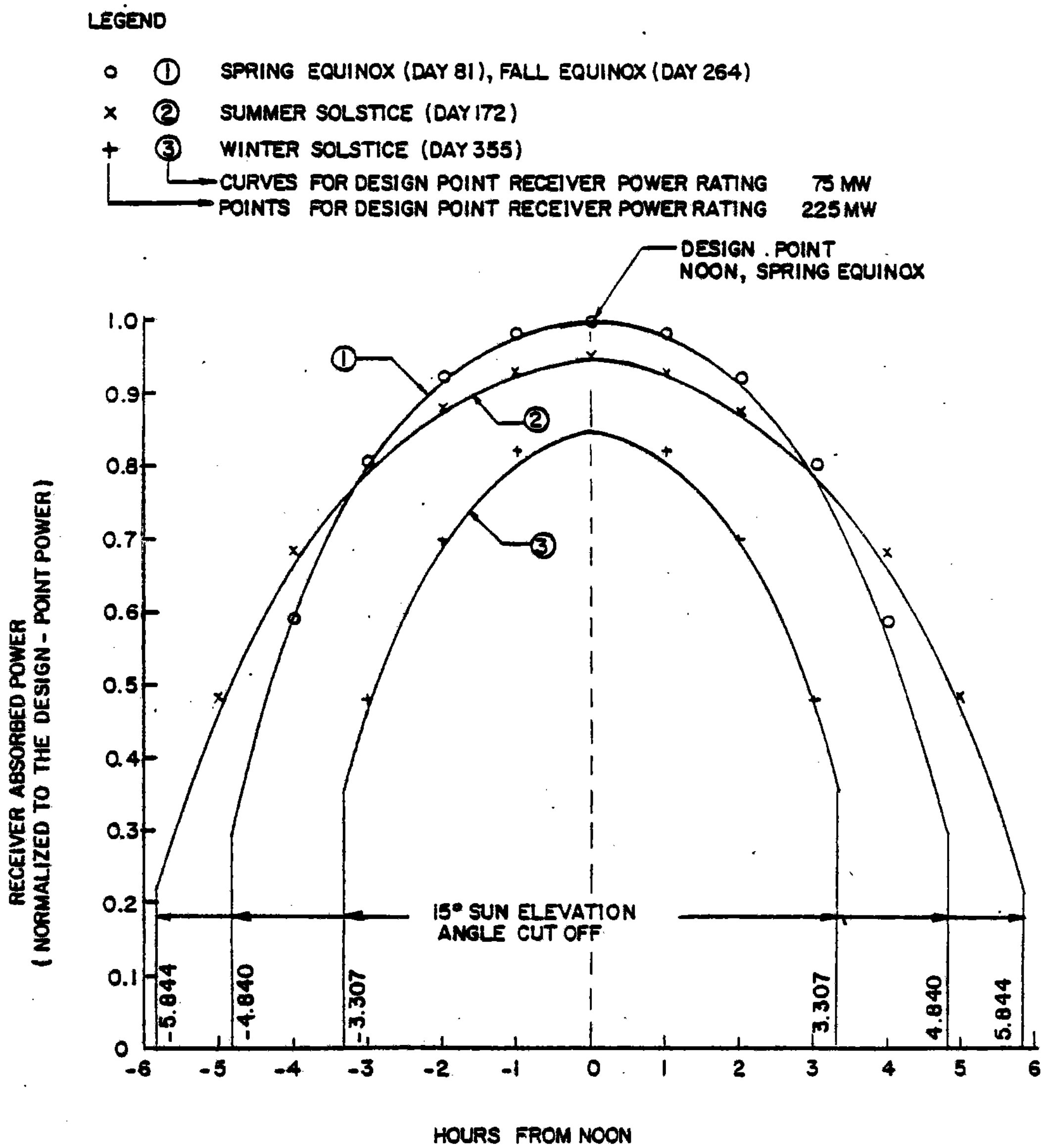
SUMMARY OF SYSTEM PARAMETERS

- SITE LOCATION: BARSTOW, CALIFORNIA
- NORTH FIELD, NO LAND CONSTRAINT
- HELIOSTATS: REFLECTIVE AREA/HELIOSTAT = 100M^2
  REFLECTIVITY = 0.89
  MIRROR PANELS FOCUSED AND CANTED
  AT SLANT RANGE
- RECEIVER: SINGLE CAVITY WITH CANTED APERTURE
- SINGLE POINT AIMING STRATEGY
- DESIGN POINT: NOON, SPRING EQUINOX
  INSOLATION = 0.95 KW/M^2

SUMMARY OF AVAILABLE DATA

- APERTURE SIZE
- TOWER HEIGHT
- HELIOSTAT FIELD LAYOUT
- RECEIVER CAVITY DIMENSIONS AND FLUX DISTRIBUTION
- DESIGN POINT PERFORMANCE
- ANNUAL POWER PRODUCTION
- ANNUAL AVERAGE PERFORMANCE

NORMALIZED DIURNAL RECEIVER ABSORBED POWER



PROCESS STUDIES & SELECTION

1-22-5004
JULY 10, 1985

BASIC REACTIONS

REFORMING:

$$CH_4 + 2H_2O \text{ HEAT} \longrightarrow 4H_2 + CO_2$$

$$0.6024H_2 + 0.3012O_2 + 1.1325N_2 \longrightarrow 1.1325N_2 + 0.3012H_2O$$

$$CH_4 + 1.6988\ H_2O + \text{HEAT} \longrightarrow 3.3976H_2 + 1.1325N_2 + CO_2$$

NITRIC ACID:

$$NH_3 + 2O_2 \longrightarrow HNO_3 + H_2O + \text{HEAT}$$

SHIFT REACTION:

$$CO + H_2O \longrightarrow H_2 + CO_2 + \text{HEAT}$$

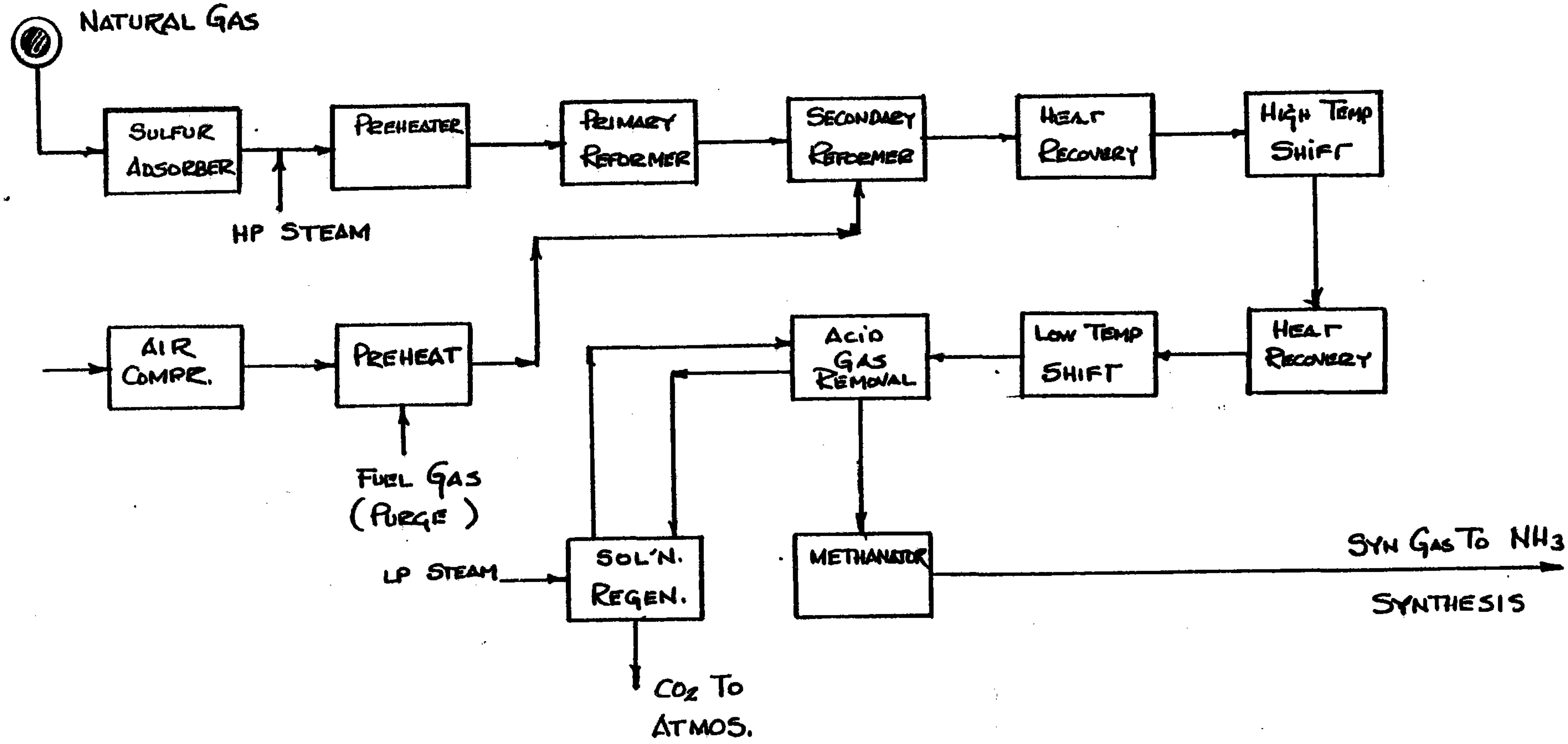
METHANATION:

$$CO + H_2 \longrightarrow CH_4 + H_2O + \text{HEAT}$$

AMMONIA SYNTHESIS:

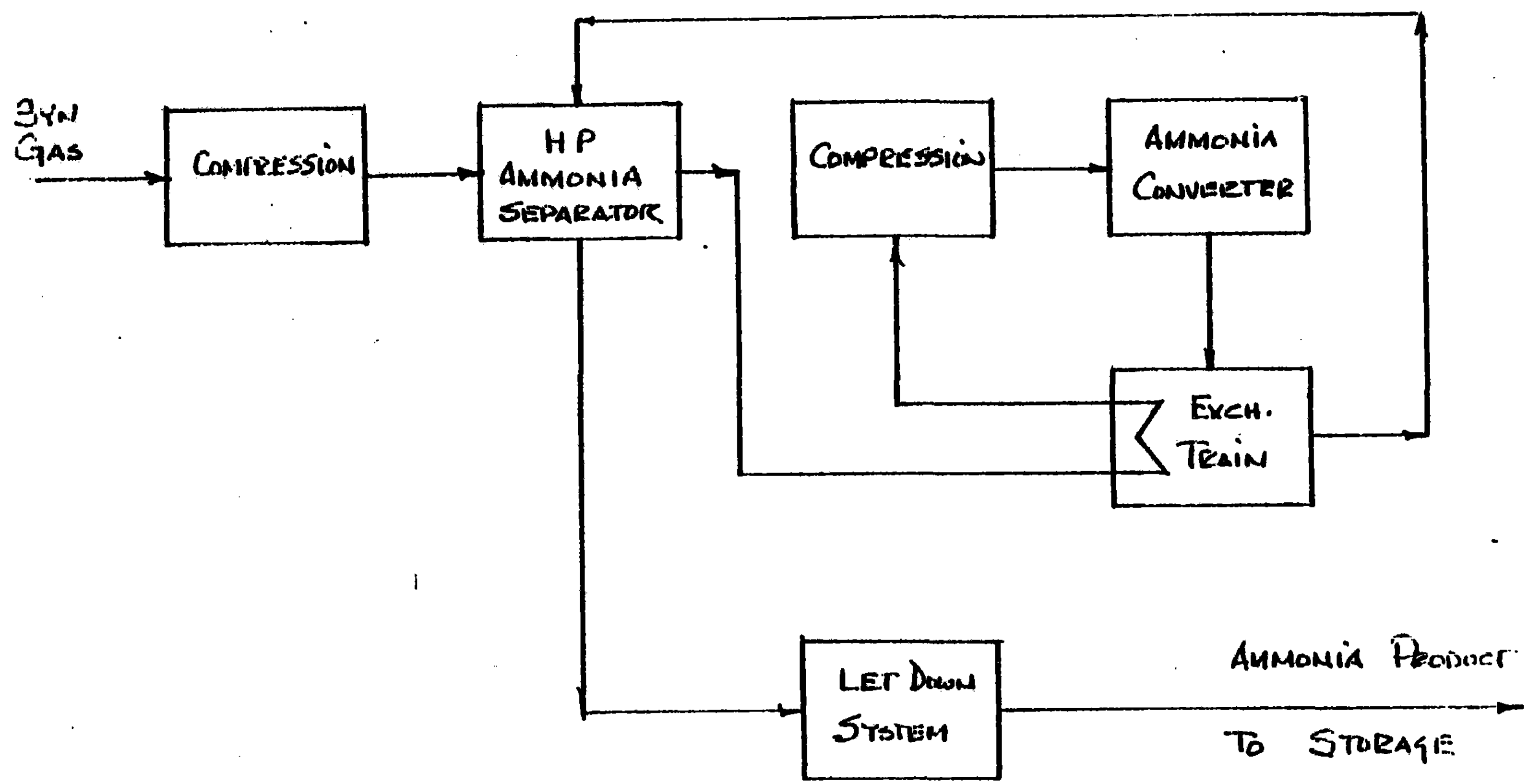
$$3H_2 + N_2 \longrightarrow 2NH_3 + \text{HEAT}$$

1-22-50021
JULY 10, 1985



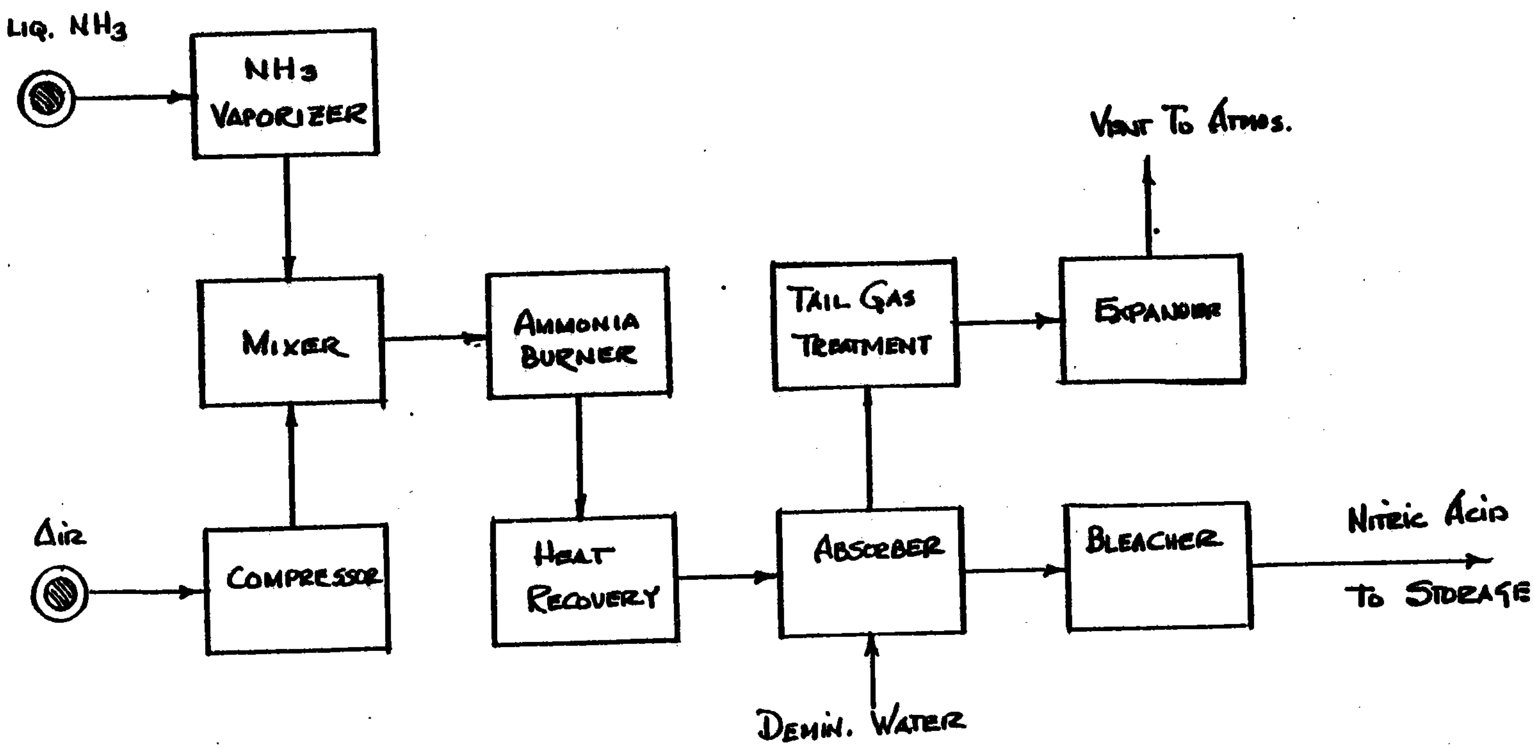
SYN. GAS PREPARATION UNIT.

1-22-5004
July 10, 1985



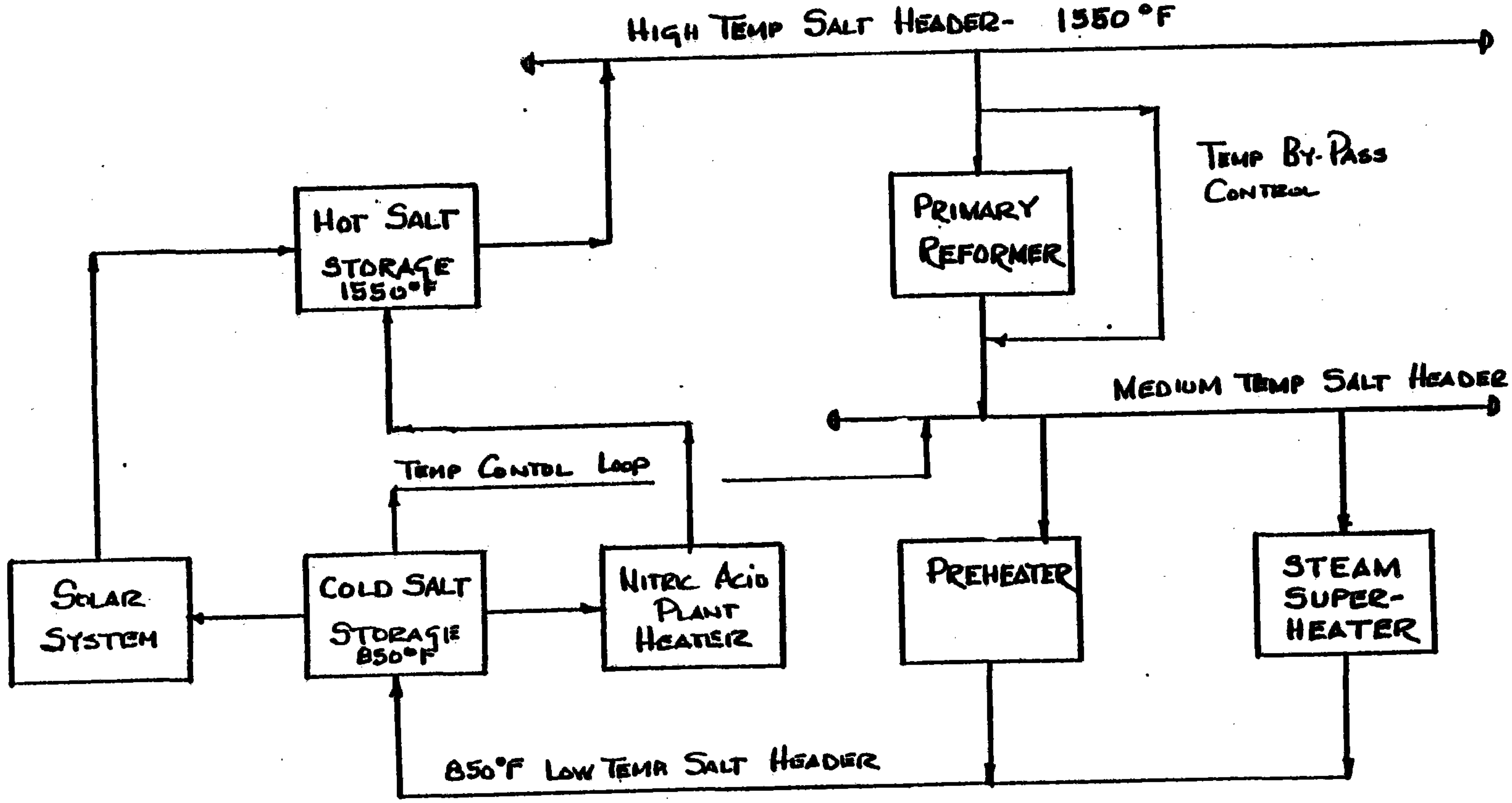
Ammonia Synthesis

1-22-5009
JULY 10, 1985



NITRIC ACID PLANT

1-28-5004
JULY 10, 1985



SALT LOOP – BLOCK FLOW DIAGRAM

1-22-5004
JULY 10, 1985

AMMONIA PLANT

CAPACITY	1000 T/D (10.50 Kg/Sec)
DESIGN OPERATING FACTOR	94%

PRIMARY REFORMER OPERATING CONDITIONS:

OUTLET PRESSURE	430 PSIG (2.96 MPa)
OUTLET TEMPERATURE	1444°F (784°C)
STEAM/CARBON RATIO	3.5 (MOLE BASIS)
METHANE LEAKAGE (DRY)	12.95%
CARBON CONVERSION	59.54%

SECONDARY REFORMER OPERATING CONDITIONS:

OUTLET PRESSURE	420 PSIG (2.89 MPa)
OUTLET TEMPERATURE	1757°F (958)
Air/Primary Feed	1.32 MOLE RATIO
METHANE LEAKAGE (DRY)	0.50%
CARBON CONVERSION	94.11%
H_2/N_2 Ratio	2.51

1-22-5004
JULY 10, 1985

NATURAL GAS COMPOSITION

COMPOSITION	MOLE %
CH_4	93.0
C_2H_6	4.0
C_3+	1.1
CO_2	0.5
N_2	1.4
	100.0
M.W.	17.22
SULFUR	5 PPMV (MAX)
PRESSURE	600 PSIG (4.14 MPa)
TEMPERATURE	60°F (15.6°C)
LHV	941 BTU/SCF (48.24 MJ/kg)
HHV	1043 BTU/SCF (53.44 MJ/kg)

1-22-5004
JULY 10, 1985

ASSUMED SITE CONDITIONS

SITE ELEVATION	2105 FT (633 m)
AMBIENT PRESSURE	13.58 PSIA (93.63 kPa)
SUMMER DRY BULB	104°F (40°C)
SUMMER WET BULB	72°F (22.2°C)
WINTER DRY BULB	19°F (-7.2°C)

1-22-5004
JULY 10, 1985

TYPICAL REQUIREMENTS

NATURAL GAS REQ'D	LATEST COMMERCIAL TECHNOLOGY	TYPICAL OLDER TECHNOLOGY	SELECTED DESIGN
PROCESS	22.860	23.00	22.318
FUEL	4.640	10.80	11.774 [1]
	27.500	33.80	34.092

UNITS AS MM BTU/SHORT TON - HHV

PROCESS THEORETICAL = 19.927 MMBTU/ST

	LATEST	TYPICAL	SELECTED
PROCESS	83.13 %	68.05 %	65.46 %
FUEL	16.87	31.95	34.54
	100.00	100.00	100.00

(1) NATURAL GAS EQUIVALENT.

1-22-5004
JULY 10, 1985

CATALYST

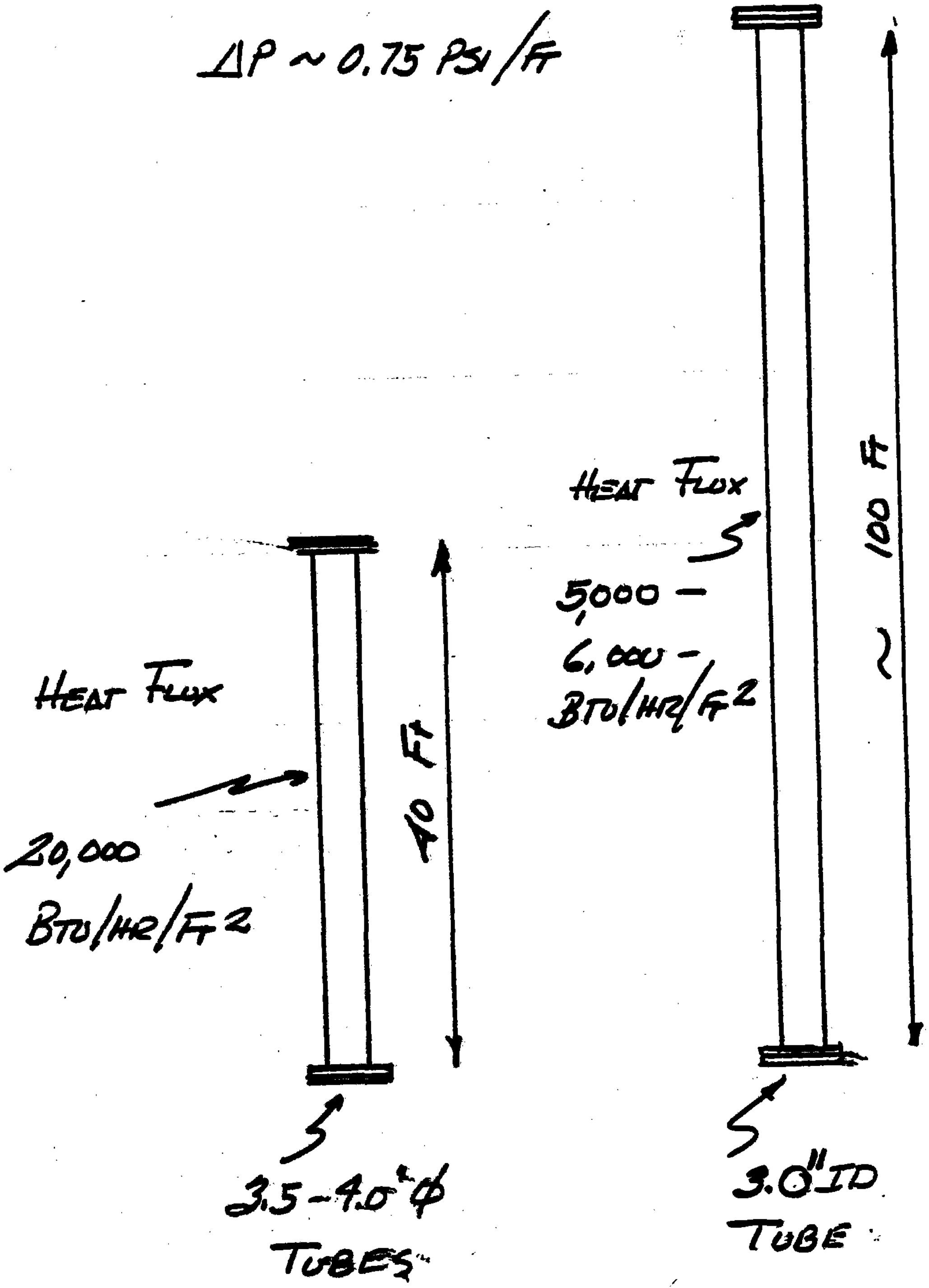
COMPOSITION

Ni	16	-	25%
Al_2O_3	45	-	86
TiO_2	<3	-	12.5
Ni/FT^3 CATALYST	8	-	18 LBS/FT^3
BULK DENSITY	50	-	90 LBS/FT^3
TYPICAL SIZE	5/8" x 5/8" x 1/4" RINGS (16 mm x 16 mm x 6 mm)		

REFORMER DESIGN

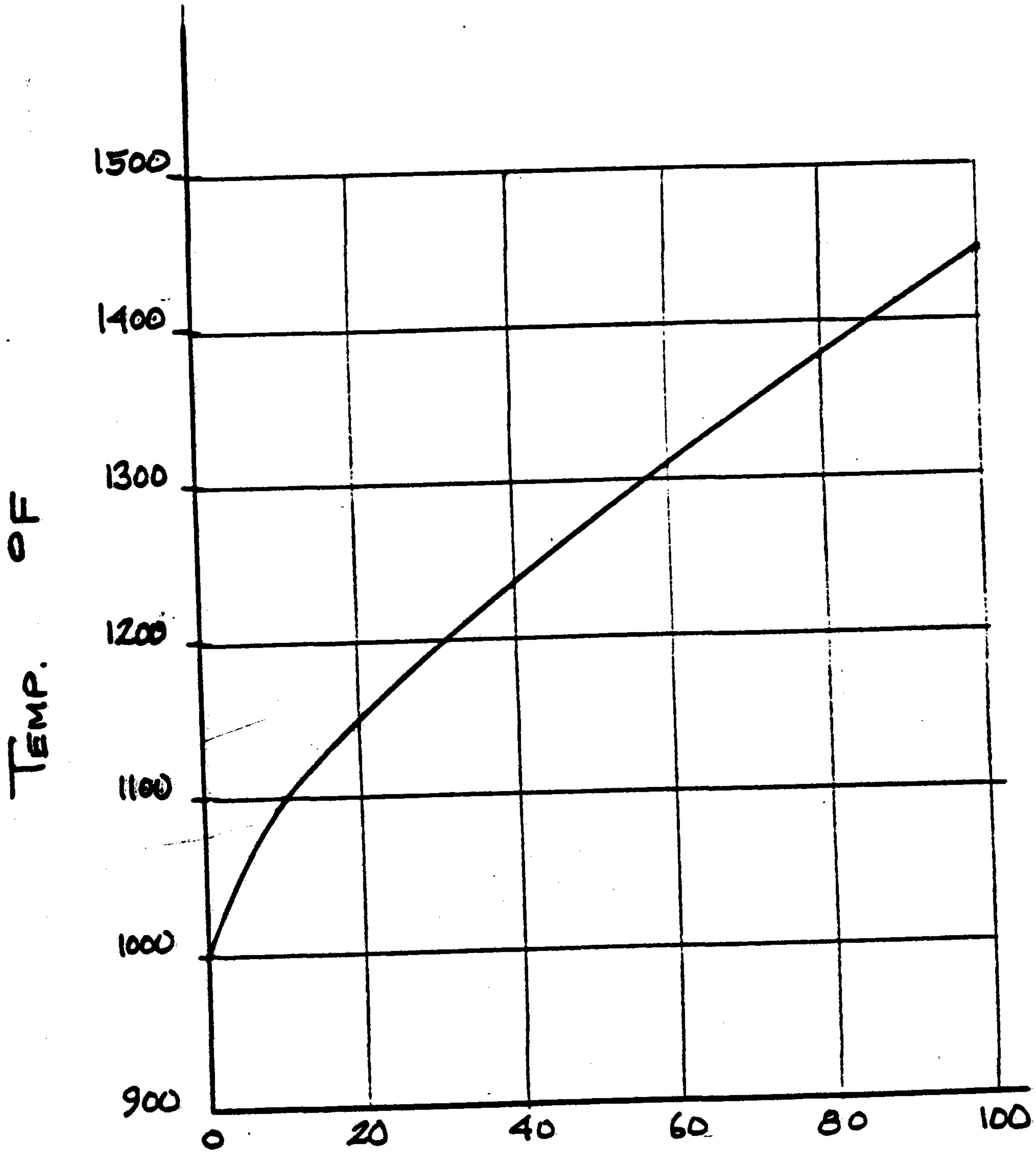
NORMAL | SOLAR

$\Delta P \sim 0.75$ PSI/FT

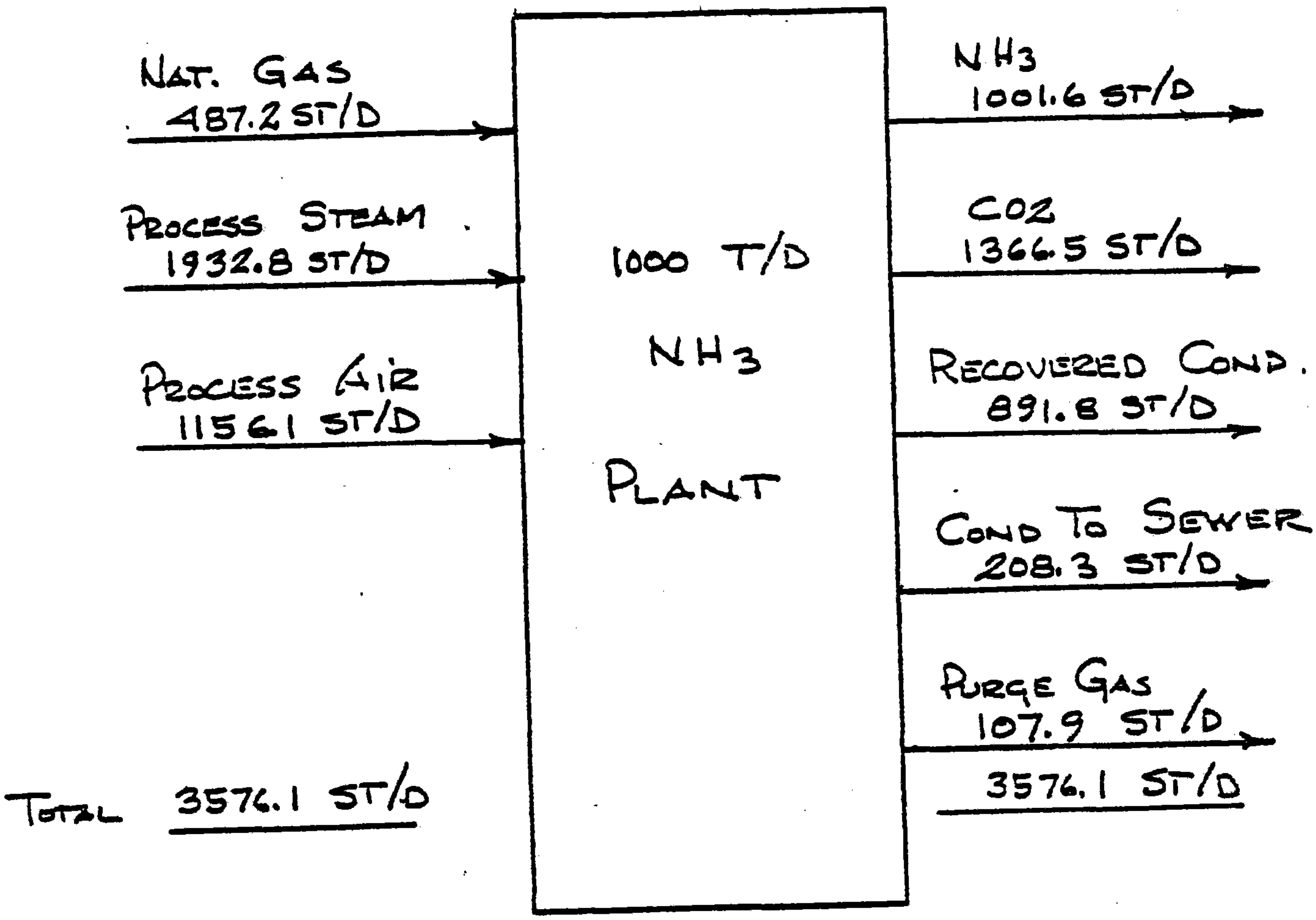


1-22-5004
10 JULY 1985

REFORMER TEMPERATURE PROFILE - PROCESS SIDE

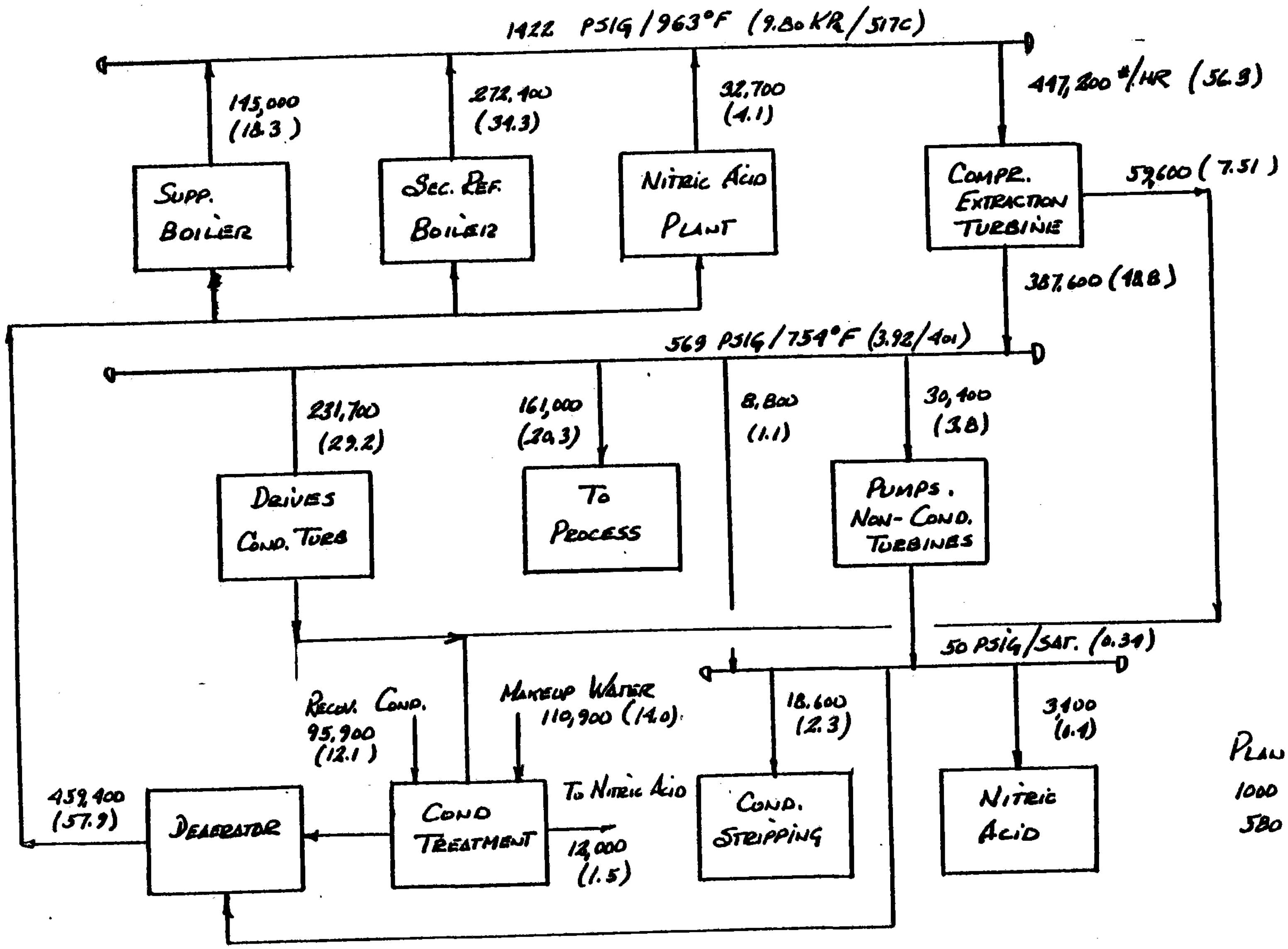


1-22-500 4
10 JULY 1985



OVERALL NH_3 PLANT MATERIAL BALANCE

1-22-5004
10 July 1985



PLANT STEAM BALANCE
1000 ST/D NH_3
580 ST/D HNO_3

PROCESS SIMULATION

- SIMULATION MODEL
  & OPERATING STRATEGY

- RESULTS OF PARAMETRIC STUDY

SIMULATION MODEL

- RECEIVER DOES NOT OPERATE AT POWER LEVELS OF LESS THAN 20%
- RECEIVER PERFORMANCE BY LINEAR INTERPOLATION OF DELSOL 2 RESULTS
- RANDOMIZED CLOUDINESS FACTOR

SIMULATION MODEL

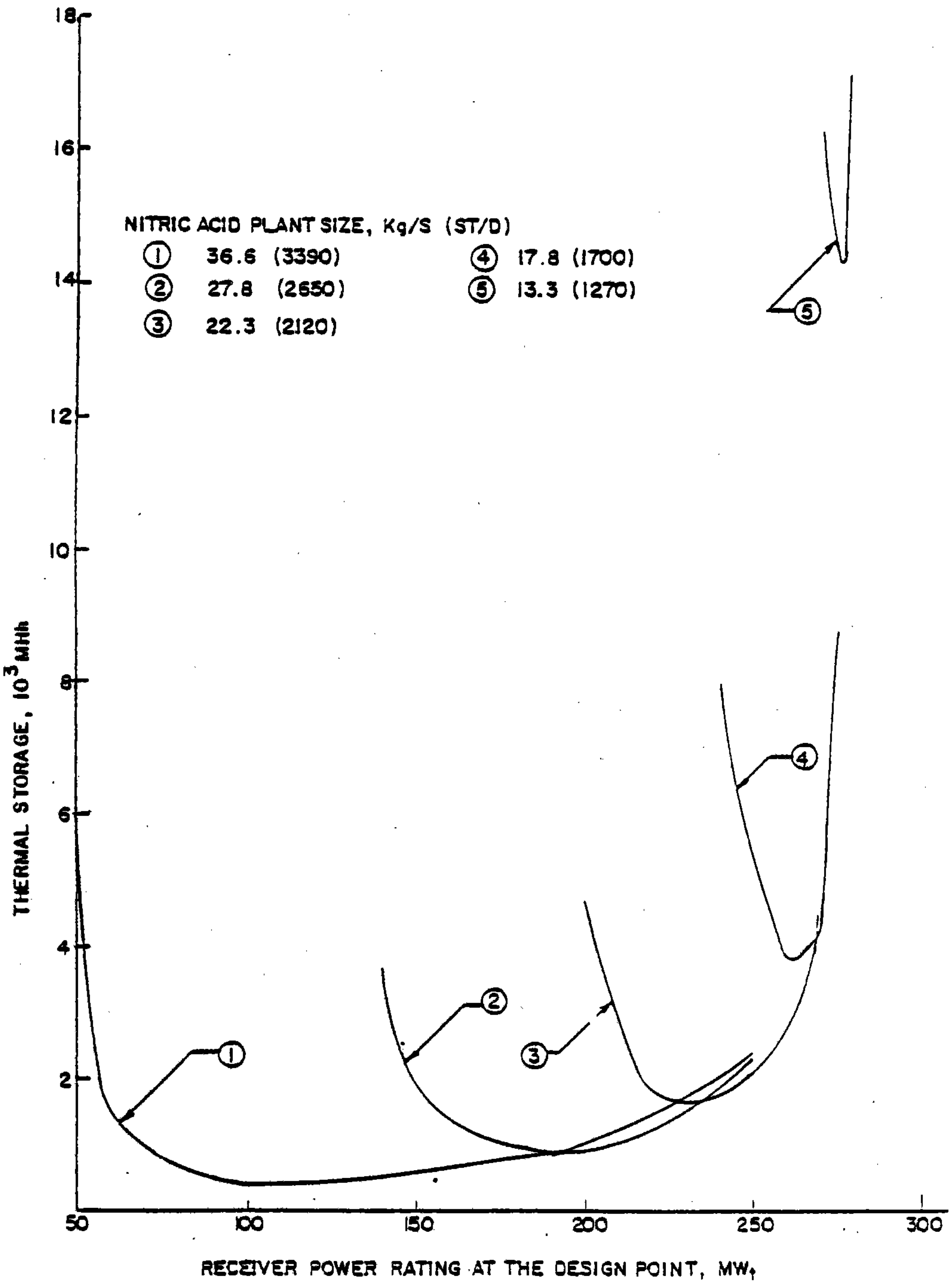
- QUASI-STEADY STATE

- PERFORMANCE DETERMINED AT HOURLY INTERVALS

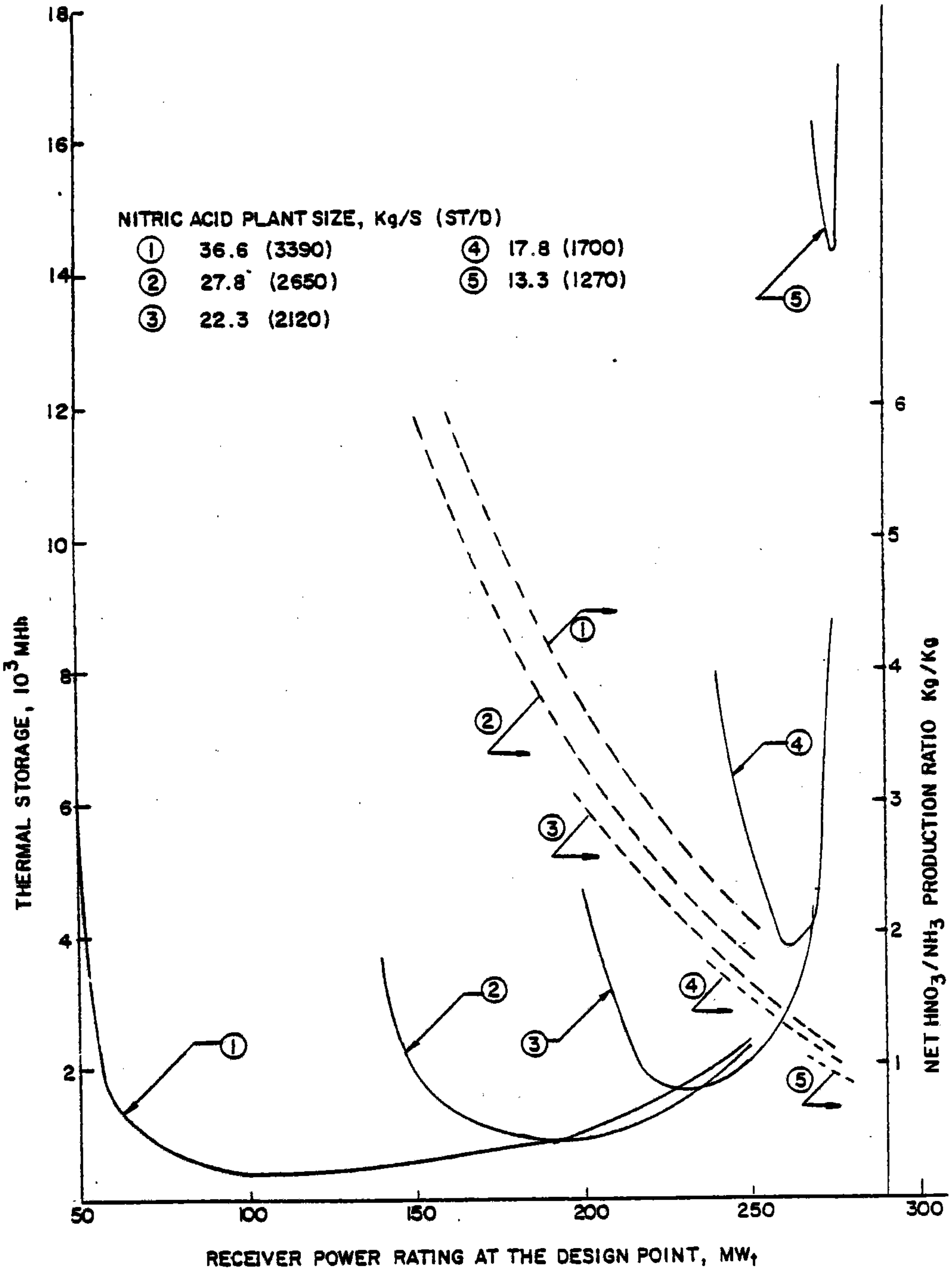
SIMULATION MODEL

- CONTROL STRATEGY TO
  MINIMIZE PRODUCTION OF HNO_3,
  MAXIMIZE USE OF INSOLATION

RESULTS OF PARAMETRIC STUDY -- PLANT SIZES



RESULTS OF PARAMETRIC STUDY -- PLANT SIZES & PRODUCTION RATIO



RESULTS OF PARAMETRIC STUDY

"LARGE" NITRIC ACID PRODUCTION CAPACITY

- LOW THERMAL STORAGE REQUIREMENTS
- INSENSITIVITY TO RECEIVER POWER RATING
- HIGH HNO_3: NET NH_3 PRODUCTION RATIO

RESULTS OF PARAMETRIC STUDY (CTD)

DECREASED NITRIC ACID PRODUCTION CAPACITY

- INCREASED ACCEPTABLE MINIMUM POWER RATING
- HNO_3: NET NH_3 PRODUCTION RATIO FALLS

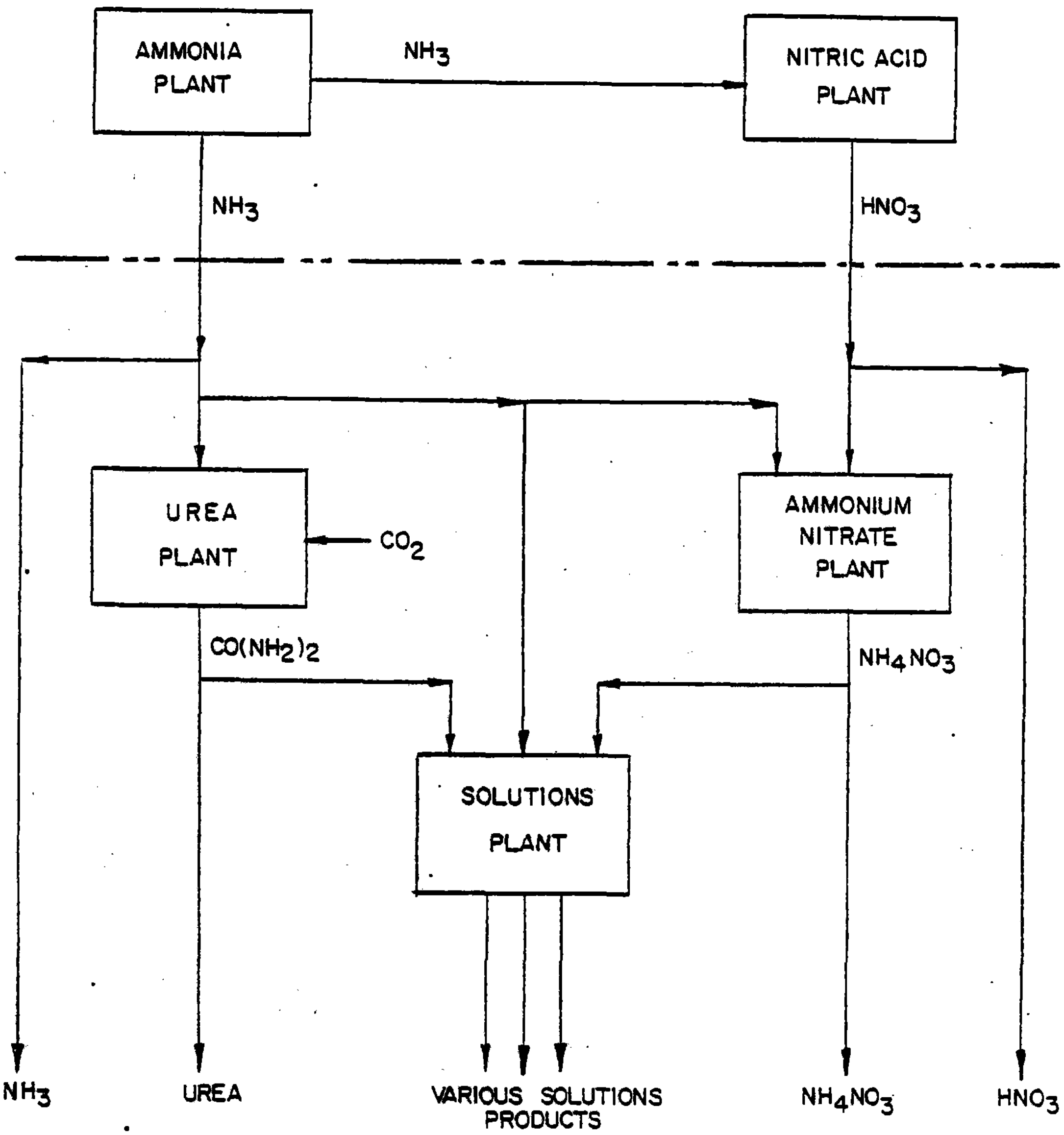
"SMALL" NITRIC ACID PRODUCTION CAPACITY

- SEASONAL THERMAL STORAGE
- LOW HNO_3: NET NH_3 PRODUCTION RATIO

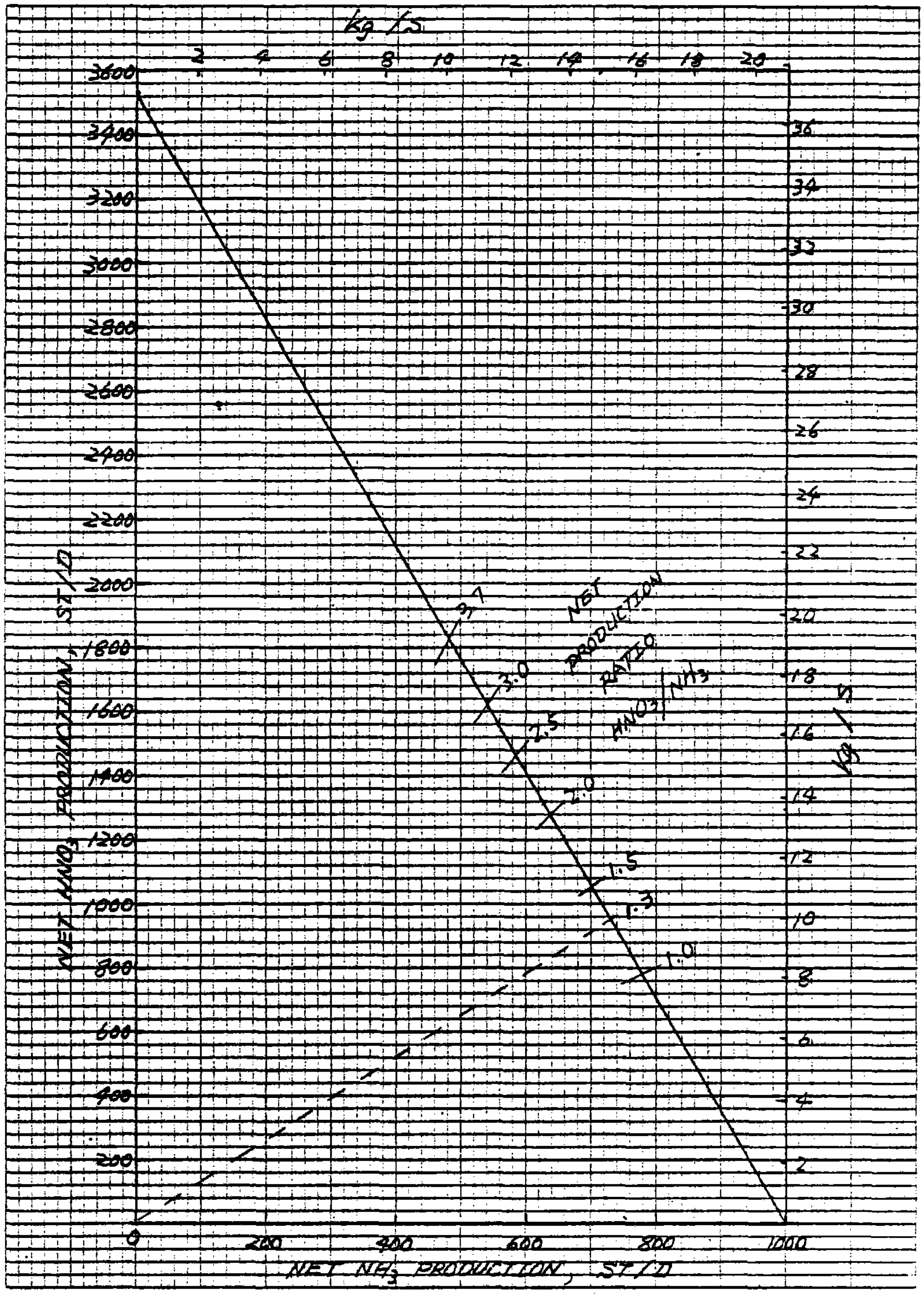
PRODUCT MIX AND PLANT SELECTION

- NET HNO_3/NH_3 PRODUCTION RATIO
- HNO_3 PLANT SIZE
- RECEIVER POWER RATING
- THERMAL STORAGE REQUIREMENT

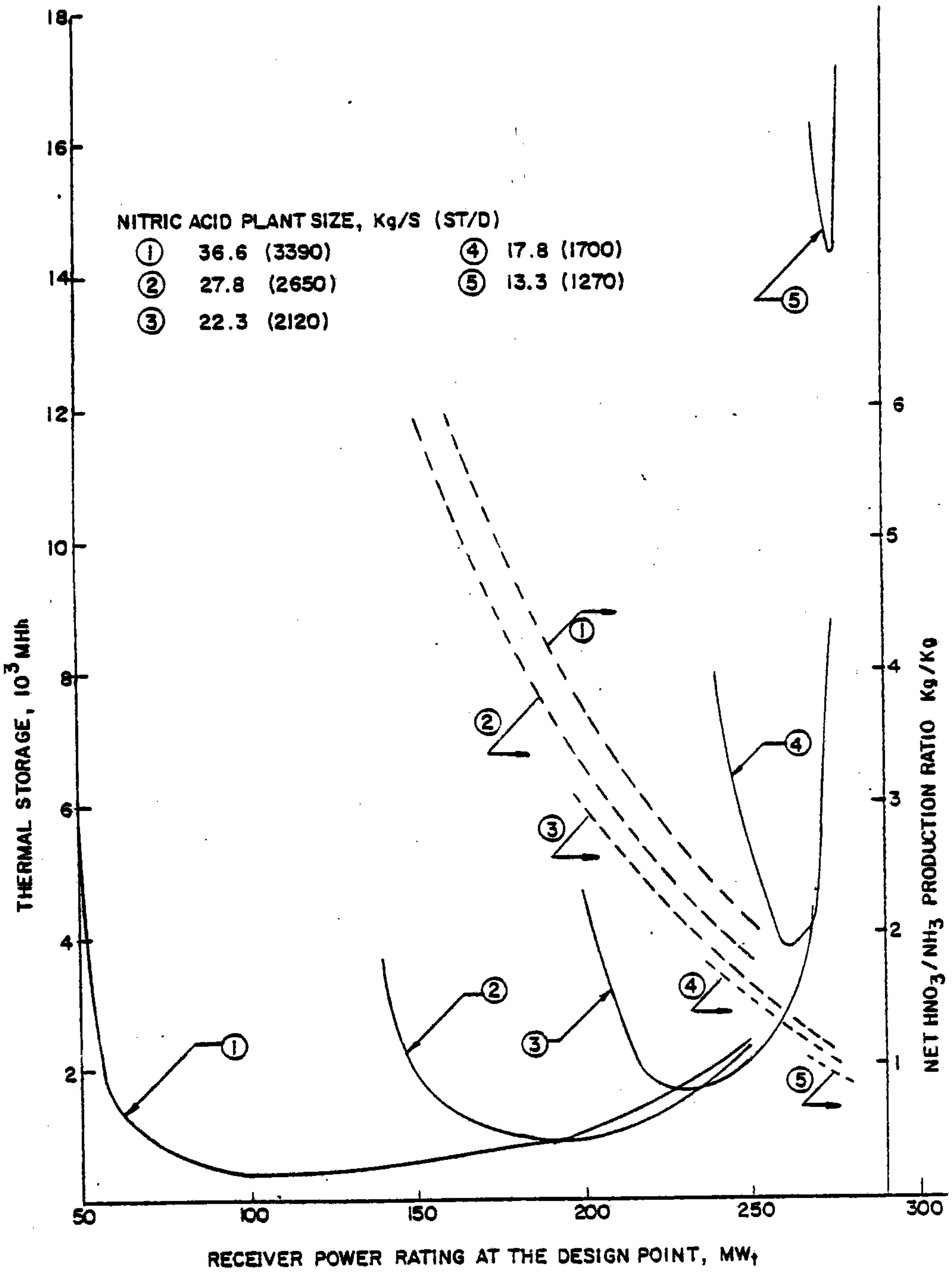
PRODUCT UTILIZATION OF A FERTILIZER PLANT



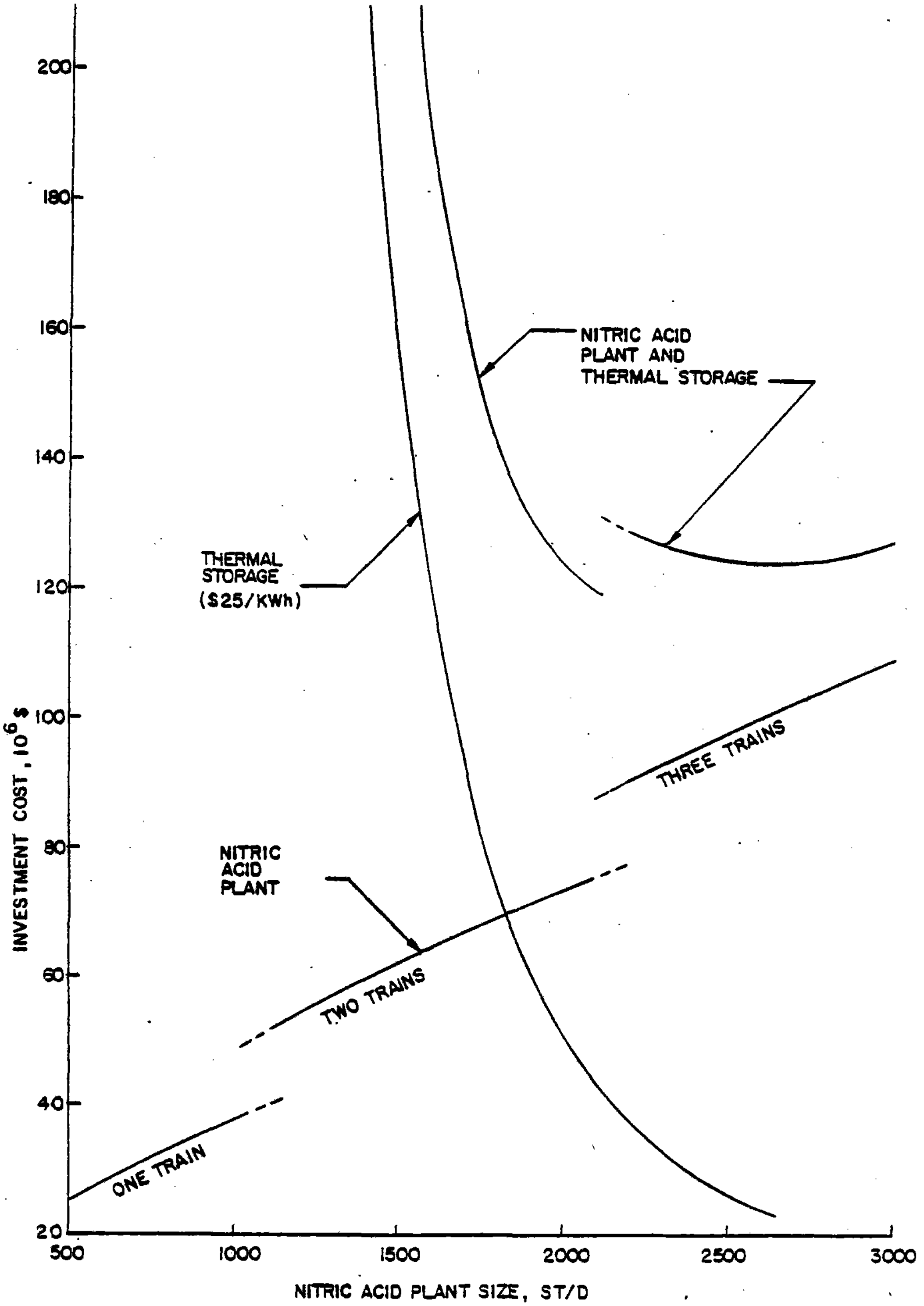
NET AMMONIA VS. NET NITRIC ACID PRODUCTION



RESULTS OF PARAMETRIC STUDY -- PLANT SIZES & PRODUCTION RATIO



COST OF NITRIC ACID PLANT AND THERMAL STORAGE



SELECTED PLANT SIZES

- AMMONIA PLANT : 10.5 KG/S (1000 ST/D)
  CONSTANT LOAD
- NITRIC ACID PLANT: TWO 11 KG/S (1050 ST/D) TRAINS
  TOTAL 22 KG/S (2100 ST/D)
  5 TO 1 TURN-DOWN
- RECEIVER : 230 MWT AT THE DESIGN POINT
- THERMAL STORAGE : 1700 MWH

TASK 3 -- FACILITY DESIGN

SUBTASK 3.1 -- COMPONENT/SUBSYSTEM DESIGN

- SOLAR RECEIVER
- THERMAL STORAGE TANKS AND PIPING
- PRIMARY REFORMER/PREHEATER
- AMMONIA BURNER/SALT HEATER
- MOLTEN SALT HEATER STEAM SUPERHEATER
- AMMONIA PLANT
- NITRIC ACID PLANT
- SUPPLEMENTARY FIRED STEAM GENERATOR AND AIR HEATER

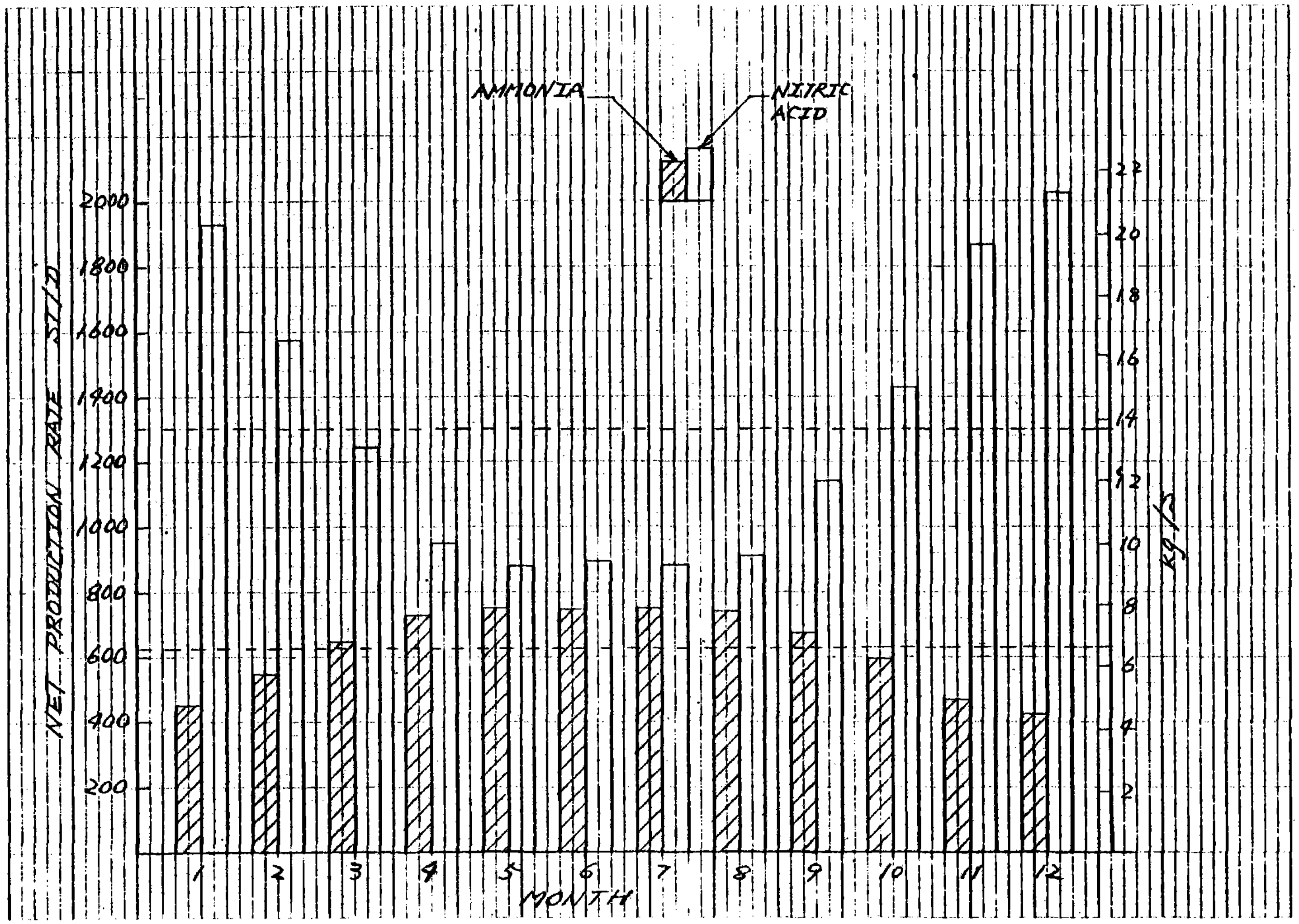
SUBTASK 3.2 -- SYSTEM DESIGN

SUBTASK 3.3 -- CONTROL AND OPERATING STRATEGY

SYSTEM DESIGN AND PERFORMANCE

- INTEGRATE COMPONENTS/SUBSYSTEM INTO A TOTAL SYSTEM
- REFINE PROCESS FLOW DIAGRAM AND MASS AND ENERGY BALANCES
- CALCULATE DESIGN POINT AND ANNUAL SYSTEM EFFICIENCIES
- PROJECT ANNUAL PRODUCTION AND SOLAR CONTRIBUTION

ESTIMATED MONTHLY NET PRODUCTION OF AMMONIA & NITRIC ACID



MAJOR COMPONENTS

- STEAM REFORMER
- HIGH-TEMPERATURE STORAGE TANKS
- SOLAR RECEIVER
- AMMONIA BURNER
- SUPERHEATER

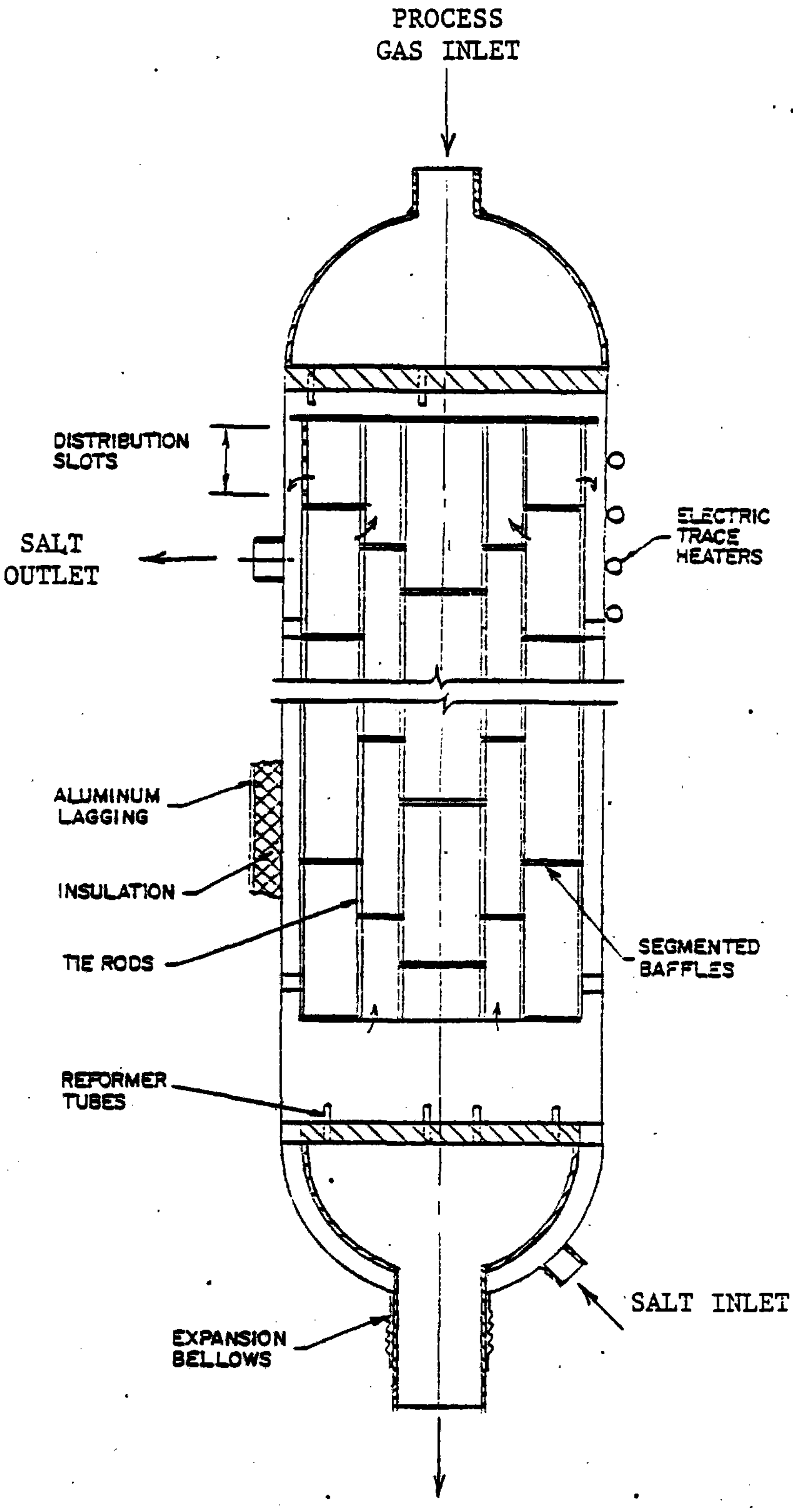
COMPONENTS DESIGN LIFE (YEARS)

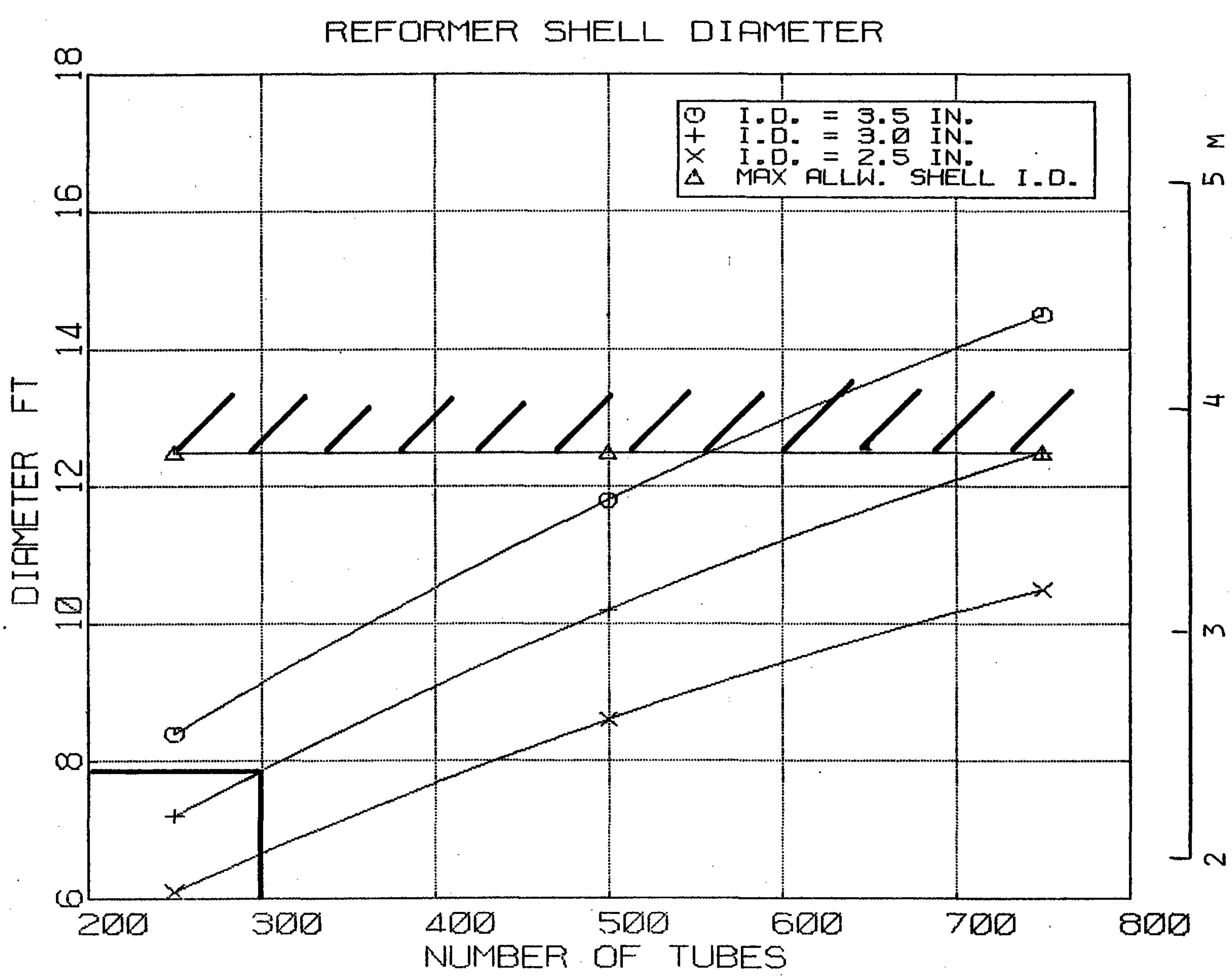
● CONVENTIONAL PLANT	20
● VESSELS, DRUMS, PUMP CASING, PIPING AND HEAT EXCHANGERS	10
● HEAT EXCHANGER TUBING, PUMP INTERNALS, REMOVABLE VESSEL INTERNALS AND FIRED HEATER TUBING	5

STEAM REFORMER FEATURES

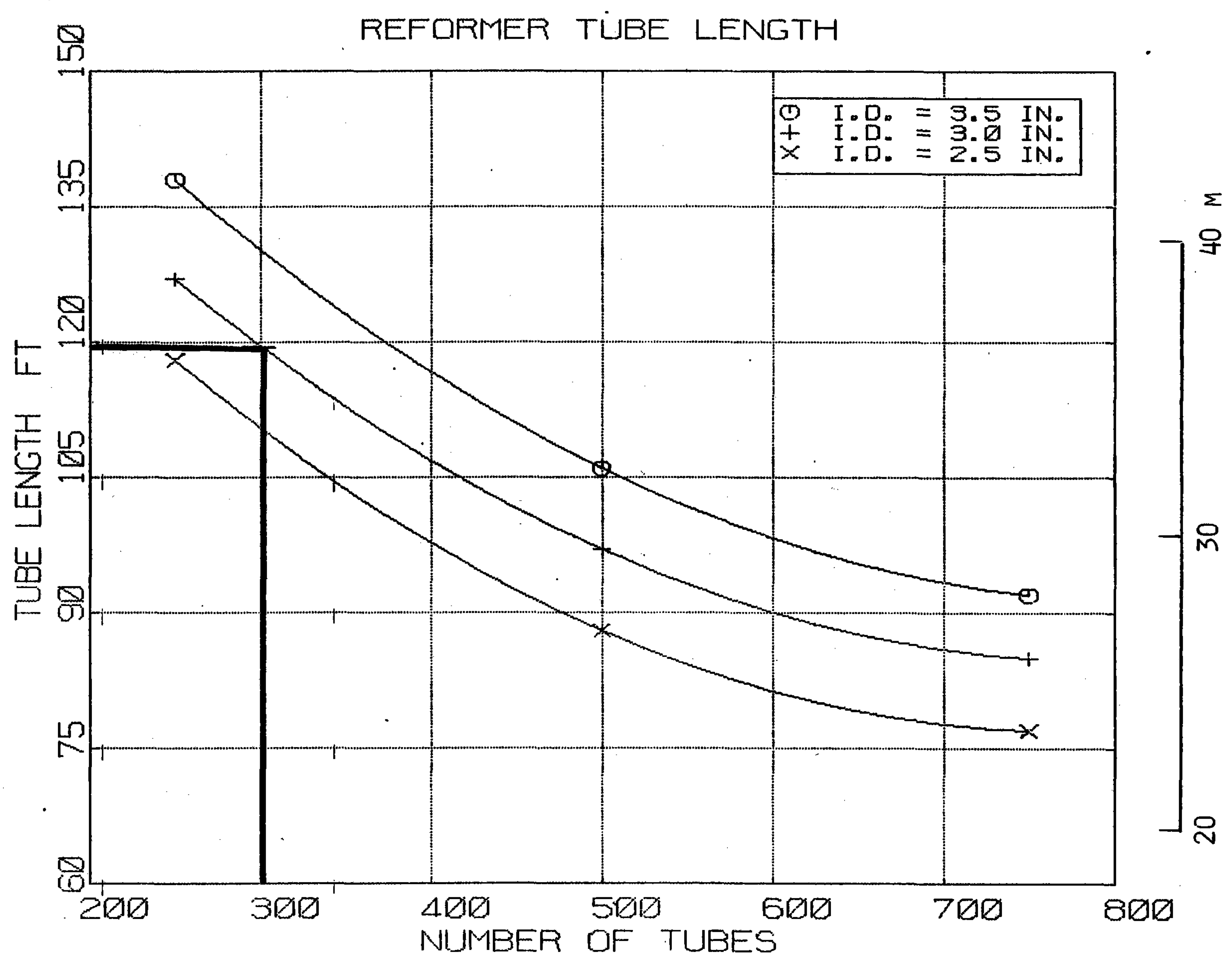
- VERTICAL STRAIGHT-TUBE, SHELL-AND-TUBE HEAT EXCHANGER
- SINGLE PASS, COUNTERFLOW ARRANGEMENT
- PROCESS GAS FLOWING INSIDE CATALYST-FILLED TUBES
- SEGMENTED BAFFLES TO PROMOTE BETTER SALT MIXING
- EXPANSION BELLOWS TO ACCOMMODATE DIFFERENTIAL THERMAL EXPANSION

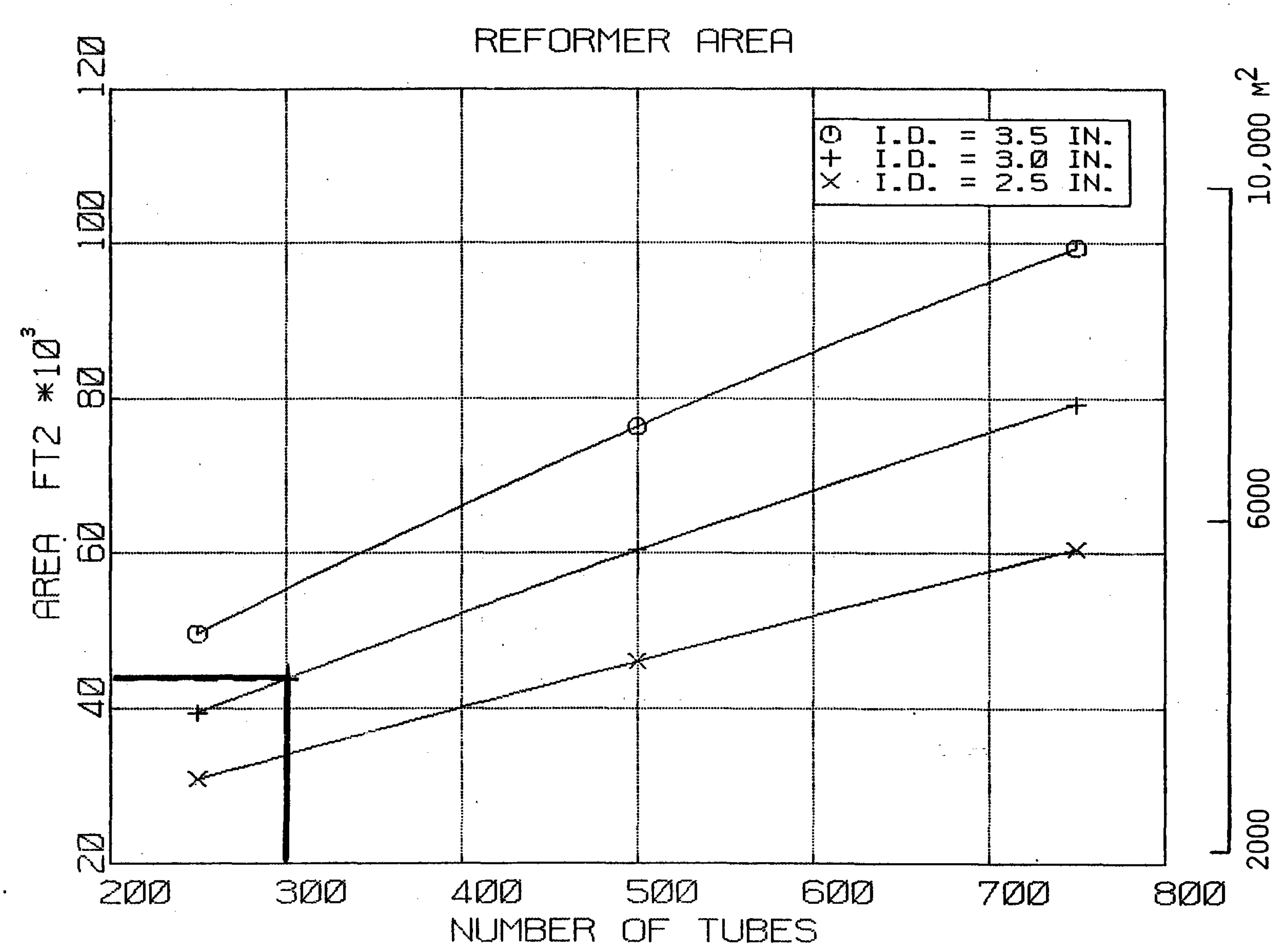
MOLTEN SALT STEAM REFORMER





REFORMER SHELL DIAMETER
I.D. = 3.5 IN.
I.D. = 3.0 IN.
I.D. = 2.5 IN.
MAX ALLW. SHELL I.D.
DIAMETER FT
NUMBER OF TUBES
200
300
400
500
600
700
800
6
8
10
12
14
16
18
2
3
4
5 M


REFORMER TUBE LENGTH
I.D. = 3.5 IN.
I.D. = 3.0 IN.
I.D. = 2.5 IN.
TUBE LENGTH FT
150
135
120
105
90
75
60
200
300
400
500
600
700
800
NUMBER OF TUBES
40 M
30
20

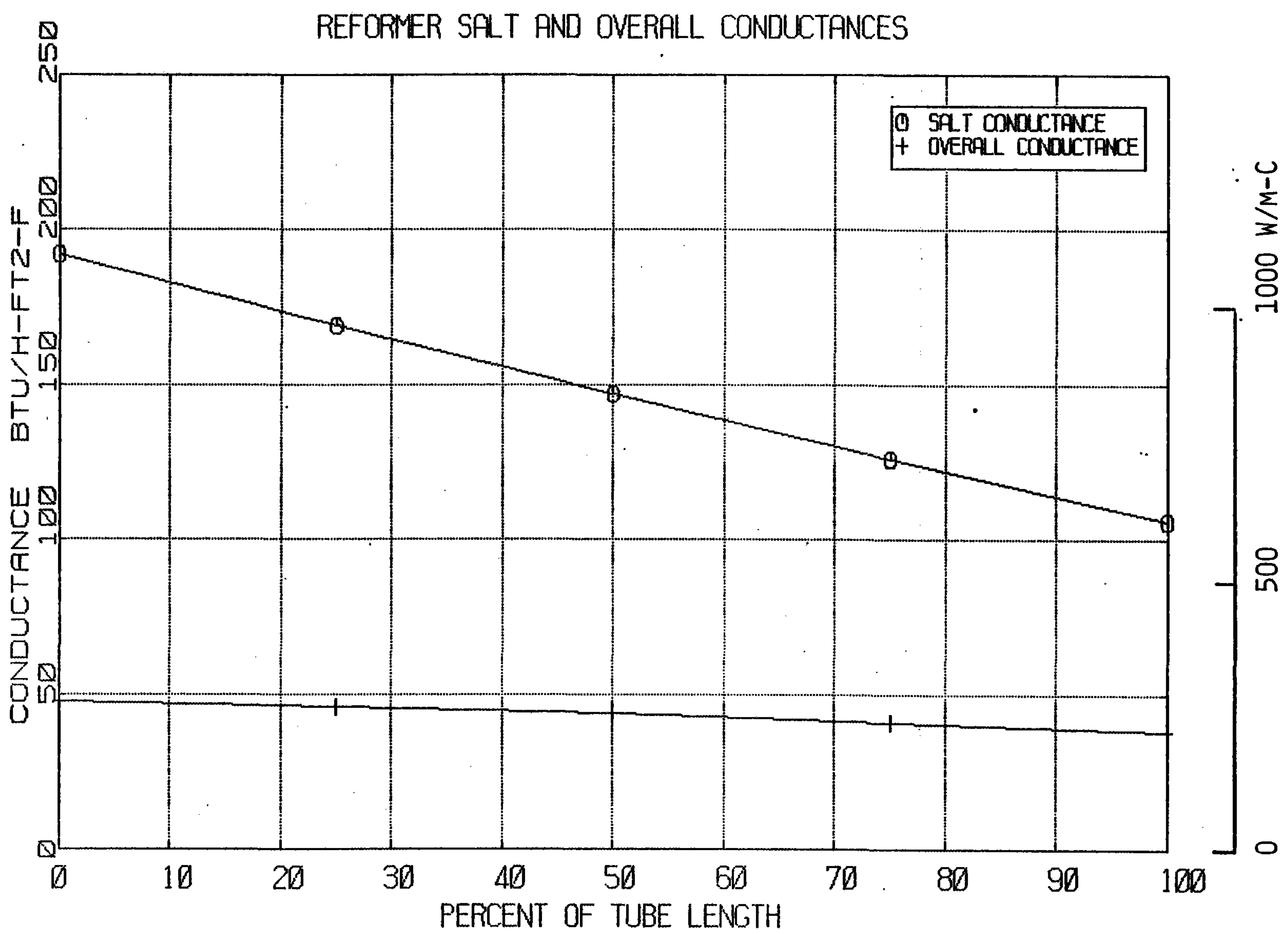

REFORMER AREA
I.D. = 3.5 IN.
I.D. = 3.0 IN.
I.D. = 2.5 IN.
AREA FT2 *10³
20
40
60
80
100
120
200
300
400
500
600
700
800
NUMBER OF TUBES
2000
6000
10,000 M²

STEAM REFORMER DIMENSIONS

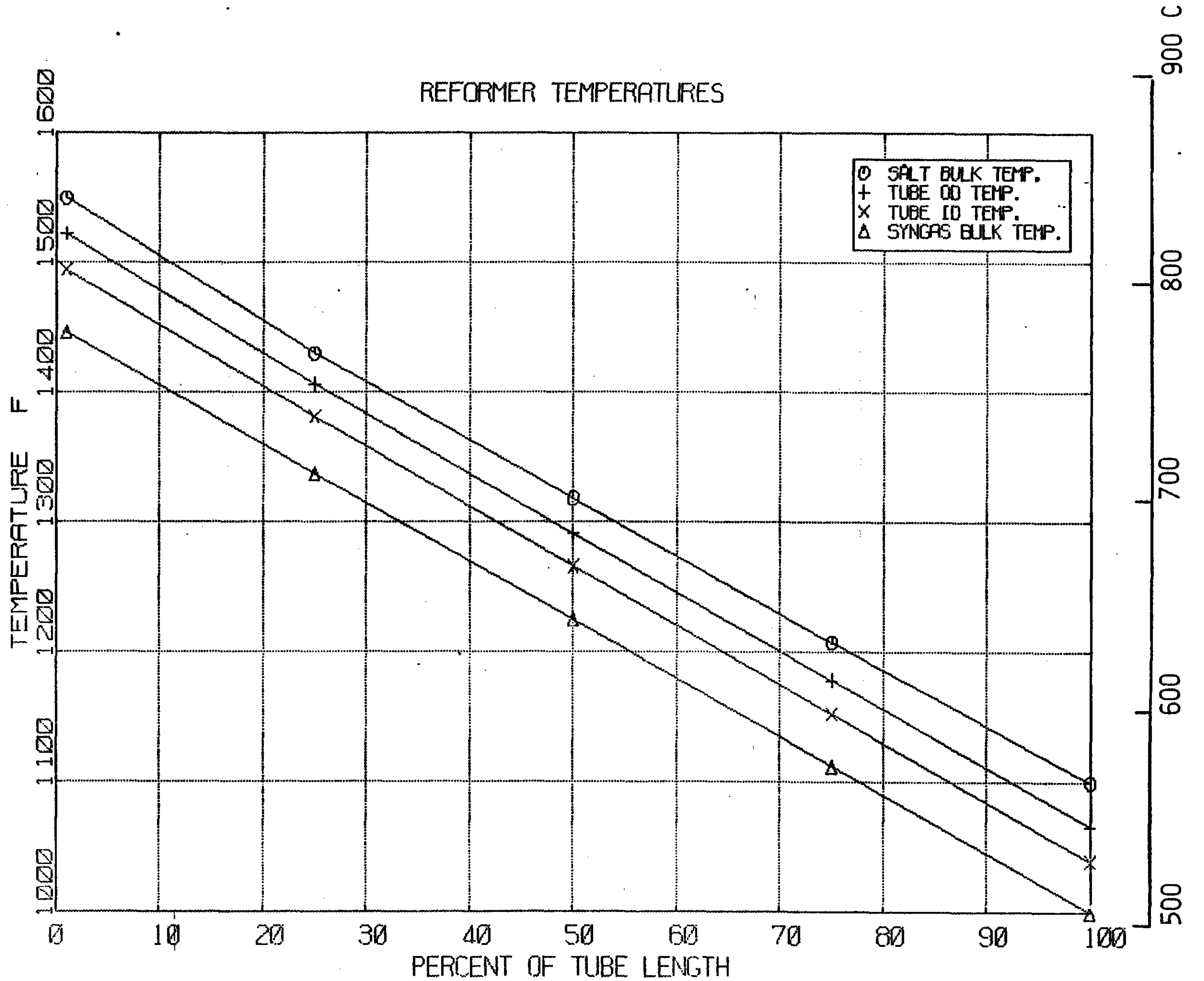
TUBE OUTSIDE DIAMETER, MM (IN.)	120 (4.750)
TUBE INSIDE DIAMETER, MM (IN.)	76 (3.000)
TUBEWALL THICKNESS, MM (IN.)	22 (0.875)
TUBE SPACING/O.D. RATIO	1.100
NUMBER OF TUBES	300
TUBEWALL METAL	INCONEL 600
SHELL INSIDE DIAMETER, M (FT)	2.4 (7.9)
TOTAL HEAT TRANSFER AREA, M^2 (FT^2)	4125 (44,400)
TUBE LENGTH, M (FT)	36.3 (119)

STEAM REFORMER PERFORMANCE

THERMAL DUTY, MWT	55.0
TUBE SIDE FLUID	PROCESS GAS
MASS VELOCITY, KG/S-M^2 (LB/H-FT^2)	9.2 (6790)
CONDUCTANCE, W/M^2-°C (BTU/H-FT^2-°F)	935 (165)
INLET TEMPERATURE, °C (°F)	538 (1000)
OUTLET TEMPERATURE, °C (°F)	788 (1450)
SHELL SIDE FLUID	MOLTEN CARBONATE SALT
FLOW RATE, KG/S (LB/H)	116.2 (920,000)
MASS VELOCITY, KG/S-M^2 (LB/H-FT^2)	101 (74,300)
CONDUCTANCE, W/M^2-°C (BTU/H-FT^2-°F)	601 TO 1088 (106 TO 192)
INLET TEMPERATURE, °C (°F)	843 (1550)
OUTLET TEMPERATURE, °C (°F)	593 (1100)
OVERALL CONDUCTANCE, W/M^2-°C (BTU/H-FT^2-°F)	215 TO 272 (38 TO 48)



REFORMER SALT AND OVERALL CONDUCTANCES
SALT CONDUCTANCE
OVERALL CONDUCTANCE
CONDUCTANCE BTU/H-FT2-F
0
50
100
150
200
250
1000 W/M-C
0
500
PERCENT OF TUBE LENGTH
0
10
20
30
40
50
60
70
80
90
100



REFORMER TEMPERATURES
SALT BULK TEMP.
TUBE OD TEMP.
TUBE ID TEMP.
SYNGAS BULK TEMP.
TEMPERATURE F
1000
1100
1200
1300
1400
1500
1600
0
10
20
30
40
50
60
70
80
90
100
PERCENT OF TUBE LENGTH
500
600
700
800
900 C

STORAGE SUBSYSTEM KEY ISSUES

- INLET/OUTLET TEMPERATURES
- CAPACITY
- TYPE
- TANK DIMENSIONS
- COST

SERI's STORAGE SUBSYSTEM SPECIFICATIONS

TEMPERATURE SWING, °C (°F)	425 TO 900 (797 TO 1653)
CAPACITY, MW	1800 (300 MW X 6 H)
HEAT LOSS RATE	2%/DAY MAX.
SALT INVENTORY, KG (LB)	7.5×10^6 (16.5×10^6)
HOT SALT VOLUME, M^3 (FT^3)	3600 (127,100)
CHARGE TIME	9 HOURS
DISCHARGE TIME	6 HOURS
TEMPERATURE LIMITS OF LINERS, °C (°F)	
INCONEL	550 (1022)
CARBON-STEEL	300 (572)
CONCRETE	65 (119)

SERI's STORAGE SUBSYSTEM CONFIGURATIONS

CONCEPTS	COST \$/KW* LOW/HIGH
RAFT THERMOCLINE	24/34
DUAL-MEDIA THERMOCLINE	15/23
TWO-TANK (HOT/COLD)	--/25

*DOES NOT INCLUDE INSTALLATION AND O&M COSTS

RAFT TANK STORAGE SUBSYSTEM

- ADVANTAGES
  - -- HOT AND COLD FLUIDS DO NOT COME IN CONTACT
  - -- NOT TOO SEVERE TEMPERATURE CYCLING

- DISADVANTAGES
  - -- FREQUENT SIDEWALL TEMPERATURE CYCLING
  - -- QUESTIONABLE RAFT STABILITY AT HIGH TEMPERATURE AND LARGE DIAMETERS
  - -- TOO MANY TECHNICAL UNCERTAINTIES
  - -- DEMONSTRATED ONLY IN THE LABORATORY AT NEAR AMBIENT CONDITIONS
  - -- MOST EXPENSIVE OF THE THREE CONCEPTS

DUAL-MEDIA STORAGE SUBSYSTEM

- ADVANTAGES
  - -- PROVEN CONCEPT (SOLAR ONE AT 300°C)
  - -- SOLID MEDIUM (MAGNESIA PELLETS) LESS EXPENSIVE THAN MOLTEN SALT
  - -- SLOPED-SIDEWALL DESIGN HAS THE POTENTIAL OF BEING THE LOWEST COST SYSTEM
- DISADVANTAGES
  - -- PELLETS AND TANK SIDEWALLS SUBJECT TO LARGE TEMPERATURE CHANGES AND GRADIENTS
  - -- LACK OF DEMONSTRATED INTEGRITY OF PELLETS IN MOLTEN SALT AT 900°C
  - -- UNCERTAINTY OF THERMOCLINE STABILITY
  - -- SLOPE STABILITY OF SIDEWALLS IS UNCERTAIN

TWO-TANK STORAGE SUBSYSTEM

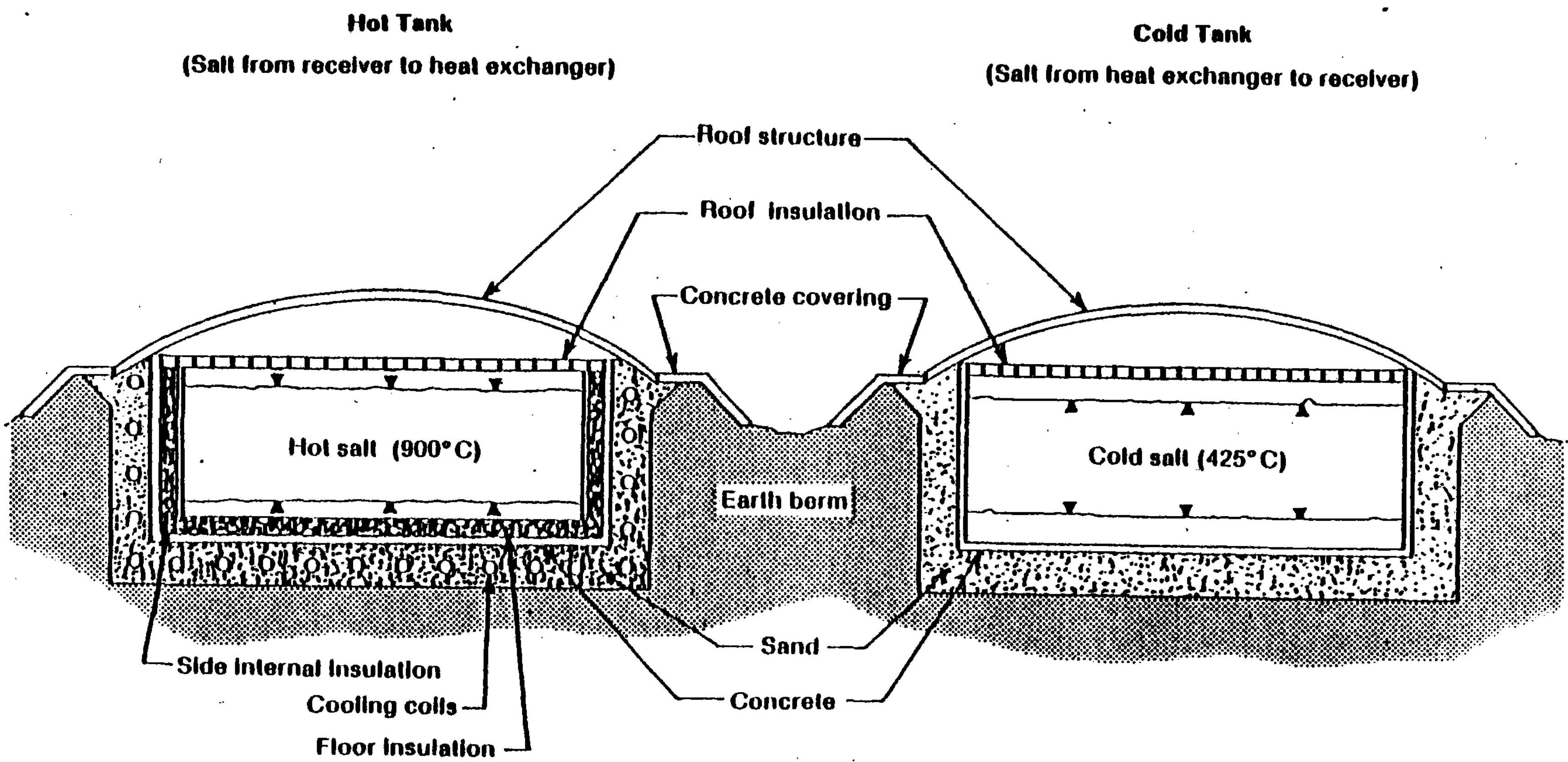
- ADVANTAGES
  - -- HOT AND COLD FLUIDS DO NOT COME IN CONTACT
  - -- NOT TOO SEVERE TEMPERATURE CYCLING
- DISADVANTAGES
  - -- TWO TANKS REQUIRED
  - -- FREQUENT SIDEWALL PRESSURE CYCLES

STORAGE SUBSYSTEM CONCEPT SELECTION

TWO-TANK (COLD/HOT) CONCEPT SELECTED

- COST IS SIMILAR TO DUAL-MEDIA CONCEPT
- FEWER TECHNICAL UNCERTAINTIES

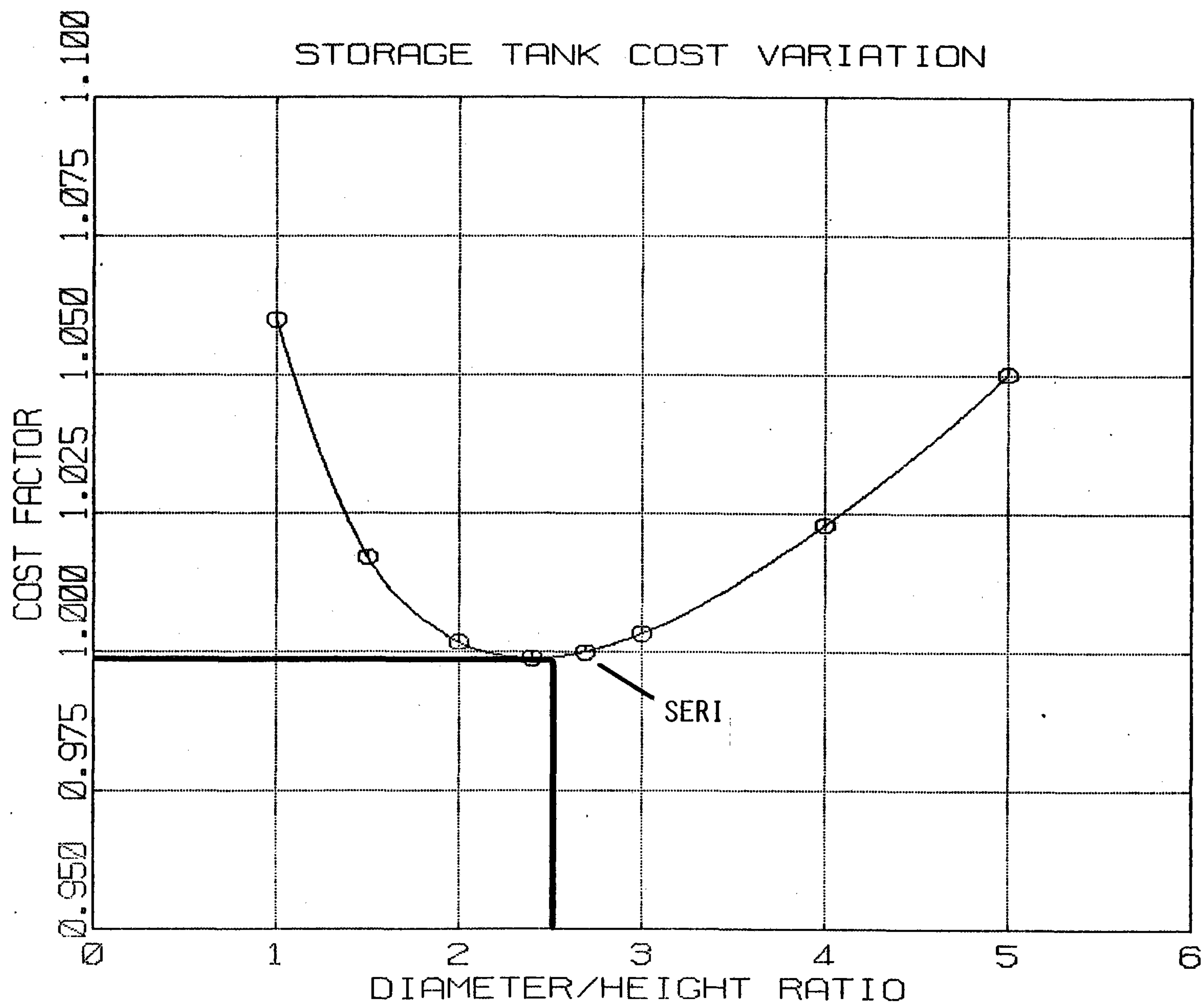
SERI's TWO-TANK STORAGE CONCEPT

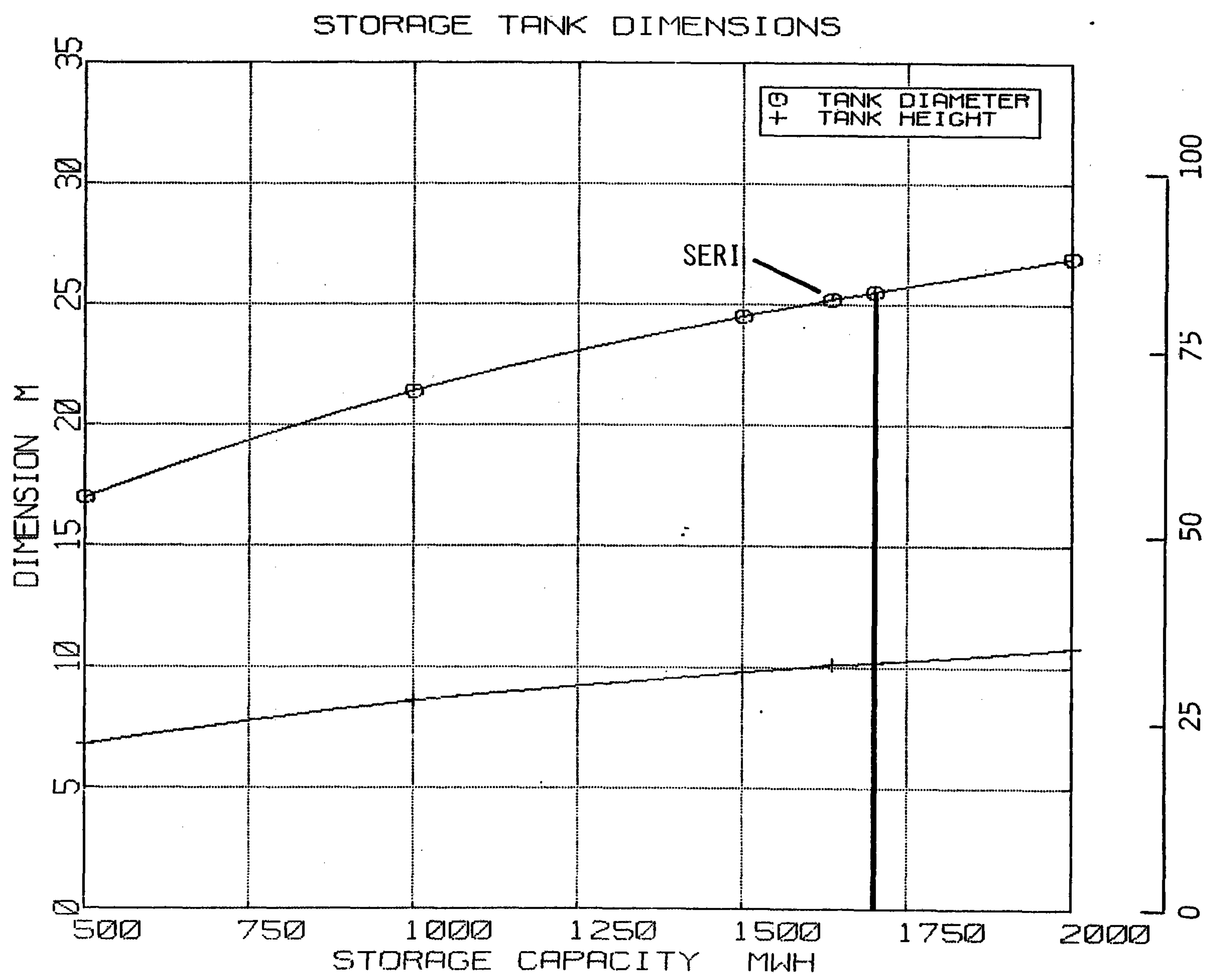


STORAGE TANKS COST ANALYSIS

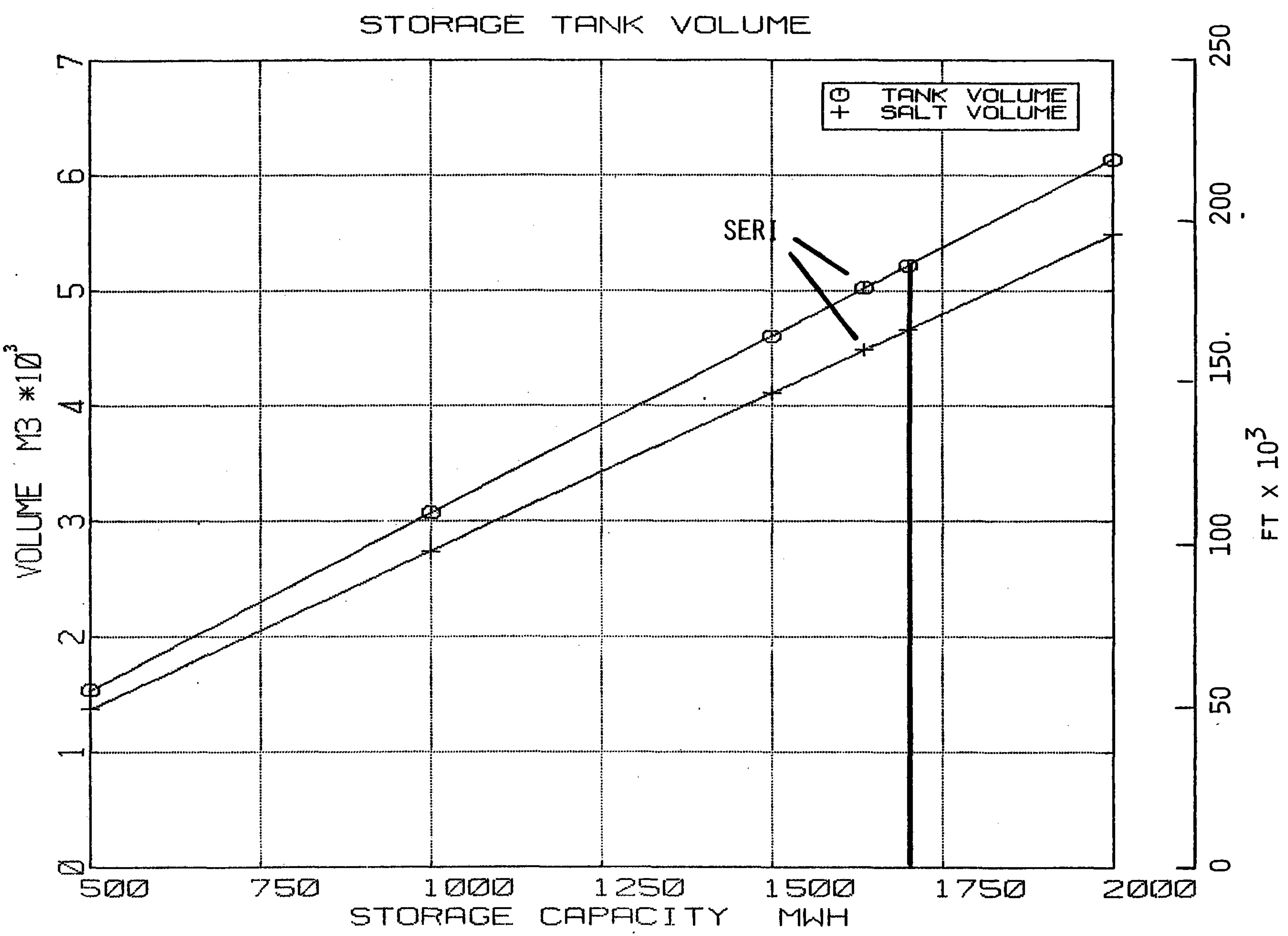
COST	=	WALLS	+	TOP	+	BOTTOM	+	SALT	+	COLD TANK
	=	25%	+	9%	+	5%	+	55%	+	6%

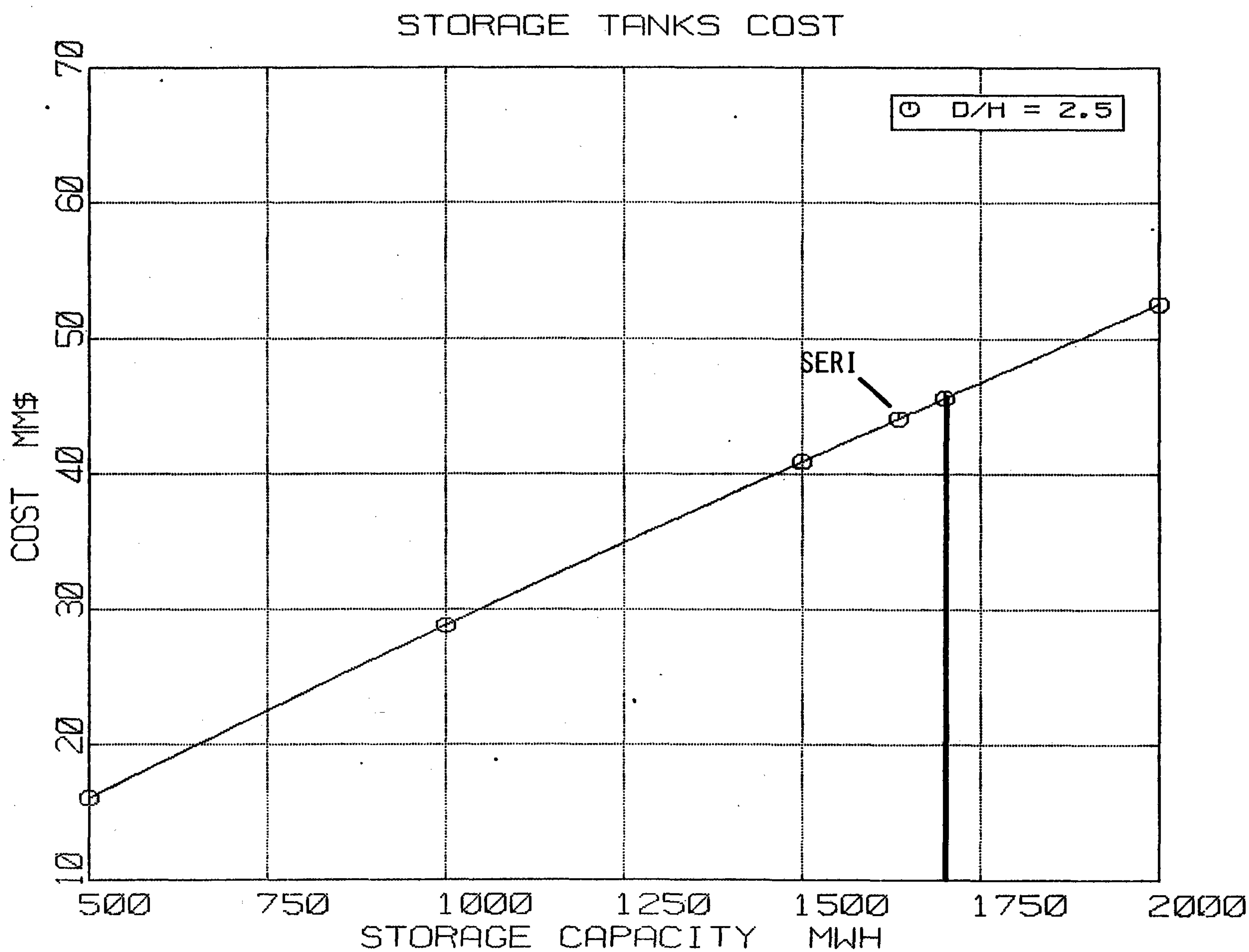
- BASED ON SERI's DATA (4/85)
- ASSUMPTIONS: -- WALL/TOP/BOTTOM COSTS PROPORTIONAL TO AREA
  -- SALT/COLD TANK COSTS PROPORTIONAL TO VOLUME


STORAGE TANK COST VARIATION
COST FACTOR
1.100
1.075
1.050
1.025
1.000
0.975
0.950
0
1
2
3
4
5
6
DIAMETER/HEIGHT RATIO
SERI

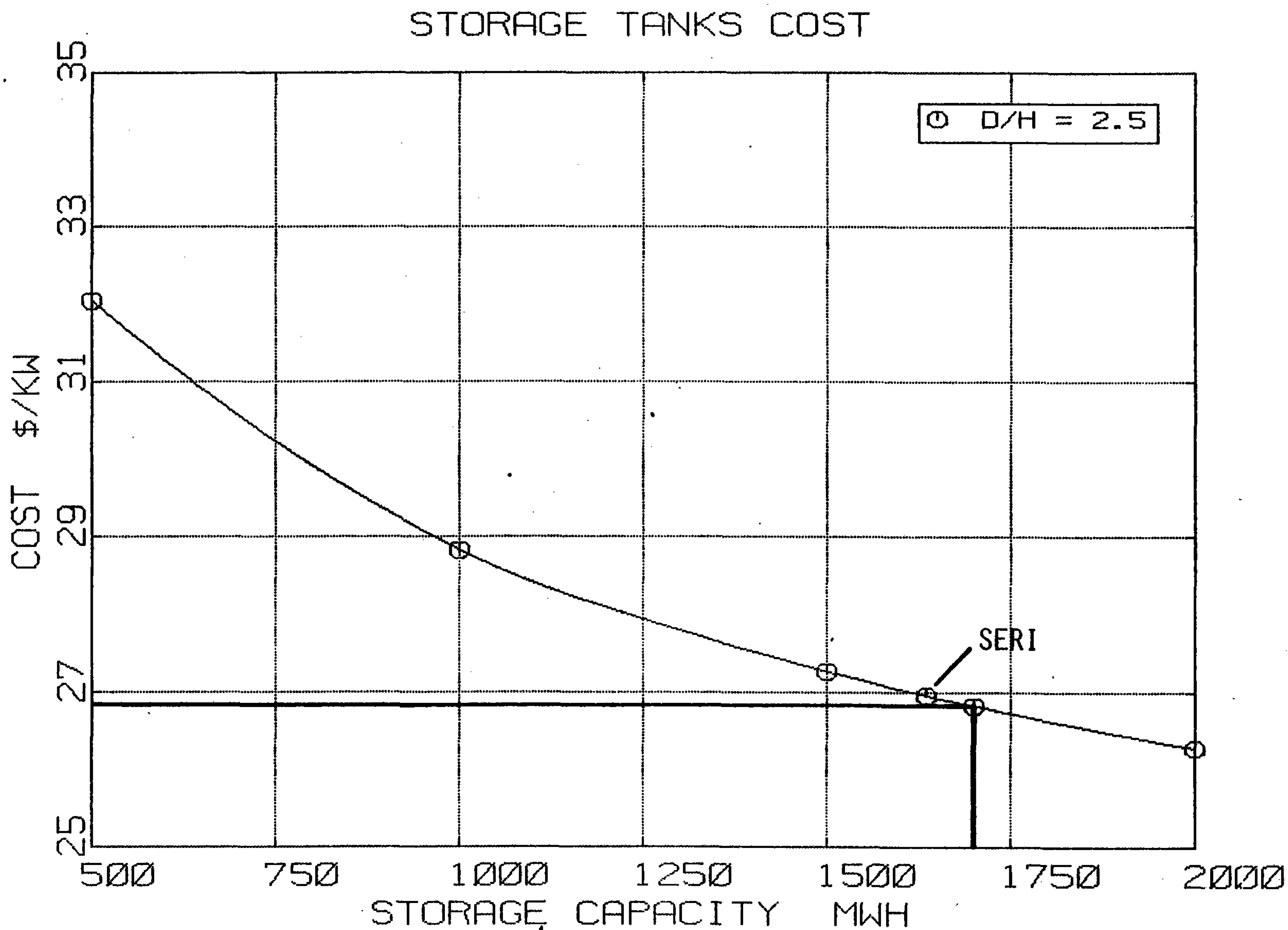


STORAGE TANK DIMENSIONS
TANK DIAMETER
TANK HEIGHT
SERI
DIMENSION M
0
5
10
15
20
25
30
35
500
750
1000
1250
1500
1750
2000
STORAGE CAPACITY MWH
0
25
50
75
100


STORAGE TANK VOLUME
TANK VOLUME
SALT VOLUME
SERI
VOLUME M3 *10^3
FT x 10^3
STORAGE CAPACITY MWH
0
1
2
3
4
5
6
7
500
750
1000
1250
1500
1750
2000
0
50
100
150.
200
250



STORAGE TANKS COST
D/H = 2.5
SERI
COST MM$
70
60
50
40
30
20
10
500
750
1000
1250
1500
1750
2000
STORAGE CAPACITY MWH


STORAGE TANKS COST
D/H = 2.5
SERI
COST $/KW
25
27
29
31
33
35
500
750
1000
1250
1500
1750
2000
STORAGE CAPACITY MWH

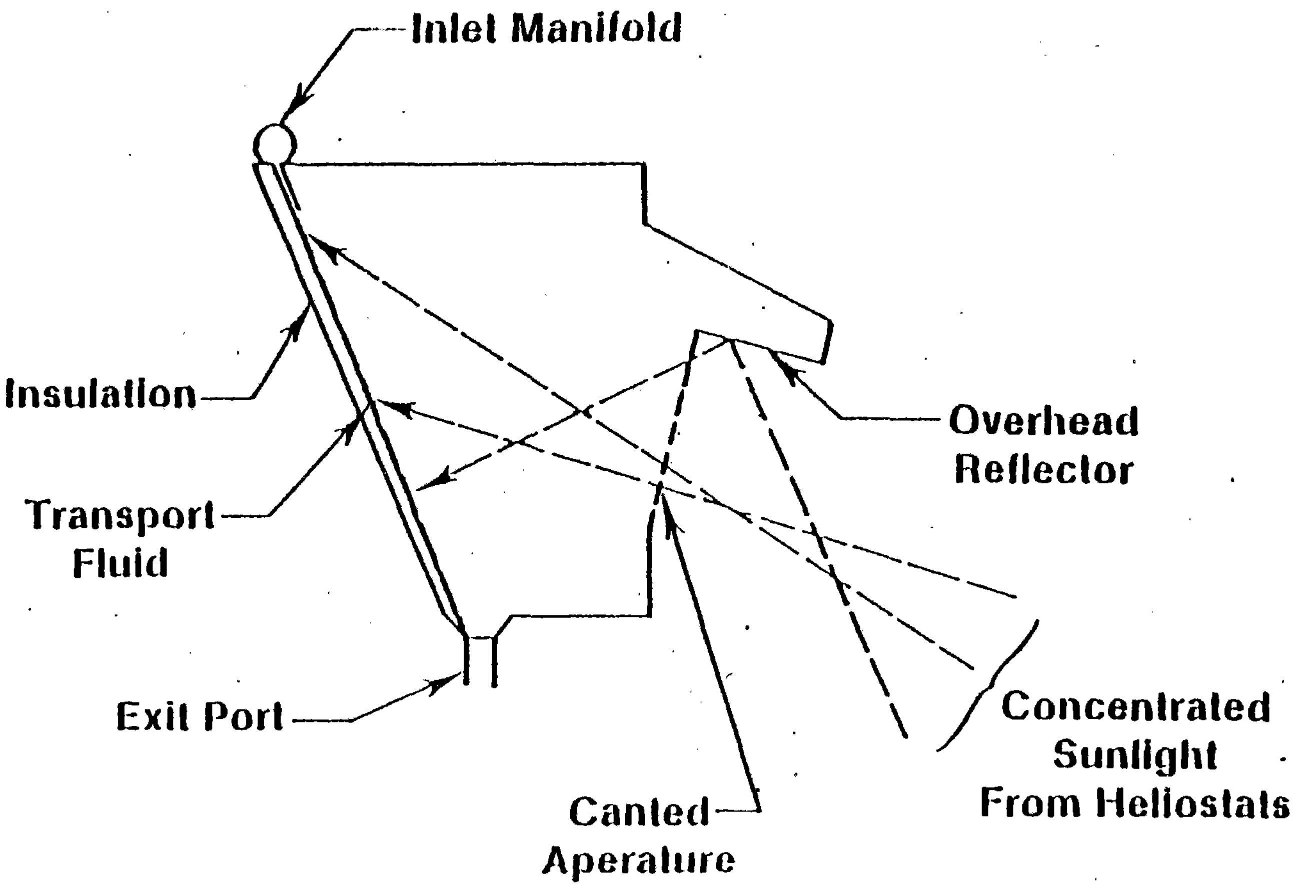
TWO-TANK SYSTEM COMPARISON

ITEM	SERI	SF&C
CAPACITY, MWH	1800	1700
COLD TEMPERATURE, °C (°F)	425 (797)	454 (850)
HOT TEMPERATURE, °C (°F)	900 (1653)	843 (1550)
TEMPERATURE RISE, °C (°F)	475 (856)	389 (700)
TANK VOLUME, M^3 (FT^3)	5000 (177,000)	5220 (184,000)
SALT VOLUME, M^3 (FT^3)	4500 (159,000)	4660 (165,000)
DIAMETER, M (FT)	25.8 (84.6)	25.5 (83.7)
TANK HEIGHT, M (FT)	9.6 (31.5)	10.2 (33.5)
SALT HEIGHT, M (FT)	8.6 (28.2)	9.1 (29.9)
D/H	2.7	2.5
COST, $/KW	25	27

SOLAR RECEIVER

TYPE	DIRECT ABSORPTION/CAVITY
DESIGN POWER, MW	230
WORKING FLUID	MOLTEN CARBONATE SALT (Li_2CO_3-Na_2CO_3-K_2CO_3)
SALT INLET TEMPERATURE, °C (°F)	454.4 (850)
SALT OUTLET TEMPERATURE, °C (°F)	843.3 (1550)
SALT TEMPERATURE RISE, °C (°F)	388.9 (700)
MASS FLOW, KG/S (LB/H)	321 (2.542×10^6)

SERI's DIRECT ABSORPTION RECEIVER CONCEPT



AMMONIA BURNER

- DESIGN SIMILAR TO CONVENTIONAL UNITS
- SAME FUEL (AMMONIA)
  -- SAME COMBUSTION GAS FLOW RATES, FURNACE VOLUMES AND GAS FLOW AREAS
- MOLTEN CARBONATE SALT RATHER THAN WATER/STEAM
- HIGHER TUBEWALL TEMPERATURES (HOTTER FLUID)
  -- SMALLER LMTD
  -- SMALLER RADIATION COEFFICIENT
  -- HIGHER AREA REQUIREMENTS
- CYCLING DUTY

COMPARISON OF AMMONIA BURNER CONDUCTANCES

$W/m^2\text{-}^\circ C$ ($Btu/h\text{-}ft^2\text{-}^\circ F$)

• INSIDE	
-- Water/steam	5700 to 57,000 (1000 to 10,000)
-- Molten salt	6000 to 28,000 (1000 to 5000)
• OUTSIDE	
-- Flue gas (convention and radiation)	60 to 500 (10 to 80)

MOLTEN SALT AMMONIA BURNER