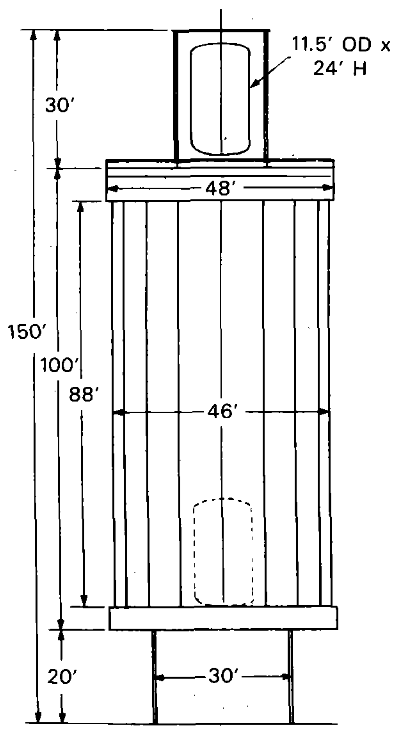
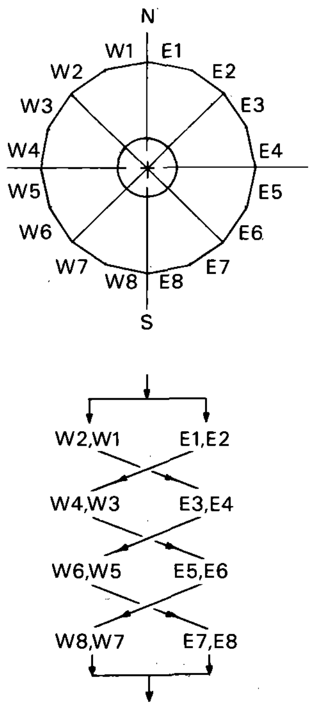
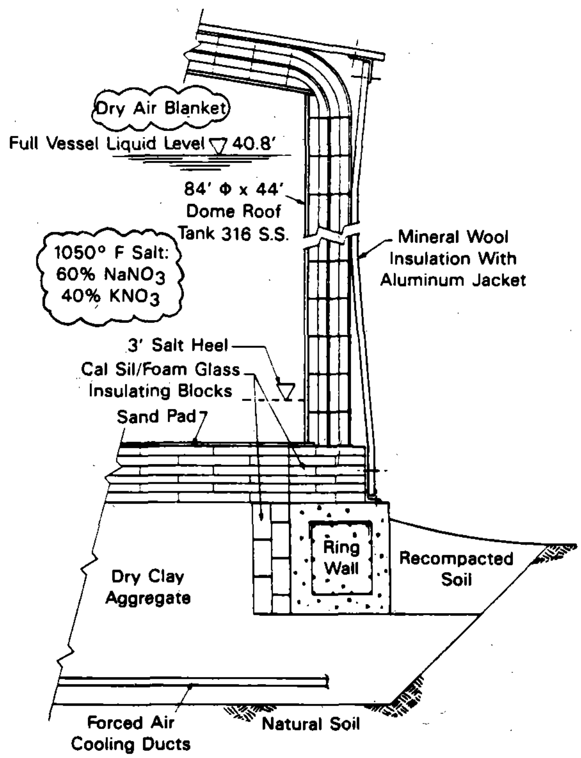
REPORT NO. DOE/AL/38741-2
VOLUME 2 — APPENDICES

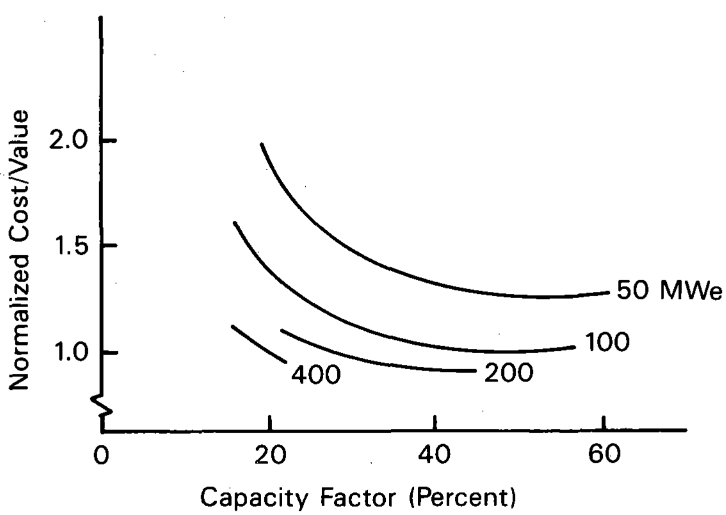
SEPTEMBER 1988

ALTERNATE UTILITY TEAM
UTILITY SOLAR CENTRAL RECEIVER STUDY









ARIZONA PUBLIC SERVICE COMPANY

BLACK & VEATCH ENGINEERS-ARCHITECTS

CBI INDUSTRIES

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

OLIN CORPORATION

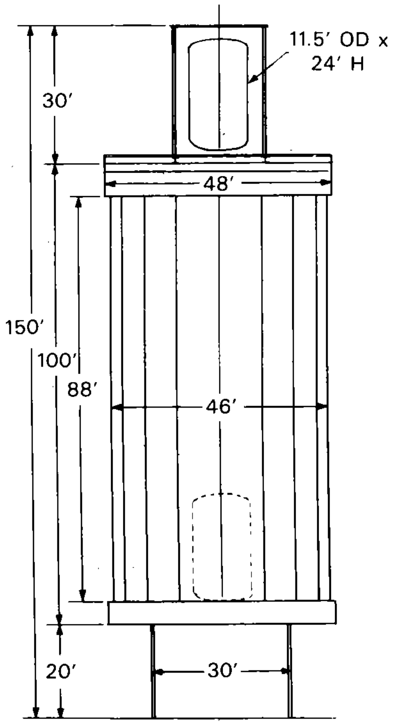
PRECISION CONTR ND INSTRUMENTATIO

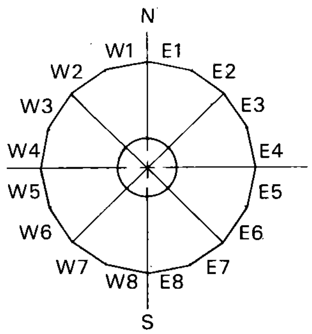
UNIVERSITY OF HOUSTON

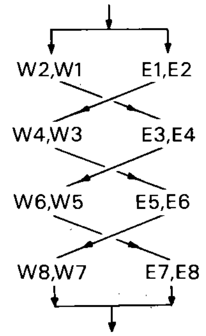
REPORT NO. DOE/AL/38741-2
VOLUME 2 — APPENDICES

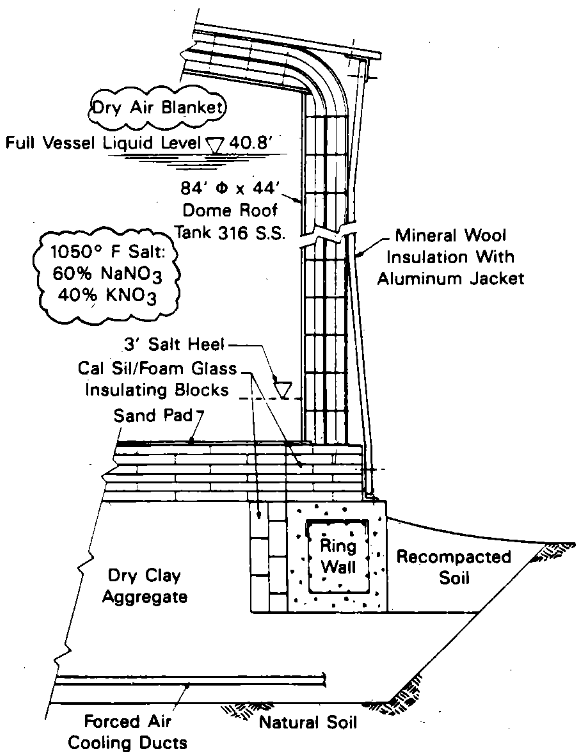
SEPTEMBER 1988

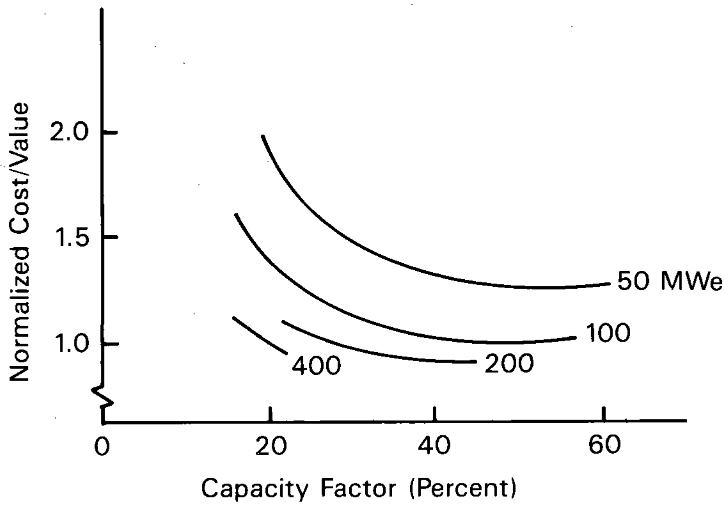
ALTERNATE UTILITY TEAM UTILITY SOLAR CENTRAL RECEIVER STUDY











ARIZONA PUBLIC SERVICE COMPANY

BLACK & VEATCH ENGINEERS-ARCHITECTS

CBI INDUSTRIES

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

OLIN CORPORATION

PRECISION CONTROLS AND INSTRUMENTATION

UNIVERSITY OF HOUSTON

ALTERNATE UTILITY TEAM

UTILITY SOLAR CENTRAL RECEIVER STUDY

FINAL REPORT

ACKNOWLEDGMENT

Arizona Public Service Company (APS) and the other members of the Alternate Utility Team (AUT) acknowledge the Department of Energy for their financial support of the Technical Review Committee during the utility study project. Moreover, APS and the AUT express their appreciation to the members of the Technical Review Committee for their many contributions to the project.

CONTENTS

		Page
1.0	EXECUTIVE SUMMARY	1-1
1.1	BACKGROUND	1-1
1.2	BASE-LINE PLANT	1-3
1.3	COMMON DATA	1-4
1.4	TRADE STUDIES	1-8
1.5	PREFERRED COMMERCIAL PLANT	1-14
1.6	RECOMMENDATIONS	1-14
2.0	INTRODUCTION	2-1
2.1	BACKGROUND	2-1
2.2	PROJECT OBJECTIVES	2-3
2.3	PROJECT ORGANIZATION	2-3
2.4	FINAL REPORT ORGANIZATION	2-4
3.0	BASE-LINE PLANT CONCEPT	3-1
3.1	KEY BASE-LINE PLANT CHARACTERISTICS	3-1
3.2	COLLECTOR SUBSYSTEM	3-3
3.3	RECEIVER SUBSYSTEM	3-3
3.4	THERMAL STORAGE SUBSYSTEM	3-6
3.5	SOLAR STEAM GENERATOR SUBSYSTEM	3-7
3.6	ELECTRIC POWER GENERATION SUBSYSTEM/BALANCE-OF-PLANT SYSTEMS	3-8
3.7	MASTER CONTROL SUBSYSTEM	3-9
3.8	BASE-LINE PLANT PERFORMANCE ESTIMATE	3-12
3.9	BASE-LINE PLANT COST ESTIMATES	3-15
4.0	COMMON DATA	4-1
4.1	ROLE OF COMMON DATA IN THE STUDY	4-1
4.2	EXTERNAL RECEIVER	4-2
4.3	THERMAL STORAGE SUBSYSTEM	4-19
4.4	CAVITY RECEIVER	4-27
4.5	RECEIVER TOWER	4-32
4.6	ELECTRIC POWER GENERATION SUBSYSTEM/STEAM GENERATOR SUBSYSTEM/BALANCE-OF-PLANT SYSTEM COMMON DATA	4-36
4.7	OTHER DATA	4-36

CONTENTS (Continued)

		Page
5.0	TRADE STUDIES	5-1
5.1	PERFORMANCE AND ECONOMICS	5-1
5.2	HELIOSTAT TYPE SELECTION	5-4
5.3	NUMBER OF COLLECTOR/RECEIVER MODULES	5-8
5.4	COLLECTOR FIELD/RECEIVER CONFIGURATION	5-9
5.5	PLANT SIZE AND CAPACITY FACTOR	5-30
5.6	DEGREE OF PLANT AUTOMATION	5-34
5.7	OPERATING TEMPERATURE	5-45
6.0	PREFERRED COMMERCIAL PLANT	6-1
6.1	KEY PREFERRED PLANT CHARACTERISTICS	6-1
6.2	COLLECTOR SUBSYSTEM	6-3
6.3	RECEIVER SUBSYSTEM	6-6
6.4	THERMAL STORAGE SUBSYSTEM	6-7
6.5	SOLAR STEAM GENERATOR SUBSYSTEM	6-8
6.6	ELECTRIC POWER GENERATION SUBSYSTEM/BALANCE-OF-PLANT SYSTEMS	6-9
6.7	MASTER CONTROL SUBSYSTEM	6-9
6.8	PREFERRED PLANT PERFORMANCE	6-12
6.9	PREFERRED PLANT COST ESTIMATES	6-14
7.0	RECOMMENDATIONS	7-1
7.1	COLLECTOR	7-1
7.2	RECEIVER	7-1
7.3	OTHER	7-2
8.0	REFERENCES	8-1

APPENDIX A GUIDELINES FOR TRADE STUDIES AND CONCEPTUAL DESIGNS

APPENDIX B ALLOWABLE FLUX LEVELS ON TUBE-TYPE RECEIVERS

APPENDIX C MOLTEN SALT STORAGE TANK DATA

APPENDIX D ALTERNATE UTILITY TEAM, UTILITY SOLAR CENTRAL RECEIVER STUDY SALT MAINTENANCE

CONTENTS (Continued)

LIST OF TABLES

		Page
TABLE 1-1	ALTERNATE UTILITY TEAM MEMBERS AND RESPONSIBILITIES	1-2
TABLE 1-2	SUMMARY OF TRADE STUDY RESULTS	1-9
TABLE 1-3	KEY CHARACTERISTICS--BASE-LINE AND PREFERRED PLANTS	1-17
TABLE 3-1	PARTIAL LIST OF BALANCE-OF-PLANT SYSTEMS	3-10
TABLE 3-2	BASE-LINE PLANT PERFORMANCE	3-13
TABLE 3-3	AUXILIARY POWER REQUIREMENTS FOR BASE-LINE PLANT	3-14
TABLE 3-4	CAPITAL COST CODE OF ACCOUNTS LEVEL 2 DETAIL FOR BASE-LINE PLANT	3-17
TABLE 4-1	RECEIVER SUBSYSTEM COMMON DATA--ORIGINAL FLUX LIMIT	4-14
TABLE 4-2	RECEIVER SUBSYSTEM COMMON DATA--HIGHER FLUX LIMIT	4-16
TABLE 4-3	THERMAL STORAGE COMMON DATA SUMMARY SHEET	4-28
TABLE 4-4	CAVITY SALT RECEIVER DATA	4-30
TABLE 4-5	TOWER COST ESTIMATES	4-35
TABLE 4-6	GROSS HEAT RATE COMMON DATA	4-37
TABLE 4-7	AUXILIARY POWER REQUIREMENT COMMON DATA FOR EPGS/BOP	4-38
TABLE 4-8	HOT SALT PUMP POWER REQUIREMENT COMMON DATA	4-40
TABLE 4-9	EPGS, BOP, AND STEAM GENERATOR SUBSYSTEM COSTS COMMON DATA	4-41
TABLE 4-10	ANNUAL PLANT OPERATION AND MAINTENANCE COST COMMON DATA	4-42
TABLE 4-11	PIPE SIZES FOR SALT CIRCULATION LOOP PIPING	4-53
TABLE 5-1	SUMMARY OF TRADE STUDY RESULTS	5-2
TABLE 5-2	ADJUSTED WEIGHTS FOR CAVITY AND EXTERNAL RECEIVERS	5-14
TABLE 5-3	ADJUSTED CAPITAL COSTS FOR CAVITY AND EXTERNAL RECEIVERS	5-15
TABLE 5-4	SUMMARY OF OTHER CONSIDERATIONS	5-28
TABLE 5-5	ANNUALIZED COST DIFFERENTIAL	5-42

CONTENTS (Continued)

LIST OF TABLES (Continued)

		Page
TABLE 6-1	KEY DIFFERENCES BETWEEN BASE-LINE AND PREFERRED PLANTS	6-2
TABLE 6-2	PREFERRED PLANT PERFORMANCE	6-13
TABLE 6-3	CAPITAL COST CODE OF ACCOUNTS LEVEL 2 DETAIL FOR PREFERRED COMMERCIAL PLANT	6-15

LIST OF FIGURES

FIGURE 1-1	SYSTEM FLOW DIAGRAM	1-5
FIGURE 1-2	PREFERRED PLANT SITE PLAN	1-15
FIGURE 1-3	PREFERRED PLANT POWER BLOCK PLAN	1-16
FIGURE 3-1	SYSTEM FLOW DIAGRAM	3-2
FIGURE 3-2	BASELINE PLANT SITE PLAN	3-4
FIGURE 3-3	BASELINE PLANT POWER BLOCK PLAN	3-5
FIGURE 3-4	BASELINE PLANT MASTER CONTROL SUBSYSTEM	3-11
FIGURE 3-5	PIPE CHART DEPICTION OF CAPITAL COSTS FOR BASELINE PLANT	3-16
FIGURE 4-1	ALLOWABLE FLUX LEVELS FOR MOLTEN SALT RECEIVER DESIGN	4-6
FIGURE 4-2	BASELINE (390 MWt) RECEIVER DIMENSIONS AND FLOW CIRCUITRY	4-11
FIGURE 4-3	COMPARISON OF ABSORBED FLUX WITH ALLOWABLE LIMIT--343 MWt RECEIVER AT DESIGN POINT	4-18
FIGURE 4-4	SOLAR CENTRAL RECEIVER STUDY TYPICAL HOT TANK (1,200 MWht SHOWN)	4-24
FIGURE 4-5	CAPITAL COSTS VERSUS THERMAL STORAGE CAPACITY	4-29
FIGURE 4-6	TOWER COST VERSUS TOWER HEIGHT	4-33
FIGURE 4-7	TOWER DESIGN DIMENSIONS AND ASSUMED RECEIVER DATA	4-34
FIGURE 4-8	FOSSIL FIRED SALT MELTER FOR SALT CHARGING	4-49
FIGURE 4-9	MIX TANK ARRANGEMENT FOR INVENTORY SALT CHARGING	4-50
FIGURE 5-1	PHYSICAL DIMENSIONS OF HELIOSTATS	5-5

CONTENTS (Continued)

LIST OF FIGURES (Continued)

		Page
FIGURE 5-2	HELIOSTAT TYPE SELECTION COST DATA	5-7
FIGURE 5-3	COST OF THERMAL ENERGY FOR SINGLE, DOUBLE, AND QUADRUPLE EXTERNAL RECEIVER MODULE SYSTEMS	5-10
FIGURE 5-4	COST OF THERMAL ENERGY VERSUS ANNUAL THERMAL ENERGY	5-18
FIGURE 5-5	COST OF THERMAL ENERGY VERSUS ANNUAL THERMAL ENERGY-RECEIVER COST SENSITIVITY	5-20
FIGURE 5-6	COST OF THERMAL ENERGY VERSUS ANNUAL THERMAL ENERGY-RECEIVER ENERGY SENSITIVITY	5-21
FIGURE 5-7	COST OF THERMAL ENERGY VERSUS ANNUAL THERMAL ENERGY-TOWER COST SENSITIVITY	5-23
FIGURE 5-8	NORMALIZED COST/VALUE RATIO VERSUS CAPACITY FACTOR	5-24
FIGURE 5-9	COST OF ENERGY VERSUS CAPACITY FACTOR	5-26
FIGURE 5-10	COST/VALUE VERSUS CAPACITY FACTOR	5-32
FIGURE 5-11	COST/VALUE VERSUS NET PLANT RATING	5-33
FIGURE 5-12	COST OF ELECTRICAL ENERGY	5-35
FIGURE 5-13	COST/VALUE VERSUS CAPACITY FACTOR	5-36
FIGURE 5-14	BASELINE MASTER CONTROL SYSTEM	5-40
FIGURE 5-15	MASTER CONTROL SUBSYSTEM MORE AUTOMATED THAN BASELINE	5-41
FIGURE 6-1	PREFERRED PLANT SITE PLAN	6-4
FIGURE 6-2	PREFERRED PLANT POWER BLOCK PLAN	6-5
FIGURE 6-3	PREFERRED PLANT MASTER CONTROL SUBSYSTEM	6-11
FIGURE 6-4	PIE CHART DEPICTION OF CAPITAL COSTS FOR PREFERRED PLANT	6-18

APPENDICES

Appendices are included in this report to provide additional detail and support for various sections of the main body. The following appendices are included.

- Appendix A--Guidelines for Trade Studies and Conceptual Designs

  Guidelines issued by APS and PG&E to provide guidance and a starting point for the trade studies. The document provides basic design values for various plant systems and cost estimating.
- Appendix B--Allowable Flux Levels on Tube-Type Receivers

  Summary of a design method for determining the allowable flux levels on a receiver. This method was presented at a workshop conducted by SNL at the CRTF.
- Appendix C--Molten Salt Storage Tank Data

  Detailed information provided by CBI regarding their cost estimates and design of the thermal storage tanks.
- Appendix D--Salt Maintenance

  Detailed information provided by Olin Chemical regarding the use of nitrate salt and design considerations necessitated by this use.

APPENDIX A
GUIDELINES FOR TRADE STUDIES AND CONCEPTUAL DESIGNS

092688

SOLAR CENTRAL RECEIVER UTILITY STUDY

GUIDELINES FOR

TRADE STUDIES

AND

CONCEPTUAL DESIGNS

A-1

September 15, 1987

Revision 6

092688

INTRODUCTION

In an effort to expedite the study effort and to reach mutual agreement on certain study input parameters, the Arizona Public Service Company and Pacific Gas and Electric Company developed the following Solar Central Receiver Utility Study Guidelines. These guidelines are the common basis for comparing Phase I study activities. They are not intended to preclude innovation in design. But users of these guidelines should recognize that deviations from these guidelines must be justified and the impact of the deviations quantified.

The purpose of the guidelines is to indicate to each study team a set of initial "default" input parameters for the trade studies and conceptual designs. As the trade study analyses take place, it is expected that these guidelines will be revised to more appropriately reflect the results of subsystem and component analysis. The revised guidelines will, in turn, serve as the basis for comparing the commercial plant conceptual designs.

092688

UTILITY STUDY GUIDELINES, GROUND RULES, AND TRADE STUDY

INPUT SPECIFICATIONS

Table of Contents

		Page
I.	PLANT LEVEL SPECIFICATIONS	1
	A. Design/Performance/Operationals	1
	B. Site Parameters	2
	C. Cost/Financial	3
II.	COLLECTOR SYSTEM	5
	A. Configuration/Performance	5
	Heliostat Sketch (Figure II.1)	5A
	B. Collector System Costs	6
III.	RECEIVER SYSTEM	7
	A. Configuration/Performance	7
	B. Coolant Properties and Handling	8
	C. Cost and Scaling Relations	8
IV.	TOWER	8
	A. Design Performance	8
	B. Cost and Scaling Relations	9
V.	PUMPS	9
	A. Design/Configuration	9
	B. Cost and Scaling Relations	9

UTILITY STUDY GUIDELINES, GROUND RULES, AND TRADE STUDY

INPUT SPECIFICATIONS

Table of Contents
(Continued)

		Page
VI.	THERMAL STORAGE	9
	A. Design/Configuration	9
	B. Cost and Scaling Relations	10
VII.	PIPING SYSTEM	10
	A. Design/Configuration	10
	B. Cost and Scaling Relations	10
VIII.	HEAT EXCHANGERS	10
	A. Design/Performance/Configuration	10
	B. Cost and Scaling Relations	11
IX.	ELECTRICAL POWER GENERATION	11
	A. Configuration/Performance	11
	B. Cost and Scaling Relations	12
X.	PLANT SUPPORT SYSTEMS	12

092688

UTILITY STUDY GUIDELINES FOR TRADE STUDIES AND CONCEPTUAL DESIGNS

LIST OF ATTACHMENTS
Following Page 12 of the Guidelines

STRAWMAN BASELINE PLANT CONFIGURATION/CRITERIA

ATTACHMENT "A" - Delsol III Cost Scaling Relationships and Reference Cost Information

ATTACHMENT "B" - Environmental Conditions -- Barstow, California

ATTACHMENT "C" - Utility Consensus Guidelines -- Balance of Plant Redundancy

ATTACHMENT "D" - Comments on DELSOL3 Cost Scaling Relationships and Default Input Values

ATTACHMENT "E" - Molten Nitrate Salt Properties for Utility Studies

ATTACHMENT "F" - Solar Central Receiver Mechanical Systems

ATTACHMENT "G" - Solar Sun Shape

ATTACHMENT "H" - Stressed Membrane Mirror Replacement Costs

ATTACHMENT "I" - Design Cloud Information

ATTACHMENT "J" - Allowable Flux Limits for Receiver Design

ATTACHMENT "K" - Cost Estimating Guidelines

092688

UTILITY STUDY GUIDELINES

I. Plant Level Specifications

A. Design/Performance/Operational

			Trade Study Spec Value	Spec Source
Y *	1.	Plant configuration	Central Receiver	Master program plan
Y	2.	a. Conceptual design plant layout	Surround Field	
N *	3.	Plant net rating	TBD (100 MW_e nominal)	Study issue (Baseline Plant)
N *	4.	Plant capacity factor	TBD (30 percent)	Study issue (Baseline Plant)
N *	5.	Plant solar multiple	TBD (1.5)	Study issue (Baseline Plant)
Y	6.	a. Conceptual design Solar Multiple	1.8	
N	7.	Dispatch strategy	TBD	Study issue
N *	8.	Plant design point	TBD (Winter Soltice Noon)	Study issue (Baseline Plant)
Y *	9.	Power generation cycle	Steam Rankine cycle	Master program plan
Y *	10.	Thermal storage configuration	Two tank-molten salt	Master program plan
N *	11.	Tower type	Concrete (steel towers optional for small modules)	Utility Ad Hoc Committee
Y *	12.	Control system type	Distributed digital	State of the art
Y	13.	Design life	30 years	Normal practice
Y	14.	Plant availability (exclusive of sunshine schedule outage)	0.90 (Includes 20 days/year schedule outage)	Utility Ad Hoc Committee
Y *	15.	Redundancy in design	Solar facilities-see below EPGS/BOP-See Attachment "C"	Utility Ad Hoc Committee
Y *	16.	Technology readiness date	1996	Utility Ad Hoc Committee
Y	17.	Operating staff	2 Operator (minimum)	Utility Ad Hoc Committee
Y	18.	Staffing approach	Normal utility approach	Utility Ad Hoc Committee

* Candidate strawman baseline specification
Y = Guideline for conceptual design
N = Not guideline for conceptual design

Trade Study Spec Value Spec Source

092688

B. Site Parameters

			Trade Study Spec Value	Spec Source
Y *	1.	Insolation, Wind & Temperature	1985 Barstow	Utility Ad Hoc Committee
Y	2.	Land constraints	None	Judgment
Y	3.	Seismic acceleration		Utility Ad Hoc Committee
		a. Operating	0.125 g horizontal	Uniform Building Code - Class-1
		b. Safe shutdown	0.25 g horizontal	
		c. Response spectrum	NRC Guide 1.60	Utility Ad Hoc Committee
		d. Damping Value	NRC Guide 1.61	Utility Ad Hoc Committee
Y	4.	Operating temperature (ambient)		Modified Solar One
		a. Dry bulb	16-120° F	
		b. Wet bulb	14-77° F	
Y	5.	Wind @ 10 m elevation		Solar One
		a. Operating (sustained)	35 mph	(See Attachment "B")
		b. Survive in high wind stow position (sustained and gusts	90 mph	
		c. Average daytime (Summer)	14.5 mph	
		d. Average daytime (Winter)	8.5 mph	
		e. Wind velocity/height dependency	$V=V_{10m} (H/10m)^{.15}$	
Y	6.	Atmospheric pressure (2000 ft. elev.)	13.72 psia	Solar One
Y	7.	Precipitation Max rate	6 in/hr for 2 min 2.4 in/hr for 30 min	Solar One
Y	8.	Snow load	5 lb/ft^2	Solar One

* Candidate strawman baseline specification
Y = Guideline for conceptual design

			Trade Study Spec Value	Spec Source
Y	9.	Ice buildup	2 in.	Solar One
Y	10.	Hail	1 in diameter @ 75 ft/sec	Solar One
Y	11.	Soil load bearing	(See Attachment B)	Solar One
Y	12.	Raw water chemistry		Solar One site
		a. Total cations	780 mg/l	
		b. Total anions	780 mg/l	
		c. Silica	35 mg/l	
		d. Fluoride	0.8 mg/l	
		e. Boron	0.6 mg/l	
		f. Iron	0.43 mg/l	
		g. Total dissolved residue	870 mg/l	
		h. PH	7.4	
Y	13.	Design Cloud Parameters	(Information provided Attachment I)	Design Issue

C. Cost/Financial

			Trade Study Spec Value		Spec Source
		a. Trade Studies	DI(EXT) = 0.23		
	1.	Fixed cost (buildings, roads improvements, master control, etc.)	(See Attachment A)		DELSOL data base
Y	2.	Cost factor (DI) for A&E			
		a. Conceptual design	1st	Nth plant	
		Engineering services & Construction mgmt.	10%	9.0% of directs	
		Owner's costs	7.5%	6.0% of directs	
		Management reserve	5%	0.0%	
			22.5%	15.0%	
N	3.	Contingency factor (CONT)	CONT = 0.15		Attachement D
N		a. Conceptual Design			Cost Data Management System Code of Accounts
		Land	0%		
		Structures & Improvements	10%		
		Collector System			Included in delivered price
		Receiver System	15%		
		Thermal Storage System	15%		

* Candidate strawman baseline specification
Y = Guideline for conceptual design
N = Not guideline for conceptual design

092688

			Trade Study Spec Value	Spec Source
		Steam Generator System	15%	
		Electric Power Generation System	10%	
		Master Control System	15%	
Y	4.	Spare parts factor	0.01 (DELSOL default)	DELSOL data base (Does not include spare receiver panels.)
Y *	5.	Ownership	Utility	Utility Ad Hoc Committee
	6.	Levelized energy cost analysis	Constant year, 1986 dollars	Utility Ad Hoc Committee
N		a. (Value analysis as appropriate for trade study.)	(see Attachment "A")	DELSOL program
Y		b. Conceptual design	Constant year, 1Q, 1987$	
Y	7.	DELSOL Formula VB-1	Add "+ 0.06CCT"	Attachment D
			Change "NYTCON" to $\frac{2\ \text{NYTCON}}{3}$	Attachment D
Y	8.	DELSOL Formula VB-2	NYTCON = construction schedule in years	
Y	9.	Fixed charge rate option	IFCR = 0	Attachment D
Y	10.	Fixed charge rate	FCR = 0.105	Attachment D
Y	11.	Discount rate	DISRT = 0.065	Attachment D
Y	12.	General inflation rate	RINF = 0.00	Attachment D
Y	13.	Plant operating life	NYOP = 30	Attachment D
N	14.	Plant construction period	NYTCON = (TBD)	Study Issue (Strawman is 5 yr)
Y	15.	Interest during construction factor	AFDC = 0.0214	Attachment D
			(1-year construction period)	Attachment D
			AFDC = 0.0433	Attachment D
			(2-year construction)	Attachment D
			AFDC = 0.0657	Attachment D
			(3-year construction)	Attachment D
			AFDC = 0.0886	Attachment D

Y = Guideline for conceptual design
N = Not guideline for conceptual design

II. COLLECTOR SYSTEM

A. Configuration/Performance

		Item	Trade Study Spec Value	Spec Source
Y	1.	Type	Stretched membrane on the conceptual designs	
Y	2.	Clean reflectivity:	0.94	Utility Ad Hoc Committee
Y	3.	Average reflectivity:	0.91	Solar One
Y	4.	Pointing/tracking error: (1 sigma)	1.5 mrad reflected beam each axis	Sandia Spec/Attachment
N	5.	Mirror slope error: (1 sigma)	2.0 mrad reflected beam each axis	Sandia Spec/Attachment
N	6.	Mirror panel focal length:	TBD (Maximum slant range for the field)	Study Issue (Baseline Plant)
N	7.	Heliostat (cant) focal length:	TBD (Single heliostat cant and focal length assumed) for "strawman".	Study Issue
Y	8.	System availability:	0.97	
Y	9.	Heliostat availability:	0.99	Solar One
Y	10.	Heliostat-to-heliostat minimum reflector panel clearance:	1 ft.	Solar One/Judgment
	11.	Emergency defocus time		Saguaro Preliminary Design Spec.
N		a. Trade Study	90 seconds	
Y		b. Conceptual Design	5 seconds	Stressed Membrane Vendor
N	* 12.	Glass heliostat dimensional data:	(See Figure II.1)	Sandia data dump
N	13.	Stretched membrane heliostat dimensional data:	(See Figure II.1)	Sandia data dump
Y	14.	Beam Characterization System	TBD	Utility Ad Hoc Committee

* - Candidate strawman baseline specification
Y = Guideline for conceptual design
N = Not guideline for conceptual design

092688

092688

		Trade Study Spec Value	Spec Source
		(4-year construction)	Attachment D
		*AFDC = 0.1119	Attachment D
		(5-year construction)	Attachment D
		AFDC = 0.1357	Attachment D
		(6-year construction)	Attachment D
	16. Collector Sys. O&M rate		
N	a. Trade Study	RHOM = 0.01	
Y	b. Conceptual Design	TBD	
	17. BOP O&M rate		
N	a. Trade Study	RNHOM = 0.015	
Y	b. Conceptual Design	TBD	
Y	18. Investment tax credit	TC = 0.00	Attachment D
Y	19. Property tax & insurance rate	PTI = 0.02	Attachment D
Y	20. Income tax rate (combined state/federal)	TR = 0.403 (Use current tax rate of 28% in conceptual designs.)	Attachment D
Y	21. Debt fraction	FDEBT = 0.45	Attachment D
Y	22. Debt interest rate	RDEBT = 0.10	Attachment D
Y	23. Return on equity	ROE = 0.145	Attachment D
Y	24. Depreciation life	NDEP = 15 yr.	Attachment D
Note 1	25. Commercial plant economics (conceptual plant analysis)	Utilities should use their own respective values in assessing their conceptual design.	Utility Ad Hoc Committee (Utilities to prepare recommendations.)
Y	a. Regulated rate of return		
Y	b. Cost of capital		
Y	26. Cost of Salt Delivered to Barstow	$0.33 per pound	PG&E
Y	27. Cost of Sodium Delivered to Barstow	$0.85 per pound	PG&E

Y = Guideline for conceptual design
N = Not guideline for conceptual design

Note 1: Each utility should run economics by guideline values in addition to the utility's own values.

	Item	Trade Study Spec Value	Spec Source
	B. Collector System Costs		
N *	1. Glass heliostat:	120 $\$/m^2$	Utility Ad Hoc Committee
Y	2. Stretched membrane heliostat:		Utility Ad Hoc Committee
	a. Trade study	90 $\$/m^2$	
	b. Conceptual design 1st plant	100 $\$/m^2$**	Stressed Membrane Vendor
	c. Conceptual design Nth plant	75 $\$/m^2$**	Stressed Membrane Vendor
Y	3. Land cleared and grubbed:	$1550/acre	
Y	4. Wiring	Included in $\$/m^2$ costs above	Attachment D

III. RECEIVER SYSTEM

	Item	Trade Study Spec Value	Spec Source
	A. Configuration/Performance		
*	1. Configuration:		Study issue (North facing cavity is Baseline plant)
N	a. Trade study	TBD	
Y	b. Conceptual design	External	
Y	2. Surface absorptivity (new):	0.96	Utility Ad Hoc Committee
N *	3. Surface absorptivity (average)	0.92	Solar One
Y *	4. Surface emittance:	0.89	Pyromark paint
	5. Peak design heat flux limit:		Sandia data dump
N	a. Trade studies	$0.68\ MW/m^2$ (Salt)	
	(target values for DELSOL)	$1.46\ MW/m^2$ (Sodium)	Sandia data dump
Y	b. Conceptual designs	Modified ASME Code N47	Attachment J
Y	6. Equivalent 30 year cycle life:	20,000 cycles	Attachment J (B & W-FW-Sandia consensus)

* Candidate strawman baseline specification
Y = Guideline for conceptual design
N = Not guideline for conceptual design
** = Indludes contingencies

		Trade Study Spec Value	Spec Source
Y	7. Convective loss model		Based on Sandia studies
	External receiver	DELSOL default	Design issue
	Cavity receiver	DELSOL default	Design issue
Y	8. Wind speed for convective loss estimates	8.5 mph @ 10 m elev.	Solar One design (average winter day value)
N	9. Fill or drain time (above the top of tower)	10 minute max	Judgment
N	10. Receiver turn down ratio	Salt system 5:1 Na system 6.5:1	Utility Ad Hoc Committee Bechtel
Y	11. Maximum receiver tube length	100 ft.	
Y	12. Ancillary equipment	Lightning protection Lighting Instrument air Service air Inert gas Service water Lifts and hoists	Judgment

B. Coolant Properties and Handling

Y	1. Salt Conditioning and fill		
Y	2. Sodium Conditioning and fill		

C. Cost and Scaling Relations

		Cavity Receiver: use default value	DELSOL program Attachment D
NA		External salt receiver CREC1 = $\$24.1 \times 10^6$ ARECRF = $1136.0 M^2$	
NA		Na Receiver CREC1 = $\$15.4 \times 10^6$ ARECRF = $607.0 m^2$	Attachment D

---

* Candidate strawman baseline specification
Y = Guideline for conceptual design
N = Not guideline for conceptual design
NA = Not applicable for conceptual design

092688

	Trade Study Spec Value	Spec Source
IV. TOWER		
A. Design/Performance		
Y * 1. Type	Free standing concrete or steel (support receiver and BCS targets)	Utility Ad Hoc Committee
Y 2. Sway at receiver centerline (35 mph wind @ 10 m elev.)	Deflection of 2 feet or less	Utility Ad Hoc Committee
N 3. Height	TBD	Study result
Y 4. Tower auxiliaries	Elevators/stairways	Judgment/normal design standards
	Work stations	Judgment/normal design standards
	Pipe support points	
	Maintenance services (electrical, shop air, and lighting)	
	Aircraft warning lights	
B. Cost and Scaling Relations NA	(See Attachment A)	DELSOL program
V. PUMPS (Salt)		
A. Design/Configuration		
1. Type	Vertical	Solar 100 design
2. Redundancy	3-50% capacity pumps (for each service)	Commercial design practice (Solar 100 design)
B. Cost and Scaling Relations (Salt) NA	Use default value	DELSOL program

Y = Guideline for conceptual design
N = Not guideline for conceptual design
NA = Not applicable for conceptual design

092688

092688

	Trade Study Spec Value	Spec Source
C. Cost and Scaling Relations (Na)		
NA	Bechtel to develop algorithm for use by Bechtel	
VI. <u>THERMAL STORAGE</u>		
A. Design/Configuration		
Y 1. Approach	2 tank design	Master Program Plan
Y 2. Storage fluid	Molten salt	Master Program Plan
Y 3. Storage temperatures	1050° F/550° F	Solar 100 design
N 4. Tank capacity	TBD	Study result
Y 5. Cover gas	Dry air (carbon dioxide removed)	Design practice (molten salt)
B. Cost and Scaling Relations		
Y	Use common data input.	
VII. <u>PIPING SYSTEM</u>		
A. Design/Configuration		
Y 1. Design code	Power piping code ANSI B31.1	Normal design practice
Y 2. Insulation (salt system only)	Calcium Silicate	Category "B" program
Y 3. Freeze protection	Trace heating	MSEE and Category "B" program. Salt system interfaces per Saguaro Spec.
B. Cost and Scaling Relations		
NA	(See Attachment A) FPLH = 3.0 FPLC = 2.3	Attachment D

Y = Guideline for conceptual design
N = Not guideline for conceptual design
NA = Not applicable for conceptual design

092688

	Trade Study Spec Value	Spec Source
VIII. HEAT EXCHANGERS		
A. Design/Performance/Configuration		
N 1. Sodium/salt heat exchanger	TBD	Study Output
Y 2. Steam generator/superheater Configuration	Recirculating type, Horizontal tube-shell Separate preheater, boiler and superheater	Utility Ad Hoc Committee Solar 100 design
Y 3. Temperature range	1050-550° F salt side 460-1005°F water-steam side	Solar 100 design
Y 4. Reheater		
Configuration	Horizontal tube-shell	Utility Ad Hoc Committee
Temperature range	1050 - TBD°F salt side	Solar 100 design
	668 - 1005°F steam side	Solar 100 design
Y 5. Design Codes	ASME Section VIII	Utility Ad Hoc Committee
B. Costs and Scaling Relations		
NA	(See Attachment A) CKNREF = $\$6.2 \times 10^6$ XKN = 0.5 XHEP = 0.5	Attachment D
IX. ELECTRICAL POWER GENERATION		
A. Configuration/Performance		
N 1. Turbine cycle gross heat rate	8066 Btu/kWH	Solar 100 (Bechtel-supplied
N 2. Turbine type	Sliding pressure, tandem compound, double-flow, reheat, condensing unit.	Solar 100 (Bechtel-supplied)

Y = Guideline for conceptual design
N = Not guideline for conceptual design
NA = Not applicable for conceptual design

092688

		Item	Trade Study Spec Value	Spec Source
N	3.	Condenser back pressure	2 1/2 in Hg (wet cooling) at 120°F dry bulb, 77°F wet bulb	Solar One
N	4.	Steam conditions (See Attachment "D")	(Main Steam) 1000°F, 1815 psia (Cold Reheat Steam) 673°F, 491 psia (Hot Reheat Steam) 1000°F, 442 psia	Solar 100 (Bechtel-supplied)
N	5.	Turbine Steam Flow @ 110 MWe generator output	(Main Steam) 742,362 lb/hr (Reheat Steam) 652,741 lb/hr	Solar 100 (Bechtel-supplied)
Y	6.	Emergency power	Diesel generator to stow collector field	Utility Ad Hoc Committee
Y	7.	Power loss duration	8 hours	Utility Ad Hoc Committee
B.		Cost and Scaling Relations		
NA			Use default values (See Attachment A)	DELSOL program

X. PLANT SUPPORT SYSTEMS

	Trade Study Spec Value	Spec Source
Y	Auxiliary steam Cooling water Circulating water Sumps and drains Turbine hydraulic and lube oil Generator cooling Sampling Service water Water treatment Fire protection Instrument and service air Plant electrical	Scope of utility plant design

Y = Guideline for conceptual design

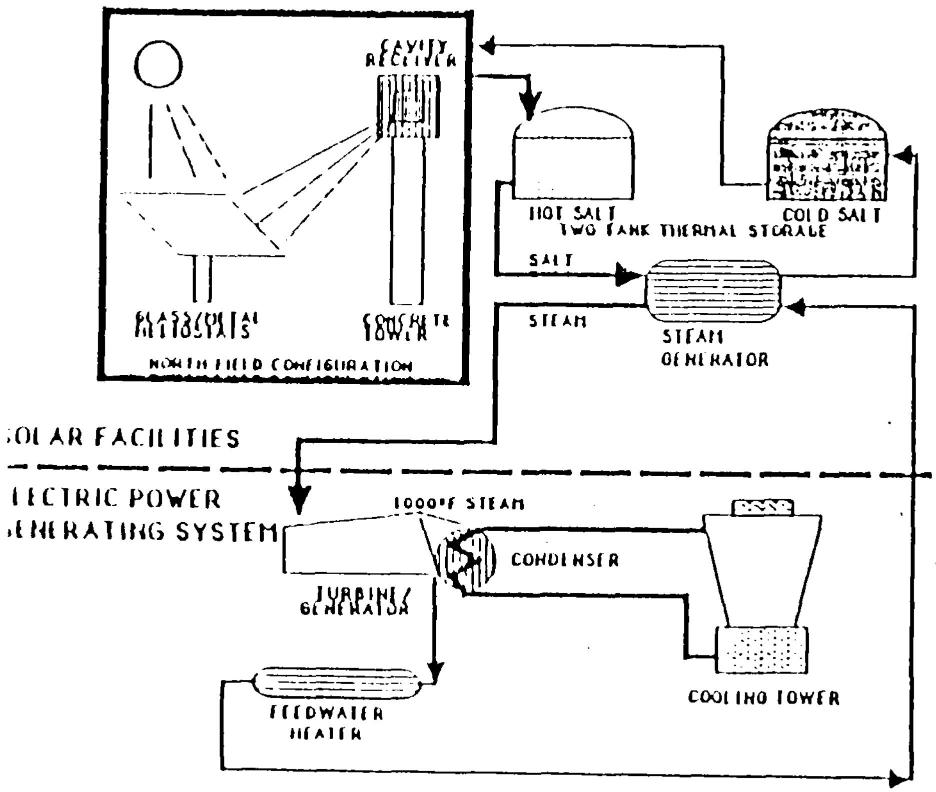
092688

STRAWMAN BASELINE PLANT

TO BE USED AS A BASIS OF COMPARISON FOR ALL DELSOL3 CALIBRATIONS

(NOT FOR CONCEPTUAL DESIGN:)

BASELINE PLANT CONFIGURATION



BASELINE PLANT CRITERIA

- RATING ------------------ 100 MW
- CAPACITY FACTOR --------- 30 %
- SOLAR MULTIPLE ---------- = 1.5
- RECEIVER CONFIGURATION
  - • CAVITY
  - EXTERNAL
- COLLECTOR FIELD CONFIGURATION
  - • NORTH
  - SURROUND
- HELIOSTAT COST ----------- 120 $/m²
- HELIOSTAT TYPE
  - • GLASS/METAL
  - STRETCHED MEMBRANE
- OPERATING DATE --------- JUNE 1996
- DISTRIBUTED DIGITAL CONTROL SYSTEM
- BARSTOW SITE PARAMETERS AND 1985 INSOLATION
- UTILITY OWNERSHIP

ATTACHMENT A

DELSOL III COST SCALING RELATIONSHIPS AND REFERENCE COST INFORMATION

UC-62a

SAND 86-8018
Unlimited Release
Printed November 1986

A USER'S MANUAL FOR DELSOL3: A COMPUTER CODE FOR CALCULATING THE OPTICAL PERFORMANCE AND OPTIMAL SYSTEM DESIGN FOR SOLAR THERMAL CENTRAL RECEIVER PLANTS

Bruce L. Kistler
Solar Central Receiver Components Division
Sandia National Laboratories, Livermore

ABSTRACT

DELSOL3 is a revised and updated version of the DELSOL2 computer program (SAND81-8237) for calculating collector field performance and layout and optimal system design for solar thermal central receiver plants. The code consists of a detailed model of the optical performance, a simpler model of the non-optical performance, an algorithm for field layout, and a searching algorithm to find the best system design based on energy cost. The latter two features are coupled to a cost model of central receiver components and an economic model for calculating energy costs. The code can handle flat, focused and/or canted heliostats, and external cylindrical, multi-aperture cavity, and flat plate receivers. The program optimizes the tower height, receiver size, field layout, heliostat spacings, and tower position at user specified power levels subject to flux limits on the receiver and land constraints for field layout. DELSOL3 maintains the advantages of speed and accuracy which are characteristics of DELSOL2.

V. System Costs and Economics

While DELSOL can be used to calculate field performance only, it also has capabilities for total system design. In DELSOL, an **optimized** system design is that combination of tower height, receiver size, and field layout which gives the lowest calculated system energy cost at a given design power level and solar multiple. In order to calculate the energy cost, both system performance and system capital and operating costs must be determined. The latter is only done during the optimization procedure; therefore, annual performance cannot be done on a system which is input by the user, since costs are unavailable. The subsystem cost models for estimating the total capital cost and the economic model for calculating the levelized energy cost are discussed below. **It is strongly suggested that the user carefully examine both the cost calculation procedures and the default values used in those calculations to verify that the resulting component costs will be appropriate for the system being examined.** Different systems and different technologies will almost certainly require modification of at least some of the reference system values discussed herein and used by DELSOL.

The units used in DELSOL input must be those specified for the individual variables, such as meters for all dimensions and dollars for all costs. The user should be aware that the output from DELSOL is not necessarily consistent in the units which are used. Specifically, land area might be in either m^2 or km^2 and annual energy might be in KWh_e or MWh_e, depending on the location in the output. Further, energy costs are quoted in mills/KWh_e, **not** cents/KWh_e. Although the values will be consistent with the labels, the user should be careful to note the correct specified units associated with any output value.

V.A. Total Cost Model

The total capital cost, CC_T, is calculated as the sum of the costs of several subsystems adjusted by a factor for uncertainties and miscellaneous expenses:

$$\begin{aligned} CC_T = & (CC_{HEL} + CC_{LAND} + CC_{WIRE} \\ & + CC_{TOW} + CC_{REC} \\ & + CC_{PUMP} + CC_{PIPE} + CC_{STORAGE} + CC_{HTXSTOR} + CC_{HTXCHG} + CC_{EPGS} \\ & + CC_{FIXED}) \\ & \times (1.0 + DI + CONT + SPTS) \end{aligned} \qquad (V.A-1)$$

As discussed in detail in Chapter 4, the optimization scheme considers one tower height/receiver size combination at a time and then builds up the heliostat field zone by zone until the desired power level(s) at the specified solar multiple is achieved for that tower and receiver. Capital cost components can be grouped according to that point in the field buildup at which they are calculated. The line grouping of the costs in Equation (V.A-1) is to clarify those costs which are similarly calculated. The tower and receiver costs (CC_{TOW}, CC_{REC}) are fixed by the values of tower height and receiver dimensions for each pass through the field buildup subroutine MAX. Heliostat, land, and wiring costs (CC_{HEL}, CC_{LAND}, and CC_{WIRE}) are updated with each zone added in the field buildup. The power or system size related costs of piping, pumping, storage, heat exchangers, and EPGS (CC_{PIPE}, $CC_{STORAGE}$, $CC_{HTXSTOR}$, CC_{HTXCHG}, and CC_{EPGS}, respectively) are calculated as each design level is reached. It is assumed that certain fixed costs (CC_{FIXED}, e.g., master control, administration buildings, roads, etc., are common to all the systems. Factors for distributable and indirect costs (DI) to cover architectural and engineering services, contractor fees, and temporary facilities, for contingencies (CONT), and for spare parts (SPTS) are added to the basic capital cost of the major component subsystems. Values are expressed as a fraction of the total direct costs. Current default values are based on Nth plant design and construction:

$$\text{DI (EXT)} = 0.16$$

$$\text{CONT (CONT)} = 0.12$$

$$\text{SPTS (SPTS)} = 0.01$$

The individual capital cost models are described below. User supplied cost parameters should include materials, fabrication, and field installation, and subcontractor fees and contingencies, if any. The default values are consistent with the near-term 1984 five year plan cost goals or with 1984 current capabilities (References 34 and 35). Should the user desire to set any subsystem cost to zero to eliminate its contribution to the system design, then the input cost parameters, not the size or scaling parameters, should be set to zero.

V.A-1. Heliostats–Heliostat prices quoted by contractors usually include field wiring and installation. Therefore, the value CH input by the user should also include these costs. DELSOL will subtract the wiring costs as described in Section V.A-3 to determine the separate cost of heliostats:

$$\begin{aligned} CC_{HEL} &= C_H \left(\frac{\$}{\text{m}^2 \text{ mirror area}} \right) \times \text{total mirror area} + \$1E6 - C_{WIRE} \\ &= C_H \left(\sum^{\text{zones}} \text{zone mirror area} \right) + \$1E6 - C_{WIRE} \end{aligned} \qquad (V.A-2)$$

Zone mirror area is determined from the zone density and land area. The constant million dollar addition is to account for a beam characterization system and for meteorological equipment. The default value is $C_H = \$120.0/m^2$ of heliostat area, which applies to a high reflectivity glass-metal heliostat. This value is consistent with stated near-term cost goals of the 1984 five year plan.

V.A-2. Land–The cost of land should be the cost of unimproved land. The area of land needed includes all of the land in each zone, increased by 30% to account for roads and additional land around the field, and increased by a fixed amount to account for the core area of the plant.

$$\begin{aligned} CC_{LAND} &= C_L\left(\frac{\$}{m^2 land}\right) \times \text{total land area} \\ &= C_L\left\{\left(\sum^{zones} \text{zone land area}\right) \times 1.3 + 0.18E6m^2\right\} \end{aligned} \qquad (V.A-3)$$

The default value is C_L (CL) $= \$0.62/m^2$ of land area.

V.A-3. Wiring–The calculated wiring costs are assumed to be included in the input heliostat cost, and are calculated and separated from heliostat costs by DELSOL according to the following:

$$C_{WIRE} = \sum_i^{zones} (C_{W,R}R_i + C_{W,\Delta R}\Delta R_i + C_{W,\Delta AZ}\Delta Az_i) \times \text{number of heliostats in zone i} \qquad (V.A-4)$$

where R_i = radial distance from the tower base to zone i
ΔR_i = average row spacing in zone i
ΔAz_i = average spacing between heliostats on the same row in zone i.

This model was supplied with the field performance results from Reference 9. It is designed to penalize heliostats placed farther out due to requirements of larger (or more) primary cables as the field grows radially from the tower, and longer plowed-in secondary line runs as the mirror density decreases with distance from the tower. From the defined zoning and density option in namelists FIELD and OPT, R_i, ΔR_i, and ΔAz_i are known. Default values for the wiring cost parameters, given for a single heliostat and as provided in Reference 35, are:

$$C_{W,R}(CWR) = \$0.03077/m$$

$$C_{W,\Delta R}(CWDR) = \$15.00/m$$ (UH suggests $0.72/m)

$$C_{W,\Delta Az}(CWDA) = \$9.00/m$$

V.A-4. Tower–The optical tower height THT is used for all performance calculations. The physical tower height THT_B, which is the actual tower height from the ground to the bottom of the receiver, is related to THT by

$$THT_B = THT + HM/2 - H/2 - W \qquad (V.A-5)$$

where HM = height of a heliostat
H = height of the receiver
W = height of a transition region from the tower to receiver; this height is assumed to be the same as the receiver diameter W. The cost of this transition region is assumed to be part of the cost of the receiver.

The cost of the actual tower is calculated as

$$\begin{aligned} CC_{TOW} &= C_{TOW1} \times e^{C_{TOW2} THTB} \qquad THTB \geq 120 \quad m \\ CC_{TOW} &= C_{TOW3} \times e^{X_{TOW} THTB} \qquad THTB < 120 \quad m \end{aligned} \qquad (V.A-6)$$

It is assumed that towers shorter than 120 m in height are steel towers, while towers of 120 m or more are concrete towers, where the difference is shown only in the cost coefficients for the above equations. The user has two options for calculating the cost of the tower:

a) <u>ITHT = 0</u>; cost based on Sandia studies (Reference 36) and repowering designs (Reference 35):

C_{TOW1} = \$0.78232E6

C_{TOW2} = 0.01130

C_{TOW3} = \$1.09025E6

X_{TOW} = 0.00879

b) <u>ITHT = 1</u>; cost based on user supplied values of CTOW1 and CTOW2 in Namelist NLCOST, where these values are used for all THTB values.

The tower cost for option a) is plotted in Figure V-1. The default choice of tower cost is ITHT = 0.

V.A-5. Receiver–The equation in DELSOL for costing receivers is of a form commonly used in the chemical process industries (References 37 and 38). This equation form, in which cost scales with receiver area, results from the fact that the receiver is a specially designed heat exchanger. The equation is

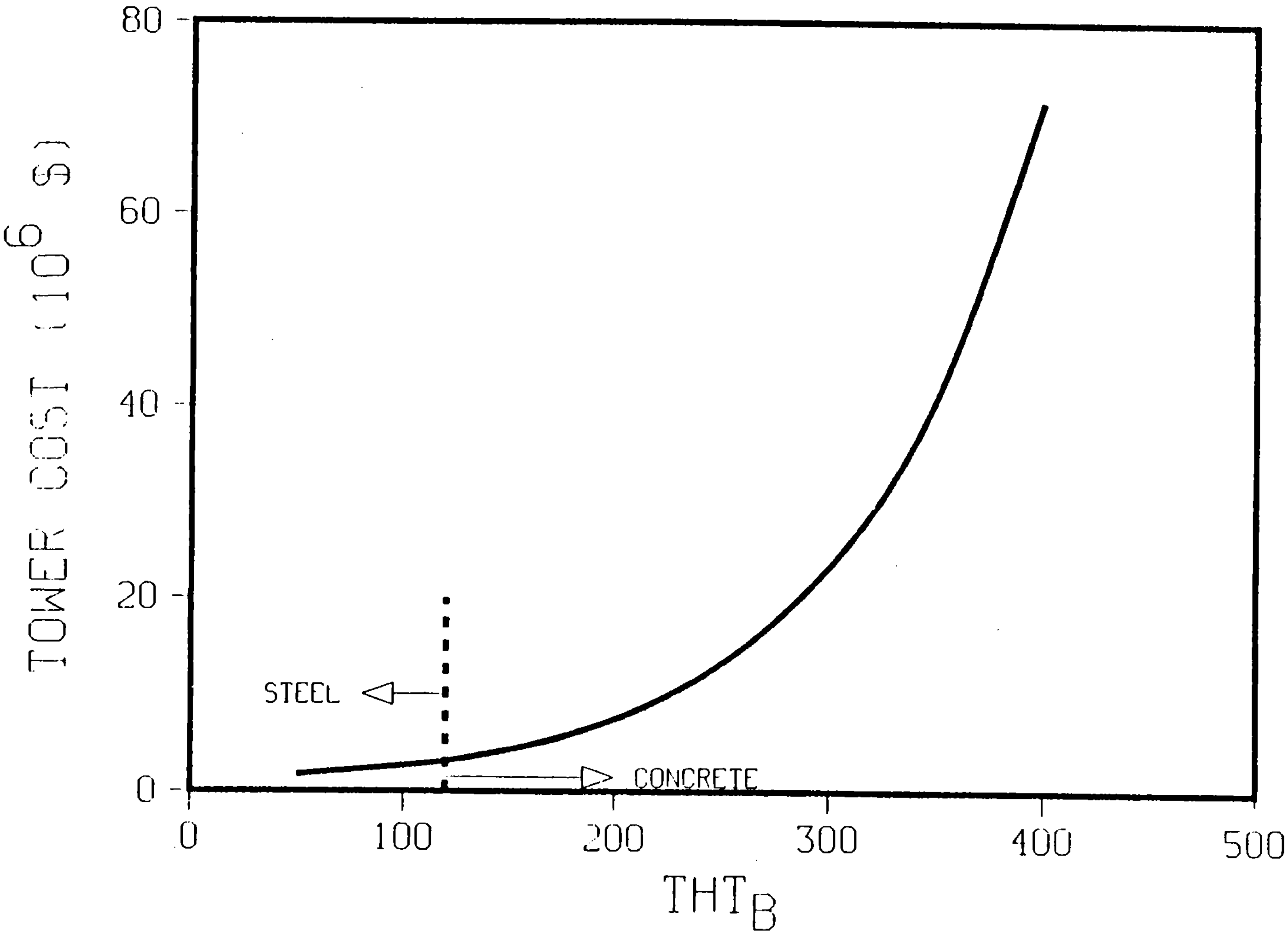


Figure V-1. Tower Cost Predicted for ITHT = 0

092688

$$CC_{REC} = C_{REC,REF} \left(\frac{A_{REC}}{A_{REC,REF}} \right)^{x_{REC}} \qquad (V.A-7)$$

where $C_{REC,REF}$ = cost of a reference design (dollars)
$A_{REC,REF}$ = heat transfer area of the reference design
A_{REC} = heat transfer area of the receiver being evaluated
x_{REC} = scaling exponent for receivers, ≤ 1.0

Default values are based on the scaling exponent commonly used for heat exchangers and on a cavity salt receiver design (Reference 8):

$C_{REC,REF}$ (CREC1) = $\$23.0 \times 10^6$

$A_{REC,REF}$ (ARECRF) = $758.0\ m^2$

X_{REC} (XREC) = 0.8

a) External and Flat Plate Receivers–The area A_{REC} is simply the product of π times the diameter (W) times the height (H) for an external receiver. For a flat plate receiver the area is RX×RY.

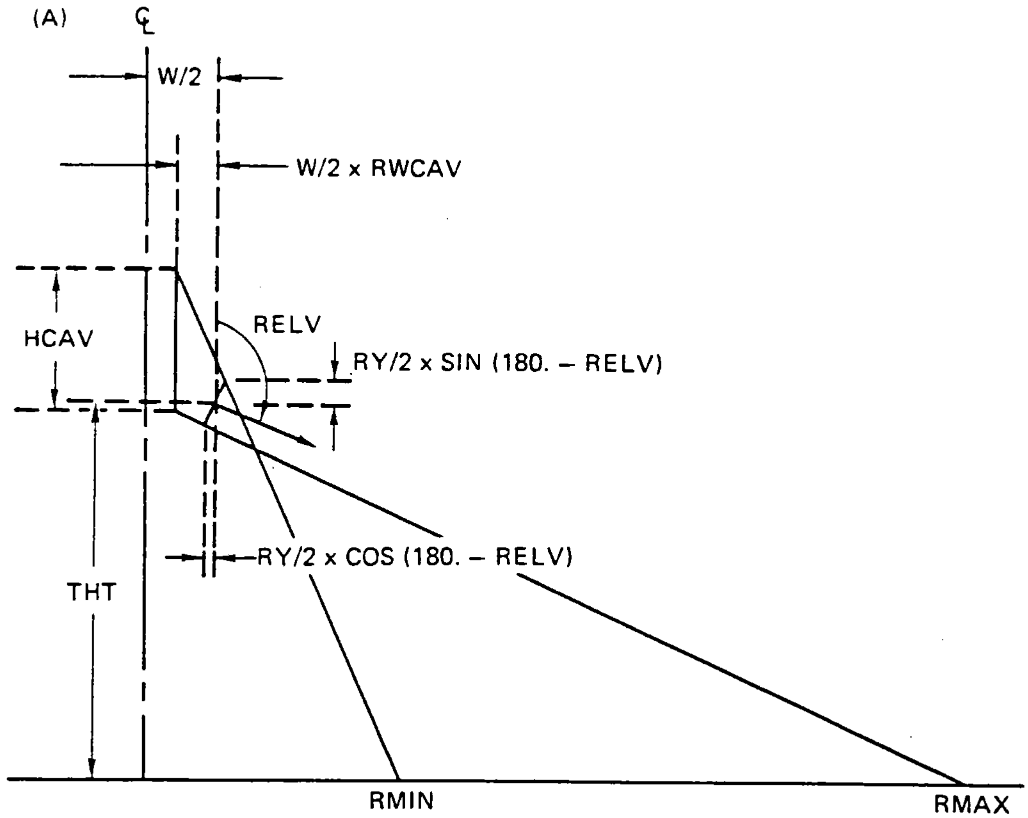
b) Cavity Receivers–The bottom of the heat absorbing surface is calculated by DELSOL (for costing purposes) so that at the given cavity depth, W/2 x RWCAV, a ray entering the bottom of the aperture from the farthest heliostat will strike the heat absorbing surface.

$$\begin{aligned} HBOT = & (THT - RY/2 \times \sin(180 - RELV)) \\ & \times \left(\frac{RMAX - W/2 + W/2 \times RWCAV}{RMAX - W/2 + RY/2 \times \cos(180 - RELV)} \right) \end{aligned} \qquad (V.A-8)$$

where RMIN and RMAX are the local minimum and maximum radii for the optimized heliostat field.

The height of the heat absorbing surface is specified in one of three ways. If the default value of the variable H is used, the heat absorbing surface height will be specified as 1.1×RY (1.1 times the aperture height). If a different value H is specified, then that value is taken to be the actual height of the heat absorbing surface. However, the height will never be allowed to be larger than that height needed to intercept a ray from the nearest heliostat entering the top of the aperture, as shown in Figure V-2a and described as

$$\begin{aligned} HTOP = & (THT + RY/2 \times \sin(180 - RELV)) \\ & \times \left(\frac{RMIN - W/2 + W/2 \times RWCAV}{RMIN - W/2 + RY/2 \times \cos(180 - RELV)} \right) \end{aligned} \qquad (V.A-9)$$



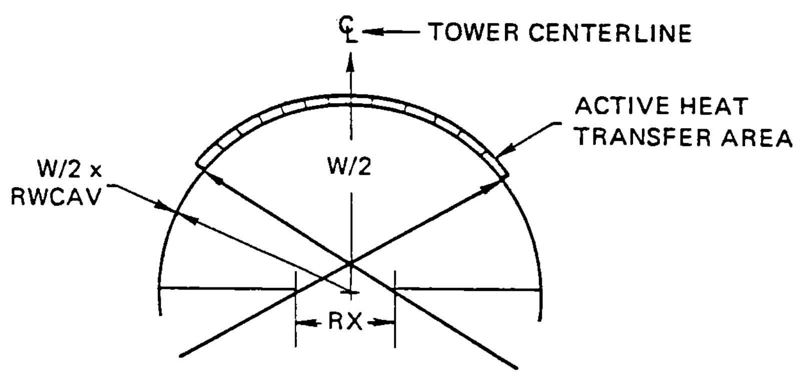


Figure V-2. a) Schematic illustrating the relationship of the height of the back wall of a cavity to other system dimensions; b) Assumed shape of the heat transfer surface in a cavity

In this case, the height of the heat absorbing surface is

$$HCAV = HTOP - HBOT$$

The circumferential width of the heat absorbing surface used in costing a cavity receiver is that portion of the cylindrical surface which can be seen through the aperture by the section of the field active for the cavity. Rays from the nearest heliostats on the boundaries of this sector are used to calculate the fraction of the surface seen (Figure V-2b). Note that if Equation (V-A-9) is used to determine the height of the heat absorbing surface, this height may be extremely sensitive to the choice of the variable RADMIN. In this case the user may find it desirable to rerun the code with values of RADMIN larger than the default in order to obtain a reasonable value for HCAV.

V.A-6. Pumps–The pump cost is assumed to be

$$CC_{PUMP} = C_{RP} + C_{SP} \qquad (V.A-10)$$

where C_{RP} = receiver/tower pump cost
C_{SP} = storage pump cost

These costs are assumed to scale from the costs for a known reference design. The scaling parameter for pump costs is the product of the head times the capacity (Reference 37). For the receiver pump, the head is proportional to the tower height, and the flow rate is the total fluid flow, i.e., EPGS and storage requirement. Thus, the fluid flow is proportional to the solar multiple times the thermal power transferred in the heat exchangers. For the storage pump, the head is assumed to change negligibly from the reference design, and the flow rate is proportional to the thermal power alone (EPGS only). These assumptions lead to the following equations for the pumping costs:

$$C_{RP} = C_{RP,REF} \left(\frac{THT \times SM \times P_{th}}{THT_{RP,REF} \times SM_{RP,REF} \times P_{th,RP,REF}} \right)^{x_{RP}} \qquad (V.A-11)$$

$$C_{SP} = C_{SP,REF} \left(\frac{P_{th}}{P_{th,SP,REF}} \right)^{x_{SP}} \qquad (V.A-12)$$

where $C_{RP,REF}$ = cost of reference receiver/tower pump ($)
THT = tower height (m)
SM = solar multiple
P_{th} = thermal power to EPGS (watts)
$THT_{RP,REF}$ = tower height for reference receiver pump design (m)

$SM_{RP,REF}$ = solar multiple for reference receiver pump design
$P_{th,RP,REF}$ = thermal power to EPGS in reference receiver pump system (watts)
x_{RP} = scaling exponent for receiver pump
$C_{SP,REF}$ = cost of reference storage pump ($)
$P_{th,SP,REF}$ = thermal power to EPGS in reference storage pump system (watts)
x_{SP} = scaling exponent for storage pump.

Default values are as follows:

$C_{RP,REF}$ (CRPREF) = $2.1 × 10^6

$THT_{RP,REF}$ (TRPREF) = 170.0 m

$SM_{RP,REF}$ (SMRP) = 1.5

$P_{th,RP,REF}$ (PRPREF) = 2.6 × 10^8 watts

x_{RP} (XRP) = 0.85

$C_{SP,REF}$ (CSPREF) = $4.70 × 10^5

$P_{th,SP,REF}$ (PSPREF) = 3.0 × 10^8 watts

x_{SP} (XSP) = 0.15

V.A-7. Piping–Piping costs are assumed to scale with tower height and with pipe diameter in relation to a reference system (Reference 39).

$$CC_{PIPE} = THT(\ell_{PH}C_{HOT,REF} + \ell_{PC}C_{COLD,REF})(\frac{D}{D_{REF}})^{x_{PIPE}} \qquad (V.A-13)$$

where ℓ_{PH} = multiplier on THT to give total hot piping run as described in Section III.G-4
$C_{HOT,REF}$ = reference hot pipe cost, including pipe, insulation, fittings, hangers, supports, installation ($/m)
ℓ_{PC} = multiplier on THT to give total cold piping run (can be different from ℓ_{PH} if expansion allowance is less)
$C_{COLD,REF}$ = reference cold pipe cost, as above ($/m)
D = pipe diameter (m)
D_{REF} = reference pipe diameter (m)
x_{PIPE} = scaling exponent for piping.

The pipe diameter is assumed to scale with the square root of the flow rate, which is in turn proportional to the product of the solar multiple times the design point thermal power delivered to the process:

$$\frac{D}{D_{REF}} = \left(\frac{SM \times P_{th}}{SM_{PIPE,REF} \times P_{th,PIPE,REF}}\right)^{0.5} \qquad (V.A-14)$$

Default values are based on a molten salt design in which hot and cold runs are the same length (allowing the total reference cost to be put in either $C_{HOT,REF}$ or $C_{COLD,REF}$):

ℓ_{PH} (FPLH) = 2.6

ℓ_{PC} (FPLC) = 2.6

$C_{HOT,REF}$ (CHPREF) = \$2.84 x 10^4

$C_{COLD,REF}$ (CCPREF) = \$0.0/m

$SM_{PIPE,REF}$ (SMPI) = 1.5

$P_{th,PIPE,REF}$ (PPIREF) = 2.6 x 10^8 watts

x_{PIPE} (XPI) = 1.06 (Reference 31)

V.A-8. Storage–In DELSOL the cost of storage is based on a reference containment cost and and size, and if the storage size exceeds a tank size limit then two smaller tanks of equal size are used instead. The equation for storage cost is

$$CC_{STORAGE} = n_{STOR}\left(C_{TK,REF}\left(1 + \frac{n_{EMPTY}}{n_{STOR}}\right)\left(\frac{V'_{TK}}{V_{TK,REF}}\right)^{x_{ST}} + C_{MED,REF}\frac{V'_{TK}}{V_{TK,REF}}\right) \qquad (V.A-15)$$

where n_{STOR} = number of storage tanks, or hot/cold pairs
n_{EMPTY} = number of spare tanks (for drainage or backup)
$C_{TK,REF}$ = reference storage media containment cost (including hot and cold tank pair, if so designed, insulation, foundation, valving, etc.) (\$)
$C_{MED,REF}$ = reference storage media cost (\$)
V'_{TK} = tank volume (m^3)
$V_{TK,REF}$ = reference tank volume (m^3)
x_{ST} = scaling exponent for tanks.

n_{STOR} is determined from an assumed maximum volume per tank:

$$n_{STOR} = \frac{V_{STOR}}{V_{TK,MAX}}$$

where V_{STOR} = total volume required for storage (m^3)
$V_{TK,MAX}$ = maximum tank volume (m^3)

For non-integer values, n_{STOR} is rounded to the next highest integer. The total storage volume is related directly to the energy in storage:

$$V_{STOR} = V_{TK,REF}\left(\frac{E_{STOR}}{E_{STOR,REF}}\right) \qquad (V.A-16)$$

where E_{STOR} is the energy in storage. The individual tank volume is:

$$V'_{TK} = \frac{V_{STOR}}{n_{STOR}} \qquad (V.A-17)$$

assuming that multiple tanks will be constructed of equal volume. If only a single tank design is desired, the user can choose an appropriately large value for $V_{TK,MAX}$.

In DELSOL, storage is initially sized for the excess energy production on the longest day, June 21st. This storage size is always calculated and used in the system optimization process. The calculation of E_{STOR} is illustrated in Figure V-3. Its value is determined by a numerical integration to give the shaded area in the figure. The nominal number of hours of storage is simply E_{STOR} divided by P_{DES}. The assumption is made that this day will require the largest storage tank, so that no energy is thrown away at any time during the year. However, for north biased fields this assumption is not necessarily valid, since due to higher field efficiencies at other days of the year the integrated value mentioned above could be higher at another day than June 21, thus leading to discarded energy when the storage tank is sized for June 21. On the other hand, it is possible that having a smaller storage tank and discarding energy may be more cost effective than never discarding energy. The user is therefore given the option of optimizing the storage size to balance the cost of the storage tank against the cost of discarding energy. This option, which is specified using the variables ISTR and NSTR (Section IV.C-5), is requested as part of system optimization, but the storage optimization and final storage tank cost calculation is done during a final performance calculation. This is the only component cost which may be recalculated during a final performance calculation.

Default values for calculating storage costs are based on a hot tank/cold tank design:

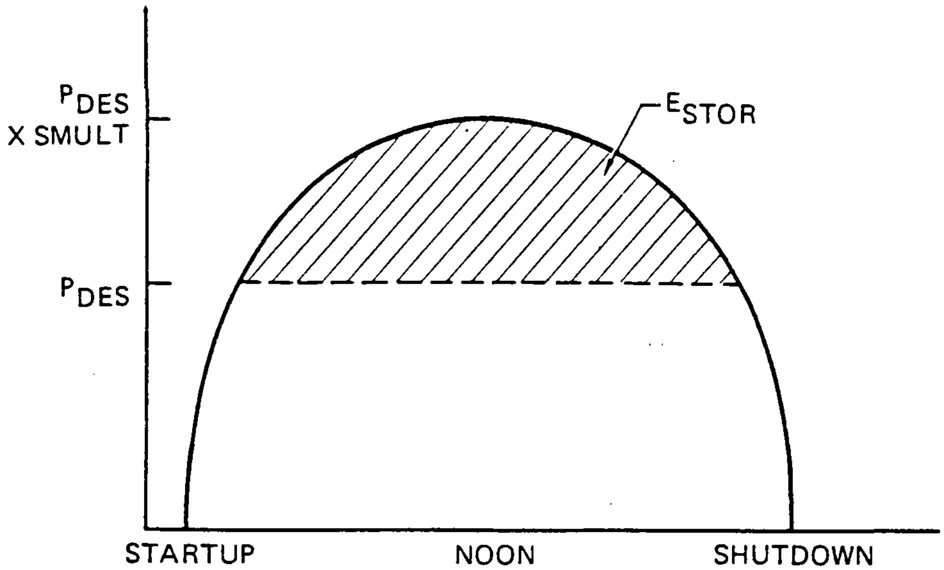


Figure V-3. Energy to storage is the excess energy produced above the design point requirement; it is given by the hatched area. The reference time in this example is noon.

$$n_{EMPTY} \text{ (EMPTY)} = 0.0$$

$$C_{TK,REF} \text{ (CSTREF)} = \$9.70 \times 10^6$$

$$C_{MED,REF} \text{ (CSTRMD)} = \$6.80 \times 10^6$$

$$V_{TK,REF} \text{ (VSTREF)} = 3740 \text{ m}^3$$

$$x_{ST} \text{ (XST)} = 0.6 \text{ (Reference 31)}$$

$$V_{TK,MAX} \text{ (VMAX)} = 1.23 \times 10^4 \text{ m}^3$$

$$E_{STOR,REF} \text{ (ESTREF)} = 6.88 \times 10^8 \text{ watt-hrs}$$

V.A-9. Heat Exchanger Between the Receiver Fluid and the Storage Fluid–For current technology systems it may be desirable to have different types of fluids for the receiver and for storage, since fluids which store energy well (e.g., molten nitrate salt) may not absorb energy in a receiver as well as other fluids (e.g., liquid sodium). In this case, a separate heat exchanger is required as an interface between the two fluids. The cost of that heat exchanger scales with thermal power at the base of the tower:

$$CC_{HTXSTOR} = C_{KN,REF} \left(\frac{P_{th}}{P_{th,KN,REF}} \right)^{x_{KN,P}} \qquad (V.A-18)$$

where $C_{KN,REF}$ = Cost of receiver fluid-to-storage fluid heat exchanger for the reference thermal power ($)

P_{th} = Actual thermal power at the base of the tower

$P_{th,KN,REF}$ = Reference thermal power at the base of the tower for the receiver fluid-to-storage fluid heat exchanger (watts)

$x_{KN,P}$ = Scaling exponent

The cost of this heat exchanger is only included if the variable ICKN = 1 (Namelist NLCOST). The default values are based on the cost of sodium steam generator heat exchangers:

$$\text{ICKN} = 0$$

$$C_{KN,REF} \text{ (CKNREF)} = \$9.0 \times 10^6$$

$$P_{th,KN,REF} \text{ (PKNREF)} = 320.0 \times 10^6 \text{ watts}$$

$$x_{KN,P} \text{ (XKN)} = 0.8$$

V.A-10. Heat Exchangers Related to Generating Electricity–There are two options for calculating heat exchanger component costs, the first of which scales the cost of a reference system based on thermal power into the heat exchangers (out of storage), and the second of which scales the cost of a reference system based on individual heat exchanger areas.

a) ICHE = 0 (default)–cost scales with thermal power into the heat exchangers based on a reference system:

$$CC_{HTXCHG} = C_{HE,REF}\left(\frac{P_{th}}{P_{th,HE,REF}}\right)^{x_{HE,P}} \qquad (V.A-19)$$

where $C_{HE,REF}$ = reference heat exchanger subsystem cost ($)
P_{th} = actual thermal power into the heat exchangers
$P_{th,HE,REF}$ = reference design thermal power into the heat exchangers (out of storage) (watts)
$x_{HE,P}$ = scaling exponent

Default values are based on proposed molten salt designs, and the total subsystem cost includes an evaporator, superheater, and reheater:

$C_{HE,REF}$ (CHEREF) = $\$15.2 \times 10^6$

$P_{th,HE,REF}$ (PHEREF) = 3.0×10^8 watts

$x_{HE,P}$ (XHEP) = 0.8

b) ICHE ≠ 0–cost scales with individual heat exchanger areas based on a reference system:

$$CC_{HTXCHG} = N_{PH}C_{PH,REF}\left(\frac{A'_{PH}}{A_{PH,REF}}\right)^{x_{HE,A}} + n_{EV}C_{EV,REF}\left(\frac{A'_{EV}}{A_{EV,REF}}\right)^{x_{HE,A}} + n_{SH}C_{SH,REF}\left(\frac{A'_{SH}}{A_{SH,REF}}\right)^{x_{HE,A}} + n_{RH}C_{RH,REF}\left(\frac{A'_{RH}}{A_{RH,REF}}\right)^{x_{HE,A}} \qquad (V.A-20)$$

where subscripts PH, EV, SH, and RH refer to the preheater, evaporator, superheater, and reheater, respectively, and:

n_i = number of type i heat exchangers
$C_{i,REF}$ = reference cost of single type i heat exchanger ($)
A_i = area of heat exchanger i (m^2)
$A_{i,REF}$ = area of reference type i heat exchanger (m^2)

$x_{HE,A}$ = scaling exponent.

n_i is calculated from a specified maximum area $A_{i,MAX}$ for a type i heat exchanger:

$$n_i = \frac{A_i}{A_{i,MAX}} \qquad (V.A-21)$$

where

$$A_i = A_{i,REF}\left(\frac{P_{th}}{P_{th,i,REF}}\right) \qquad (V.A-22)$$

and

$$A_i' = \frac{A_i}{n_i} \qquad (V.A-23)$$

For non-integer values of n_i in Equation (V.A-21), it is rounded to the next highest integer. Default values are based on sodium hockey stick designs (Reference 40), and no preheater is included. (Salt heat exchangers have not yet been studied in detail by the authors for costing according to this option.) Also, $A_{i,MAX}$ is set sufficiently large so that only single units will be built.

$C_{PH,REF}$ (CPHREF) = \$0.0

$A_{PH,REF}$ (APHREF) = 1.0 m^2

$A_{PH,MAX}$ (APHMAX) = 10^{10} m^2

$P_{th,PH,REF}$ (PPHREF) = 1.0 watt

$C_{EV,REF}$ (CEVREF) = \$3.77 × 10^6

$A_{EV,REF}$ (AEVREF) = 1300.0 m^2

$A_{EV,MAX}$ (AEVMAX) = 10^{10} m^2

$P_{th,EV,REF}$ (PEVREF) = 2.6 × 10^8 watts

$C_{SH,REF}$ (CSHREF) = \$1.24 × 10^6

$A_{SH,REF}$ (ASHREF) = 400.0 m^2

$A_{SH,MAX}$ (ASHMAX) = 10^{10} m^2

$P_{th,SH,REF}$ (PSHREF) $= 2.6 \times 10^8$ watts

$C_{RH,REF}$ (CRHREF) $= \$1.38 \times 10^6$

$A_{RH,REF}$ (ARHREF) $= 310.0\ m^2$

$A_{RH,MAX}$ (ARHMAX) $= 10^{10}\ m^2$

$P_{th,RH,REF}$ (PRHREF) $= 2.6 \times 10^8$ watts

$x_{HE,A}$ (XHEA) $= 0.6$

V.A-11. Electric Power Generating Subsystem (EPGS)–This cost, which includes the cost of the turbine plant and electric plant, is scaled from a reference system cost:

$$CC_{EPGS} = C_{EPGS,REF} \left(\frac{\eta_{TE,REF} P_{th}}{P_{EPGS,REF}} \right)^{x_{EPGS}} \qquad (V.A-24)$$

where $C_{EPGS,REF}$ = cost of reference EPGS subsystem (turbine plant and electric plant) ($)
$P_{EPGS,REF}$ = gross power rating of reference subsystem (watts)
$\eta_{TE,REF}$ = design point thermal to electric conversion efficiency (see section III.G-5).

Default values assume a 112 $MW_{E,gross}$ output and constant $\eta_{TE,REF}$ for all power levels.

$C_{EPGS,REF}$ (CEGREF) $= \$37.5 \times 10^6$

$P_{EPGS,REF}$ (PEGREF) $= 1.12 \times 10^8$

$\eta_{TE,REF}$ (ETAREF) $= 0.42$

x_{EPGS} (XEPGS) $= 0.8$

Note: This cost is automatically set to zero for a user specified industrial process heat design (IPH $\neq 0$ in Namelist NLEFF).

V.A-12. Fixed Costs–It is assumed that, regardless of plant size, all plants have some common field costs (e.g., buildings and roads, master control, etc.). The structures and improvements, as well as miscellaneous equipment, are somewhat related to the electric power output of the plant, while some other costs are related to the size and amount of other equipment (capital costs). The fixed cost algorithm is based on Reference 35, and can only be partly changed by the user:

$$CC_{FIXED} = 2.0E6 + 0.14 \times DCC + 0.093 \times P_e + C_{FIXED} \qquad (V.A - 25)$$

where DCC = all other direct capital costs
P_e = design point turbine electric power (watts)
C_{FIXED} = any other additional fixed costs

The user only has control over C_{CFIXED}, which has a default of:

C_{FIXED} (CFIXED) = \$0.0

V.B. Calculation of Levelized Energy Cost

Based on the total capital cost CC_T defined in Equation (V.A-1) using the component cost models discussed in the previous section, a levelized (or discounted average) cost of energy over the lifetime of the plant is calculated as follows (References 41 and 42):

1) The total investment at operation startup, $CC_{ST-UP,T}$, will be the current capital cost estimate, CC_T, escalated over the time period from the time of the cost estimate to the first year of construction (NYTCON), plus the interest on the borrowed investment during the construction period, i_{DC}. Note that the length of the construction period is not explicitly stated, but that time period would be factored into the value of i_{DC}.

$$CC_{ST-UP,T} = CC_T \times (1.0 + i_{DC})(1.0 + ESC)^{NYTCON} \qquad (V.B - 1)$$

In current, supposedly more valuable dollars,

$$CC_{ST-UP,cur\$} = \frac{CC_{ST-UP,T}}{(1.0 + r_{inf})^{NYTCON}} \qquad (V.B - 2)$$

where r_{inf} is the general rate of inflation, which is not necessarily equal to the capital escalation rate ESC.

2) The levelized energy cost includes both capital recovery and operating and maintenance (O&M) charges. The O&M charges are calculated as a levelized percentage of the capital cost. DELSOL splits O&M charges into heliostat and non-heliostat rates:

$$LEC = \frac{(FCR \times CC_{ST-UP,T}) + (O\&M_{H,LEV} \times CC_{ST-UP,H}) + (O\&M_{BAL,LEV} \times CC_{ST-UP,BAL})}{\text{Annual Energy}} \qquad (V.B - 3)$$

where Annual Energy = Net electric annual energy as described in Section III.H

FCR = fixed charge rate, i.e., annual charge against the capital investment to account for returns to shareholders, taxes and insurance, depreciation, debt cost, and discount rate

$O\&M_{H,LEV}$ = levelized heliostat O&M rate

$CC_{ST-UP,H}$ = heliostat subsystem capital investment at startup (includes land and wiring)

$O\&M_{BAL,LEV}$ = levelized balance of plant O&M rate

$CC_{ST-UP,BAL}$ = balance of plant capital investment at startup

V.B-1. Fixed Charge Rate–The user is allowed one of two options for determining the fixed charge rate, FCR:

a) IFCR = 0–user specified value of FCR. In this case, the values of DISRT, RINF, and NYOP still need to be specified correctly for use in calculating O&M rates.

b) IFCR ≠ 0–FCR is calculated by DELSOL based on user supplied values of economic parameters.

$$FCR = PTI + \frac{(1.0 - ITC) - (ITR \times DEP)}{(1.0 - ITR)f_{DIS}} \qquad (V.B-4)$$

where PTI = annual property tax and insurance rate

ITC = investment tax credit

ITR = income tax rate

DEP = depreciation allowance, discussed below

f_{DIS} = discount factor, discussed below.

With option b) above (IFCR≠0), the user is allowed one of two choices for calculating the depreciation allowance:

1) IDEP = 1–straight line schedule:

$$DEP = \sum_{y=1}^{Y_{DEP}} \frac{(1.0/Y_{DEP})}{(1.0 + r_{DIS})^y} \qquad (V.B-5)$$

where Y_{DEP} = depreciation life of the solar plant (years)

r_{DIS} = discount rate, discussed below.

2) IDEP = 2–sum-of-years digits schedule:

$$DEP = \sum_{y=1}^{Y_{DEP}} \frac{2(Y_{dEP} - y + 1)}{Y_{DEP}(Y_{DEP} + 1)(1 + r_{DIS})^y} \qquad (V.B-6)$$

The discount rate r_{DIS} is the effective cost of money to the owner and includes both debt cost and return on equity requirements according to:

$$r_{DIS} = [(1.0 - ITR) \times f_D \times i_D] + (1.0 - f_D) \times ROE \qquad (V.B-7)$$

where f_D = debt fraction
i_D = debt cost (interest rate on borrowed capital)
ROE = before tax return on equity.

(Note that r_{DIS} = ROE for $f_D = 0$; i.e., 100% equity financed projects.)

The discount factor is:

$$f_{DIS} = \sum_{y=1}^{Y_{OP}} \frac{1.0}{(1.0 + r_{DIS})^y} \qquad (V.B-8)$$

where Y_{OP} = economic operating life of the plant (years).

V.B-2. Levelized O&M Rates–The levelized O&M rates are determined from the initial rate, $O\&M_i$; the yearly inflation and discount rates, r_{inf} and r_{DIS}, respectively; and the plant operating life, Y_{OP}:

$$O\&M_{LEV} = \frac{\sum_{y=1}^{Y_{OP}} \frac{O\&M_y}{(1+r_{DIS})^y}}{\sum_{y=1}^{Y_{OP}} \frac{1}{(1+r_{DIS})^y}} = \frac{O\&M_i \sum_{y=1}^{Y_{OP}} \frac{(1+r_{inf})^y}{(1+r_{DIS})^y}}{\sum_{y=1}^{Y_{OP}} \frac{1}{(1+r_{DIS})^y}} \qquad (V.B-9)$$

Default values are based mostly on 1984 5-year plan economics:

i_{DC} (AFDC) = 0.0318 (assumes a 3-year construction period)

ESC (ESC) = 0.00

NYTCON (NYTCON) = 0 (assumes plant construction begins now)

r_{inf} (RINF) = 0.00

IFCR (IFCR) = 0

FCR (FCR) = 0.0615

$O\&M_{h,i}$ (RHOM) = 0.015

$O\&M_{BAL,i}$ (RNHOM) = 0.015

PF (PF) = 0.9

r_{DIS} (DISRT) = 0.0315

PTI (PTI) = 0.01

ITC (TC) = 0.10

ITR (TR) = 0.48

f_D (FDEBT) = 0.5431

i_D (RDEBT) = 0.11

ROE (ROE) = 0.15

IDEP (IDEP) = 2

Y_{DEP} (NDEP) = 24 years

Y_{OP} (NYOP) = 30 years

ATTACHMENT B

ENVIRONMENTAL CONDITIONS

BARSTOW, CALIFORNIA

Environmental Conditions – Barstow, California

1\. GENERAL

1.1 Scope

This document lists the environmental conditions for the 10 MWe Solar Central Receiver Pilot Plant to be located at the Southern California Edison (SCE) Cool Water Site near Barstow, California.

2\. DOCUMENTS

The following form a part of this document to the extent stated herein.

MIL-STD-810B Environmental Test Methods

Uniform Building Code - 1976 Edition, Volume I by International Conference of Building Officials

3\. ENVIRONMENTS

Environmental conditions include winds and gusts, temperature extremes, rain, sleet, hail, snow, earthquake and soil conditions as follows:

3.1 Wind

The wind speed specifications at a reference height of 10m (30 ft) shall be:

3.1.1 Speed Frequency

Speed, m/s	(mph)	Frequency, Percent
0-2	(0-4.5)	29
2-4	(4.5-9.0)	21
4-6	(9.0-13.5)	19
6-8	(13.5-18.0)	14
6-10	(18.0-22.5)	8
10-12	(22.5-27.0)	5
12-14	(27.0-31.5)	3
14-	(31.5-)	Less than 1

For the calculation of wind speed at other elevations, assume the following model:

$$V_H = V_1 (H/H_1)^c$$

Where: V_H = wind velocity at height H
V_1 = reference wind velocity
H_1 = reference height (assume 10 m, 30 ft)
c = 0.15

3.1.2 Wind Rise Rate. A maximum wind rise rate of 0.01 m/s^2 (0.02 mph/s^2). A maximum wind of 25 m/s (55 mph) from any direction may occur resulting from unusual rapid wind rise rates, such as severe thunderstorm gust fronts.

3.1.3 Survival Wind. A maximum wind speed, including gusts, of 40 m/s (90 mph).

3.1.4 Dust Devils. Dust devils with wind speeds up to 17 m/s (38 mph).

3.1.4 Sandstorm Environment. Sandstorm limits within tests per MIL-STD-810B, Method 510.

3.2 Temperature

Ambient air temperatures range from -30°C to +50°C (-20°F to + 120°F).

3.3 Precipitation

3.3.1 Rain - Average annual: 750 mm (30 in) Maximum 24-hour rate: 75 mm (3 in)

3.3.2 Ice - Freezing rain and ice deposts in a layer up to 50 mm (2 in) thick.

3.3.3 Hail -

Diameter	25 mm (1 in)
Specific Gravity	0.9
Terminal Velocity	23 m/s (75 ft/s)

3.3.4 Snow - Maximum 24-hour rate: 0.3m (1 ft.); maximum loading: 250 Pa (5 lbs/ft^2).

3.4 Insolation

3.4.1 Maximum Flux. Direct normal nominal insolation of 1100 watts/square metre maximum at the plant site.

3.4.2 Rate of Change. The maximum rate of change of incident flux shall be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the pilot plant site at a velocity of 20 m/s (45 mph).

3.5 Earthquate

Seismic zone 3 (Uniform Bldg. Code).

3.6 Soil Properties

The surface deposits of silty sand, which extends to depths of from 0.3m to 1.5m (1 ft to 5 ft), are only moderately firm and become weaker when wet. The sand below a depth of about 1.5m (5 ft) is firm but contains thin layers of relatively soft silt. In general, the sand is firmer below 3m (10 ft) and layers of soft silt were not encountered.

3.6.1 G, Shear Modulus, and E, Secant Modulus

$$\text{Shear Modulus} = G = \frac{\beta(h+z)}{2(1+\mu)} = \frac{\beta y}{2.6}$$

$$\text{Secant Modulus} = E = \beta(h+z) = \beta y$$

Where β = function of soil depth (see chart)
h = depth of burden
z = depth from burden
μ = constant = 0.3
y = depth from surface

Soil Depth (y)		Density		β		Secant Modulus at the free surface	
(m)	(ft)	(kg/m^3)	(Lb/ft^3)	(MPa/m)	(psi/ft)	(MPa)	(psi)
0-1.5	(0-5)	1600	(100)	1.7	(75)	0.7	(100)
1.5-3.0	(5-10)	1840	(115)	2.5	(110)	1.4	(200)
3.0-	(10-)	1920	(120)	3.4	(150)	2.1	(300)

At depth of 1.5m (5 ft) G = 10 MPa, (1500 psi)
E = 28 MPa (4000 psi)

At depth of 3.0m (10 ft) G = 32 MPa, (4600 psi)
E = 83 MPa (12,000 psi)

Geophysical data (from seismic refraction investigation) indicates a shear modulus at a strain rate of 10^{-4} m/m (in/in) of between 100 to 140 MPa (15,000 to 20,000 psi) at a depth of 3m (10 ft).

3.6.2. Bearing Capacity (allowable for standard spread or mat-type foundations).

Depth, m(ft)		Load kPa(psf)	
0.6	(2)	70	(1,500)
1.5	(5)	240	(5,000)
3.0	(10)	480	(10,000)

3.6.3 Penetration Data. The number of blows required to drive a materials sampler 300mm (12 in) was recorded for a number of borings. To a depth of 7.5m (25 ft) a weight of 725 kg (1600 lb) (Kelly weight) falling a distance of 0.3m (1 ft) was used to drive the 76mm (3 in) diameter sampler.

Number of Blows to Drive an LC&A Sampler 300m (12 in)

Depth (m)	(ft)	Average	Range	No. of Samples
0 - 1.5	(0-5)	2.6	0 - 9	74
1.5 - 3.0	(5-10)	4.2	1 - 10	42
3.0 - 4.5	(10-15)	5.9	2 - 11	31
4.5 - 6.0	(15-20)	8.0	4 - 15	19
6.0 - 7.5	(20-25)	9.0	5 - 20	17

Note: There does not appear to be a direct conversion between these data and a standard penetration test, so the results are qualitative in nature

3.6.4 Water Table. Below 30 m (100 ft)

ENCLOSURE III
EXHIBIT V

Environmental Conditions - Barstow, California

1. GENERAL

1.1 Scope

This document lists the environmental conditions for the 10 MWe Solar Central Receiver Pilot Plant to be located at the Southern California Edison (SCE) Cool Water Site near Barstow, California.

2. DOCUMENTS

The following form a part of this document to the extent stated herein.

MIL-STD-810B Environmental Test Methods

Uniform Building Code - 1976 Edition, Volume I by International Conference of Building Officials

3. ENVIRONMENTS

Environmental conditions include winds and gusts, temperature extremes, rain, sleet, hail, snow, earthquake and soil conditions as follows:

3.1 Wind

The wind speed specifications at a reference height of 10m (30 ft) shall be:

3.1.1 Speed Frequency

Speed, m/s	(mph)	Frequency, Percent
0-2	(0-4.5)	29
2-4	(4.5-9.0)	21
4-6	(9.0-13.5)	19
6-8	(13.5-18.0)	14
6-10	(18.0-22.5)	8
10-12	(22.5-27.0)	5
12-14	(27.0-31.5)	3
14-	(31.5-)	Less than 1

For the calculation of wind speed at other elevations, assume the following model:

$$V_H = V_1(H/H_1)^c$$

Where: V_H = wind velocity at height H
V_1 = reference wind velocity
H_1 = reference height (assume 10 m, 30 ft)
c = 0.15

3.1.2 Wind Rise Rate. A maximum wind rise rate of 0.01 m/s^2 (0.02 mph/s^2). A maximum wind of 25 m/s (55 mph) from any direction may occur resulting from unusual rapid wind rise rates, such as severe thunderstorm gust fronts.

3.1.3 Survival Wind. A maximum wind speed, including gusts, of 40 m/s (90 mph).

3.1.4 Dust Devils. Dust devils with wind speeds up to 17 m/s (38 mph).

3.1.4 Sandstorm Environment. Sandstorm limits within tests per MIL-STD-810B, Method 510.

3.2 Temperature
Ambient air temperatures range from $-30^{\circ}C$ to $+50^{\circ}C$ ($-20^{\circ}F$ to $+ 120^{\circ}F$).

3.3 Precipitation

3.3.1 Rain - Average annual: 750 mm (30 in) Maximum 24-hour rate: 75 mm (3 in)

3.3.2 Ice - Freezing rain and ice deposts in a layer up to 50 mm (2 in) thick.

3.3.3 Hail -

Diameter	25 mm (1 in)
Specific Gravity	0.9
Terminal Velocity	23 m/s (75 ft/s)

3.3.4 Snow - Maximum 24-hour rate: 0.3m (1 ft.); maximum loading: 250 Pa (5 lbs/ft^2).

3.4 Insolation

3.4.1 Maximum Flux. Direct normal nominal insolation of 1100 watts/square metre maximum at the plant site.

3.4.2 Rate of Change. The maximum rate of change of incident flux shall be assumed as that which would result from the passage of an opaque cloud across an otherwise clear sky where the sharp leading or trailing edges of the shadow move across the pilot plant site at a velocity of 20 m/s (45 mph).

3.5 Earthquate

Seismic zone 3 (Uniform Bldg. Code).

3.6 Soil Properties

The surface deposits of silty sand, which extends to depths of from 0.3m to 1.5m (1 ft to 5 ft), are only moderately firm and become weaker when wet. The sand below a depth of about 1.5m (5 ft) is firm but contains thin layers of relatively soft silt. In general, the sand is firmer below 3m (10 ft) and layers of soft silt were not encountered.

3.6.1 G, Shear Modulus, and E, Secant Modulus

$$\text{Shear Modulus} = G = \frac{\beta(h+z)}{2(1+\mu)} = \frac{\beta y}{2.6}$$

$$\text{Secant Modulus} = E = \beta(h+z) = \beta y$$

Where β = function of soil depth (see chart)
h = depth of burden
z = depth from burden
μ = constant = 0.3
y = depth from surface

Soil Depth (y)		Density		β		Secant Modulus at the free surface	
(m)	(ft)	(kg/m^3)	(Lb/ft^3)	(MPa/m)	(psi/ft)	(MPa)	(psi)
0-1.5	(0-5)	1600	(100)	1.7	(75)	0.7	(100)
1.5-3.0	(5-10)	1840	(115)	2.5	(110)	1.4	(200)
3.0-	(10-)	1920	(120)	3.4	(150)	2.1	(300)

At depth of 1.5m (5 ft) G = 10 MPa, (1500 psi)
E = 28 MPa (4000 psi)

At depth of 3.0m (10 ft) G = 32 MPa, (4600 psi)
E = 83 MPa (12,000 psi)

Geophysical data (from seismic refraction investigation) indicates a shear modulus at a strain rate of 10^{-4} m/m (in/in) of between 100 to 140 MPa (15,000 to 20,000 psi) at a depth of 3m (10 ft).

3.6.2. Bearing Capacity (allowable for standard spread or mat-type foundations).

Depth, m(ft)		Load kPa(psf)	
0.6	(2)	70	(1,500)
1.5	(5)	240	(5,000)
3.0	(10)	480	(10,000)

3.6.3 Penetration Data. The number of blows required to drive a materials sampler 300mm (12 in) was recorded for a number of borings. To a depth of 7.5m (25 ft) a weight of 725 kg (1600 lb) (Kelly weight) falling a distance of 0.3m (1 ft) was used to drive the 76mm (3 in) diameter sampler.

Number of Blows to Drive an LC&A Sampler 300m (12 in)

Depth (m)	(ft)	Average	Range	No. of Samples
0 - 1.5	(0-5)	2.6	0 - 9	74
1.5 - 3.0	(5-10)	4.2	1 - 10	42
3.0 - 4.5	(10-15)	5.9	2 - 11	31
4.5 - 6.0	(15-20)	8.0	4 - 15	19
6.0 - 7.5	(20-25)	9.0	5 - 20	17

Note: There does not appear to be a direct conversion between these data and a standard penetration test, so the results are qualitative in nature

3.6.4 Water Table. Below 30 m (100 ft)

ATTACHMENT C

UTILITY CONCENSUS GUIDELINES

EGGS/BALANCE OF PLANT REDUNDANCY

ATTACHMENT C

UTILITY CONCENSUS GUIDELINES
EPGS/BALANCE OF PLANT REDUNDANCY

I. INTRODUCTION

Definitions

Balance of plant -- That portion of the solar power generating facility that consists of the turbine, condenser, condensate feedwater, cooling tower and all other associated auxilliary equipment.

Redundancy

Those major plant components which are considered to be the less reliable (available), and which may result in either 100% loss of the unit or require several months outage to repair or replace. Redundancy is usually incorporated into the design by using more than a single (one) item of equipment.

II. BACKGROUND

The degree of redundancy to be incorporated into a plant design is generally determined by past operating experience and/or utility preference. Following is a discussion of experience with Solar One.

Solar One

The design of Solar One incorporates a minimum of redundancy (one boiler feed pump, one condensate pump, one condenser vacuum pump). Two each of: raw service water pumps, service & instrument air compressors and circulating water pumps were also included. It is probable that two circulating water pumps were included to save on auxilliary power during winter generation and not for redundancy. The P&ID also indicate that control false bypasses were not included.

III. RECOMMENDATIONS

Based on good operating experience with generating units of 100 to 200 MW in size; the peaking application of the solar generating facility (similar to current gas turbine applications); and satisfactory operation of Solar One;

it is recommended that a minimum of redundancy be incorporated into the balance of plant which is to be used for the utility study.

It is further recommended that the design be based on the following:

1. A single turbine, condenser, de-aerator, and single string feedwater heaters.

2. Delete the in-line condensate polish unit, leave space for the addition at a later date.

3. Two 100% condenser vacuum pumps (Nash-type), raw water service pumps, service & instrument and compressors, bearing cooling water, hydrogen and lube oil cooler pumps, two 50% condensate pumps, steam generator feed pumps (each with motor and hydraulic coupling), boiler circulating pumps, circulating water pumps (use horizontal split case rather than vertical pullout).

4. One each, service water storage tank, condensate storage, and raw water demineralizer. One auxilliary boiler (electric) to provide steam to the de-aerator and turbine seals after extended outage.

5. Usual design practice for piping and valves; except no bypass around control valves; individual drains from feedwater heaters to condenser including water induction provisions, and nitrogen blanketing, mainteam piping, with desuperheater to bypass turbine to condenser, which is required to match turbine metal and main steam temperature during startup.

6. The control system for the balance of plant is expected to be conventional and will be incorporated into the plant master control design.

DLT
12-15-86

ATTACHMENT D

SOLAR CENTRAL RECEIVER TECHNOLOGY ADVANCEMENT STUDY

COMMENTS ON DELSOL III COST SCALING RELATIONSHIPS

AND DEFAULT INPUT VALVES

SOLAR CENTRAL RECEIVER TECHNOLOGY ADVANCEMENT STUDY
COMMENTS ON DELSOL III COST SCALING RELATIONSHIPS
AND DEFAULT INPUT VALUES

Total Cost Model. The DI(EXT) default value of 0.16 for distributable and indirect costs appears low. A representative number is 0.23, which includes 12.5 percent for field indirect costs, 7 percent for engineering and home office costs, and 2 percent for architect-engineer fees.

The contingency (CONT) default value of 12 percent also appears low. Bechtel estimating practice indicates a value of 15 percent.

Land. In California, the land value (CL) of $\$0.62/m^2$ (\$2500/acre) represents a price for prime agricultural land currently under cultivation. The Carrisa Plains plant cost estimate assumed a land cost of \$1000/acre for that arid, dry-farming area. Land prices at sites identified by PGandE in the San Joaquin Valley are \$200-\$300/acre for barren land without surface water rights and suitable for cultivation of row crops, \$3000-\$5000/acre for vineyards and \$6000-\$8000/acre for orchards.

A purchase price of \$950/acre should be used. The SCR site impact study made by Bechtel for PGandE anticipated this price for uncultivated land with surface water nearby. If the site occupies more than two-thirds of any one 640-acre section, purchase of the entire section should be assumed.

R&D/5459E/kn

Clearing and grubbing should cost roughly \$600/acre, based on Bechtel estimates for other fairly flat sites. A perimeter fence should cost roughly \$12/lineal foot.

Receiver. The receiver default cost value corresponds to a unit cost of \$30,300/m^2, and is intended to reflect cavity receiver cost. For external receivers, representative unit costs are \$21,200/m^2 for nitrate salt designs and \$25,400 for sodium designs. This is based on a compilation of data from the following sources:

- Carrisa Plains final design effort
- PGandE evaluation of commercial size central receiver plants
- Sandia National Laboratories Livermore

The corresponding input values are CREC1 = \$24.1 $X10^6$ and ARECRF = 1136.0m^2 for nitrate salt receivers, and CREC1 = \$15.4 X 10^6 and ARECRF = 607.0m^2 for sodium receivers.

Pumps. The reference pump cost $C_{RP,REF}$ in formula V.A-11 seems appropriate for nitrate salt receivers, without provisions for hydraulic recovery at the base of the tower. For sodium receivers in a closed loop with a sodium-to-salt heat exchanger, a new reference pump cost will be developed by PGandE/Bechtel.

Piping. The default values for FPLH and FPLC assumed that the hot and cold pipe runs are the same length. Actually, the expansion loop

R&D/5459E/kn

requirements in the hot piping are approximately twice the requirements in the cold piping. Allowing for expansion loops, and assuming that the pipe run lengths outside of the tower are equal to one-half the tower height, representative values for FPLH and FPLC become 3.0 and 2.3, respectively. Recommended pipe cost algorithms are shown in Appendix J to the consensus guidelines.

Storage. The hot and cold tank cost (CSTREF) of $\$9.7 \times 10^6$ for a 688 MWht system appears high. Based on vendor information obtained for the PGandE Evaluation of Commercial Size Central Receiver Plants, a representative cost for externally insulated tanks in a 688 MWht system is $\$3.7 \times 10^6$.

The maximum tank volume (VMAX) of $1.23 \times 10^4 m^3$ (146 ft. dia X 26 ft. high) should be readily achieved with existing tank technology.

Based on a budgetary estimate from Struthers Wells Corp. for a double tube, double tubesheet design, the cost of a 320 MWt intermediate heat exchanger (CKNREF) should be $\$6.2 \times 10^6$. The cost scaling exponent (XKN) should be 0.5, based on steam generator cost information from Babcock and Wilcox (see next item).

Heat Exchangers. The steam generator cost scaling exponent (XHEP) should be 0.5, based on data from Babcock and Wilcox in its Sandia steam generator design report.

Financial Calculations. Formula V.B-2, in order to correctly deflate the total investment over the entire construction period, needs to use an exponent representing the entire construction period. NYTCON should therefore be set equal to the construction period in years.

R&D/5459E/kn

For the formula V.B-1 on page 131 to correctly account for escalation during construction, the exponent now labelled "NYTCON" should equal two-thirds of the construction period. Since NYTCON is used to represent the full construction period in formula V.B-2, the exponent in formula V.B-1 should be changed from "NYTCON" to "$\frac{2\ NYTCON}{3}$".

Formula V.B-1 does not include allowances for construction period expenses, owner's services directly associated with the project, plant startup expenses, property taxes and insurance during construction, and sales taxes. These are typically estimated to be 6 percent of the plant cost in year "0" of the construction schedule, and are not subjected to escalation and AFDC calculations. Adding the term "$+ 0.06CC_T$" to formula V.B-1 will account for these items.

Representative parameters for private utility financing of power plant construction are given below. These parameters are based on the following assumptions:

- PGandE financial structure - specifically, return on equity and interest rate on debt as outlined in the Second Application to the California Public Utilities Commission (August 20, 1986) concerning avoided cost payments to qualifying facilities.
- Levelized 30-year general inflation rate of 5 percent.
- Constant year, 1986 dollars.
- New federal tax regulations.
- Depreciation based on 150 percent declining balance, switching to straight line depreciation, for a total of 15 years.

The resulting DELSOL3 financial parameters are as follows:

- Escalation rate (ESC) of 0.00
- General inflation rate (RINF) of 0.00
- Fixed charge rate (FCR) of 0.105
- Heliostat field O&M rate (RHOM) of 0.010

R&D/5459E/kn

- Balance of plant O&M rate (RNHOM) of 0.015
- Discount rate (DISRT) of 0.065
- Property tax and insurance rate (PTI) of 0.02
- Investment tax credit (TC) of 0.00
- Combined federal and state income tax rate (TR) of 0.403
- Debt fraction (FDEBT) of 0.50
- Debt interest rate (RDEPT) of 0.095 (nominal, current year value)
- Return on equity (ROE) of 0.1403 (nominal, current year value)
- Depreciation life (NDEP) of 15 years
- Plant operating life (NYOP) of 30 years

The DELSOL input IFCR is set equal to zero when using the fixed charge rate given above, and in this case the depreciation formulas (IDEP) listed in DELSOL3 are disregarded. They are not appropriate for current utility financing analyses. A 150 percent declining balance, switching to straight line depreciation when advantageous, should be used. An example of this approach, for a plant investment of $200, is shown below.

	150 Percent declining balance		Straight Line
Year	Depreciation, $	Balance, $	Depreciation, $
1	20.00	180.00	13.33
2	18.00	162.00	12.86
3	16.20	145.80	12.46
4	14.58	131.22	12.15
5	13.12	118.10	11.93
6	11.81	106.29	11.81
7	10.63	95.66	11.81
8	9.57	86.09	11.81
9	8.61	77.48	11.81
10	7.75	69.73	11.81
11	6.97	62.76	11.81
12	6.28	56.48	11.81
13	5.65	50.83	11.81
14	5.08	45.75	11.81
15	4.58	41.17	11.81

In years 1 through 5, the 150 percent method yields higher depreciation figures than the straight line approach, and therefore would be used. In years 6 through 15, however, the depreciation method switches to straight line because the straight line values are greater than the 150 percent figures. This approach was used in calculating the fixed charge rate above.

The interest during construction (AFDC) default value of 0.0318 assumes a 0-year construction period, which is clearly not realistic. Assuming that the center of gravity in the expenditure of construction funds occurs two-thirds of the way through the construction period, the real AFDC factors for construction periods of 1 to 6 years, with a nominal discount rate of 11.9 percent and a levelized escalation rate of 5 percent, are as follows:

Construction Period, Yrs	AFDC Factor
1	0.0214
2	0.0433
3	0.0657
4	0.0886
5	0.1119
6	0.1357

The AFDC factor used in the trade studies should reflect the anticipated plant construction schedule.

R&D/5459E/kn

12/19/86

NEW PIPE COST ALGORITHM ATTACHMENT D

$$DH = A\,(PTH)^{1/2}$$

$$DC = B\,(PTH)^{1/2}$$

$$CPIPE = THT\left[FPLH\left(C + D\times DH + E\times DH^2\right) + FPLC\left(F + G\times DC\right)\right]$$

SALT

$$A = B = \frac{16/39.37}{\sqrt{390\times 10^6}} = \frac{20.58}{10^6}$$

$C = -205.6$

$D = 12{,}957.$

$E = 0.0$

$F = 205.5$

$G = 7250.$

SODIUM

$$A = \frac{26/39.37}{\sqrt{410\times 10^6}} = \frac{32.61}{10^6}$$

$$B = \frac{22/39.37}{\sqrt{410\times 10^6}} = \frac{27.60}{10^6}$$

$C = 2606.$

$D = 2400.$

$E = 9369.$

$F = 599.$

$G = 6469.$

ATTACHMENT E

MOLTEN NITRATE SALT PROPERTIES FOR UTILITY STUDIES

"REVISED" LIST

MOLTEN NITRATE SALT PROPERTIES FOR UTILITY STUDIES

(T in ^{o}F)

(1) $\mu = 60.2844 - 0.17236T + 1.76176 \times 10^{-4} T^2 - 6.11408 \times 10^{-8} T^3$ lbm/ft-hr

(2) $C_p = .345 + 2.28 \times 10^{-5}\ T$ Btu/lbm-^{o}F

(3) $k = .253208 + 6.26984 \times 10^{-5}\ T$ Btu/hr-ft-^{o}F

(4) $T = 15{,}131.6\ [-1+(1+H/2610.20)^{1/2}]$ ^{o}F (H in Btu/lbm)

(5) $\rho = 131.2 - 0.02221\ T$ lbm/ft^3

Sodium Properties

Nuclear Systems Materials Handbook (See Attachment)

Babcock & Wilcox Company

WAA/gdo-6375v

8/26/86

092688

(F)	(LBM/FT3)	(BTU/HR-FT-F)	(BTU/L..-F)	(LBM/HR-FT)	TS00020/DESIGN TERMINAL LINESIZE(13) CALL 'TS0341.CBLIB.LOAD(SODPRPS)'	(B..U/LBM)
200.00	57.965	50.634	.33126	1.7118	.11107E-01	67.654
210.00	57.884	50.454	.33061	1.6644	.10852E-01	70.964
220.00	57.804	50.276	.32996	1.6194	.10607E-01	74.266
230.00	57.723	50.097	.32932	1.5768	.10370E-01	77.563
240.00	57.642	49.919	.32869	1.5363	.10141E-01	80.853
250.00	57.561	49.742	.32806	1.4978	.99195E-02	84.137
260.00	57.481	49.565	.32745	1.4611	.97060E-02	87.414
270.00	57.400	49.388	.32683	1.4262	.94999E-02	90.686
280.00	57.319	49.212	.32623	1.3929	.93010E-02	93.951
290.00	57.238	49.036	.32563	1.3611	.91090E-02	97.210
300.00	57.157	48.860	.32504	1.3307	.89239E-02	100.46
310.00	57.076	48.685	.32446	1.3017	.87452E-02	103.71
320.00	56.994	48.511	.32388	1.2739	.85730E-02	106.95
330.00	56.913	48.336	.32331	1.2473	.84068E-02	110.19
340.00	56.832	48.163	.32274	1.2218	.82466E-02	113.42
350.00	56.751	47.989	.32219	1.1973	.80922E-02	116.64
360.00	56.669	47.816	.32164	1.1738	.79433E-02	119.86
370.00	56.588	47.644	.32109	1.1513	.77999E-02	123.08
380.00	56.507	47.472	.32056	1.1296	.76616E-02	126.28
390.00	56.425	47.300	.32003	1.1087	.75284E-02	129.49
400.00	56.344	47.129	.31950	1.0886	.74001E-02	132.69
410.00	56.262	46.958	.31899	1.0693	.72764E-02	135.88
420.00	56.181	46.787	.31848	1.0507	.71574E-02	139.06
430.00	56.099	46.617	.31798	1.0327	.70427E-02	142.25
440.00	56.017	46.448	.31748	1.0154	.69322E-02	145.42
450.00	55.936	46.279	.31699	.99867	.68259E-02	148.60
460.00	55.854	46.110	.31651	.98252	.67235E-02	151.76
470.00	55.772	45.941	.31603	.96691	.66249E-02	154.93
480.00	55.690	45.773	.31556	.95182	.65300E-02	158.08
490.00	55.608	45.606	.31510	.93722	.64387E-02	161.24
500.00	55.527	45.439	.31465	.92310	.63508E-02	164.39
510.00	55.445	45.272	.31420	.90943	.62661E-02	167.53
520.00	55.363	45.106	.31376	.89618	.61847E-02	170.67
530.00	55.281	44.940	.31332	.88335	.61063E-02	173.81
540.00	55.199	44.775	.31290	.87090	.60308E-02	176.94
550.00	55.116	44.610	.31248	.85883	.59582E-02	180.06
560.00	55.034	44.445	.31206	.84712	.58882E-02	183.19
570.00	54.952	44.281	.31166	.83576	.58210E-02	186.31
580.00	54.870	44.117	.31126	.82472	.57562E-02	189.42
590.00	54.788	43.954	.31086	.81399	.56938E-02	192.53
600.00	54.705	43.791	.31048	.80357	.56338E-02	195.64
610.00	54.623	43.628	.31010	.79344	.55760E-02	198.74
620.00	54.541	43.466	.30972	.78359	.55204E-02	201.84
630.00	54.458	43.305	.30936	.77401	.54668E-02	204.93
640.00	54.376	43.143	.30900	.76468	.54151E-02	208.03
650.00	54.293	42.983	.30864	.75560	.53654E-02	211.11

(F)	(LBM/FT3)	(BTU/HR-FT-F)	(BTU/LBM-F)	(LBM/HR-FT)		(BTU/LBM)
660.00	54.211	42.822	.30830	.74675	.53175E-02	214.20
670.00	54.128	42.662	.30796	.73814	.52714E-02	217.28
680.00	54.046	42.503	.30763	.72974	.52269E-02	220.36
690.00	53.963	42.344	.30730	.72156	.51840E-02	223.43
700.00	53.881	42.185	.30698	.71358	.51426E-02	226.50
710.00	53.798	42.026	.30667	.70580	.51027E-02	229.57
720.00	53.715	41.869	.30637	.69820	.50642E-02	232.64
730.00	53.633	41.711	.30607	.69079	.50270E-02	235.70
740.00	53.550	41.554	.30578	.68356	.49911E-02	238.76
750.00	53.467	41.397	.30549	.67650	.49565E-02	241.82
760.00	53.384	41.241	.30522	.66960	.49230E-02	244.87
770.00	53.301	41.085	.30495	.66286	.48907E-02	247.92
780.00	53.219	40.930	.30468	.65628	.48594E-02	250.97
790.00	53.136	40.775	.30442	.64984	.48291E-02	254.01
800.00	53.053	40.620	.30417	.64355	.47999E-02	257.06
810.00	52.970	40.466	.30393	.63740	.47715E-02	260.10
820.00	52.887	40.313	.30369	.63138	.47441E-02	263.14
830.00	52.804	40.159	.30346	.62549	.47175E-02	266.17
840.00	52.721	40.006	.30324	.61973	.46917E-02	269.20
850.00	52.638	39.854	.30303	.61408	.46667E-02	272.24
860.00	52.555	39.702	.30282	.60856	.46425E-02	275.27
870.00	52.471	39.550	.30261	.60315	.46189E-02	278.29
880.00	52.388	39.399	.30242	.59786	.45960E-02	281.32
890.00	52.305	39.248	.30223	.59267	.45738E-02	284.34
900.00	52.222	39.098	.30205	.58758	.45522E-02	287.36
910.00	52.139	38.948	.30187	.58260	.45312E-02	290.38
920.00	52.056	38.799	.30170	.57771	.45107E-02	293.40
930.00	51.972	38.649	.30154	.57293	.44908E-02	296.42
940.00	51.889	38.501	.30139	.56823	.44715E-02	299.43
950.00	51.806	38.352	.30124	.56362	.44526E-02	302.44
960.00	51.722	38.205	.30110	.55911	.44341E-02	305.46
970.00	51.639	38.057	.30096	.55468	.44162E-02	308.47
980.00	51.556	37.910	.30083	.55032	.43987E-02	311.47
990.00	51.472	37.764	.30071	.54605	.43816E-02	314.48
1000.0	51.389	37.617	.30060	.54186	.43649E-02	317.49
1010.0	51.305	37.472	.30049	.53775	.43487E-02	320.49
1020.0	51.222	37.326	.30039	.53371	.43327E-02	323.50
1030.0	51.138	37.181	.30030	.52974	.43172E-02	326.50
1040.0	51.055	37.037	.30021	.52584	.43020E-02	329.50
1050.0	50.971	36.893	.30013	.52201	.42872E-02	332.51
1060.0	50.888	36.749	.30006	.51825	.42726E-02	335.51
1070.0	50.804	36.606	.29999	.51455	.42584E-02	338.51
1080.0	50.721	36.463	.29993	.51091	.42445E-02	341.51
1090.0	50.637	36.321	.29988	.50734	.42309E-02	344.51
1100.0	50.553	36.179	.29984	.50383	.42176E-02	347.50
1110.0	50.470	36.037	.29980	.50037	.42044E-02	350.50

092688

092688

T (F)	RHO (LBM/FT3)	RK (BTU/HR-FT-F)	CP (BTU/LBM-F)	RMU (LBM/HR-FT)	PR	H (BTU/LBM)
1110.0	50.470	36.037	.29980	.50037	.42046E-02	350.50
1120.0	50.386	35.896	.29976	.49698	.41920E-02	353.50
1130.0	50.302	35.755	.29974	.49363	.41796E-02	356.50
1140.0	50.219	35.615	.29972	.49035	.41674E-02	359.50
1150.0	50.135	35.475	.29971	.48711	.41555E-02	362.49
1160.0	50.051	35.335	.29970	.48393	.41438E-02	365.49
1170.0	49.968	35.196	.29971	.48080	.41326E-02	368.49
1180.0	49.884	35.058	.29971	.47771	.41215E-02	371.48
1190.0	49.800	34.919	.29973	.47468	.41107E-02	374.48
1200.0	49.716	34.782	.29975	.47169	.41001E-02	377.48
1210.0	49.632	34.644	.29978	.46875	.40898E-02	380.48
1220.0	49.549	34.507	.29982	.46585	.40799E-02	383.47
1230.0	49.465	34.371	.29986	.46300	.40701E-02	386.47
1240.0	49.381	34.235	.29991	.46019	.40606E-02	389.47
1250.0	49.297	34.099	.29997	.45742	.40514E-02	392.47
1260.0	49.213	33.964	.30003	.45469	.40425E-02	395.47
1270.0	49.129	33.829	.30010	.45200	.40337E-02	398.47
1280.0	49.045	33.694	.30018	.44935	.40254E-02	401.47
1290.0	48.962	33.560	.30026	.44674	.40172E-02	404.47
1300.0	48.878	33.426	.30035	.44417	.40093E-02	407.48
1310.0	48.794	33.293	.30045	.44163	.40017E-02	410.48
1320.0	48.710	33.160	.30055	.43913	.39943E-02	413.49
1330.0	48.626	33.028	.30066	.43667	.39873E-02	416.49
1340.0	48.542	32.896	.30078	.43424	.39805E-02	419.50
1350.0	48.458	32.765	.30091	.43184	.39740E-02	422.51
1360.0	48.374	32.633	.30104	.42948	.39678E-02	425.52
1370.0	48.290	32.503	.30118	.42714	.39618E-02	428.53
1380.0	48.206	32.372	.30132	.42485	.39562E-02	431.54
1390.0	48.122	32.243	.30147	.42258	.39508E-02	434.56
1400.0	48.038	32.113	.30163	.42034	.39458E-02	437.57
1410.0	47.954	31.984	.30180	.41813	.39410E-02	440.59
1420.0	47.870	31.855	.30197	.41595	.39365E-02	443.61
1430.0	47.786	31.727	.30215	.41379	.39324E-02	446.63
1440.0	47.702	31.600	.30234	.41167	.39285E-02	449.65
1450.0	47.618	31.472	.30253	.40957	.39250E-02	452.68
1460.0	47.534	31.345	.30273	.40751	.39217E-02	455.70
1470.0	47.450	31.219	.30293	.40546	.39189E-02	458.73
1480.0	47.366	31.093	.30315	.40345	.39161E-02	461.76
1490.0	47.282	30.967	.30337	.40145	.39139E-02	464.79
1500.0	47.198	30.842	.30359	.39949	.39119E-02	467.83

ATTACHMENT E-1

REFERENCES

1. SNL INTERNAL MEMO, TO DISTRIBUTION FROM D. B. DAWSON, APRIL 26, 1982. SUBJECT: REVISED PHYSICAL PROPERTY VALUES FOR MOLTEN NITRATE SALTS.

2. LETTER TO DC SMITH (B&W) FROM PE SKVARNA (SCE), DATED 8-15-86.

3. LETTER TO PE SKVARNA (SCE) FROM WA ALLMAN (B&W) DATED 8-26-86.

COPIES OF THE REFERENCES FOLLOW.

Sandia National Laboratories
Albuquerque, New Mexico 87185
Livermore, California 94550

date: April 26, 1982

to: Distribution

from: D. B. Dawson - 8453

subject: Revised Physical Property Values for Molten Nitrate Salts

When molten nitrate salt mixtures were first chosen as a promising candidate for solar thermal heat transfer and storage applications, it was recognized that there was little or no good data on the physical properties of these salt mixtures above about 400-450°C. We obtained preliminary values for physical properties in the 450-600°C range by extrapolating existing lower-temperature data (primarily from Janz et al, Reference 1). This data has been supplied to contractors working on molten salt receiver, steam generator, and storage subsystems, with the understanding that it be used to provide a common data base for sizing and analyzing these designs.

Simultaneously, Sandia initiated a number of in-house and external studies to provide additional physical property data, with particular emphasis on measuring these properties in the 450-600°C range to replace current values obtained by extrapolation. Most of these studies have now been completed, and the results can be used to generate more representative expressions for the temperature-dependence of molten salt physical properties. Where available, these expressions have been plotted in the accompanying figures, and revised values for various temperatures calculated. The new plots and tabular calculated values are compared with the "old" values and expressions specified in various RFQ's for molten salt subsystem studies. In some cases, experimental data used to generate the new expressions is also shown.

Revised values of density and absolute viscosity are from Nissen (References 2 and 3). His measurements were made for a 50/50 mole percent mixture of $NaNO_3/KNO_3$ (46/54 wt pct), rather than the 60/40 wt pct mixture selected for most current solar applications. However, Nissen also points out that surface tension, viscosity, and density vary less than 1 percent over a fairly broad range of $NaNO_3/KNO_3$ mixtures (Ref. 4), so his measured values for 50/50 mole pct mixtures should be considered valid for the 60/40 wt pct mixture as well, within the limits of experimental accuracy. Revised values of heat capacity for a 60/40 wt pct mixture of $NaNO_3/KNO_3$ have been reported by Carling (Ref. 5). Sandia has funded Oye at the Norwegian Institute of Technology (NIT) to provide thermal conductivity measurements for several different $NaNO_3/KNO_3$ salt mixtures. That contract is not scheduled to be completed until June, 1982, and we have received no results to date. Interestingly, Nissen reports that we may be able to "back out" some heat capacity values from the NIT thermal conductivity study.

Old (RFQ) and revised values of density, viscosity, and heat capacity are compared in Figures 1-3. Table I also compares RFQ and new values of these properties at various temperatures. Wherever possible, these revised values of physical properties should be used to replace the data we have been using up to this point. Best-fit expressions for the temperature-dependence of the new data have been developed, and are presented below as well as plotted in Figure 1-3.

Density - Best-fit expressions and values from these expressions at various temperatures are plotted in Figure 1. Values based on Nissen's new data (References 2 and 3) are from 0.8 percent to 1.1 percent higher than values we have been using. The new best-fit expression* gives excellent agreement with the experimental data. The following expressions may be used instead of tabular values:

$$\rho(g/cm^3) = 2.090 - 6.36 \times 10^{-4}T\ (°C)$$

$$\rho(lb/ft^3) = 131.2 - 2.221 \times 10^{-2}T\ (°F)$$

Viscosity - Old and new values of viscosity for 50/50 mole pct mixtures of $NaNO_3/KNO_3$ are plotted in Figure 2, and compared with Nissen's experimental data (References 2 and 3). The values used to date were based on extrapolation of data from Janz et al (Ref. 1) above 450°C, assuming a single value of activation energy. Nissen's data (References 2 and 3) shows that a change in activation energy occurs at about 385°C, with the result that extrapolated viscosity values are about 10 percent lower than measured values in the 500-600°C region. Nissen provides a cubic best-fix expression which is within about ± 3 percent of his experimental data points. If it is desired to use tabular values of viscosity rather than the expression below, then we recommend values based on Nissen's experimental data (Table I) rather than values calculated from the expression:

$$\eta(mPa \cdot s) = 22.714 - 0.120T + 2.281 \times 10^{-4}T^2 - 1.474 \times 10^{-7}T^3\ \ (T\ in\ °C)$$

x 2.4192

(comparable expressions in other units would require curve-fitting a new equation)

Specific Heat - A substantial change in Sandia-specified values for specific heat of 60/40 wt pct $NaNO_3/KNO_3$ is proposed on the basis of Carling's data (from Ref. 5). As shown in Figure 3, the direction

*Nissen offers slightly different expressions for the temperature-dependence of density in Reference 2 (SAND80-8040) and Reference 3 (J. of Chem. and Eng. Data). The expression from Ref. 3, shown here, is preferred.

of temperature dependence is changed, with the result that new values are 10.5 percent lower than existing specified values at 300°C, but 5.7 percent higher at 600°C. The temperature-invariant value of 0.366 cal/g-°C recommended by Martin Marietta, Ref. 6 (based on data generated by Janz), is a reasonably good approximation of the newest values from Carling. The values attributed to Carling in Figure 3 were calculated from a linear fit of experimental data:

$$C_p\ (cal/g\text{-}°C) = 0.345 + 4.11 \times 10^{-5} T\ (°C)$$

$$C_p\ (BTU/lb\text{-}°F) = 0.345 + 2.28 \times 10^{-5} T\ (°F)$$

Thermal Conductivity - No change in currently-recommended values of thermal conductivity is proposed, pending completion of the studies at NIT.

Sandia will request that the revised values of physical properties shown herein be used for all future in-house and outside contracted studies. For contracts and studies currently in progress, changes in design or performance calculations occasioned by these new properties may be made at the option of the contractor, but we will not insist upon it. However, we should expect:

a) some assessment of what (if any) impact these changes in properties would have, and

b) inclusion of the new physical properties in reports issued by contractors, in a manner which clearly indicates that they (and not the RFQ values) should be used in all future work.

References

1. G. J. Janz, U. Krebs, H. E. Siegenthaler, and R. P. T. Tompkins, J. Phys. Chem. Ref. Data, 1972, vol. 1, p. 587.

2. D. A. Nissen, "Thermophysical Properties of the Equimolar Mixture $NaNO_3$-KNO_3 from 300-600°C," SAND80-8040, November 1980.

3. D. A. Nissen, same title, J. of Chem. and Eng. Data, in press.

4. D. A. Nissen, memorandum to D. B. Dawson, SNLL, March 22, 1982.

5. R. W. Mar, et al, "Progress Report: Molten Nitrate Salt Technology Development," SAND82-8220, April 1982.

6. Martin Marietta Corp., "Alternate Central Receiver Power System, Phase II," Vol. I, Final Report on Contract Sandia - 18-6879C, May 1981.

DBD:8453:ls

Distribution:
C. Mangold, DOE/HQ
C. McFarland, DOE/HQ
J. Swisher, DOE/HQ
W. Clancey, B&W
G. Grant, B&W
J. Hechmer, B&W
G. Carli, FW
S. Goidich, FW
R. Zoschak, FW
T. Tracey, MM
C. Finch, MDAC
S. Goldstein, Olin
B. Gupta, SERI
L. Napolitano, 8122
M. Abrams, 8122
R. Gallagher, 8124
J. Kraabel, 8124
W. Winters, 8124
D. Schuster, 8310
D. Nissen, 8312
R. Carling, 8313
R. Mar, 8313
L. Gutierrez, 8400
A. Skinrood, 8452
P. De Laquil, 8453
W. Delameter, 8453
W. Peila, 8453
W. Wilson, 8453
D. Dawson, 8453

092688

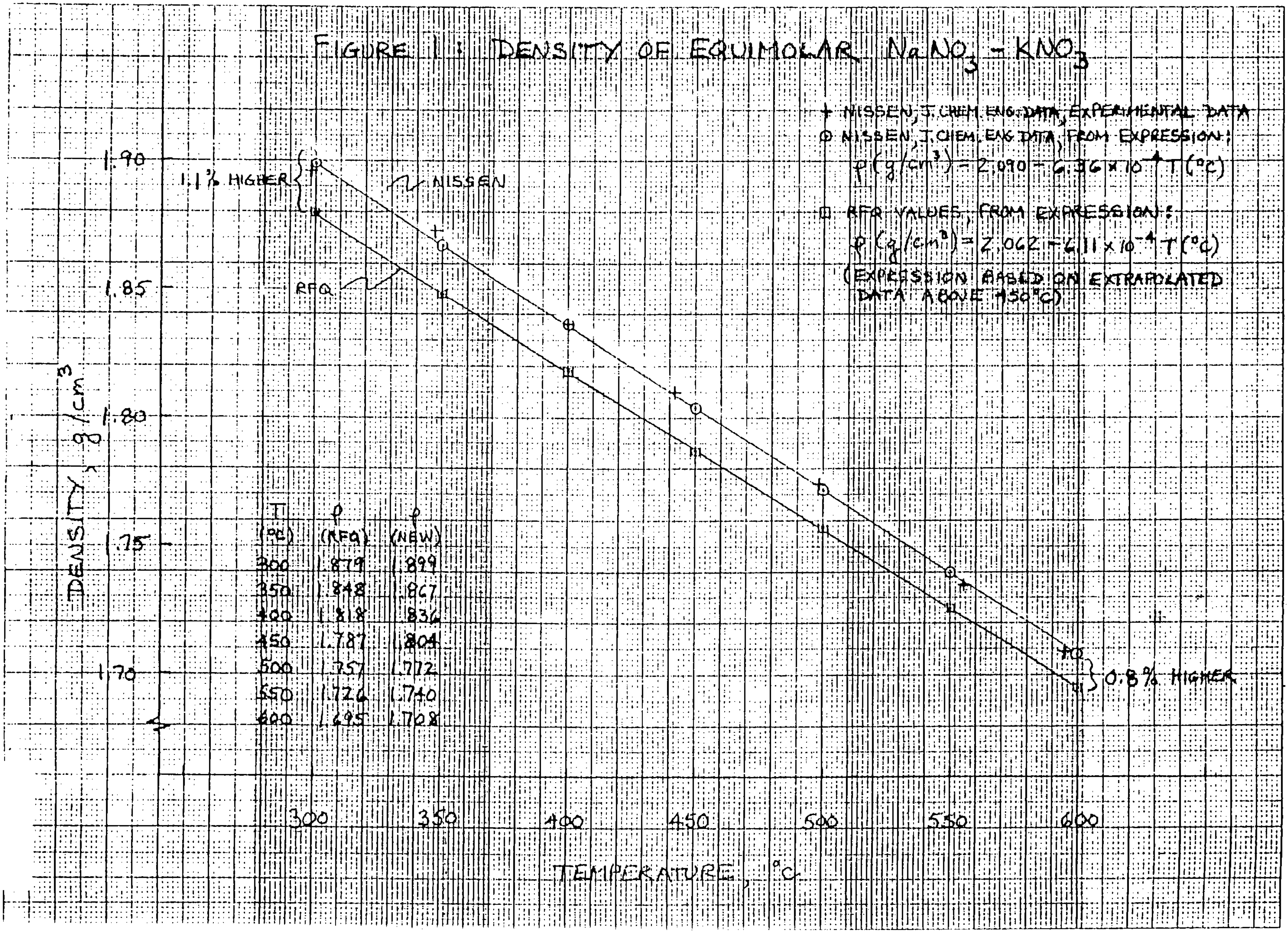
TABLE I: Comparison of Old* and Revised Values of Physical Properties for Molten Nitrate Salts (60 wt pct $NaNO_3$/40 wt pct KNO_3)

Temperature, °C	Density (g/cm^3) RFQ	Density (g/cm^3) New	Viscosity (mPa • s) RFQ	Viscosity (mPa • s) New	Heat Capacity (cal/g-°C) RFQ	Heat Capacity (cal/g-°C) New
300	1.879	1.899	3.22	3.22	0.399	0.357
350	1.848	1.867	2.29	2.27	0.389	0.359
400	1.818	1.836	1.80	1.78	0.381	0.361
450	1.787	1.804	1.43	1.53	0.374	0.363
500	1.757	1.772	1.21	1.30	0.366	0.366
550	1.726	1.740	1.05	1.14	0.358	0.368
600	1.695	1.708	0.93	1.03	0.350	0.370

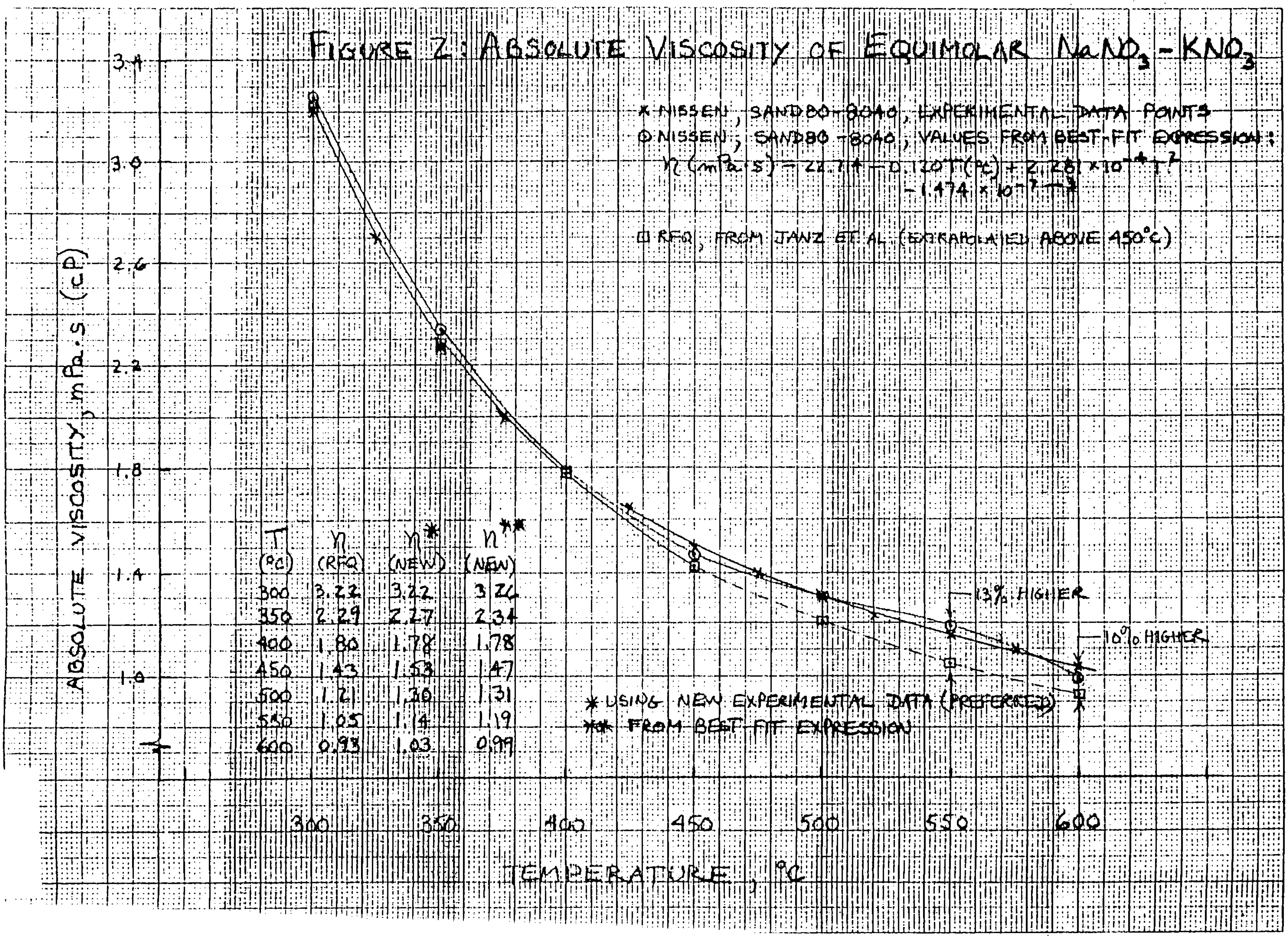
*RFQ values supplied by SNLL for use in SRE contracts to date.

Date: 5/20/82

FIGURE 1: DENSITY OF EQUIMOLAR $NaNO_3 - KNO_3$



T (°C)	ρ (RFQ)	ρ (NEW)
300	1.879	1.899
350	1.848	1.867
400	1.818	1.836
450	1.787	1.804
500	1.757	1.772
550	1.726	1.740
600	1.695	1.708



T (°C)	η (RFQ)	η* (NEW)	η** (NEW)
300	3.22	3.22	3.26
350	2.29	2.27	2.34
400	1.80	1.78	1.78
450	1.43	1.53	1.47
500	1.21	1.30	1.31
550	1.05	1.14	1.19
600	0.93	1.03	0.99

* USING NEW EXPERIMENTAL DATA (PREFERRED)

** FROM BEST FIT EXPRESSION

FIGURE 3: HEAT CAPACITY OF 60 WT. PCT. $NaNO_3$ / 40 WT. PCT. KNO_3

T (°C)	Cp (RFQ)	Cp (NEW)
300	0.399	0.357
350	0.389	0.359
400	0.381	0.361
450	0.374	0.363
500	0.366	0.366
550	0.358	0.368
600	0.350	0.370

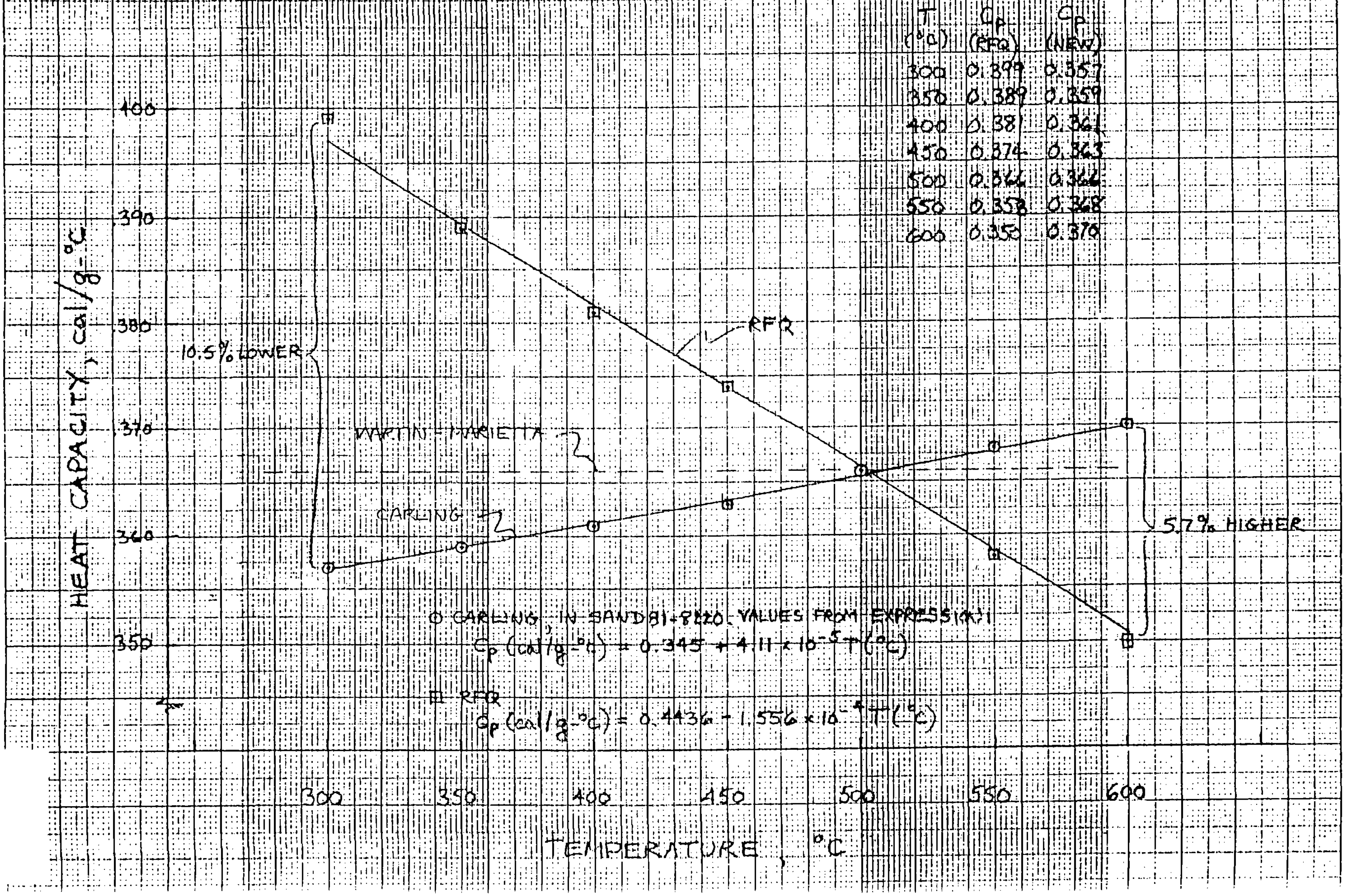


TABLE 1

Thermophysical properties of liquid 60% sodium nitrate and 40% potassium nitrate by weight.

1. density (1) $\rho(g/cm^3) = 2.062 - 6.11 \times 10^{-4} T\ (^\circ C)$

   $300^\circ C < T < 600^\circ C$

2. Specific heat (1) $Cp(cal/g\text{-}C) = 0.4436 - 1.556 \times 10^{-4} T\ (^\circ C)$

   $300^\circ C < T < 600^\circ C$

Temp. °C	Absolute Viscosity (1) (Pa-sec) x 1000	Conductivity w/m-k (2)
300	3.22	0.500
350	2.29	0.510
400	1.80	0.519
450	1.42	0.529
500	1.21	0.539
550	1.05	0.549
600	0.93	0.558

(1) Unpublished data taken at SNLL.
(2) From Reference 4 values from 500°C to 600°C are extrapolated.

Southern California Edison Company

P.O BOX 800
2244 WALNUT GROVE AVENUE
ROSEMEAD, CALIFORNIA 91770

August 15, 1986

Mr. D. C. Smith, Performance Engineer
Nuclear Equipment Division
Babcock & Wilcox
c/o Mr. John Otts, Supervisor
Solar Thermal Test Facility
Division 6222
Sandia National Laboratories
Albuquerque, NM 87185

Dear Dave:

At the last Utilities' Study Ad Hoc Subcommittee Meeting, B&W shared with us a table of nitrate salt properties and some reference material.

Dr. Charles Trilling has reviewed this material in detail and has found some inconsistencies which he documented in a memo to me (copy attached). Additionally, he recommends we use Dawson's correlation for molten salt viscosity and the entholpy correlation be deleted from the list since it does not provide any independent information.

May I have your thoughts on his recommendations? Please give me a call on 818:302-1Ø96.

Thanks!

Sincerely,

Paul

P. E. Skvarna

PES:gal
Enclosure
cc: C. A. Trilling (w/att.)

W.A. ALLMAN
AUG 25 1986

092688

August 12, 1986

P. E. SKVARNA

SUBJECT: Molten Salt Physical Properties Data Handed out by B&W at July 16, 1986, Ad Hoc Subcommittee Meeting for the Development of Utility Consensus Guidelines

At the July 16, 1986, meeting, B&W provided a handout on molten salt and sodium physical properties which they recommended be included in the Utility Consensus Guidelines. A copy of the first draft of this handout is attached.

I have not had a chance to verify the sodium properties. I have, however, taken a look at the molten salt relationships. While no reference was given, it was stated that these data come from Dan Dawson's work at SNLL. I assume that the appropriate reference is still Dawson's memo of April 26, 1982, "Revised Physical Property Values for Molten Nitrate Salts" (copy also attached).

For convenience, I have numbered the equations shown by B&W (1), (2), (3), (4), and (5). The specific heat and density relationships, Equations (2) and (5) are taken directly from Dawson's memo. While Dawson does not give any thermal conductivity data, Equation (3) seems to fit data presented by Olin and appears to be the best available at this time.

The viscosity data, Equation (1), is slightly at variance with Dawson's recommendation. The temperature versus entholpy relationship, Equation (4), is a derived relationship (obtained by integration of Equation (2)) and does not belong in the Guidelines. Moreover, as shown, it is in direct disagreement with Equation (2) and, therefore, appears to be incorrect.

With respect to the viscosity, Dawson's recommended equation after conversion to English units becomes:

$$\mu = 60.2844 - 0.17236T + 1.76176 \times 10^{-4} T^2 - 6.11408 \times 10^{-8} T^3 \text{ lb/ft h} \qquad (6)$$

The following table compares the viscosity values given by Dawson and those calculated by B&W's Equation (1) (the data are shown in centipoises, with 1 cp = 2.419 lb/ft h):

Temperature		Viscosity Centipoises			
		Dawson			B&W
°C	°F	Original RFQ	"New" Data	Best Fit Expression (Equation (6))	Equation (3)
300	572	3.22	3.22	3.26	3.20
350	662	2.29	2.27	2.34	2.34
400	752	1.80	1.78	1.78	1.77
450	842	1.43	1.53	1.47	1.42
500	932	1.21	1.30	1.31	1.21
550	1022	1.05	1.14	1.19	1.07
600	1112	0.93	1.03	0.99	0.92

The B&W correlation appears to agree well with Dawson's original RFQ data. Its results, however, are definitely low in comparison with Dawson's "new" data at temperatures above 450°C (842°F). It is recommended that, unless more recent information has become available, Dawson's correlation (Equation (6) in English units) be used for molten salt viscosity rather than the B&W correlation.

Turning to B&W's temperature versus entholpy correlation (Equation (4)), this correlation should have been directly derivable from the specific heat correlation (Equation (2)) since:

$$H = \int_0^T c_p \, dT = \int_0^T (0.345 + 2.28 \times 10^{-5} T) \, dT$$

$$= 0.345 T + 1.14 \times 10^{-5} T^2$$

This quadratic can be solved for T, giving:

$$T = 15{,}131.579 \left[-1 + \sqrt{1 + H/2610.197} \right] \qquad (7)$$

Equation (7) is obviously quite different from B&W's Equation (4). The following table compares the results:

	Temperature (°F)	
Entholpy (Btu/lb)	Equation (7)	B&W's Equation (4)
200	569.01	469.36
250	708.07	594.22
300	845.92	722.60
350	982.59	854.79
400	1118.11	991.18

Another comparison can be made by solving B&W's Equation (4) for H and differentiating to obtain the specific heat. The following results are obtained:

$$H = 0.4464 T - 0.00004322 T^2$$

$$c_p = \frac{dH}{dT} = 0.4464 - 0.00008644\ T \qquad (8)$$

Equation (8) obviously provides specific heat values in disagreement with B&W's Equation (2).

It is recommended that the temperature versus causes entholpy correlation (Equation (4)) be deleted from the list of molten salt properties, since it does not provide any independent information and since, as written, it is inaccurate.

C. A. Trilling 8/12/86
C. A. TRILLING

Babcock & Wilcox
a McDermott company

Nuclear Equipment Division
91 Stirling Avenue
P. O. Box 271
Barberton, Ohio 44203-0271
(216) 753-4511

August 26, 1986

Mr. P.E. Skvarna
Southern California Edison Company
P.O. Box 800
2244 Walnut Grove Avenue
Rosemead, California 91770

Reference: (1) Letter to D.C. Smith (B&W) from P.E. Skvarna (SCE), dated August 15, 1986.
(2) Letter to Distribution from D.B. Dawson (SNLL), dated April 26, 1982.

Dear Paul:

Dave Smith passed the Reference (1) letter on to me and asked me to review the attached comments of Dr. Trilling. B&W concurs with the comments on both the viscosity equation and the enthalpy equation. Equations (1) and (4) on the list provided by B&W at the July 16 Ad Hoc Subcommittee meeting are not based on the information on salt properties contained in Reference (2). The two equations were copied inadvertently from an outdated list. B&W has been using the information in Reference (2) for design and analysis work since about mid-1982.

Attached is a revised list of the molten nitrate salt properties. I have left Equation (4) for temperature versus enthalpy on the list for consistency, although Dr. Trilling's observation that it does not provide any independent information is correct. I leave it to your discretion as to whether to include the equation in the Utility Guidelines.

If I can be of further assistance, give me a call at (216) 860-6549.

Very truly yours,

Wes Allman

WAA/gdo-6375v
Attachment
cc:
A. D. Seigneur
D. C. Smith
D. B. Young

092688

ATTACHMENT E-2

Comments on each of the property equations and source of information.

VISCOSITY

The equation, metric units, is shown in Reference 1. Reference 1 provides references for the equation. It appears that the following reference applies to the viscosity equation.

> D.A. Nissen, "Thermophysical Properties of the Equimolar Misture $NaNO_3$ from 300°-600°C, SAND80-8040, November 1980.

The equation was converted to engineering units by Trilling and by B&W with essentially the same results - see the following:

NITRATE SALT VISCOSITY EQUATION

Reference : Letter to D.S. Smith from Paul Skvarna (SCE), 8-15-86

$$\mu = 22.714 - .120T + 2.281 \times 10^{-4}T^2 - 1.474 \times 10^{-7}T^3 \text{ mPa - sec}$$

T in °C

Convert the equation to English units

To convert from mPa - sec to lbm/ft-hr, multiply by 2.4192
(centipoise)

$$\mu = 54.9497 - .290304C + 5.51820 \times 10^{-4}C^2 - 3.56590X \times 10^{-7C3} \text{ lbm/ft-hr}$$

Temp. in °C

Convert to °F

$$C = .55556F - 17.778$$
$$C^2 = .30865F^2 - 19.754F + 316.06$$
$$C^3 = .17147F^3 - 10.975F^2 + 175.59F - 5.4872F^2 + 351.19F - 5618.9$$
$$C^3 = .17147F^3 - 16.462F^2 + 526.78F - 5618.9$$

$$\mu = 54.9497$$
$$- .290304 (.55556F - 17.778)$$
$$+ 5.51820 \times 10^{-4} (.30865F^2 - 19.754F + 316.06)$$
$$- 3.56590 \times 10^{-7} (.17147F^3 - 16.462F^2 + 526.78 - 5618.9)$$

$$\mu = 54.9497$$
$$+ 5.16102 - .161281F$$
$$+ 1.74408 \times 10^{-1} - 1.09007 \times 10^{-2}F + 1.70319 \times 10^{-4}F^2$$

$$+ 2.00364 \times L0^{-3} - 1.87844 \times 10^{-4}F - 5.870818 \times 10^{-6}F^2$$
$$- 6.11445 \times 10^{-8}F^3$$
$$\mu = 60.2871 - .17237f + 1.76189 \times 10^{-4}F^2 - 6{:}11445 \times 10^{-8}F^3 \text{ lbm/ft-hr}$$

Temp. in °F

The above equation is essentially the same as Equation (6) of the attachment to Reference Letter. The differences are probably due to round-off error and/or the difference in conversion factor: 2.419 vs 2.4192.

Calculate the viscosity using the above equation and compare to the values in the Table in the attachment to the Reference.

°C	°F	μ (mPa - sec)
300	572	3.26
350	662	2.34
400	752	1.78
450	842	1.47
500	932	1.31
550	1022	1.19
600	1112	.99

Values same as Eq. (6) values calculated in attachment to Reference,

Conclusion:

Accept the equation in the attachment to the reference letter.

$$\mu = 60.2844 - 0.17236T + 1.76176 \times 10^{-4}T^2 - 6.11408 \times 10^{-8}T^3$$
lbm/ft.hr.
T in °F

SPECIFIC HEAT

The equation is shown in Reference 1. Reference 1 provides the following reference for the equation:

R.W. Mar, et al, "Progress Report; Molten Nitrate Salt Technology Development," SAND82-8220, April, 1982

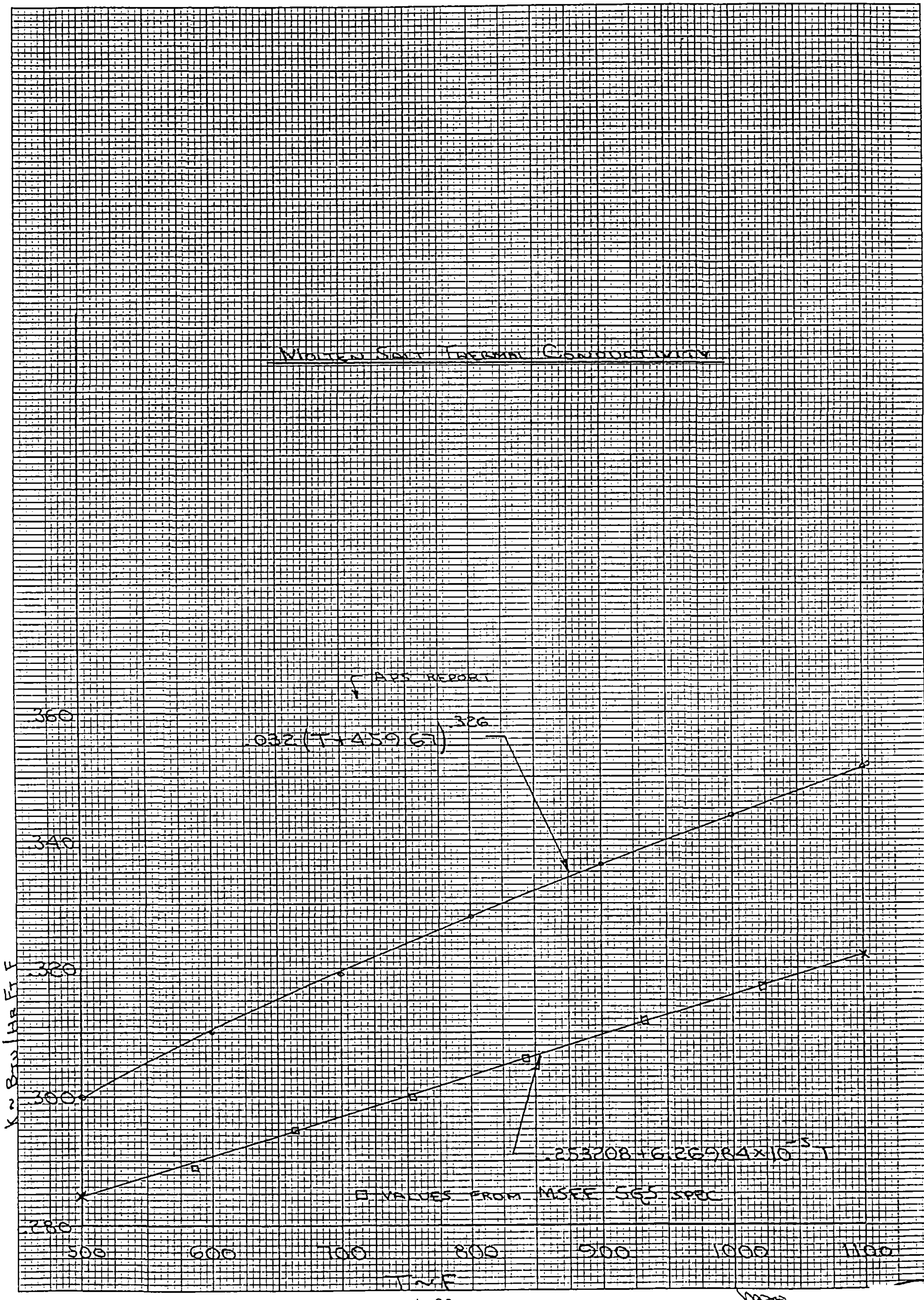
Thermal Conductivity

The equation fits the data points given to B&W in the MSEE Steam Generator specification (dated 3-18-82). This spec. gives the following reference:

"Background for Preparation of Quotes Dealing With Molten Salt Steam Generator SRE."

Trilling notes in Reference 3 that the equation "seems to fit the data presented by Olin."

Next sheet: plot of points from steam generator spec. and curve fit of those points.



MOLTEN SALT THERMAL CONDUCTIVITY
APS REPORT
.032 (T+459.67)^.326
.253208 + 6.26984×10^-5 T
□ VALUES FROM MSEE SGS SPEC
.360
.340
.320
.300
.280
K ~ BTU/HR FT F
500
600
700
800
900
1000
1100
T ~ F

7-17-84

Temperature as a Function of Enthalpy

This equation is derived from the equation for specific heat. (see p E-2-5.) Reference 3 outlines the derivation; B&W concurs with the derivation. The only difference between the equation supplied by B&W and Trilling's equation is that B&W rounded off the constants.

Density

The equation is shown in Reference 1. Reference 1 provides reference for the equation. It appears that the following reference applied to the density equation.

D.A. Nissen, "Thermophysical Properties of the Equimolar Mixture $NaNO_3$ - KNO_3 from 300 - 600°C, J. of Chem. and Eng. Data, in press.

Note: Checked with M&W library. Reference is:

Vol. 27, Issue No. 3, p. 269 - 273, 1982

ATTACHMENT F

SOLAR CENTRAL RECEIVER MECHANICAL SYSTEMS

SOLAR CENTRAL RECEIVER MECHANICAL SYSTEMS

MAIN POWER CYCLE AND AUXILIARIES

EPGS

- Steam Generator (WATER SIDE)
- Main Steam
- Main Turbine
- Condensate
- Feedwater
- Feedwater Heater Extraction Steam, Drains, and Vents
- Condensate Demineralizer
- Auxiliary Feedwater

BOP

- Raw Water Supply
- Demineralized Water Makeup Transfer and Storage
- Condensate and Feedwater Chemical Control
- Raw Water Pretreatment

EPGS

STEAM GENERATOR CONTROLS AND AUXILIARIES

- Steam Generator (SALT SIDE)

TURBINE-GENERATOR CONTROLS AND AUXILIARY SYSTEMS

- Steam Seals
- Main Turbine and Generator Lube Oil

EPGS Stator Cooling

BOP Lube Oil Transfer, Storage, and Purification

EPGS Condenser Air Removal

EPGS Main Turbine Control Oil

CIRCULATING WATER

EPGS Circulating Water

BOP:

Cooling Tower Makeup and Blowdown

Travelling Screens and Screenwash

Circulating and Service Water Chemical Injection

COOLING WATER

Service Water

Closed Cooling Water

AUXILIARY STEAM

Auxiliary Steam Generator

Auxiliary Steam Supply

HVAC

Plant Heating

Administration Building HVAC

Shop and Warehouse HVAC

Control Building HVAC

FUEL

Standby Diesel Fuel Oil

SERVICES

Compressed Air

Fire Protection

Domestic Water

BOP

Cranes, Hoists, Elevators and Motor Operated Doors

Service Gases

Standby Diesel Generator

DRAINS

Sanitary Drainage

Storm Drain

Acid Waste

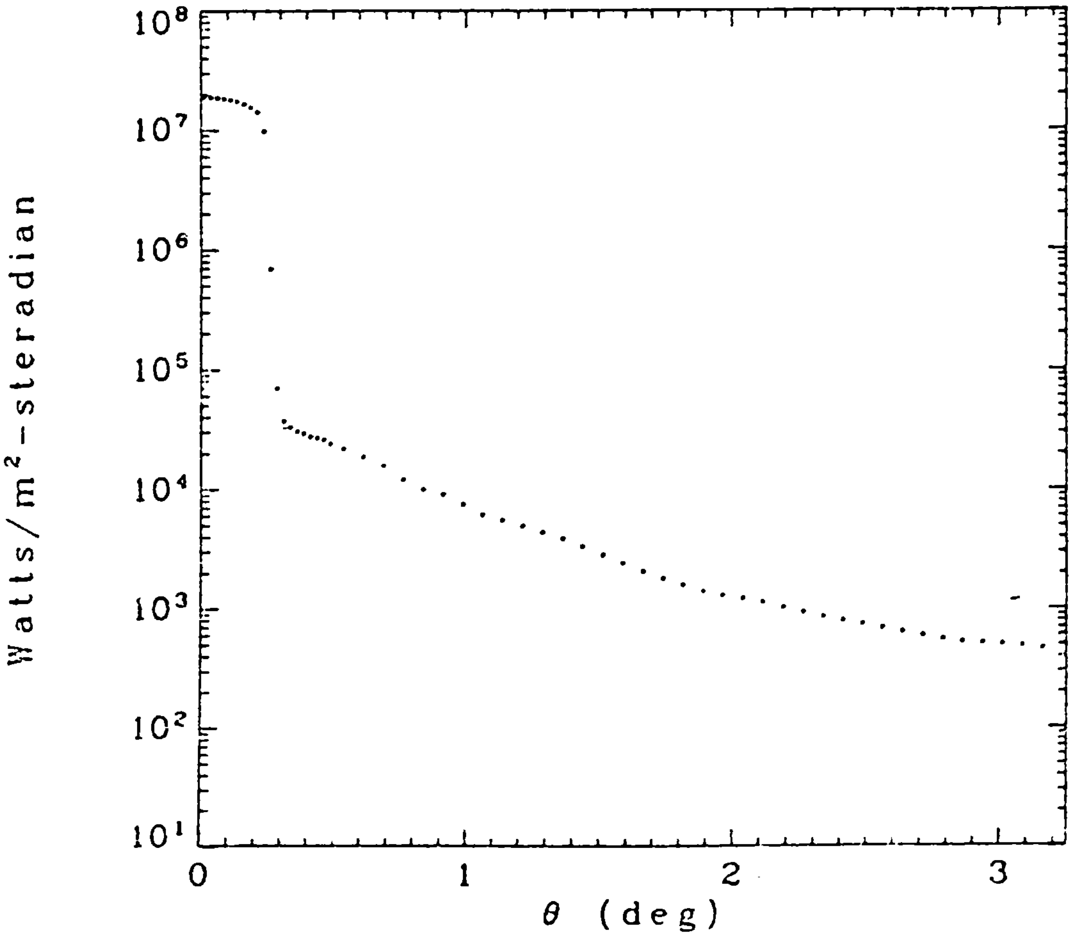
Oily Waste

Gravity Collection

Waste Water Treatment

76/ 6/ 2 9:29 LST SCOPE 2

C/(C+S) = 2.9% NI = 938 W/m²



SCOPE 2 DATE = 760602 SOLAR TIME = 9.49 PYRH. = 938.7 W/MSQ CIRCUM. RATIO = .029

POINT	ANGLE DEGREES	ANGLE RADIANS	SCAN W/MSQ-STERAD	SCAN NORMALIZED
1	.0125	.000218	.188E+08	.100E+01
2	.0375	.000654	.187E+08	.996E+00
3	.0625	.001091	.185E+08	.985E+00
4	.0875	.001527	.182E+08	.967E+00
5	.1125	.001963	.178E+08	.950E+00
6	.1375	.002400	.173E+08	.920E+00
7	.1625	.002836	.164E+08	.875E+00
8	.1875	.003272	.155E+08	.822E+00
9	.2125	.003709	.141E+08	.750E+00
10	.2375	.004145	.978E+07	.520E+00
11	.2625	.004581	.697E+06	.371E-01
12	.2875	.005018	.711E+05	.378E-02
13	.3125	.005454	.376E+05	.200E-02
14	.3375	.005890	.335E+05	.178E-02
15	.3625	.006327	.310E+05	.165E-02
16	.3875	.006763	.296E+05	.158E-02
17	.4125	.007199	.279E+05	.148E-02
18	.4375	.007636	.272E+05	.145E-02
19	.4625	.008072	.262E+05	.139E-02
20	.4875	.008508	.243E+05	.129E-02
21	.5375	.009381	.220E+05	.117E-02
22	.6125	.010690	.189E+05	.101E-02
23	.6875	.011999	.159E+05	.847E-03
24	.7625	.013308	.122E+05	.651E-03
25	.8375	.014617	.101E+05	.538E-03
26	.9125	.015926	.915E+04	.487E-03
27	.9875	.017235	.759E+04	.404E-03
28	1.0625	.018544	.623E+04	.331E-03
29	1.1375	.019853	.560E+04	.298E-03
30	1.2125	.021162	501E+04	.267E-03
31	1.2875	.022471	.442E+04	.235E-03
32	1.3625	.023780	.392E+04	.208E-03
33	1.4375	.025089	.335E+04	.178E-03
34	1.5125	.026398	.284E+04	.151E-03
35	1.5875	.027707	.243E+04	.129E-03
36	1.6625	.029016	.208E+04	.111E-03
37	1.7375	.030325	.180E+04	.957E-04
38	1.8125	.031634	.159E+04	.845E-04
39	1.8875	.032943	.141E+04	.752E-04
40	1.9625	.034252	.130E+04	.692E-04
41	2.0375	.035561	.123E+04	.655E-04
42	2.1125	.036870	.115E+04	.610E-04
43	2.1875	.038179	.104E+04	.552E-04
44	2.2625	.039488	.940E+03	.500E-04
45	2.3375	.040797	.869E+03	.462E-04
46	2.4125	.042106	.804E+03	.428E-04
47	2.4875	.043415	.746E+03	.397E-04
48	2.5625	.044724	.696E+03	.370E-04
49	2.6375	.046033	.645E+03	.343E-04
50	2.7125	.047342	.599E+03	.318E-04
51	2.7875	.048651	.559E+03	.297E-04
52	2.8625	.049960	.527E+03	.280E-04
53	2.9375	.051269	.514E+03	.273E-04
54	3.0125	.052578	.504E+03	.268E-04
55	3.0875	.053887	.488E+03	.260E-04
56	3.1625	.055196	.465E+03	.248E-04

092688

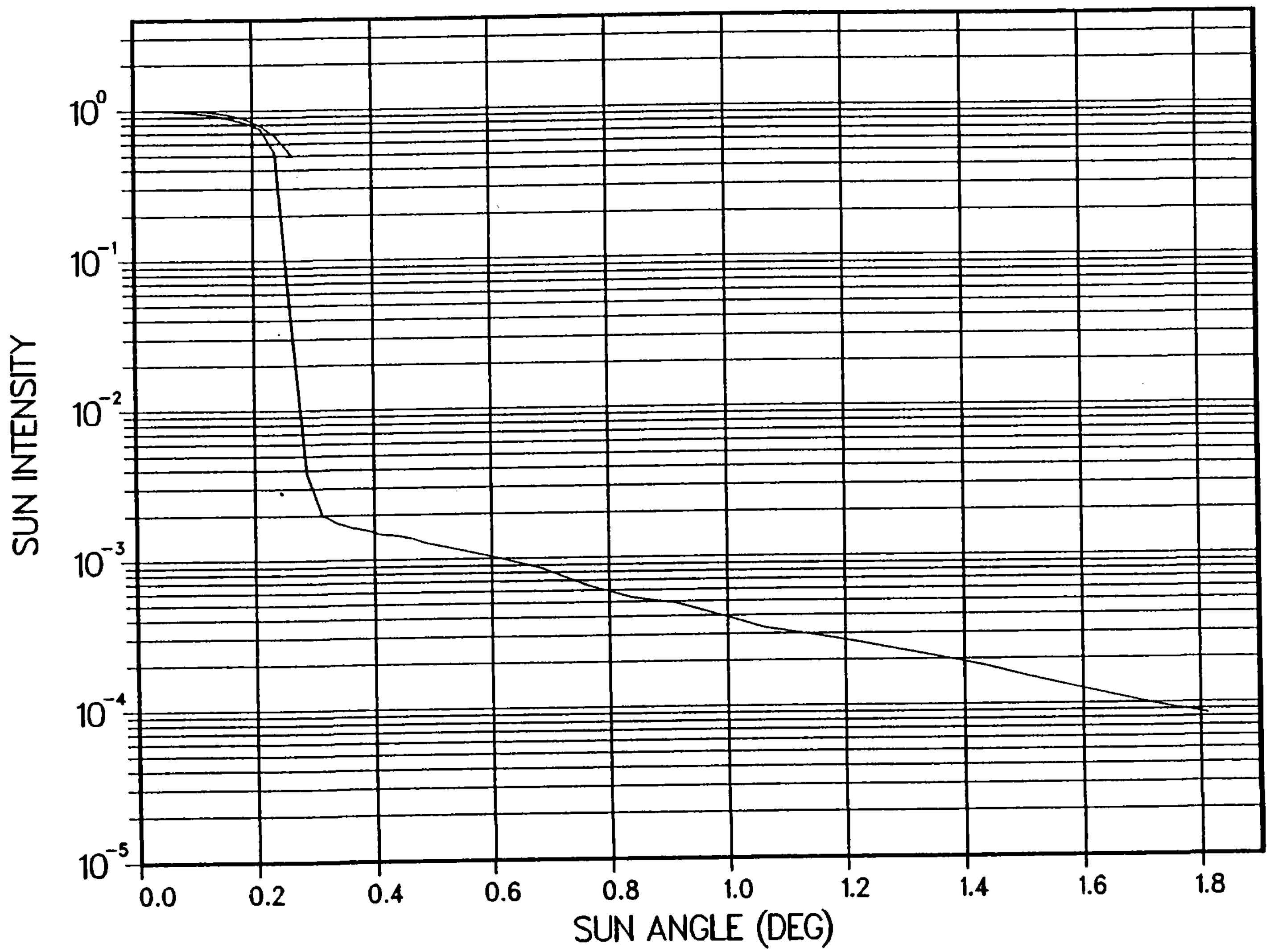
.0125	.100E+01	.100E+01	.100E+01
.0375	.996E+00	.996E+00	.995E+00
.0625	.989E+00	.985E+00	.986E+00
.0875	.978E+00	.967E+00	.972E+00
.1125	.967E+00	.950E+00	.953E+00
.1375	.932E+00	.920E+00	.927E+00
.1625	.907E+00	.875E+00	.892E+00
.1875	.859E+00	.822E+00	.848E+00
.2125	.794E+00	.750E+00	.785E+00
.2375	.627E+00	.520E+00	.557E+00
.2625	.133E+00	.371E-01	.151E+00
.2875	.939E-03	.378E-02	.345E+01
.3125	.434E-03	.200E-02	.307E+01
.3375	.313E-03	.178E-02	.282E-01
.3625	.227E-03	.165E-02	.259E-01
.3875	.179E-03	.158E-02	.237E-01
.4125	.158E-03	.148E-02	.215E-01
.4375	.139E-03	.145E-02	.197E-01
.4625	.120E-03	.139E-02	.181E-01
.4875	.109E-03	.129E-02	.166E-01
.5375	.942E-04	.117E-02	.139E-01
.6125	.783E-04	.101E-02	.107E-01
.6875	.668E-04	.847E-03	.835E-02
.7625	.585E-04	.651E-03	.651E-02
.8375	.520E-04	.538E-03	.512E-02
.9125	.462E-04	.487E-03	.408E-02
.9875	.418E-04	.404E-03	.330E-02
1.0625	.384E-04	.331E-03	.271E-02
1.1375	.355E-04	.298E-03	.225E-02
1.2125	.330E-04	.267E-03	.188E-02
1.2875	.309E-04	.235E-03	.159E-02
1.3625	.291E-04	.206E-03	.135E-02
1.4375	.273E-04	.178E-03	.117E-02
1.5125	.256E-04	.151E-03	.101E-02
1.5875	.242E-04	.129E-03	.880E-03
1.6625	.228E-04	.111E-03	.788E-03
1.7375	.213E-04	.957E-04	.692E-03
1.8125	.202E-04	.845E-04	.618E-03

angle (deg)

normalised

File
SOL1:[SOLAR.BAKO.]
SUNSHADOCR.DAT

DELSOL SUNSHAPE AND 2.9 CR



ATTACHMENT H

STRESSED MEMBRANE MIRROR REPLACEMENT COSTS

Stressed Membrane Heliostat Mirror Replacement Costs

Assumptions:

1. Reflector cost assumes mass production
2. Replacement occures over a two year period during 15th and 16th year of plant operation
3. Solar plant contains 3000 heliostats
4. Heliostat size is 150 m^2
5. Single shift, 5 day work week
6. 50 weeks per year
7. On site building is available

Labor:

Activity	No Of People	Time	Man Hours
Remove Mirror Module	2	.5 hr	1 hr
Transport Mirror	1	.5	0.5
Remove Old Mirror	2	1.0	4
Apply New Mirror	2	.5	1
Apply Edge Seals	2	.5	1
Transport To Field	1	.5	0.5
Install On Heliostat	2	.5	1
			9 mhr/module

Assume net production of 7 mirrors per 8 hr day X 250 days/yr X .8 (good weather days) = 1400 mirrors/year

Crew size:

Mirror Refurbishment	9
Work Coordinator/planner	1
Utility worker	1
Supervisor	1
Total Crew Size	12

Cost Estimate: 1986 Dollars

Labor Cost Per Mirror Module: 12 men X 2080 hr/yr X \$20.00/hr / 1400 mirrors/yr		\$357.00
Capital Cost: \$100,000.00/3000 mirrors		\$33.00
Reflector Cost: \$4.16/m^2 X 154m^2		\$641.00
Solvent and Misc Cost:		\$50.00
	Subtotal:	\$1111.00
Return on Investment And	Taxes:20%	\$222.00
	Total Cost:	\$1333.00/Mirror \$8.90/m^2

SPECO

SOLAR POWER ENGINEERING COMPANY, INC.

PO Box 91, Morrison, CO 80465 USA (303) 697-8144

January 6, 1987

Refer to 87-UCR-13

Arizona Public Service Company
2124 West Cheryl Drive
Phoenix, Arizona 80521-1892

Attention Mr. Eric R. Weber
Project Manager

Subject : Cloud Models

Gentlemen:

In response to an Action Item from the Ad Hoc Committee, the following is submitted for your consideration.

- o The passage of clouds is a stochastic process which must be accounted for in design by "bracketing models" representative of nominal and worst case conditions.

- o The worst case transients are highly design-dependent and cannot be established as "common data" except for type of clouds to be considered. The following two (generic) types are recommended:

  - Edge Clouds defined as clouds with advancing (or receeding) boundaries larger than collector field dimensions.

  - Group Clouds represented by one or more "puffs" casting shadows that are smaller than the dimensions of the collector field.

- o The flux transients caused by these clouds may be classified as:

  - Self-Similar, characterized by the fact that the ratios of fluxes at arbitrary locations on the absorber surfaces of a single control zone remain invariant during the transient.

  - Dissimilar transients during which both the levels and relative distribution of the fluxes vary.

    The response of fluid temperature to a dissimlar transient is typically in the form of a "temperature wave" propagating along the flow path. The function of the control system is to dampen the temperature wave at the receiver outlet.

- o Worst case combinations of velocity, size, direction, and shape associated with these types of transients must be determined for each design and size of solar plant.Accordingly, control requirements and the disposition of temperature excursions should be regarded as design issues.

Yours very truly,

SOLAR POWER ENGINEERING CO.

Tibor Buna
Project Manager

cc: J.C. Grosskreutz, B&V
D.B. Young, B&W
SPECO Distribution A

ATTACHMENT J

ALLOWABLE FLUX LIMITS FOR RECEIVER DESIGN

ATTACHMENT J

Babcock & Wilcox
a McDermott company

Nuclear Equipment Division
91 Stirling Avenue
P.O. Box 271
Barberton, OH 44203
(216) 753-4511

December 18, 1986

Bechtel National, Inc.
Engineers - Constructors
Fifty Beale Street
P.O. Box 3965
San Francisco 94119

Attn: Mr. Pat Delaquil

Subject: PG&E Utility Team, Utility Solar Central Receiver Study - Allowable Flux Limits for Receiver Design

Gentlemen,

Enclosed are four figures and one table that define allowable absorbed heat flux limits for 1.0 in and 1.5 in O.D. receiver tubes with a 0.065 in. wall thickness for both sodium and salt fluids and 316 SS receiver material. A range of heat transfer coefficients were considered for each fluid (1000, 1500, 2000 Btu/h-F-ft^2 for salt and 6000, 8000, 10000, 12000 for sodium). The limits were calculated based on ASME Code Case N-47 design fatigue curves (no creep calculation) with a design life of 20,000 cycles. For the salt receiver, the tube I.D. temperature was limited to 1112°F to prevent salt decomposition and limit corrosion. Additionally, recommended heat flux limits are presented in Table 1 that replace values previously reported. Because of recent improvements in the method used to calculate flux limits, higher values havè been attained.

J Phil Reed

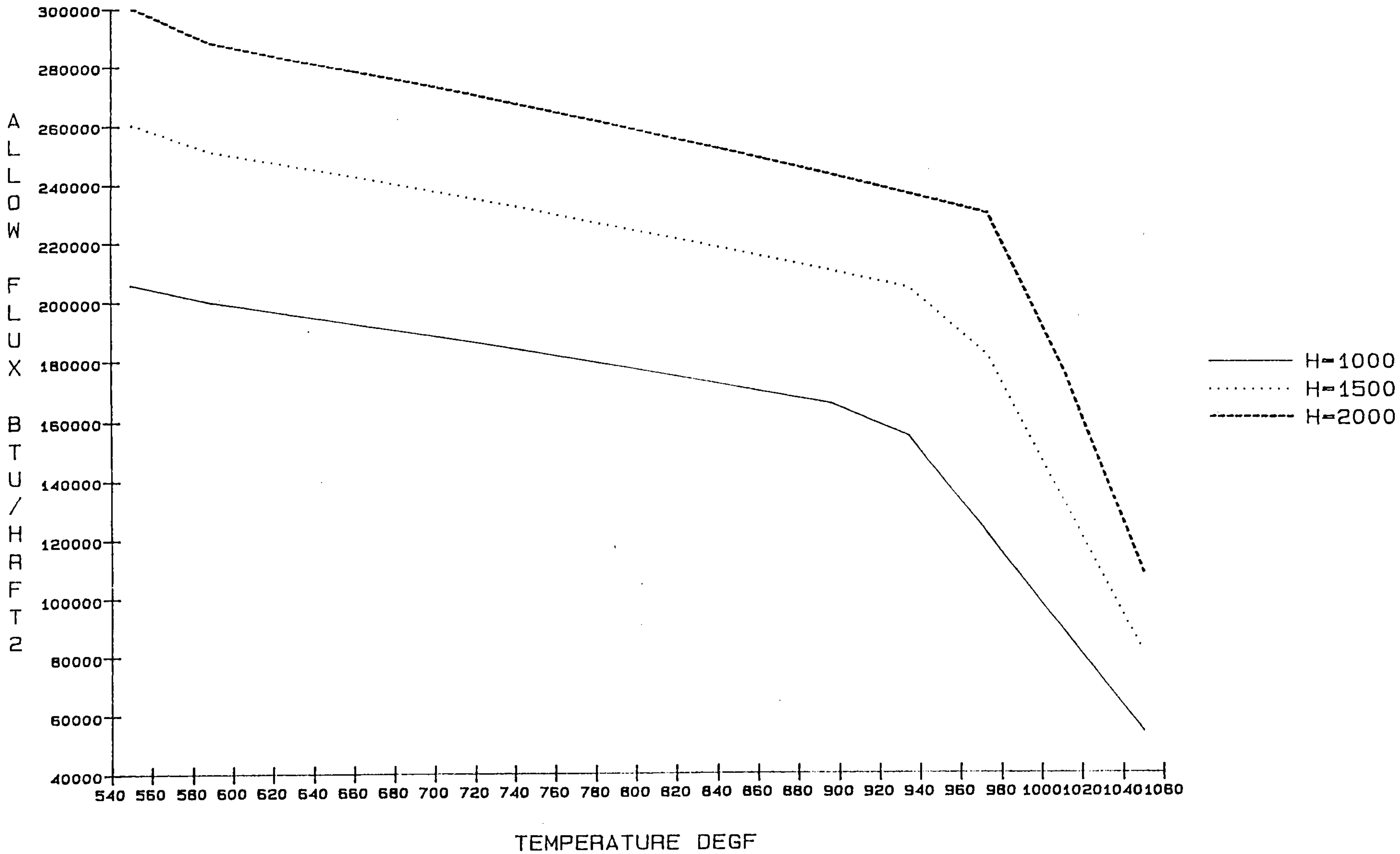
J. P. Reed

JPR/tlj-5263i

cc:
- D. J. Aleman
- W. A. Allman
- C. Dalton (Wash.)
- J. C. Egan (Bechtel)
- T. V. Narayanan (FW)
- P. A. Pfund
- D. C. Smith (Albq.)
- D. Thornburg (APS)
- L. Vant (Hull)
- E. R. Weber (APS)
- S. F. Wu (FW)
- D. B. Young

092688

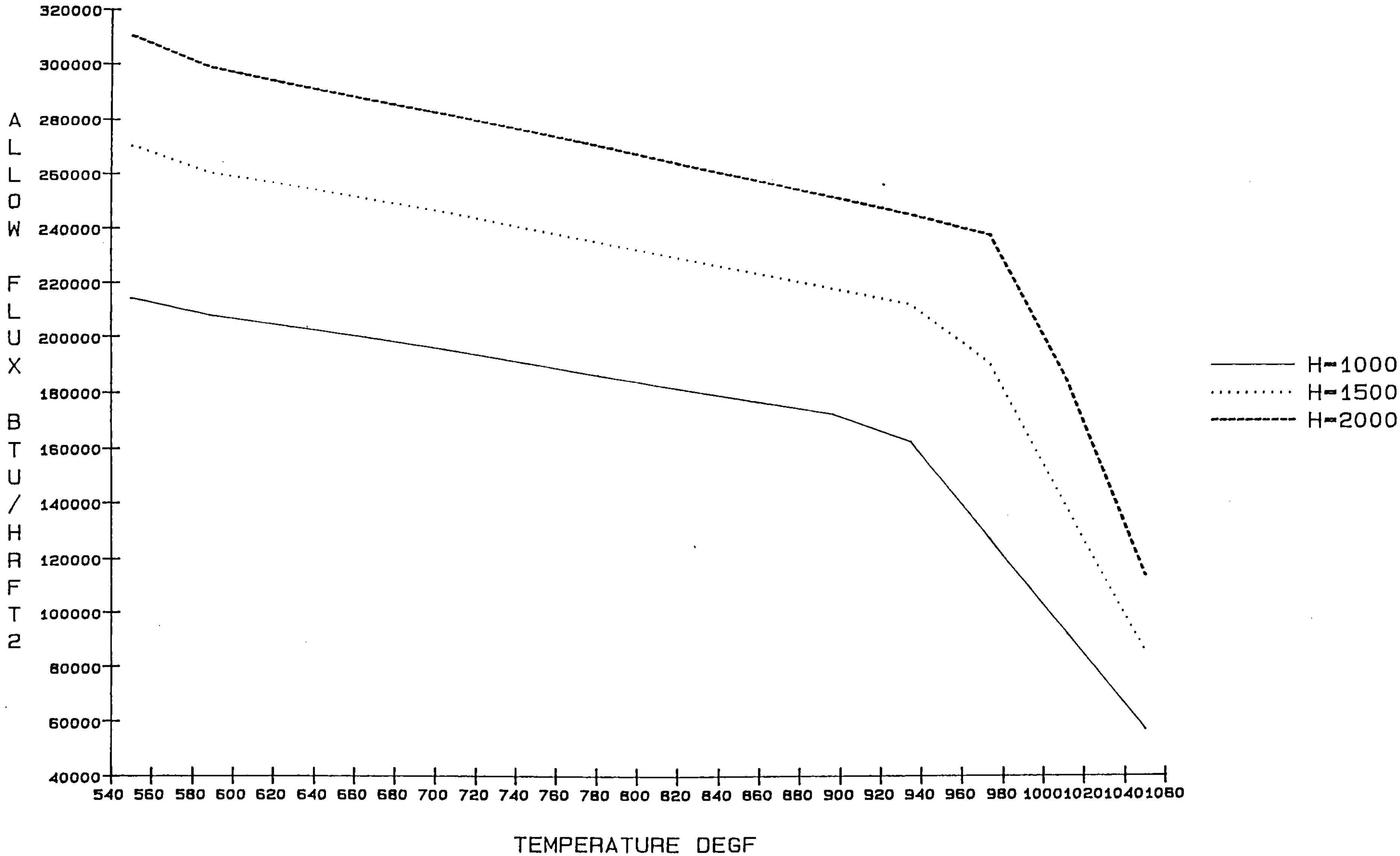
TEMPERATURE VS. ALLOW FLUX - 1"OD



A-109

092688

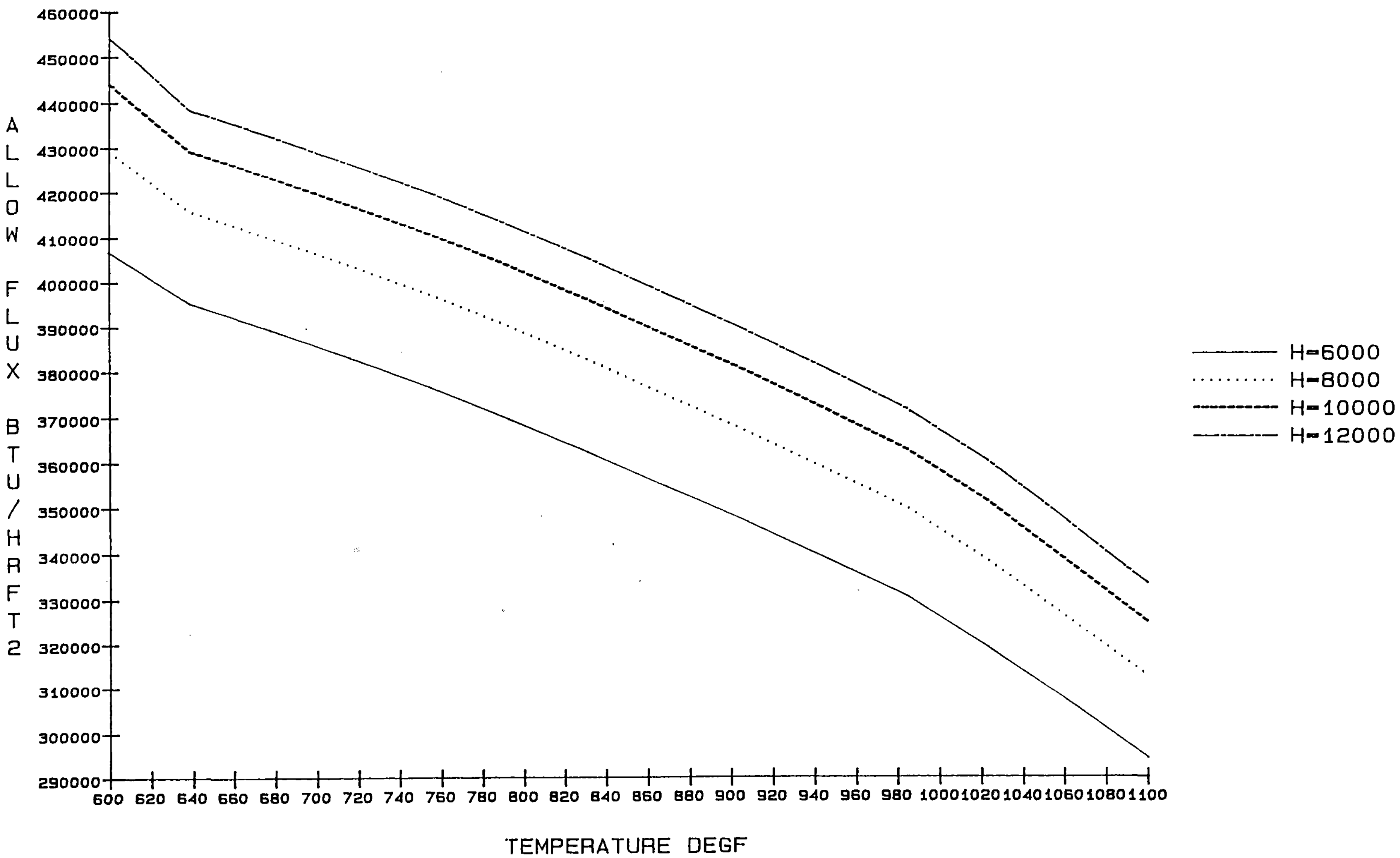
TEMPERATURE VS. ALLOW FLUX - 1.5"OD

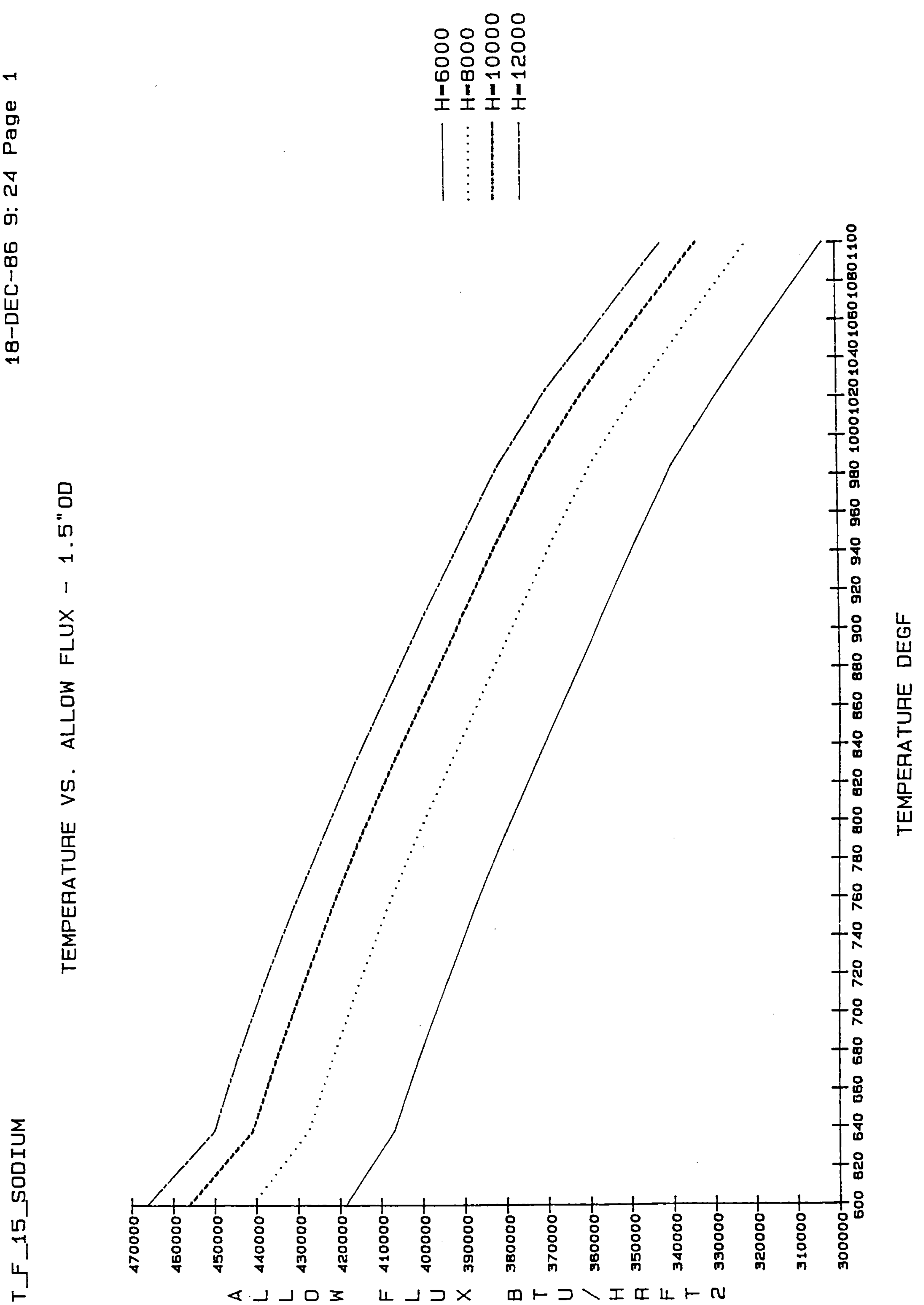


T_F_1_SODIUM

18-DEC-86 9: 25 Page 1

TEMPERATURE VS. ALLOW FLUX - 1"OD



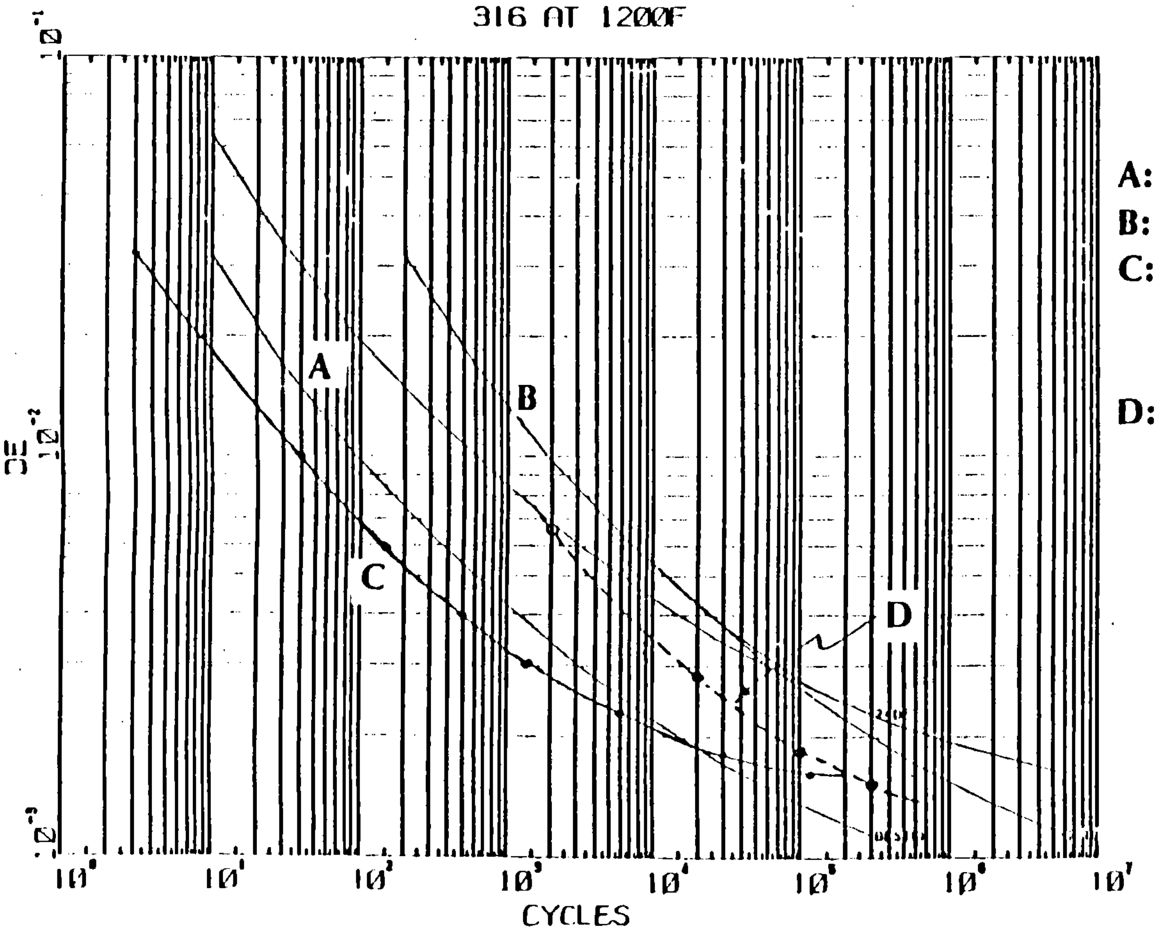

T_F_15_SODIUM
18-DEC-86 9:24 Page 1
TEMPERATURE VS. ALLOW FLUX - 1.5"OD
H=6000
H=8000
H=10000
H=12000
ALLOW FLUX BTU/HRFT2
470000
460000
450000
440000
430000
420000
410000
400000
390000
380000
370000
360000
350000
340000
330000
320000
310000
300000
600
620
640
660
680
700
720
740
760
780
800
820
840
860
880
900
920
940
960
980
1000
1020
1040
1060
1080
1100
TEMPERATURE DEGF

RECOMMENDED ALLOWABLE HEAT FLUX

TUBE MATERIAL	316 SS	
FLUID	15 yr	30 yr
SALT		
Peak Allow. Absorbed Heat Flux, KBtu/hr-ft^2 (MW/m^2)	263 (.84)	230 (.73)
Avg. Heat Flux, KBtu/hr-ft^2 (MW/m^2)	105 (0.33)	92 (.29)
SODIUM		
Peak Allow. Absorbed Heat Flux, KBtu/hr-ft^2 (MW/m^2)	516 (1.64)	449 (1.42)
Avg. Heat Flux, KBtu/hr-ft2 (MW/m^2)	195 (.62)	163 (.52)

5263i

STRAIN RANGE vs. NO OF ALLOWABLE CYCLES



A: N-47 Curve
B: Base Curve
C: Provisional Design Curve (Equation Suggested by W. B. Jones)
D: 1.5 Factor on Strain Range from Base Curve

ATTACHMENT "K"

ARIZONA PUBLIC SERVICE COMPANY
UTILITY SOLAR CENTRAL RECEIVER STUDY

COST ESTIMATING GUIDELINES

1.0 INTRODUCTION

The guidelines for procedures which will be used to direct and coordinate the development of the conceptual design capital cost estimates are described in this document. The Cost Estimating Guidelines contain summary information on the cost estimating plan, a brief description of the capital cost components, and a discussion of the differences in approach for estimating the cost of the first commercial plant (110 MWe gross) versus the n^{th} commercial plant (220 MWe).

2.0 COST ESTIMATING PLAN

2.1 OBJECTIVES

One objective of the cost estimating plan is to prepare a Project Cost Estimate based on the conceptual designs of the first and n^{th} commercial solar thermal central receiver power plants. Another objective is that the accuracy of the estimates will be commensurate with the current level of design. A final objective is that the estimate will be developed and presented in a similar manner to that of the PG&E team so the UCB Technical Committee can easily compare the estimates of the APS and PG&E teams.

2.2 USE OF THE ESTIMATE

The primary use of the estimates is as a basis for economic evaluation of the first and n^{th} commercial plants. A critical output of this conceptual design effort is a refined evaluation of the solar thermal central receiver power plant economics. The cost estimate is a fundamentally important input to that evaluation process.

2.3 ASSIGNMENT OF RESPONSIBILITY

The responsibility for preparing the Project Cost Estimate is shared by the members of the APS team as shown in Attachment A.

2.3.1 Project Participants

The project team consists of the following participants.

- APS - Arizona Public Service Company
- B&V - Black & Veatch
- B&W - Babcock & Wilcox
- PDM - Pitt-Des Moines
- SPECO - Solar Power Engineering Company
- UH - University of Houston

2.3.2 Overall Responsibility -- B&V

APS has assigned B&V the overall responsibility for preparing the Project Cost Estimate. This responsibility includes coordination of the Project Cost Estimate preparation. As part of the coordination activities, B&V will provide estimating procedures and standard estimate forms. In addition, B&V is responsible for collecting, compiling and reviewing the Project Cost Estimate forms and other information supplied by the other participants. The review will include the following elements.

- Checking for estimate completeness and overlaps in scope.
- Determining estimate uncertainties and how each was addressed.
- Comparing this project estimate to those of similar projects.
- Auditing each participant's backup of costs, as required.

Further, B&V will prepare the final cost estimate report using the Cost Data Management System (CDMS) code of accounts as shown in Attachment B.

2.3.3 Responsibility of Each Participant

Each project participant is responsible for estimating the capital cost of a portion of the conceptual design. Primary responsibility for cost elements is assigned in the Responsibility Matrix.

2.4 APPROACH

The approach which will be used to develop the Project Cost Estimate consists of collecting, presenting and reviewing the elements of the estimate.

2.4.1 Collection of Costs

The approach which will be used for preparing the Project Cost Estimate is based on the use of systems. Because the plant is defined in terms of systems and the design is developed by system, the systems approach to cost estimating is a convenient way to ensure completeness of the estimate. Each system in the plant has a unique function; further, the design of each system is defined by system drawings, descriptions, lists and specifications. These system design documents form the basis for identifying the cost elements in each system.

2.4.2 Presentation of Costs

Costs will be presented so that totals can be obtained for each system as well as by CDMS Cost Code.

2.4.3 Total Capital Cost Estimate

The total project capital cost estimate includes the direct costs, indirect costs and allowance for funds used during construction (AFUDC). The collection and presentation of direct costs, as described above, will be based on January 1, 1987 dollars. To these direct costs will be added indirect costs such as general indirect costs, engineering and related services, field construction management, and APS's administrative and general expenses. Finally, AFUDC will be included in the total estimate based on the time from cost outlay for procurement and construction contracts to initial plant operation.

3.0 CAPITAL COST COMPONENTS

The Project Cost Estimate will include all capital costs associated with the first and n^{th} commercial solar thermal central receiver power plants. The major components of these capital costs include direct cost, indirect cost, and AFUDC.

3.1 DIRECT COST

The direct cost component will include costs for all plant systems. These costs will be identified for each cost element based on the approach described in Section 2. All direct costs will be expressed in January 1, 1987 dollars. Cost estimates shall be prepared using the form shown on Table 1.

The bulk of the direct cost component will consist of procurement and construction costs for the equipment and materials required for normal plant operation. However, in addition to these costs, the direct cost component includes spare parts, sales and use tax, freight and insurance, and contingency. Finally, because different approaches to collecting costs exist, this section presents several specific clarifications on the approach to be used in this Project Cost Estimate for other direct costs.

3.1.1 Procurement Costs

Procurement costs include the cost of equipment and materials which are necessary for the normal operation of the plant. If the item is shop fabricated by the firm making the estimate (as would be the case for B&W for the receiver or steam generator), the cost of engineering the item should be entered in the engineering column of Table 1. Next, the cost of material and labor for the fabrication should be entered in the fabrication column in Table 1. If the item requires no shop fabrication by the firm making the estimate (as would be the case for B&V for the turbine generator), the estimated cost should be entered in the procurement column of Table 1.

3.1.2 Construction Costs

Construction costs are those costs incurred in erecting the item in the field. The construction cost should be entered in the construction column of Table 1.

3.1.3 Spare Parts, Tax, Freight and Insurance

An initial inventory of spare parts, as well as sales and other appropriate taxes will be included in the capital cost estimate. Further, all procurement cost shall be based on delivery to the jobsite.

3.1.4 Contingency

Contingency will be assigned by B&V for each system according to the cost basis of the items in that system. Therefore, each participant should clearly indicate on the cost estimate form the letter designation of the cost basis for each item. However, if the participant believes he can provide a better contingency for his estimate, he may insert a percentage figure in place of the letter. The cost basis classes are defined in Table 2.

3.1.5 Other Direct Cost

Firms differ somewhat in the manner in which they estimate certain cost items. Among the items which are often estimated or collected differently are those described in the following subsections. These descriptions are provided so that all costs in the Project Cost Estimate will be estimated in a consistent manner.

3.1.5.1 Temporary Construction Facilities

Each key participant involved in plant construction (e.g. major equipment suppliers and construction contractors) will furnish additional facilities as required for his portion of the work; the cost of these temporary construction facilities will be included in the direct cost. Each major construction participant will furnish his own offices and crew quarters as a direct cost.

Facilities required by APS will be included in indirect costs as part of the owner's cost. For this estimate, facilities required by APS (owner's costs estimated by B&V) will include the following.

- o Temporary offices for use only by APS.
- o Warehouse facilities for total project.
- o All construction roads and laydown areas.
- o All construction utilities furnished to each contractor's buildings, etc. excluding telephone service.

3.1.5.2 Construction Services

Construction services which will be required are described as follows:

- o Site cleanup

  Each contractor is responsible for his own cleanup, including placing all waste materials in proper containers; these costs shall be considered as direct costs. Emptying containers and final disposal is included in indirect cost.

- Medical services

  Medical services will be included as an indirect cost as part of field construction management services.

- Construction equipment maintenance and servicing

  Each construction contractor will include the maintenance and servicing of construction equipment in his direct cost.

3.1.5.3 <u>Field Offices Supplies</u>

Cost for APS field office supplies will be included as an indirect cost; this will be part of owner's costs. The costs of office supplies for all other construction participants will be included as direct costs.

3.1.5.4 <u>Construction Supplies</u>

The costs for APS construction supplies will be included as an indirect cost; this will be part of owner's costs. Construction supply costs for all other construction participants will be included as direct costs.

3.1.5.5 <u>Field Craft Benefits, Payroll Burdens and Insurance</u>

These expenses will be included as part of field construction costs. These costs will be direct costs.

3.1.5.6 <u>Equipment Rental</u>

Equipment rental costs will be included as part of field construction costs. These costs will be direct costs.

3.1.5.7 <u>Construction Contractor Profit</u>

The profit for each construction contractor will be a direct cost.

3.1.5.8 <u>Field Staff--Including Subsistence and Travel</u>

These costs for each construction contractor will be included in the direct cost.

3.1.5.9 <u>Land and Land Rights</u>

Land and land rights will be included as direct costs.

3.1.6 Direct Cost Responsibility

The responsibility of project participants to provide direct costs is as follows.

- Procurement of Equipment and Materials - Each participant will estimate his portion whether it be shop fabricated (both material and labor) or procured.

- Construction - Each participant will estimate his portion, whether it be on a furnish and erect or separate construction contract basis.

- Spare Parts, Tax, Freight and Insurance - B&V will estimate these direct costs for each system based on discussions with APS and each participant.

- Contingency - B&V will estimate contingency for each system based on the cost basis listed on the cost estimate forms by each participant.

- Other Direct Cost - B&V will estimate these costs based on discussions with APS and each participant.

3.2 INDIRECT COST

The indirect cost component is comprised of the following categories.

- Owner's Costs
- Engineering Services
- Construction Management

3.2.1 Owner's Costs

Owner's costs include the following.

- Relay checkout and testing
- Instrumentation and control equipment calibration
- Checkout and testing
- Systems and plant startup, including operating crew during test and initial operation period
- Operating crew training
- Electricity and water used during construction
- Fuel for construction heating
- Fuel used during test and initial operation period (this is the actual fuel cost minus credit for energy produced)

- All taxes other than sales tax
- Water rights and landscaping
- APS office engineering
- Costs incurred in the permit and licensing process other than legal expense (engineering services)
- Insurance premiums (each contractor is assumed to include all of his workmen's compensation, other required labor related insurance, performance bond and liability insurance for his equipment and tools and for APS furnished equipment which he handles and erects which is included in direct cost)
- APS temporary construction facilities
- APS field office supplies
- APS construction supplie
- General and administrative expenses (such as executive management, accounting, financing, planning, and public relations)

3.2.2 Engineering Services

Engineering services include the following.

- A/E services
- Outside consultants, including engineering design and related services performed during final design by project participants other than B&V and APS
- Procurement services
- Legal expense

3.2.3 Construction Management

Construction management costs include the following.

- Field management and office staff
- Field contract administration
- Field inspection and quality assurance
- Project control
- Technical direction and management of startup and testing
- Cleanup expense for portion not included in direct cost construction contracts
- Safety and medical services
- Guards and other security services
- Field office equipment and supplies
- Field computer services
- Telephone and other utility bills associated with temporary services associated with construction management

3.2.4 Indirect Cost Responsibility

B&V will estimate indirect cost for each system based on discussions with APS and each participant who provides direct cost estimates.

4.0 APPROACH TO ESTIMATING COSTS FOR 1^{st} AND N^{th} COMMERCIAL PLANTS

The following is a general description of the approach to be used in estimating the costs for the first and n^{th} commercial solar thermal central receiver power plants.

4.1 FIRST PLANT (110 MWe gross)

As the cost basis for the first commercial plant, each participant should assume that an experiment has been conducted at the CRTF for a design more recent than for Category B or that a similar experiment has been conducted at Solar One. Further, it shall be assumed that an additional experiment, of an intermediate scale of approximately 30 MW_e, has been conducted.

4.2 N^{th} PLANT (220 MWe gross)

The cost basis for the n^{th} commercial plant shall be that solar thermal central receiver technology is mature and that 6 to 8 commercial scale plants have been built and operated, including plants in the 200 MW_e size. The estimate should account for cost reductions in engineering, tooling, and other costs which will be reduced (as compared to the first plant) due to a well defined technology.

092688

TABLE 1
ARIZONA PUBLIC SERVICE COMPANY
UTILITY SOLAR CENTRAL RECEIVER STUDY
COMMERCIAL PLANT
COST ESTIMATE FORM

Plant 1^{st}____________ N^{th}____________ Estimated By__________________ Date______

Subsystem______________________________ Checked By__________________ Date______

		Shop Fabrication Cost			Equip. & Mat. Cost		Field Const. Costs		
Item Description	CDMS Account Code	Engineering	Fabrication	Cost Basis Class	Procurement	Cost Basis	Construction	Cost Basis	Total Cost

TABLE 2

COST BASIS CLASSES

Class	Items	Contingency Percent
A	Scope Definition Could Vary Slightly; Large amount of Recently Contracted Cost and/or Vendor Quotations Known	10
B	Scope Definition is Fairly Accurate; Costs Based on Recent Experience	20
C	Scope Definition is Somewhat Vague; Cost Basis Has Little Recent Experience	30

ATTACHMENT A

ARIZONA PUBLIC SERVICE COMPANY
UTILITY SOLAR CENTRAL RECEIVER STUDY

RESPONSIBILITY MATRIX

CDMS Cost Code	Equipment Description	Design Responsibility
0	Land	APS System Functional Design
1	Structures and Improvements	B&V System Functional Design
1.1	Site Improvements	
	- Yard Work	B&V
	- Roads and Parking	B&V
	- Field Grading	B&V
1.2	Buildings	
	- Administration	B&V
	- Generation	B&V
	- Control Center	B&V
	- Security	B&V
	- Water Treatment	B&V
	- Warehouse	B&V
	- Others	B&V
2	Collector System	University of Houston System Functional Design
2.1	Heliostats	UH/SPECO
2.2	Foundations	UH/SPECO
2.3	Field Wiring	UH/SPECO
2.4	Controls	UH/SPECO
2.5	Beam Characterization System	UH/SPECO

ATTACHMENT A (CONT'D)

CDMS Cost Code	Equipment Description	Design Responsibility
3.0	Receiver System	B&W System Functional Design
3.1	Receiver	
	- Structural	B&W
	- Absorber Panels and Headers	B&W
	- Hot and Cold Surge Tanks	B&W
	- Recirculation Pump(s)	B&W
	- Insulation and Heat Trace	B&W
	- Air Supply	B&W
	- Other Equipment	B&W
3.2	Tower	
	- Structure	B&V
	- Foundation	B&V
	- Equipment Room	B&V
	- Other Equipment	B&V
3.3	Riser and Downcomer	B&V
3.4	Receiver Pumps	B&V
3.5	Intermediate Heat Exchanger	---
3.6	Controls, Instrumentation, and Wiring	B&W/B&V
4	Thermal Storage System	PDM System Functional Design
4.1	Tanks	
	- Cold Salt Tank(s)	PDM
	- Hot Salt Tank(s)	PDM
	- Drain Tank(s)/Pumps	PDM/B&V
	- Instrumentation	PDM
4.2	Foundations	
	- Tanks	PDM
	- Cooling Equipment	PDM
	- Berms	PDM
4.3	Storage Media	PDM
4.4	Piping	
	- Cover Gas Piping and Conditioning System	B&V
	- Interconnecting Piping	B&V
4.5	Controls, Instrumentation and Wiring	PDM/B&V

ATTACHMENT A (CONT'D)

CDMS Cost Code	Equipment Description	Design Responsibility
5	Steam Generation System	B&W System Functional Design
5.1	Heat Exchangers	
	- Preheater	B&W
	- Evaporator	B&W
	- Superheater	B&W
	- Reheater	B&W
	- Steam Drum	B&W
5.2	Structures	
	- Supports	B&W
	- Foundations	B&W
5.3	Piping	B&W
5.4	Pumps	
	- Hot Salt	B&V
	- Other Circulating Pumps	B&W
5.5	Auxiliary Equipment	B&W
5.6	Controls, Instrumentation and Wiring	B&W
6	Electric Power Generation System	B&V System Functional Design
6.1	Mechanical Equipment	
	- Turbine Generator	B&V
	- Condenser	B&V
	- Cooling Tower	B&V
	- Deaerator	B&V
	- Feedwater Heaters	B&V
	- Pumps	B&V
	- Other Equipment	B&V
6.2	Piping	B&V
6.3	Electric Equipment	
	- Generator Transformers	B&V
	- Auxiliary Transformers	B&V
	- Switchgear & Bus Duct	B&V
	- Cable	B&V
	- Other Equipment	B&V
6.4	Controls And Instrumentation	B&V/SPECO

ATTACHMENT A (CONT'D)

CDMS Cost Code	Equipment Description	Design Responsibility
7	Master Control System	SPECO System Functional Design
7.1	Computers	SPECO
7.2	Control Room Equipment	SPECO
7.3	Data Acquisition System	SPECO
7.4	Wiring and Instrumentation	SPECO
8	Fossil Hybrid System	B&W System Functional Design
8.1	Steam Generator (or Salt Heater)	B&W
8.2	Stack	B&W
8.3	Interconnecting Piping	B&W/B&V
8.4	Fuel Gas Supply	B&W/B&V
8.5	Control and Instrumentation	B&W

ATTACHMENT B

COST DATA MANAGEMENT SYSTEM
FOR SOLAR THERMAL CENTRAL RECEIVER POWER PLANTS

CAPITAL COST CODES OF ACCOUNTS

Account	Title
0	Land
1	Structures and Improvements
2	Collector System
3	Receiver System
4	Thermal Storage System
5	Steam Generation System
6	Electric Power Generation System
7	Master Control System
8	Fossil Hybrid System
9	Total Direct Cost
10	Indirect Cost
11	AFUDC
12	Total Capital Cost

ATTACHMENT B (CONT'D)

CAPITAL COST CODE OF ACCOUNTS
LEVEL 2 DETAIL

Account	Title
0	Land
1	Structures and Improvements
1.1	Site Improvements
1.2	Buildings
1.3	Not Used
1.4	Not Used
1.5	Not Used
1.6	Not Used
1.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
1.8	Contingency
2	Collector System
2.1	Heliostats
2.2	Foundations
2.3	Field Wiring
2.4	Controls
2.5	Beam Characterization System
2.6	Not Used
2.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
2.8	Contingency
3	Receiver System
3.1	Receiver
3.2	Tower
3.3	Riser/Downcomer
3.4	Receiver Pumps
3.5	Intermediate Heat Exchanger
3.6	Controls, Instrumentation, and Wiring
3.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
3.8	Contingency
4	Thermal Storage System
4.1	Tanks
4.2	Foundations
4.3	Storage Media
4.4	Piping
4.5	Controls, Instrumentation, and Wiring
4.6	Not Used
4.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
4.8	Contingency

ATTACHMENT B (CONT'D)

Account	Title
5	Steam Generation System
5.1	Heat Exchangers
5.2	Structures
5.3	Piping
5.4	Pumps
5.5	Auxiliary Equipment
5.6	Controls, Instrumentation, and Wiring
5.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
5.8	Contingency
6	Electric Power Generation System
6.1	Mechanical Equipment
6.2	Piping
6.3	Electric Equipment
6.4	Controls and Instrumentation
6.5	Not Used
6.6	Not Used
6.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
6.8	Contingency
7	Master Control System
7.1	Computers
7.2	Control Room Equipment
7.3	Data Acquisition System
7.4	Wiring and Instrumentation
7.5	Not Used
7.6	Not Used
7.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
7.8	Contingency
8	Fossil Hybrid System
8.1	Steam Generator
8.2	Stack
8.3	Interconnecting Piping
8.4	Fuel Gas Supply
8.5	Control and Instrumentation
8.6	Not Used
8.7	Spare Parts, Tax, Freight and Insurance, and Other Direct Costs
8.8	Contingency
9	Total Direct Cost

APPENDIX B
ALLOWABLE FLUX LEVELS
ON TUBE-TYPE RECEIVERS

APPENDIX B

Allowable Flux Levels on Tube-type Receivers

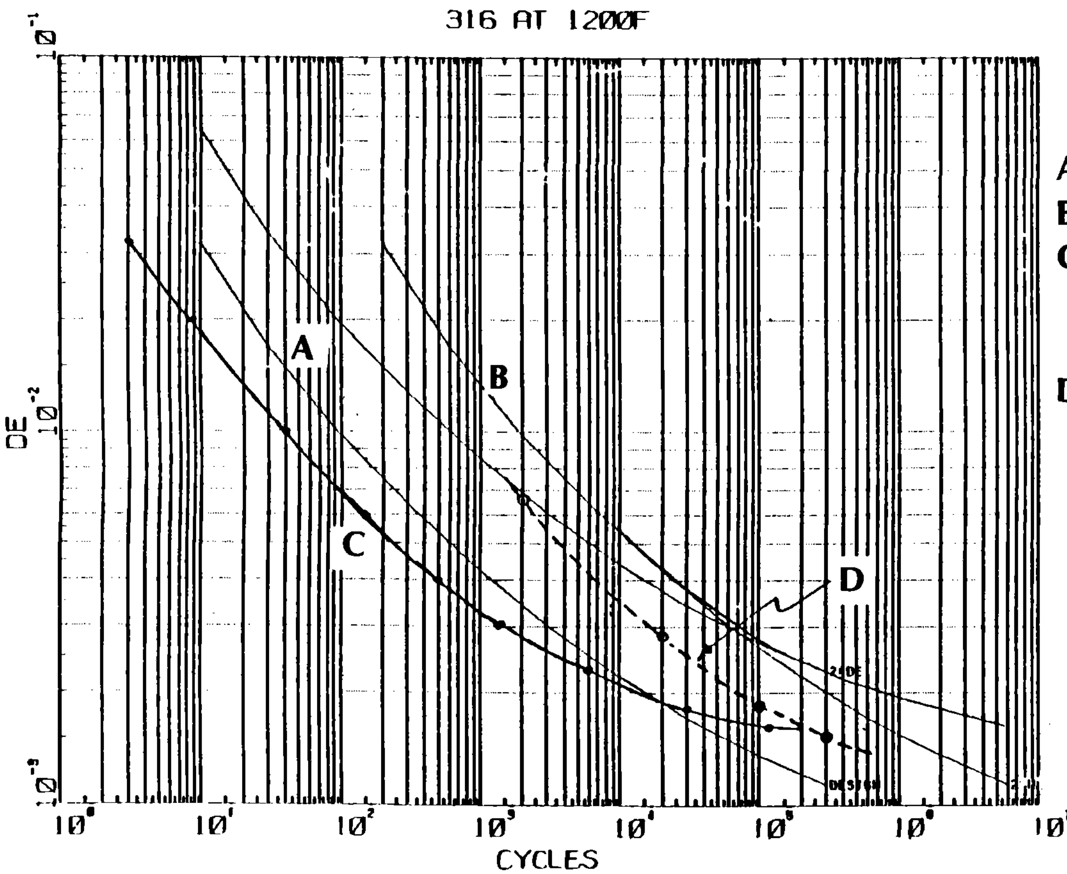
In order to reach a consensus on the criteria for allowable flux levels for the molten salt and sodium receiver designs, a workshop organized by Sandia National Laboratories was conducted at Central Receiver Test Facility, Albuquerque, New Mexico, on December 4, 1986. A summary of the provisional design method, which was recommended by W. B. Jones as a result of this workshop, may be seen in Ref. [1]. This method may be summarized as follows: The N-47 fatigue curve for stainless steel type 316 at 1200°F is Curve A in Figure 1. Develop a base curve by increasing the life by a factor of 20 and the strain range by a factor of 2. Curve B represents this base curve. Let us designate the cycles on the baseline curve as N_{fo}. The new design curve is given by:

$$N_f = \frac{N_{fo}}{10}\left(\frac{\nu}{\nu_o}\right)^{1-k}\gamma^{-f} \qquad (1)$$

or by applying a factor of safety 1.5, on the strain range, whichever is more conservative, ν_o was assumed to be 0.4 s^{-1} and k as 0.86 (Ref. 1). ν is given by:

$$\frac{1}{\nu} = t_1 \qquad (2)$$

where t_1 is the heating and cooling time, but does not include the time of steady operation. (For Alloy 800H the time of steady compression should not be neglected while calculating the frequency ν). Equation (1) may be rewritten as:



A: N-47 Curve

B: Base Curve

C: Provisional Design Curve (Equation Suggested by W. B. Jones)

D: 1.5 Factor on Strain Range from Base Curve

STRAIN RANGE VS. NUMBER OF ALLOWABLE CYCLES
FIGURE 1

$$N_f = \frac{N_{fo}}{F} \qquad (3)$$

where F is a factor given by:

$$F = 10 \left(\frac{\nu}{\nu_o} \right)^{K-1} \gamma^{f}$$

F is the counterpart of the factor of 20 on cycles used in arriving at the N-47 design curves. The values of F as a function of t, is given below:

t_1 (minutes)	F
15	46
30	50
60	55

Using a factor of 50, the new design curve, given by Equation (1), is shown in Figure 1 (Curve C). The design curve generated by applying a factor of 1.5 on the strain range is the Curve D in Figure 1. For design cycles below the range of 200,000 cycles, Curve C is more conservative than Curve D. It may be noted that at about 20,000 cycles Curve C intersects with the N-47 Curve A. Thus, for 20,000 cycles and below C is the preferred design curve, and for cycle lives above 20,000, the N-47 design curve is preferable. In any case, in this analysis the equivalent design cycles were assumed to be 20,000; hence, both curves would yield the same result.

Design Cycles

During the design life of 30 years the receiver will see about 11,000 diurnal cycles. During this period the receiver will also see several thousand cloud cover cycles. The stress or strain excursions during the cloud cycles are estimated to be less severe than during the diurnal cycles. Hence, the damage caused by each cloud cycle is less than that caused by the diurnal cycle. Based on the studies reported in Ref. [2], it was the consensus at the workshop that the cloud cycles may be considered equivalent to 9,000 diurnal cycles. Thus, it was deemed adequate if the receiver can survive 20,000 diurnal cycles or "design cycles".

Several analyses were performed in order to determine the transient temperature gradients and stress during the dry heat stages of daily startup. It was concluded that the dry heating can be accomplished within about 15 minutes without the transient stresses exceeding the steady state stresses. Thus no additional fatigue damage due to the dry heating need to be considered.

Allowable Flux Levels

The allowable flux levels are determined for molten-salt receiver by the following criteria:

(a) The tube life should be no less than 20,000 "design cycles"; and,

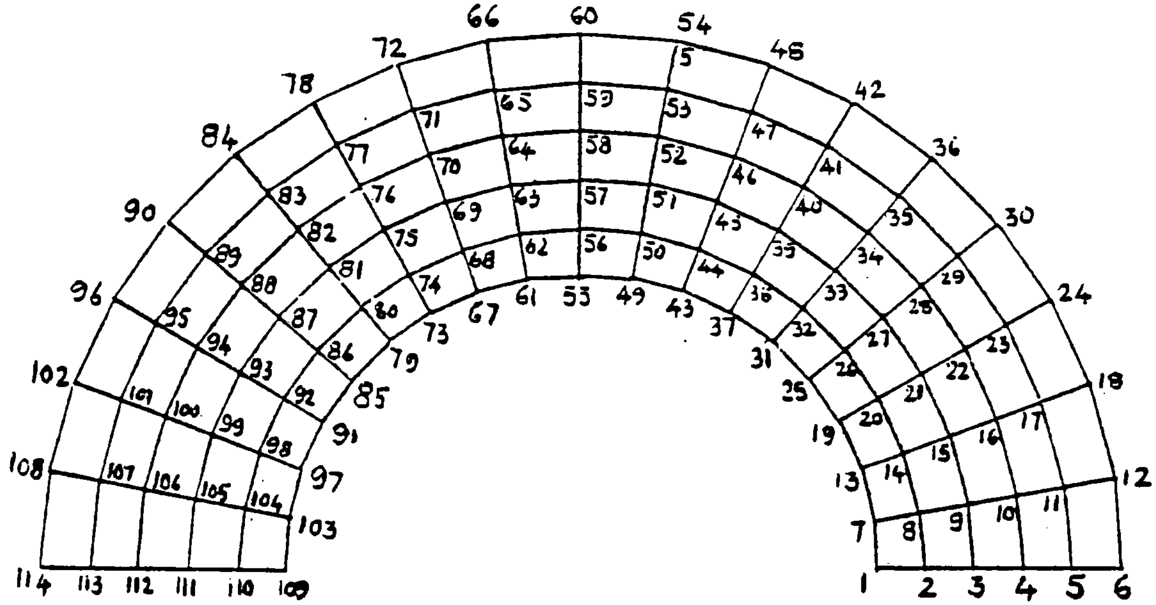
(b) Maximum salt film temperature should not exceed 1100°F.

In order to satisfy the first criteria, we first performed a two-dimensional temperature distribution analysis using FWDC in-house computer program NONAX. The input for this analysis are the tube diameter and thickness; heat flux, thermal conductivity; inside film coefficient, and bulk fluid temperature. The output is the temperature distribution at the tube cross section.

Using the above temperature distribution, elastic stress analysis was performed, again using NONAX. The computer model used in the thermal and stress analyses are shown in Figure 2. Generalized plane strain conditions were assumed. The input for stress analysis includes tube geometry, temperature distribution, coefficient of thermal expansion (∞), modulus of elasticity (E), and Poisson's ratio (ν). The output includes all stress components (σ_r, σ_Θ, σ_z, $\gamma_{r\Theta}$), Von Mises effective stress and effective strain. As proposed in Ref. [3], the inelastic strain range for fatigue calculations was obtained by increasing the effective strain by 10-percent. Using the criteria that the inelastic strain range should not exceed the allowable strain range for 20,000 cycles, the allowable flux levels were calculated. Recognizing the fact that for a given tube geometry and heat transfer coefficient, the temperature gradients, stresses, and strains are linearly proportional to the flux; a simple post-process computer program was written to do the above calculations. The calculations were repeated for different geometries and heat transfer coefficients.

The allowable flux levels for 1-in. and 1.5-in. OD tubes are shown in Figures 3 and 4. Results for three different heat transfer coefficient values (1000, 1500, and 2000 Btu/h·°F·ft^2) are included. In Figure 3 it may be noted that the portion ABC of the allowable flux curve is governed by the creep-fatigue life criteria. CD is governed by the salt film temperature criteria.

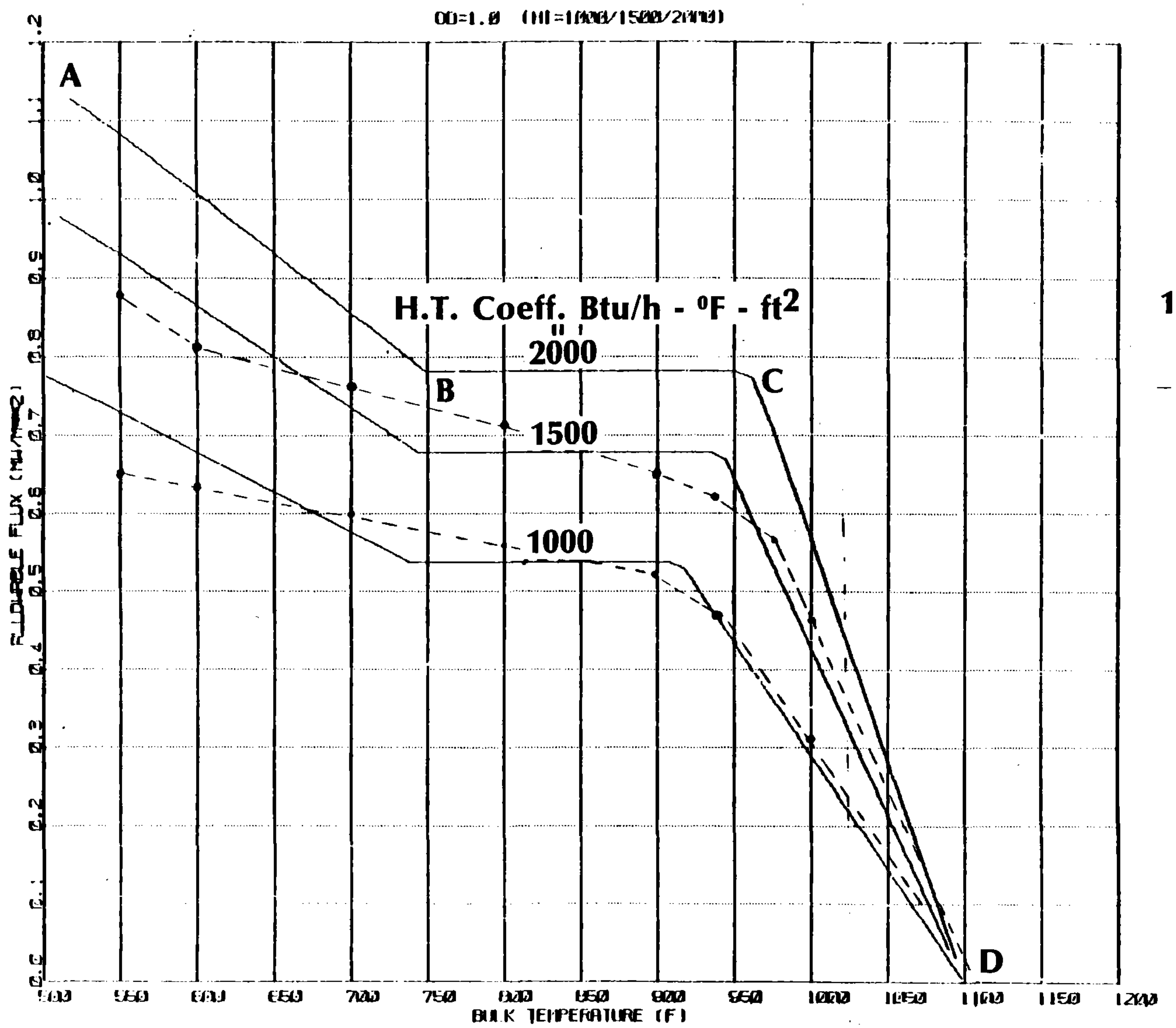
092688



NONAX COMPUTER MODEL
FIGURE 2

092688

B-7

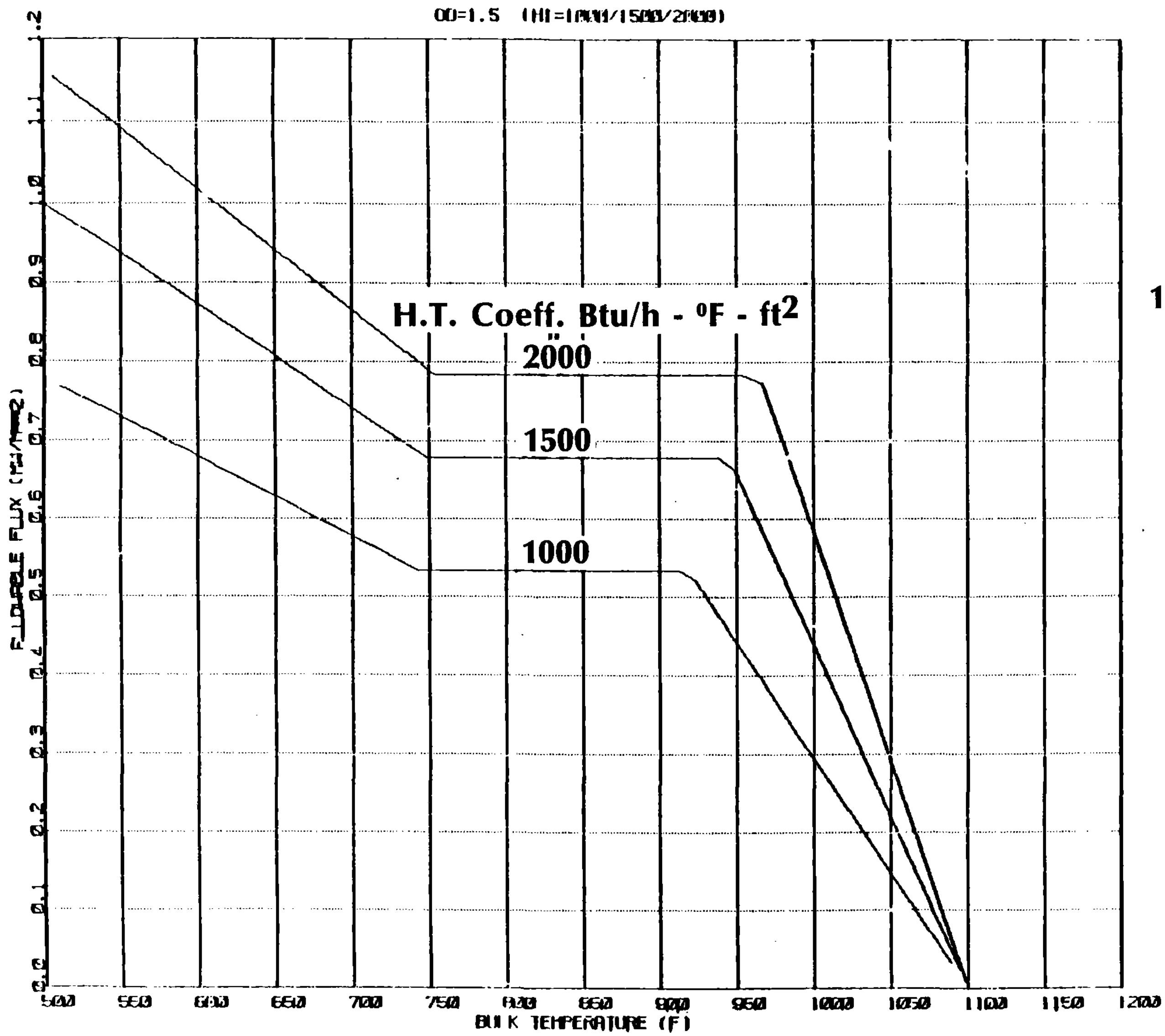


1" O.D. x 0.065" WALL

---- B&W CURVES

ALLOWABLE FLUX LEVELS FOR MOLTEN SALT RECEIVER
FIGURE 3

092688



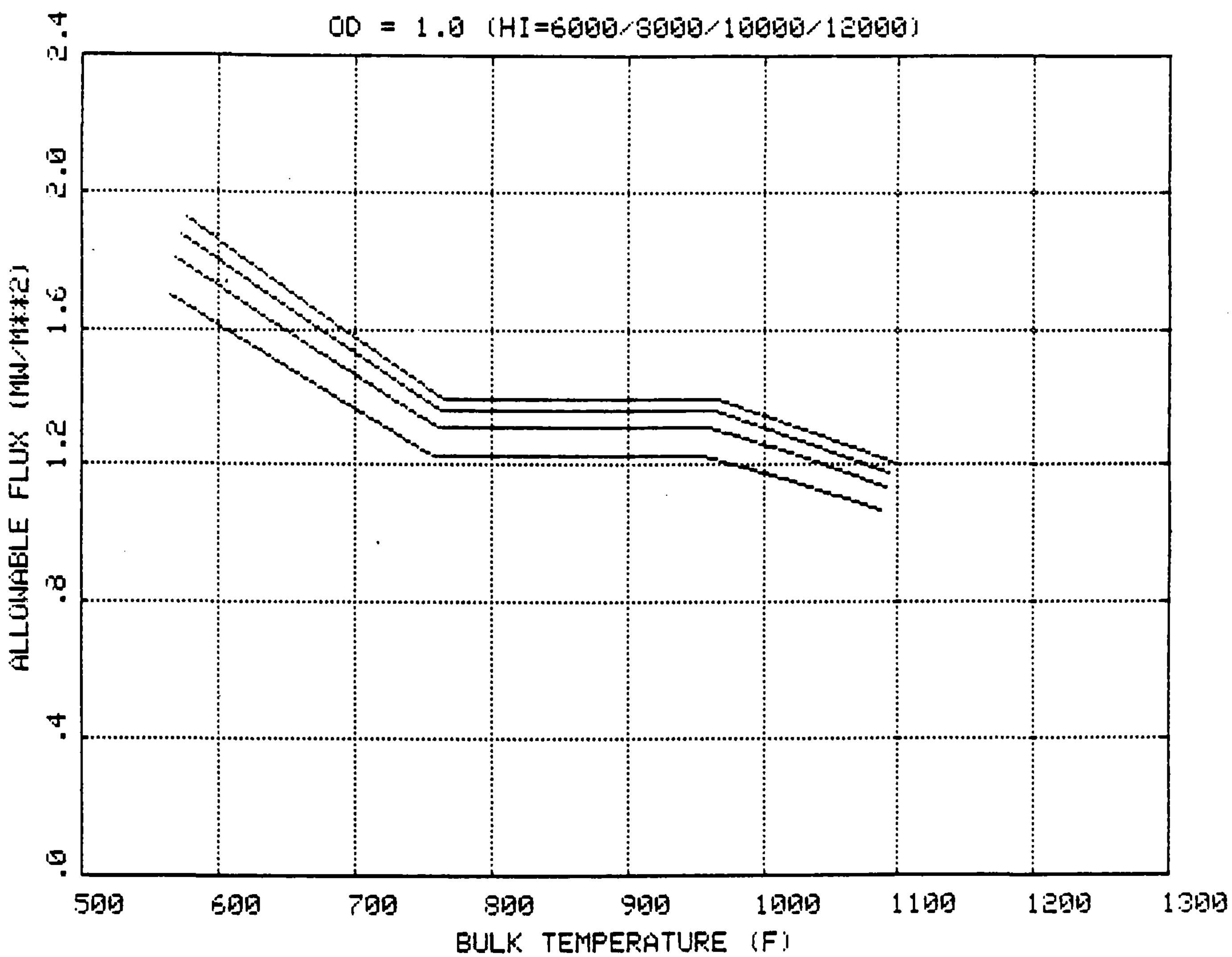
1.5" O.D. x 0.065" WALL

ALLOWABLE FLUX LEVELS FOR MOLTEN SALT RECEIVER
FIGURE 4

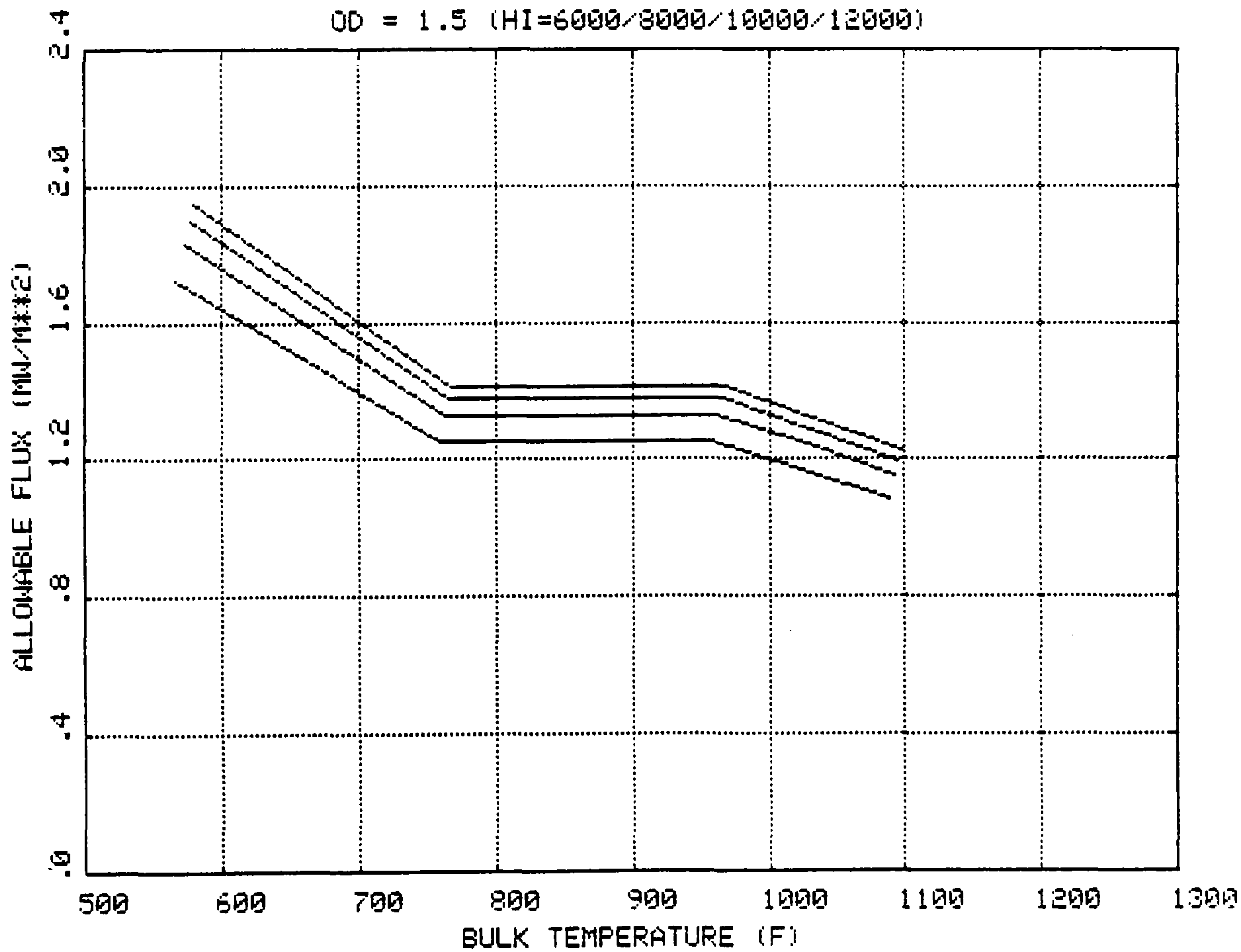
The region BC is flat because N-47 recommends the same fatigue curves in the temperature range of 1000 to 1200°F. These curves were distributed to the study teams (Ref [4]) for comparison. The corresponding allowable flux limits for the 1-in. OD tube (h_i = 1500 Btu/hr·°F·ft^2), developed by Babcock & Wilcox Company (Ref. [5]), are also plotted for comparison purposes.

The allowable flux levels for sodium receiver tubes are shown in Figures 5 and 6. In these figures the tube outer diameters are 1.0-in. and 1.5-in. The wall thickness is 0.065-in. Flux limit curves for heat transfer values of 6000, 8000, 10,000, and 12,000 Btu/hr·ft^2·°F were generated. The results indicate that the tube diameter has negligible effect on flux limit as long as the wall thickness remains the same.

It may be noted that the allowable flux levels shown in Figures 3 through 6 are somewhat lower than those shown in Ref. [2]. This difference is due to the discrepancies in strain calculations which in turn are due to the differences in computer codes and the approximations used. After discussions with B. L. Kistler of Sandia National Laboratories (Livermore), it was concluded that about 5 or 6 percent of the differences in strain calculations could be attributed to the inherent differences in the computer codes. The remainder of the difference is, perhaps, due to the assumptions made in the calculations. For example, our calculations assume that the elastic-plastic-creep strain ranges are 10-percent higher than the elastic strain ranges[3]. In Ref. [2], the two-dimensional strains are approximated from one-dimensional calculations, in addition to the assumptions involved in approximating the inelastic strains from elastic analysis.



ALLOWABLE FLUX LEVELS
FOR SODIUM RECEIVER
FIGURE 5



ALLOWABLE FLUX LEVELS
FOR SODIUM RECEIVER
FIGURE 6

Based on the allowable fluxes shown in Figures 3 and 4, and discussions held during the December 19, 1986 Conference Call (Ref.[6]), we have arrived at a recommended absorbed heat flux limit curve for sizing molten salt receivers for the trade study (Ref. [7]). This curve is shown in Figure 7, which is applicable for a receiver design with a salt velocity inside tubes around 10ft/s. As shown in the figure, over the baseline molten salt receiver operating temperature range, the absorbed heat flux limit remains constant at 0.65 MW/m^2 (206,000 Btu/h ft^2) for the salt bulk temperature from 550°F to 950°F, and decreases linearly thereafter to 0.22 MW/m^2 (69,700 Btu/h ft^2) as the bulk temperature reaching 1050°F.

As the trade study proceeded, receiver design with a higher salt velocity of 3.8 m/s (12.5 ft/s) were considered. A heat flux limit curve established for this velocity is also depicted in Figure 7. The allowable absorbed flux in this case is 0.75 MW/m^2 (238,000 Btu/h-ft^2) and decreases to 0.3 MW/m^2 (95,000 Btu/h-ft^2) at salt outlet temperature of 566°C (1050°F). These two flux limit curves were consequently used as guidelines for generating salt receiver common data

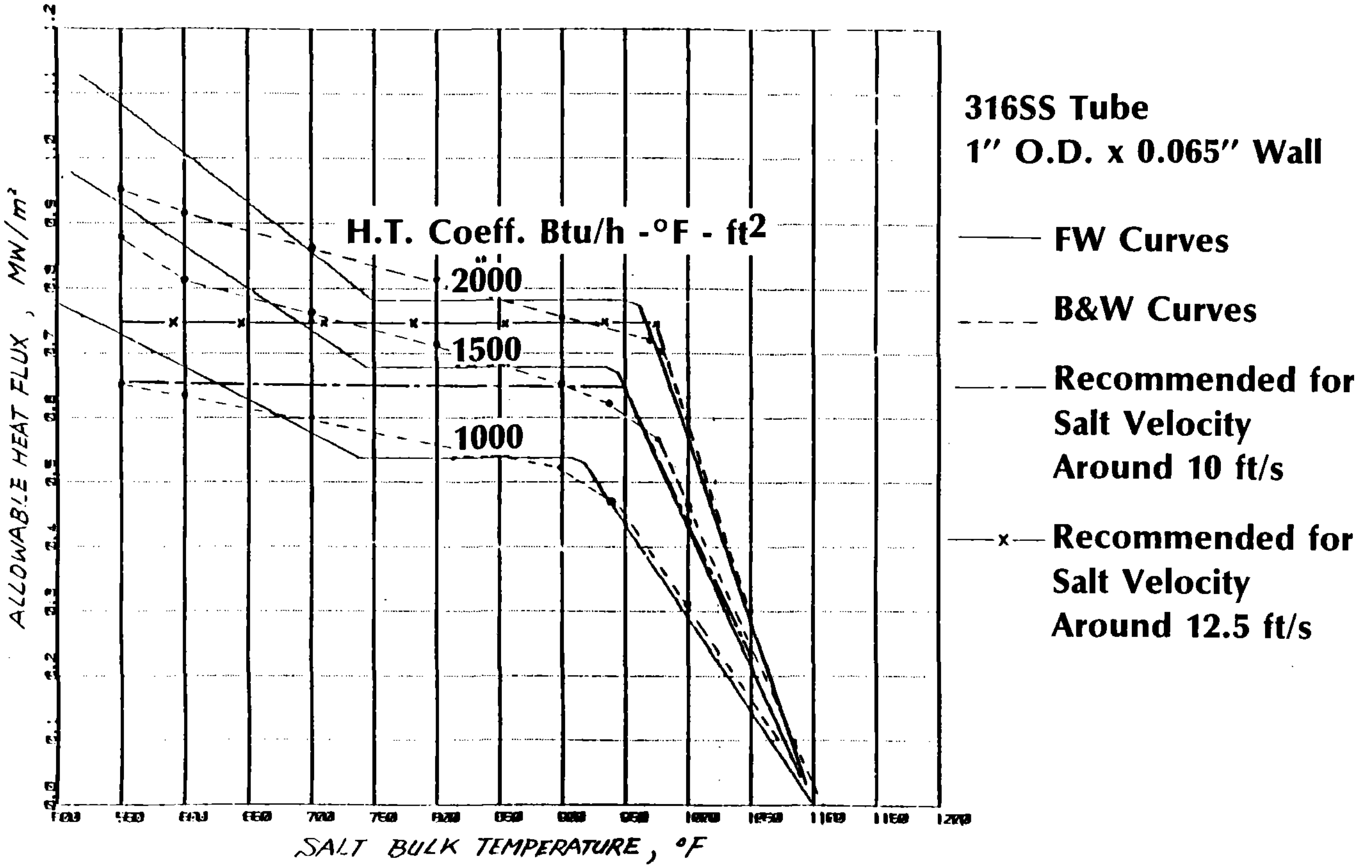
References

[1] Provisional Design Method for Solar Receivers, Memo from Wendell Jones to J. T. Holmes, December 9, 1986.

[2] B. L. Kistler, "Fatigue Analysis of a Solar Central Receiver Design Using Measured Weather Data", SNLL Draft Report, February 1986.

[3] Narayanan, T. V., et al., "Structural Design and Life Assessment of a Molten Salt Receiver," Journal of Solar Energy Engineering, Transactions of the ASME, Vol. 196, August 1985.

[4] Letter from S. F. Wu to J. E. Harder dated December 17, 1986 Subjecty "Alternate Utility Team, Utility Solar Central Receiver Study - Allowable Flux Limits for Receiver Design".



ALLOWABLE FLUX LEVELS FOR MOLTEN SALT RECEIVER DESIGN
FIGURE 7

092688

[5] Letter from J. P Reed to P. DeLaquil, dated December 18, 1986. Subject "PG&E Utility Team, Utility Solar Central Receiver Study - Allowable Flux Limits for Receiver Design"

[6] Conference Call of December 19, 1986, with participation of J. E. Harder (B&V), P. DeLaquil (Bechtel), J. P. Reed (B&W), D. Smith (B&W), T. V. Narayanan (FW), and S. F. Wu (FWDC).

[7] Letter from S. F. Wu to J. E. Harder, dated December 23, 1986. Subject "Alternate Utility Team, Utility Solar Central Receiver Study - Allowable Flux Limits for Molten Salt Receiver"

APPENDIX C
MOLTEN SALT STORAGE TANK DATA

APPENDIX C

CONTENTS

	Page
Thermal Storage Cost Data	C-1
Thermal Storage Tank Design Basis	C-11
Thermal Storage Tank Design	C-14
Thermal Storage Tank Foundation and Insulation Design	C-16
Thermal Storage Tank Nozzle Design	C-18
Containment Dike Design	C-20
Thermal Storage Tank Instrumentation	C-21
Thermal Storage Tank Leak Detection	C-23
Thermal Storage Tank Ullage Pressure Control	C-24
Thermal Storage Tank Trade Study Considerations	C-25
Elevated Temperature Storage Tank Installations	C-28

ALTERNATE UTILITY TEAM - SOLAR CENTRAL RECEIVER STUDY

TABLE 1 - SUMMARY SHEET

Plant Capacity	Capital Costs	Operating & Maintenance Costs (Per Year)	Daily Heat Losses (Million Btu/day)
1200 MWHt - 2 Tanks (1050°F Oper.)	4834.8^k	16.7^k	33.0
3000 MWHt - 3 Tanks	10047.6^k	22.4^k	68.1
150 MWHt - 2 Tanks	1445.5^k	12.3^k	9.4

The above data is for preliminary designs of thermal storage units. Tables 2 thru 5 present the itemized values contributing to the above cost and heat loss summaries.

ALTERNATE UTILITY TEAM - SOLAR CENTRAL RECEIVER STUDY

TABLE 2 - STORAGE TANK CAPITAL COSTS (See note 1)

STORAGE CAPACITY	STORAGE VESSELS		CAPITAL COSTS					
	TANK	TANK DIMENSIONS	STEEL CYLINDER, BOTTOM, ROOF, NOZZLES	EXTERIOR INSULATION (See note 3)	FOUNDATION (See note 4)	DIKES (See note 5)	MISCELLANEOUS & MECHANICAL (See note 6)	TOTAL
1200 MWHt	550°F "COLD" TANK 1050°F HOT TANK	1@ 84'ø x 40' 1@ 84'ø x 44'	$2655.0 K	$843.0 K	$572.7 K	$30.0 K	$734.1 K	$4834.8 K
3000 MWHt (See note 7)	550°F "COLD" TANK 1050°F HOT TANK	1@ 122'ø x 46' 2@ 90'ø x 46'	$5968.0 K	$1648.0 K	$1235.7 K	$52.0 K	$1143.9 K	$10047.6 K
150 MWHt	550°F "COLD" TANK 1050°F HOT TANK	1@ 44'ø x 24' 1@ 44'ø x 24'	$572.0 K	$266.0 K	$202.7 K	$11.9 K	$392.9 K	$1445.5 K
ALTERNATE 1200 MWHt	550°F "COLD" TANK 1050°F HOT TANK	1@ 84'ø x 40' 2@ 66'ø x 36'	$2940.0 K	$985.0 K	$661.0 K	$34.9 K	$794.1 K	$5415.0 K
ALTERNATE 3000 MWHt (See note 7)	550°F "COLD" TANK 1050°F HOT TANK	1@ 122'ø x 46' 1@ 126'ø x 48'	$6225.0 K	$1415.0 K	$1165.0 K	$46.4 K	$1068.9 K	$9920.3 K
ALTERNATE 1200 MWHt 1000°F HOT SALT TEMPERATURE	550°F "COLD" TANK 1000°F HOT TANK	1@ 85'ø x 43' 1@ 85'ø x 46'	$2824.0 K	$891.0 K	$592.7 K	$31.3 K	$750.4 K	$5089.4 K

NOTES FOR TABLE 2 - STORAGE TANK COSTS

1) Costs are for non-union labor and include administration costs and constructor profit margin.

2) Salt operating temperatures are 1050°F (hot) and 550°F ("cold"), except for last case (1000°F, 550°F).

3) Exterior insulation is blanket mineral wool in thicknesses totaling 6 inches for "cold" vessels and 12 inches for hot vessels.

4) Foundation costs include concrete ringwall, excavation and backfilling, foundation cooling ducts, foundation insulating blocks, and 3% subcontractor supervision costs.

5) Dike costs are for 2 or 3 adjoining dikes with common wall(s) in between. Assumes use of site material for walls, and includes gravel slope protection.

6) Miscellaneous and mechanical costs include: drainage system (drain sump tank, drainage system piping, drain tank pumps, drain sump pump, but no drain tank), salt heater/mixer/conveyor, ullage gas control system, foundation cooling blower, and air drying equipment.

7) 1050°F tanks built to diameters larger than 100 feet are not considered practical designs. The large thermal growths and large bottom shell course thickness are likely to cause serious structural problems.

   The 550°F "cold" tank may require stress relieving for bottom ring shell thickness which exceeds 1.5 inch.

ALTERNATE UTILITY TEAM
SOLAR CENTRAL RECEIVER STUDY

TABLE 3 - STORAGE TANK OPERATION & MAINTENANCE COSTS

Plant Capacity	No. of Storage Vessels	Yearly Operating Costs ($1000)	Yearly Maintenance Costs ($1000)	Total O&M Costs ($1000)
1200 MWHT	2	---	16.7^k	16.7^k
3000 MWHt	3	---	22.4^k	22.4^k
150 MWHt	2	---	12.3^K	12.3^K

Above figures include:

- Maintenance: Vessels
  Foundation & Dike
  Insulation
  Foundation System Cooling Blower
  Drainage System
  Ullage Gas Control System
  Miscellaneous others

Above figures assume on-site (or near site) personnel to perform maintenance tasks.

TABLE 4 - AUXILIARY POWER REQUIREMENTS - STORAGE SYSTEM

Auxiliary requirements are for:

- Electric power (KW) required to run air blowers for foundation cooling recirculation pumps for back-up recirculation heaters, drain tank pumps, sump pumps, ullage blowers, etc.
- Natural gas consumption for back-up recirculation heaters. These heaters are for maintaining salt in liquid form during extended outage periods. Also includes salt heaters for initial charging, and miscellaneous heating.

Plant Capacity	Avg. Annual Kilowatt (KW) Requirements	Peak Kilowatt (KW) Requirements	Average Gas Consumption (ft^3/hr)	Peak Gas Consumption (ft^3/hr)
1200 MWHt	26.3	56.4	124.6	43.8
3000 MWHt	37.0	76.1	266.0	76.1
150 MWHt	16.8	29.2	41.7	29.2

Notes:

1) Operating costs for auxiliary power are not considered in Tables 1 or 3.
2) Gas consumption values are for 980 Btu natural gas.

092688

ALTERNATE UTILITY TEAM - SOLAR CENTRAL RECEIVER STUDY

TABLE 5 - DAILY HEAT LOSSES

STORAGE CAPACITY	VESSEL TEMPERATURE/SIZE	HEAT LOSSES		TOTAL LOSSES BTU/DAY x 10^6	% DAILY LOSS vs RATED HEAT	RATED STORED HEAT
		BOTTOM BTU/DAY x 10^6	SHELL & ROOF BTU/DAY x 10^6			
1200 MWHt	550°F "COLD" TANK 1 @ 84′ø x 40′	0.378	15.043	15.421	0.38 %	4.0944 x 10^9 BTU
	1050°F HOT TANK 1 @ 84′ø x 44′	1.007	16.518	17.525	0.43 %	
	1050°F HOT TANKS 2 @ 66′ø x 36′	1.244	20.976	22.220	0.54 %	
3000 MWHt	550°F "COLD" TANK 1 @ 122′ø x 46′	0.797	27.702	28.499	0.28 %	10.236 x 10^9 BTU
	1050°F HOT TANK 1 @ 126′ø x 48′	2.267	30.395	32.662	0.32 %	
	1050°F HOT TANKS 2 @ 90′ø x 46′	2.312	37.326	39.638	0.39 %	
150 MWHt	550°F "COLD" TANK 1 @ 44′ø x 24′	0.104	4.372	4.476	0.88 %	0.512 x 10^9 BTU
	1050°F HOT TANK 1 @ 44′ø x 24′	0.276	4.664	4.940	0.97 %	

OUTSIDE WIND VELOCITY = 8.5 mph
EXTERIOR TEMPERATURE = 60 F

SHELL & ROOF INSULATION
"COLD" TANKS - 6" MINERAL WOOL BLANKET
HOT TANKS - 12" MINERAL WOOL BLANKET

"COLD" TANKS
18 HRS - "FULL"
6 HRS - 3 ft HEEL
HOT TANKS
6 HRS - "FULL"
18 HRS - 3 ft HEEL

COMMON DATA

STEEL CYLINDER, BOTTOM, ROOF, NOZZLES - COST CONSIDERATIONS

- Union labor.
- Administrative costs and profit margin included.
- Steel stress allowables decreased to allow for high temperature service.
- Field grading, etc. NOT included.
- Assumed standard construction procedures and designs, except that some high temperature and creep effects have been included.
- Painting NOT included, but doubtful need (insulated).
- NDE and Weld Control - typical API 650 w/spot X-ray.
- No preheat or postweld heat treatment assumed.
- Hydrotest included (but water supplied and disposed by others).
- Spiral stairway included, but would need alternate (such as stair tower) due to large thermal motions.
- Use TP 316 stainless steel prices.
- No drainage volume capacity included.
- Standard corner details assumed.
- Three (3) foot salt heel assumed for both Hot and "Cold" tanks.
- Assumed standard dome roof tank with R/D = 1.0.
- No piping loads assumed to affect tank.
- Vessels fabricated in place. Some shop items shipped to site.
- Typical CBI (or equivalent) construction/supervision flat bottom tank techniques assumed, but realize that some tighter controls likely.
- NO drain tank assumed.
- Externally insulated exterior. Foundation insulation also assumed.
- Wind effects considered on shell for buckling/uplift.
- API 650 Code used with ASME stress allowables for temperatures above 800°F.
- No charging effects considered on shell. However salt heater/mixer and conveyor included as "mechanical" equipment.
- Freeboard distance used as required for sloshing.
- API Zone 3 earthquake effects considered.

FOUNDATIONS - COST CONSIDERATIONS

- Included concrete/rebar/forming excavation.
- Structural fill and common fill 3% CBI subcontract supervision cost.
- API Zone 3 earthquake.
- Non-union labor used throughout.
- Earthwork assumed per foundation details. Excavation assumed to 5 ft. below G.L., fill used for dikes.
- Structural fill compacted per minimum field dry density equal to 95% of maximum Modified proctor Density (ASTM D1557).
- Dry clay aggregate used because of its excellent thermal insulation quality.
- Cal Sil and Foam Glass insulation costs (and sand/glass pads) included (material, labor, freight). Cal Sil used at tank walls for bearing resistance.
- Foundation cooling pipes included. Forced air convection equipment considered as "mechanical" equipment.
- Includes steel restraining ring around foundation insulation.

DIKES - COST CONSIDERATIONS

- Dike material borrowed from tank excavations.
- 6" to 12" of freeboard assumed for dikes.
- Common dike walls assumed between adjacent tank dikes.
- Includes 2" to 3" of gravel slope protection.
- Excavation/recompaction costs included.
- No special liners assumed. Salt seepage into soil assumed as acceptable.

EXTERIOR INSULATION - COST ITEMS

- Includes insulation, wire screen, pins, flashing, corrugated aluminum jacket, freight costs, jacket banding.
- Nozzle insulation included to first flange.
- Spot welding (of pins-to-shell) included.
- Insulation chosen for continuous service at 1200°F.
- Labor at union rates.
- 3% subcontractor supervision charge included.
- Basic insulation is 3 inch thick Mineral Wool blankets. Every second layer of insulation uses wire mesh backing for structural strength. Total thicknesses are 12 inches for hot tanks, 6 inches for "cold" tanks.
- Corrugated outer aluminum jackets allow for thermal expansions.

ALTERNATE UTILITY TEAM
SOLAR CENTRAL RECEIVER STUDY
DESIGN BASIS

- Contained Liquid: Eutectic Salt Mixture - 60% $NaNO_3$, 40% KNO_3

- Design Temperatures:
  - Hot Tank: 1050°F (except 1000°F for special case operating temperature)
  - Cold Tank: 550°F

- Heat Stored - Active Fluid:
  - 4.0944×10^9 Btu for 1200 MWHt plant
    10.236×10^9 Btu for 3000 MWHt plant
    0.5118×10^9 Btu for 150 MWHt plant
  - Heat capacities, densities
    c_p = 0.358 Btu/lbm-°F, ρ = 118.98 lbm/ft^3 @ 550°F
    c_p = 0.369 Btu/lbm-°F, ρ = 107.9 lbm/ft^3 @ 1050°F

- Cover Gas:
  "Dry air" (free of CO_2 and water) at 0.10 psig design pressure

- Service Life:
  30 years for tanks, supports, and stairways

- Materials:
  - Hot Tanks: A240 gr 316 (or gr 316H) stainless steel
  - Cold Tanks: A516 gr 70 carbon steel
  - Ringwalls: 5000 psi (f'_c) concrete, A615 Gr. 60 reinforcing steel

- Codes:
  - Tanks: API Stnd. 650
    Steel shell stress allowables modified for high temperature service:
    - 17.5 KSI for A516 Gr 70 @ 550°F per ASME Section VIII, Div. 1
    - 12.5 KSI for A240 Gr 316 (or 316H) @ 1050°F per ASME Nuclear Code Case N47-23. This quasi-operational stress allowable anticipates that cyclic and creep effects be considered in final design/analysis
  - Ringwalls ACI 318-83

- Seismic: API 650 Appendix E Zone 3 Earthquake - 0.18G horizontal seismic loads only (no vertical G). Product (salt) sloshing also included. Coefficients Z = 0.75, S = 1.5, I = 1.0. Allowable stresses increased 33% for seismic conditions.

- Wind: 90 mph design velocity per API 650. Allowable stresses increased 33% for wind conditions.

- Maximum Temperatures:
  - 200°F for in situ soils beneath tank foundation
  - 140°F for insulation jacket around shell and roof
  - 350°F max. for foundation concrete

- Soil:
  - Firm sand below 5 ft. depth containing thin layers of relatively soft silt
  - 5000 psf allowable soil bearing pressure at 5 ft. depth
  - Water table below 100 ft.
  - Increased soil allowable stresses by 33% for wind or seismic effects

- Vessel Loadings:
  - Roof: 45 psf total D.L. + L.L. (includes insulation)
  - Insulation on cylinder: 10 psf
  - Internal pressure: from product load plus gas blanket
  - Vacuum pressure: none
  - No nozzle loadings on shell
  - Seismic
  - Wind

- Equivalent Daily Product Loading Cycle:
  - Hot Tank
    - 6 hrs. "full" vessel
    - 18 hrs. "empty" vessel (heel only)
  - Cold Tank
    - 18 hrs. "full" vessel
    - 6 hrs. "empty" vessel (heel only)

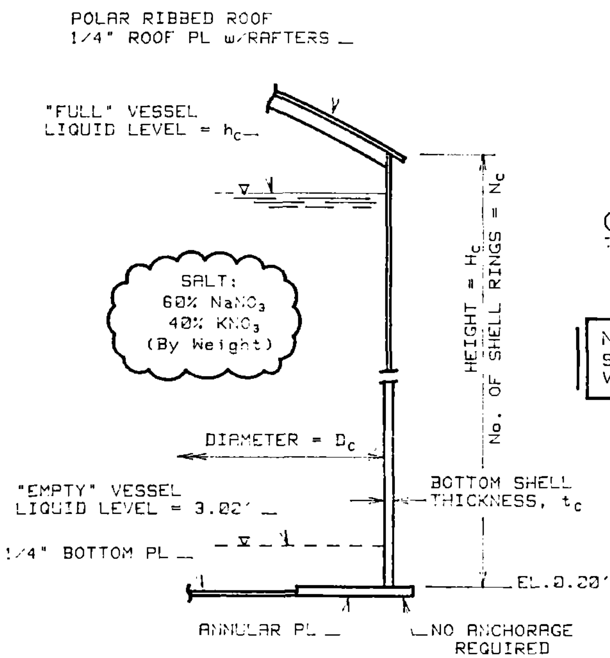
- Corrosion Allowance on Tanks:
  - 0.062 inches (total) on inside of each tank

- Shell Insulation:
  - Halide "free" insulation in contact with stainless steel tanks and/or nozzles

- Vessel Anchorage:
  - Design configuration precludes need for anchorage.

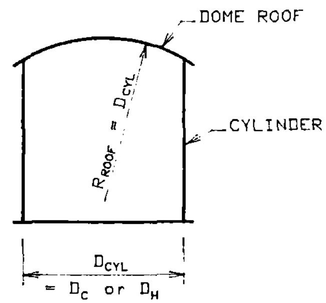
- Foundation Criteria
  - Salt product considered as live load (load factor 1.7) for ACI 318-83 concrete design.
  - Concrete and reinforcing steel strengths were reduced 33% and 20% respectively for long term elevated temperature service.
  - Outside face of concrete ringwall had 250% increase in reinforcing steel to account for stresses from thru wall thermal gradients.

- Containment Dikes
  - Individual containment dikes provided for each tank.
  - Dikes sized to contain volume of each tank, with 6" - 12" freeboard.
  - Dike height limited to 6 ft. to permit easy access to tank.



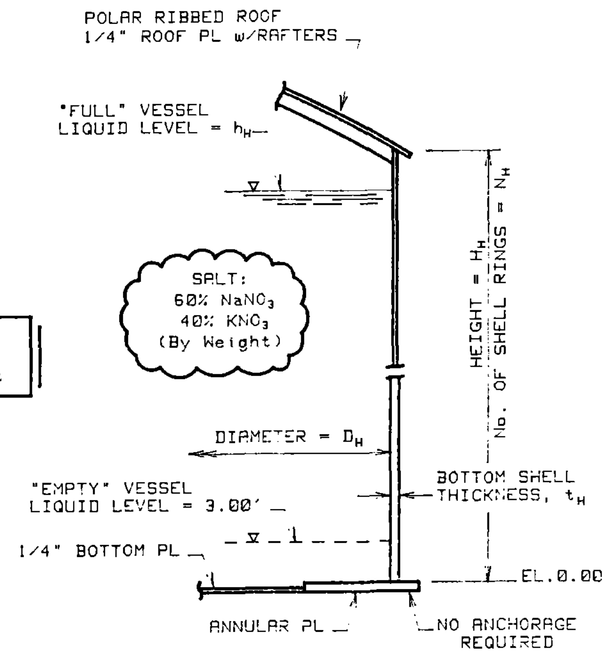
"COLD" TANK

NUMBER REQUIRED = n_C
SALT TEMPERATURE = T_C
ACTIVE SALT VOLUME: V_C @ 119 LBM/FT^3
MAT'L: A516 GR70 CARBON STEEL



TYPICAL ROOF CONFIGURATION

NOTE:
SEE TABLE "A" FOR
VALUES OF D, H, N, T, V, h, n & t



HOT TANK

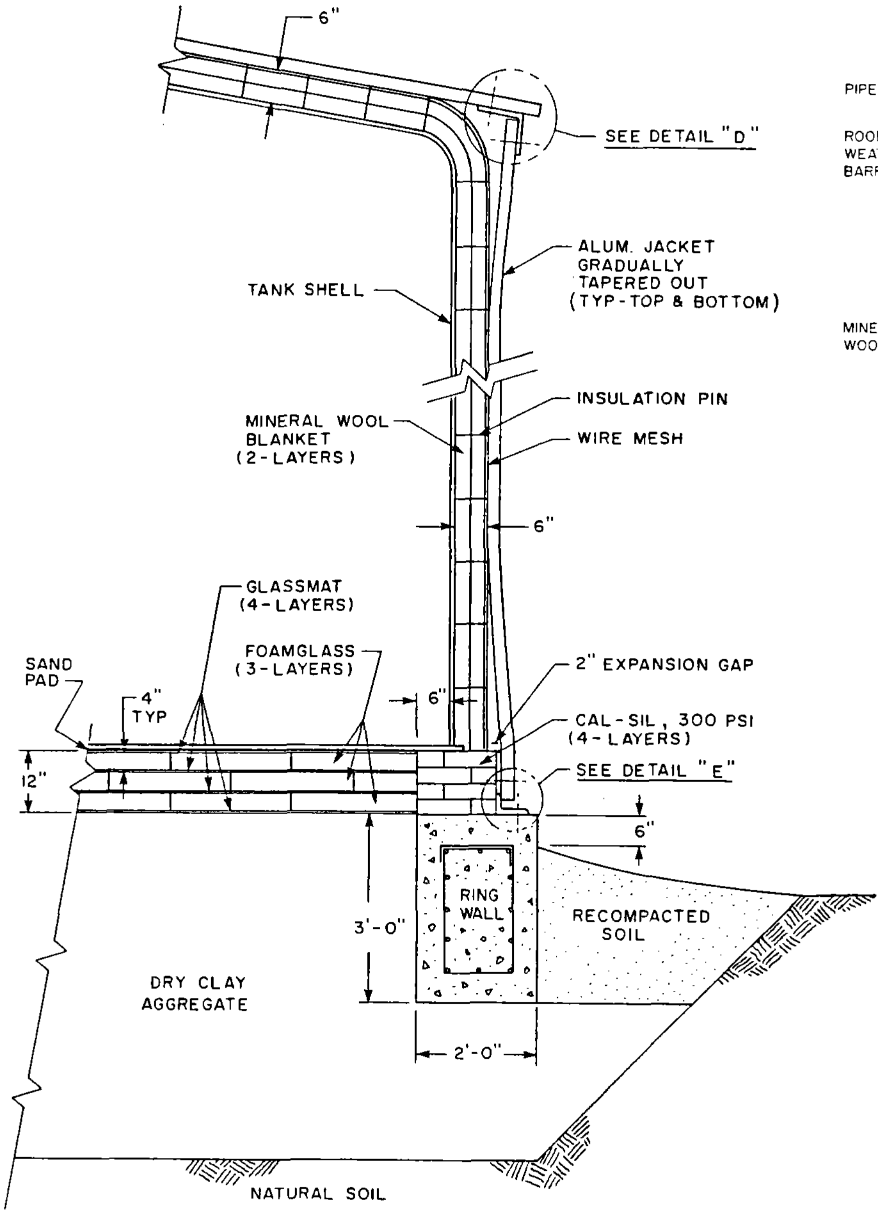
NUMBER REQUIRED = n_H
SALT TEMPERATURE = T_H
ACTIVE SALT VOLUME: V_H @ 108 LBM/FT^3
V_H @ 109 LBM/FT^3 FOR BOTTOM CASE ON TABLE A
MAT'L: 316 or 316H STAINLESS STEEL

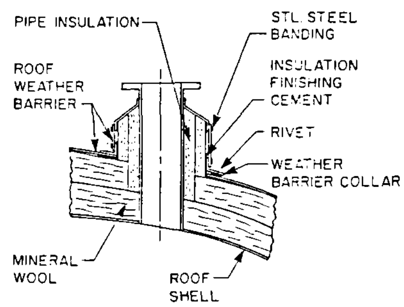
SOLAR CENTRAL RECEIVER STUDY - PRELIMINARY TANK DESIGNS

092688

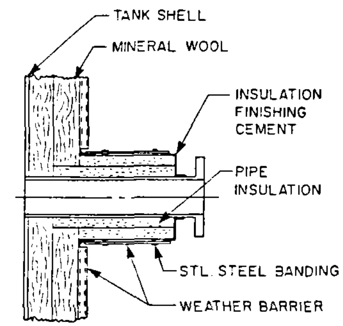
TABLE A
GEOMETRY FOR STORAGE TANK DESIGNS

STORAGE CAPACITY	REFERENCE DESIGNATION: TANK	REFERENCE DESIGNATION: TANK DIMENSIONS	SALT TEMPERATURE (°F) T_C or (T_H)	NUMBER OF TANKS REQUIRED n_C or (n_H)	TANK DIAMETER (FT) D_C or (D_H)	HEIGHT OF CYLINDER (FT) H_C or (H_H)	NUMBER OF SHELL RINGS N_C or (N_H)	ACTIVE SALT VOLUME (FT^3 EA.) V_C or (V_H)	"FULL" LIQUID LEVEL (FT) h_C or (h_H)	BOTTOM SHELL THICKNESS (IN) t_C or (t_H)
1200 MWHt	550°F "COLD" TANK	1@ 84'ø x 40'	550	1	84	40	4	189,600	37.2	1
	1050°F HOT TANK	1@ 84'ø x 44'	1050	1	84	44	5	209,100	40.8	1 1/4
3000 MWHt	550°F "COLD" TANK	1@ 122'ø x 46'	550	1	122	46	5	474,200	43.9	1 1/2
	1050°F HOT TANK	2@ 90'ø x 46'	1050	2	90	46	5	261,380 ea	44.1	1 1/2
150 MWHt	550°F "COLD" TANK	1@ 44'ø x 24'	550	1	44	24	3	23,700	18.6	3/8
	1050°F HOT TANK	1@ 44'ø x 24'	1050	1	44	24	3	26,140	20.2	3/8
ALTERNATE 1200 MWHt	550°F "COLD" TANK	1@ 84'ø x 40'		SEE	ABOVE	– 1200	MWHt	COLD T	ANK	
	1050°F HOT TANK	2@ 66'ø x 36'	1050	2	66	36	4	104,550 ea	33.6	7/8
ALTERNATE 3000 MWHt	550°F "COLD" TANK	1@ 122'ø x 46'		SEE	ABOVE	– 3000	MWHt	COLD T	ANK	
	1050°F HOT TANK	1@ 126'ø x 48'	1050	1	126	48	5	522,750	44.9	2 1/4
ALTERNATE 1200 MWHt	550°F "COLD" TANK	1@ 85'ø x 43'	550	1	85	43	5	210,860	40.2	1
(1000°F HOT SALT TEMPERATURE)	1000°F HOT TANK	1@ 85'ø x 46'	1000	1	85	46	5	230,200	43.9	1 3/8

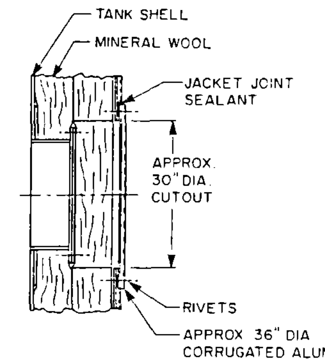




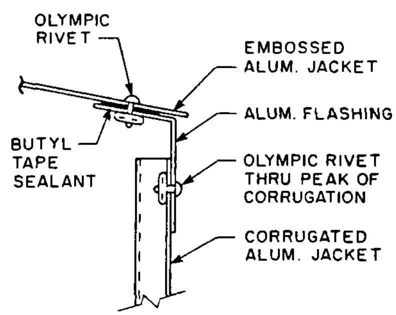
DETAIL "A"
(TYP. ROOF PENETRATION)



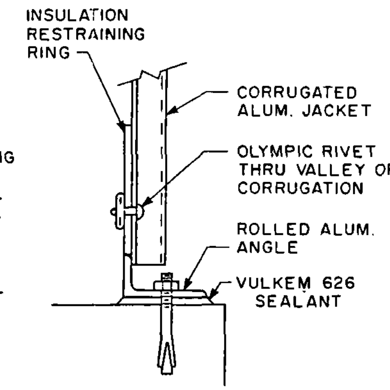
DETAIL "B"
(TYP. SIDEWALL PENETRATION)



DETAIL "C"
(MANHOLE)

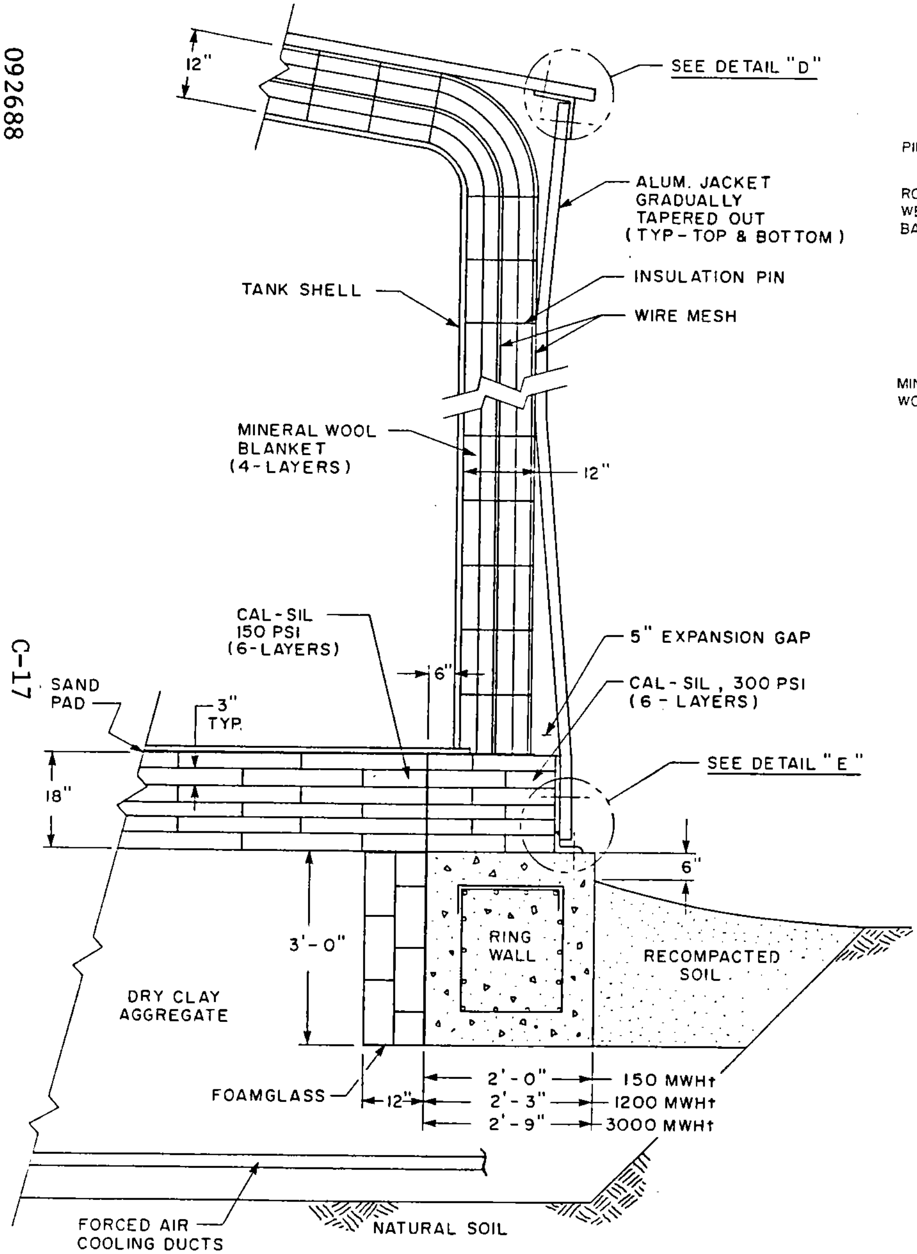


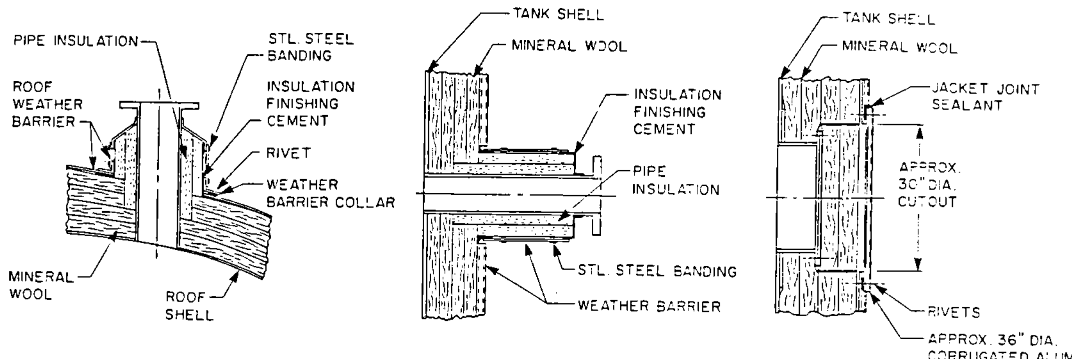
DETAIL "D"
(TOP OF JACKET)



DETAIL "E"
(RESTRAINING RING BOTTOM OF JACKET)

SOLAR CENTRAL RECEIVER STUDY
PRELIMINARY INSULATION & FOUNDATION DETAILS
"COLD" STORAGE TANK

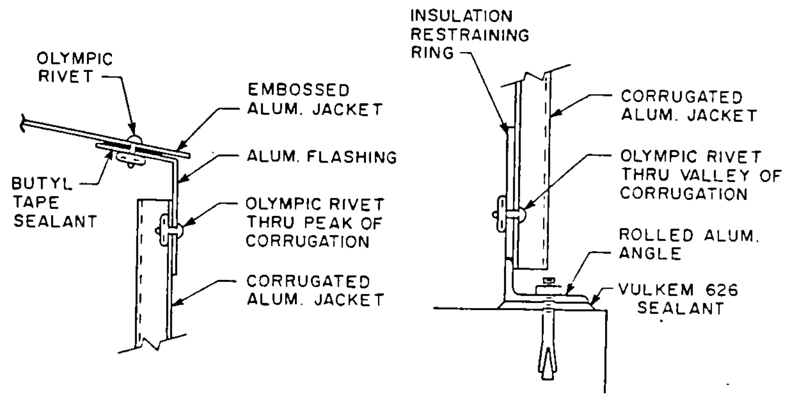




DETAIL "A" (TYP. ROOF PENETRATION)

DETAIL "B" (TYP. SIDEWALL PENETRATION)

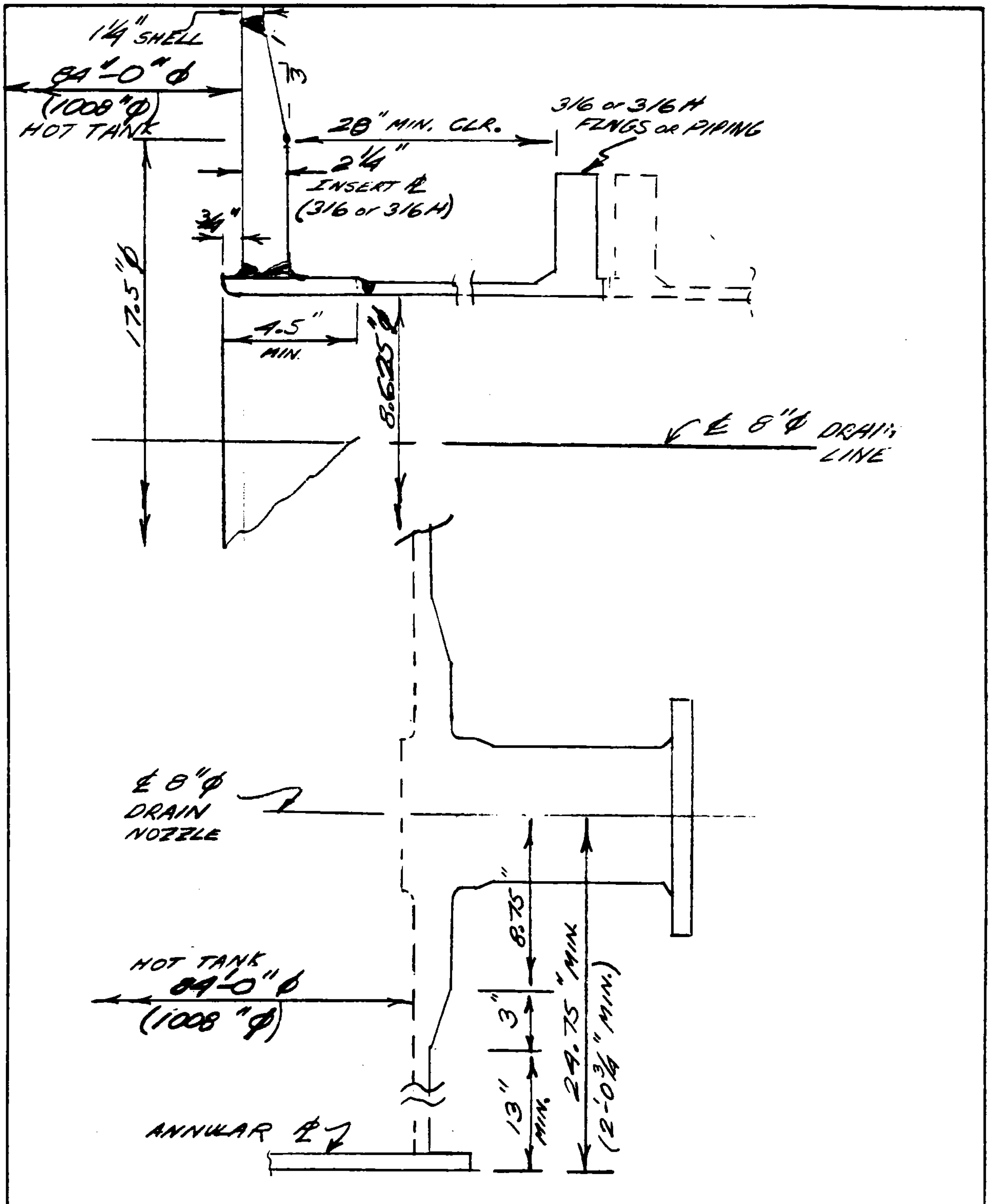
DETAIL "C" (MANHOLE)



DETAIL "D" (TOP OF JACKET)

DETAIL "E" (RESTRAINING RING BOTTOM OF JACKET)

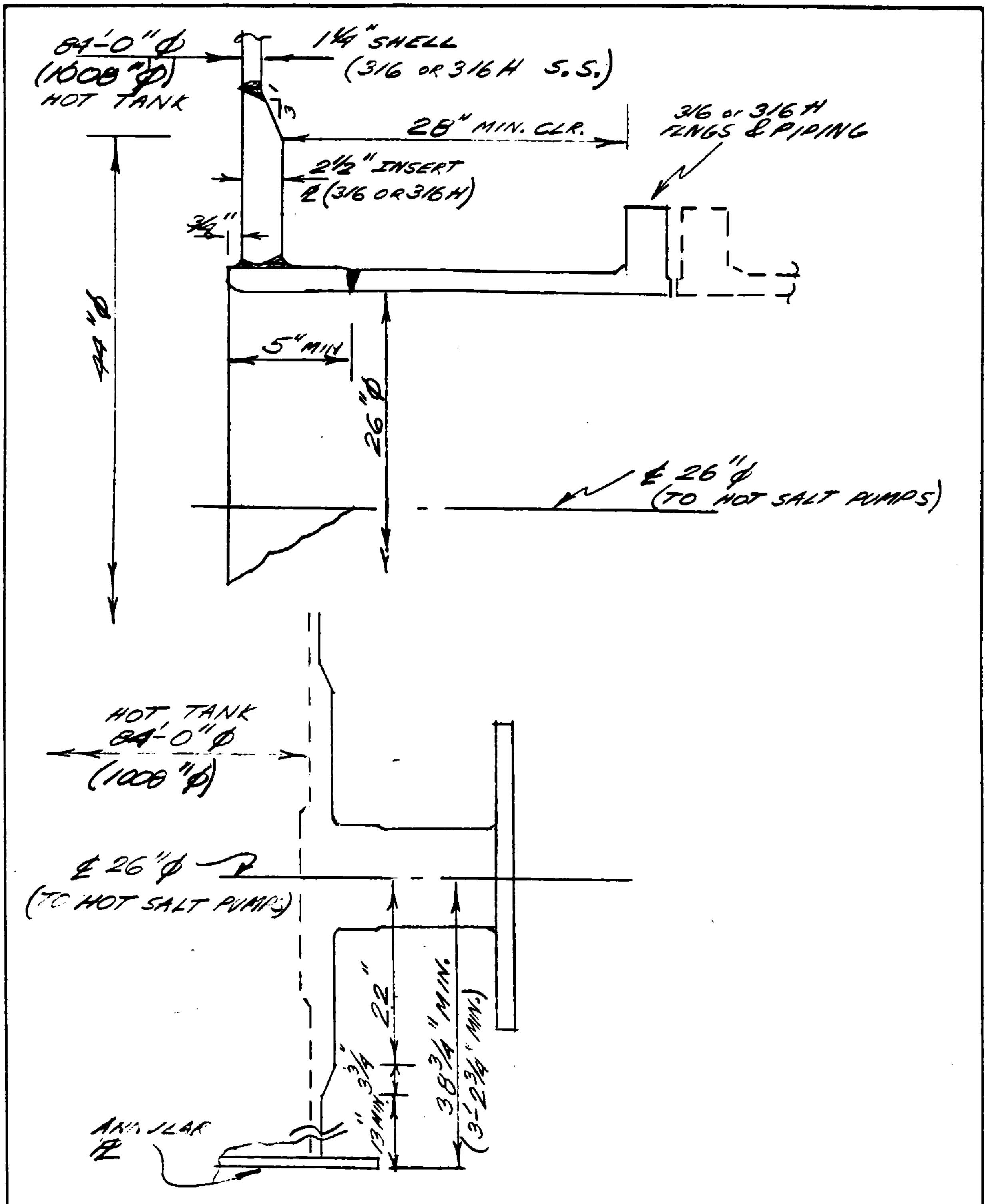
SOLAR CENTRAL RECEIVER STUDY
PRELIMINARY INSULATION & FOUNDATION DETAILS
"HOT" STORAGE TANK



SUBJECT	OFFICE	REVISION		REFERENCE NO.
LOWER NOZZLE SIZING / LOCATION -1200MWHt HOT TANK-	CBI RCE			C8333N
	MADE BY [illegible] / CHKD BY	MADE BY	CHKD BY	SHT 1 OF 2
	DATE 3/87 / DATE	DATE	DATE	

Printed in USA

GO 64 REV SEP 84

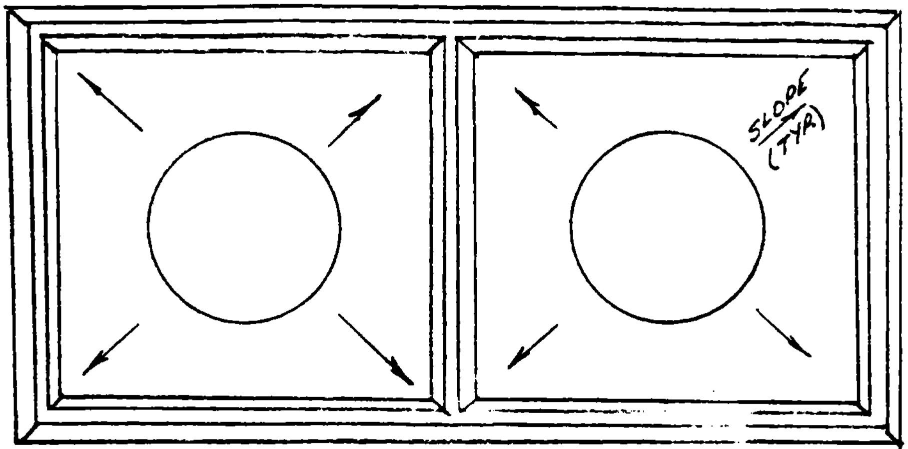


SUBJECT	OFFICE	REVISION		REFERENCE NO.
LOWER NOZZLE SIZING / LOCATION -1200 MWHT HOT TANK-	CBI RCL			C8333N
	MADE BY RTV / CHKD BY	MADE BY	CHKD BY	SHT 2 OF 2
	DATE 3/87 / DATE	DATE	DATE	

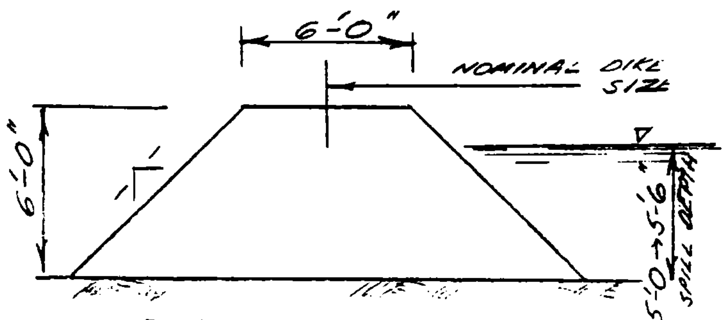
Printed in USA

GO 64 REV SEP 84

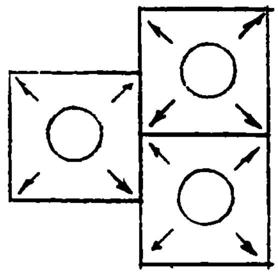
CONTAINMENT DIKES



TYPICAL TWO TANK ARRANGEMENT



TYPICAL DIKE CROSS SECTION



TYPICAL THREE TANK ARRANG.

DIKE SIZES

STORAGE	DIKES
1200 MWHt 1 HOT, 1 COLD	2@220'*220'
3000 MWHt 2 HOT, 1 COLD	1@331'*331' 2@240'*240'
150 MWHt 1 HOT, 1 COLD	2@83'*83'

STORAGE	DIKES
1200 MWHt 2 HOT, 1 COLD	1@215'*215' 2@164'*164'
3000 MWHt 1 HOT, 1 COLD	2@390'*390'
1200 MWHt 1000°F OPER. TEMP	2@230'*230'

SUBJECT	OFFICE	REVISION		REFERENCE NO.
CONTAINMENT DIKES	CBI RCE			C8863I
	MADE BY	CHKD BY	MADE BY	CHKD BY
	DATE 3/87	DATE	DATE	DATE
				SHT__ OF__

Printed In USA

GO 64 REV

CONTROLS

Level Control Loop(s)

Bubbler tubes utilizing bottled GN_2 or dry CO_2 free plant air will be connected to standard differential pressure transmitters. Transmitter output (4-20 mA or other) will be proportional to the salt storage level and will be used to:

1. Monitor Stored Product Level
2. Alarm on High/Low Liquid Level
3. Shutdown Transfer Operation on High High or Low Low Tank Level

Temperature Loop(s)

Each storage tank will include a series of thermocouples to monitor the following system temperatures:

1. Tank Vapor Space - One adjacent to the shell/dome interface
   - One in vapor line connecting hot and cold tanks.
2. Tank Bottom/Shell - Ten thermocouples will be located near the tank shell to bottom connection for monitoring temperatures during the initial heat up operations.
3. Bottom Insulation System - An optional array of thermocouples could be included for use as a bottom leak detection system. Up to 50 per tank could be required for each task.

Pressure Control Loop(s)

The hot and cold storage tank vapor space pressure will be monitored by duplicate pressure transmitters. The transmitter output will be proportional to the equalized vapor space pressure of the hot/cold storage tanks and will be used to:

1. Monitor Ullage Space Pressure
2. Sequence the vent/makeup control valves on High and Low pressures respectively.
3. Shut down transfer operations should the High High or Low Low pressure setpoints be exceeded.

THERMAL STORAGE-LEAK DETECTION METHODOLOGY

Each thermal storage tank could include an optional bottom leak detection system. During tank construction a series of thermocouples will be installed within the bottom insulation system. Rows of thermocouples will be spaced equally throughout the insulation system with consideration given for bottom seam locations. The thermocouples will initiate a high temperature alarm should a salt leak breach the insulation system causing a localized hot spot.

Corrective action will be at the discretion of the final owner.

ULLAGE SPACE PRESSURE CONTROL SYSTEM

An ullage space pressure control system is provided to maintain this pressure within storage tank design limits. The ullage (vapor) space of the hot and cold storage tanks will be connected in parallel to the pressure control system.

The pressure control system will provide a supply of dry, CO_2 free air to the ullage space as required or automatically vent excess air from the ullage space to atmosphere to maintain a relatively constant pressure. The system includes:

- A single molecular sieve bed to remove water and CO_2 from the ambient air.
- A single rotary blower to boost atmospheric air to 35 psia prior to entering the molecular sieve bed.
- Forced air cooler to cool regeneration air during the molecular sieve bed cooling cycle.
- Automatic isolation valves that will sequence to direct flow to storage or vent air to atmosphere.
- Recuperative heat exchanger to utilize waste heat during regeneration of the molecular sieve bed. Maximum regeneration air temperature is 650°F.

If vapor makeup is required, a low pressure switch will initiate the following sequence of events:

1. Sequence isolation valves
2. Start air blower and continue to operate until low pressure condition is stabilized.

Should venting be required, a high pressure switch will automatically sequence the isolation valves to permit venting to occur.

The molecular sieve will remove water and CO_2 to approximately 1 ppm concentration from normal ambient conditions of 14% RH and 350 ppm CO_2.

ALTERNATE UTILITY TEAM - SOLAR CENTRAL RECEIVER STUDY

TRADE STUDY ITEMS - STEEL CYLINDER, BOTTOM, ROOF, NOZZLES

- Sized tanks to eliminate anchorages. Anchorages cause constraint and stress problems for large thermal motions.
- Must consider future detailed stress analysis including creep fatigue. Extent of design ramifications cannot be fully ascertained yet. Selection of 316 or 316H stainless, allowable design stresses, and nozzle designs based on creep considerations.
- Flat bottom tank design selected as most economical and practical.
- External insulation chosen over internal due to economics. Detailed analysis required to justify either.
- Used conventional tank design concepts (API 650) but added extra considerations (larger annular plate, nozzle inserts, etc.).
- Allowed 33% increase in stress for seismic/wind.
- Critical elastic shell buckling considered.
- Shell-annular plate junction needs detailed investigation. Assumed butt welded corner detail for now.
- Dry air film (above salt) decreases shell temperatures significantly.
- Restraints (ex. friction) to free base expansions require consideration/ avoidance.
- Included 90 mph wind; did not govern.
- API Zone 3 seismic.
- Initial charging effects on shell need considerations later.

TRADE STUDY ITEMS - EXTERIOR INSULATION

- Design allows for traditional installation procedures.
- Design allows for large thermal motions of shell (> 5 inches for hot tanks).
- Practical thicknesses used (12 in. hot tanks, 6 in. cold tanks), but may be varied if economics dictate.
- Mineral wool chosen as good proven economical insulation. Good for continuous service at 1200°F.
- Corrugated aluminum jacket chosen to allow for circumferential growth. 140°F (hot-to-touch chosen for maximum allowable temperature.

- Alternate layers of mineral wool has wire mesh for structural strength.
- Initial moisture will be driven out of insulation. Atmospheric moisture will continually be driven out by heat.

TRADE STUDY ITEMS - FOUNDATION

- Insulation and cooling designed to limit concrete (ringwall) temperature to 350°F maximum and in-situ soil temperatures to 200°F.
- Considered long term temperature effects on concrete by reducing concrete and rebar strengths by 33% and 20% respectively.
- Considered possibility of thru-wall thermal gradient by significantly increasing outer rebar steel area.
- Used standard construction materials wherever possible.
- Use 5 ft. depth of dried clay aggregate to aid in keeping soil temperatures below 200°F. This aggregate is structurally sound and commercially available in the Barstow area.
- Used backfill to five foot depth. At that depth soil appeared; questionable above.
- Considered elevated structure to improve foundation cooling. Some disadvantages:
  - Slab likely to have critical expansion and thermal gradients.
  - Piles and/or columns supporting slab must be designed for lateral loads from earthquake and thermal motions.
  - Requires extra footing.
- Ringwall made thick enough to allow for tank sliding.
- Cal sil and foam glass insulation used with descretion as follows:
  - Cal sil used under cylindrical shell (both 550°F and 1050°F tanks) because of its higher bearing strength and insulation effects on the ringwall.
  - Foam glass used under the balance of 550°F tank for economy.
  - Cal sil used under the balance of the 1050°F tank because of higher temperature resistance than foam glass.

TRADE STUDY ITEMS - DIKES

- Individual dike for each tank. Leakage from one tank will thus NOT impinge on other tank.
- Dikes to contain full volume of each tank.
- Dike height limited to 6 ft. to allow easy access to tanks.
- Dike floors graded so rainwater drains away from tanks.

CBI ELEVATED TEMPERATURE STORAGE TANKS

(INSTALLED UNITS)

Owner/Operator Location	Medium Temperature	Tank Size(s)	Code
Solar Partners Ltd. Daggett (Barstow) CA	Hot Oil 480°F/600°F	"Cold" - 69'Ø * 40' Hot - 72.5'Ø * 40'	API 650 *
American Petrofina Port Arthur, TX	Oil/Asphalt 350°F/500°F	"Cold" - 150'Ø * 48' Hot - 80'Ø * 48'	API 650
Aramco Qasim, Saudi Arabia	Oil/Asphalt 350°F/430°F	2 @ 190'Ø * 15'	API 650
MRI/Soleras Yanbu, Saudi Arabia	Molten Salt 662°F/752°F	2 @ 16'Ø * 16'	*
	(DESIGN STUDIES - PARTIAL LIST)		
Bechtel Barstow, CA	Salt 550°F/1050°F	"Cold" - 122.5'Ø * 40' Hot - 151.5'Ø * 34'	*
Babcock & Wilcox Lucerne Valley, CA	Sodium 650°F/950°F	2 @ 75'Ø * 46'	*
Babcock & Wilcox Lucerne Valley, CA	Salt 650°F/1050°F	2 @ 120'Ø * 40'	*
Bechtel Daggett, CA	Oil ≈ 600°F	Various Sizes 69'Ø to 80'Ø	* *
Rockwell Barstow, CA	Sodium 601°F/1050°F	2 @ 40'Ø * 50'	*
Bechtel Southern California	Sodium 625°F/1065°F	2 @ 105'Ø * 51.4'	*
Bechtel Southern California	Salt 625°F/1065°F	2 @ 105'Ø * 54'	*
Chevron Richmond, CA	Asphalt 500°F	1 @ 22'Ø * 42' 1 @ 10'Ø * 30'	API 650

* API 650 Rules with stress allowables from ASME Section VIII - Divs. 1 or 2 for temperatures exceeding 500°F.

NOTE:

CBI has also designed and built numerous low temperature and cryogneic vessels.

APPENDIX D
ALTERNATE UTILITY TEAM
UTILITY SOLAR CENTRAL RECEIVER STUDY
SALT MAINTENANCE

ALTERNATE UTILITY TEAM

UTILITY SOLAR CENTRAL RECEIVER STUDY

SALT MAINTENANCE

FINAL REPORT

Prepared by
Olin Corporation
New Haven, CT.
Process Technology Center
April 1987

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States Department of Energy, nor any of their employees, nor any of their contractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

<u>TABLE OF CONTENTS</u>

1.0	SUMMARY	1
2.0	INTRODUCTION	3
3.0	DISCUSSION	4
3.1	COMMERCIAL PLANT GUIDELINES	4
3.1.1.	MOLTEN SALT PROPERTIES	4
3.1.2.	SALT CORROSION	9
3.2	COMMON DATA AND TRADE STUDIES	11
3.2.1.	SALT CHARGING	11
3.2.2.	SALT MAINTENANCE	12
3.2.3.	OPERATING PROCEDURES	26
4.0	RECOMMENDATIONS	31
5.0	BIBLIOGRAPHY	32
6.0	APPENDICES	33

1.0 SUMMARY

We reviewed the salt properties as outlined in the project guidelines and found the equations for viscosity, density, heat capacity, and thermal conductivity to agree well with literature data. However the data for thermal conductivity had a reported uncertainty of +/- 20%.

We reviewed available reports regarding corrosion from nitrate salts. Although there have been a fair number of corrosion studies for applicable materials in molten salt, most of the studies were static, immersion type experiments. Corrosion studies with thermal convection equipment shows that Incoloy 800 and 316 stainless steel are acceptably resistant with corrosion rates of ~0.3 and 0.5 mils/year, respectively at 600C (1112F). Corrosion is significantly enhanced above 600C, where the salt becomes more strongly oxidative.

Studies involving corrosion from salt contaminants were quite limited and no specific conclusions could be drawn. However, carbonate, hydroxide, and chloride contamination resulted in slightly higher molten salt corrosion rates.

Very little combined erosion and corrosion experimental results have been published to date. The information available suggests that high salt velocities will increase corrosion rates.

We determined that the best method of salt delivery to the plant site would employ the use of standard 100 ton, hopper-type rail cars. Trucks could be an option for smaller plants. No large bulk storage of salt is required.

We defined methods to melt and introduce molten salt into the thermal storage system. The melting would occur in two phases. Approximately 30% of the total salt capacity would be melted by a gas-fired salt melter. After this initial melt, the solar tower could be operated to melt the balance of the salt inventory. We sized the required melting equipment for three thermal storage sizes (150MWHt, 1200MWHt, and 3000MWHt).

We estimated the build-up rates of the major salt contaminants (carbonates, oxides, and chromium) based on data from the Molten Salt Electric Experiment. Carbonates could reach its solubility in 9 - 21 years, depending on plant size, if no precautions are taken. Although methods are available to regenerate the salt if carbonate removal is required, we recommended that a salt preventative maintenance program be employed. The air pad used in molten salt storage should be treated to remove carbon dioxide and water. This would prevent the formation of carbonates and hydroxides.

We defined conceptual operating procedures for salt melting, salt make-up, and salt spill clean-up.

A list of recommendations is presented in Section 4.0 of this report.

2. INTRODUCTION

Olin has worked with Black & Veatch as a subcontractor to perform a Utility Study for a solar central receiver. Our common goals are to describe and size a facility to produce electricity using solar energy. The plant will use molten nitrate salts to store energy to make electricity with a steam turbine.

Olin's portion of the project involved four tasks. These are summarized below:

Task 1: Review guideline document and provide recommendations for trade studies for the Thermal Storage Subsystem.
Summarize current knowledge of corrosion effects of molten nitrate salts.

Task 2: Develop and recommend salt delivery methods.
Recommend and size equipment to unload, melt and install salt into the solar plant thermal storage subsystem.
Determine potential contaminants in molten salt; estimate their build-up rates.
Develop techniques for cover gas purification.
Determine requirements for salt maintenance.

Task 9: Support and attend the mid-Phase I UCB review meeting in Albuquerque, NM.

Task 10: Provide project management and administration.
Provide monthly technical and cost reports.

3.0 DISCUSSION

3.1 COMMERCIAL PLANT GUIDELINES

3.1.1 Molten Salt Properties

The following molten salt properties were contained in the Guidelines, Ground Rules and Trade Study Input Specifications:

Density, viscosity, heat capacity and thermal conductivity. Each of these properties were given as a function of temperature. These equations were reviewed with tabular and graphical data from several sources.[1,2,3,4] The comparative results are shown in Table 1 through 4. The data agree quite well. It should be noted that although the data obtained for thermal conductivity agrees very well with the Guidelines, this data has a reported uncertainty of +/- 20%. If this salt property is critical in the design of any plant equipment, it may be required to obtain more accurate data before actual plant construction.

We would recommend a nitrate salt composed of high purity 60% sodium nitrate and 40% potassium nitrate salts, by weight. This composition provides thermal performance similar to the eutectic mixture, but at a lower cost. The recommended specifications are listed below:

NITRATE SALT SPECIFICATIONS

COMPONENT	MINIMUM, %	MAXIMUM, %
$NaNO_3$	59	61
KNO_3	39	41
NaCl		0.30
Na_2SO_4		0.30
CaO		0.03
MgO		0.03
SiO_2		0.02
Al_2O_3		0.025
Fe_2O_3		0.025
Insolubles		0.06
Na_2CO_3		0.15

The acute oral LD_{50} for this nitrate salt blend is 4g/kg (Rats). This nitrate salt is considered toxic from this route of exposure according to criteria established by the Federal Hazardous Substances Act. No information is available on the toxicity from dermal or inhalation exposure but, in all probability, it would not be considered toxic from either of these routes of exposure. The salt is not known to be carcinogenic or mutagenic but may be a skin or eye irritant. The salt will not present a hazard to health when used according to normal industrial handling practices.

TABLE 1

MOLTEN SALT PROPERTIES - DENSITY

$$\rho = 131.2 - 0.02221 (T)$$

$$\rho = LBm/ft^3$$

$$T = {}^{o}F$$

TEMPERATURE (^{o}F)	DENSITY (LB/FT^3) GUIDEINES	DENSITY (LB/FT^3) REF. DATA
500	120.1	120.7
600	117.9	118.5
700	115.7	116.3 115.9
800	113.4	113.8 113.6
900	111.2	111.2
1000	109.0	108.3
1100	106.8	105.0

TABLE 2

MOLTEN SALT PROPERTIES - VISCOSITY

$$\mu = 50.0699 + t\ (=.133924 + T\ (1.292 \times 10^{-4} + T\ (-4.26764 \times 10^{-8})))$$

μ = LBm/ft-HR

T = ^{o}F

TEMPERATURE (^{o}F)	VISCOSITY (LB/FT.HR) GUIDELINES	VISCOSITY (LB/FT-HR) REF. DATA[4]
500	10.07	10.07
600	7.01	7.02
700	4.99	4.99
800	3.77	3.78
900	3.08	3.97
1000	2.67	2.66

TABLE 3

MOLTEN SALT PROPERTIES - HEAT CAPACITY

$$Cp = 0.345 + 2.28 \times 10^{-5} T$$

$Cp = BTU/LBm^{o}F$

$T = {}^{o}F$

TEMPERATURE (^{o}F)	HEAT CAP. ($BTU/LBm^{o}F$) GUIDELINES	HEAT CAP. ($BTU/LBm^{o}F$) REF. DATA[1]
500	.356	.354
600	.359	.358
700	.361	.377
800	.363	.363
900	.366	.369
1000	.368	-
1100	.370	-

TABLE 4

MOLTEN SALT PROPERTIES - THERMAL CONDUCTIVITY

$k = 0.253208 + 6.26934 \times 10^{-5}\ T$

$k = \text{BTU/HR FT }^{\circ}\text{F}$

$T = {}^{\circ}\text{F}$

TEMPERATURE °F	(BTU/HR FT °F) GUIDELINES	(BTU/HR FT °F) REF. DATA[2]
500	.285	.285
600	.291	.291
700	.297	.297
800	.303	.303
900	.310	.309
1000	.316	.315
1100	.322	.322

NOTE: The reference data, which agrees quite well with the guidelines, has a reported uncertainty of +/- 20%.

3.1.2. Salt Corrosion

In the solar central receiver installation, the materials of construction are exposed to salt at several different temperatures which may generally range from 300C to approximately 600C depending on location within the facility. There have been a fair number of corrosion studies on the materials most likely to find application in this range, particularly the 300 series stainless steels, Incoloy 800, RA330, and some carbon steels as well. Most of these studies have been static, sample immersion type experiments, but several thermal convection flow experiments have also been performed. The reported results are generally not unambiguously interpreted; this is largely because the experiments predominantly consist only of the measurement of coupon weight changes, which are, in fact, the result of both weight-gaining and weight-depleting processes.

Overall the corrosion occurs essentially by an oxidation and dissolution process. The iron oxides produced generally form partially adherent surface scales and are of low apparent solubility in the salt melt. Chromium oxide products (chromate in particular), tend to be somewhat selectively depleted from the alloy surface. The passivation effectiveness of the oxide layer depends on a number of factors including the rate at which surfaces spall with or without stress. In the case of iron oxides for example, the most oxidized forms tend to spall the most easily in any erosive and corrosive environment. Corrosion is also significantly enhanced above 600C, where the salt solution becomes more strongly oxidative and the transport limitations are diminished.

Corrosion studies(1) with thermal convection equipment shows that Incoloy 800 (I800), and 316 stainless steel are acceptably resistant with corrosion rates of approximately 0.3 and 0.5 mils/year respectively at 600C. Chromium was the only alloying element to build up appreciably in the melt (to approximately 180 ppm in 8 months), but the chromium loss was not the major factor in the alloy sample weight losses. At 400C, the above cited rates are decreased by over a factor of ten. Further studies on steels with chromium content less than 9 weight percent showed that these materials corrode excessively at 550C but may perform adequately below 300C. Other thermal convection loop studies(9) with loop legs at approximately 600 and 350C, suggest that 304, 316, and I800 are all adequately resistive for use below 600C. Furthermore, the low carbon version of these alloys, as in 304L and 316L, are generally preferable. At temperatures above 600C, however, the stainless steels experienced excessively rapid scale spalling and chromium depletion within a few thousand hours.

The chromium depletion mentioned above appears to follow diffusion-controlled kinetics(9). Its buildup in the melt however, is likely to be insignificant in an installation with a low surface area to volume ratio. In the MSEE(10) analyses for example, chromium only increased from 4.0 to 6.5 ppm, during all of the 1984 operating year.

The corrosion rate test results of Chihoski et al[11], agreed with those cited above for I800 and 316 stainless steel. In related tests, they found RA330 and carbon steels suitable for use in the salts at temperatures up to 600C and 290C respectively. These workers also studied the effects of several anionic trace contaminants including chloride, sulfate, hydroxide, and carbonate. In general, the contaminants resulted in slightly higher corrosion rates for both parent metal and welded samples. Chloride seemed to have the most deleterious effect on I800, while carbonate and hydroxide displayed the most damaging effects on 316 and RA330. In the carbon steels, chloride and sulfate proved to be the most detrimental contaminants.

Some testing[8] has been done on certain special purpose materials for possible use in seals, gaskets, packings and valve trim. Stellite #6 and silicon carbide displayed good corrosion resistance whereas graphite composed materials, such as Crane IX187 gasket and Crane GF graphite packing, were readily degraded by the salt. It was also found that copper foil dissolved completely within 5000 hours, but aluminum Crane 100 Al and nickel Crane 100 Ni were highly resistant to salt at 400C.

Mechanical properties are essentially unaffected by the salt environment. Creep experiments[1] with I800 in salt baths showed no measurable effect of the salt on structural properties, although surface oxide formation was accelerated by sample deformation. Fatigue crack growth rate studies showed that the fatigue response of I800 is not significantly affected by the salt at 600C. In terms of surface finish, it is apparent that the rougher finishes tend to corrode more rapidly and less uniformly but a quantitative relationship is lacking.

Very little combined erosion and corrosion experimental results have been published to date. The little information available[8] suggests that due to the mechanism of this corrosion, high salt velocities will undoubtedly result in increased corrosion rates relative to those observed in static immersion or thermal convection loop studies. However, there is currently no reliable means of correlating corrosion enhancement with hydraulic conditions.

3.2 Common Data and Trade Studies

3.2.1. Salt Charging

The amount of salt required for a Solar Central Receiver Power Plant will depend on many factors including plant size, mode of operation and theory of operation. We have investigated three thermal storage sizes: 150MWHt, 1200MWHt and 3000MWHt. Based on information from Chicago Bridge and Iron, the salt working capacity, which was used to size the hot and cold salt storage tanks, is given below:

PLANT SIZE	SALT WORKING CAPACITY (LBS)
150 MWHt	2,682,000
1200 MWHt	22,658,000
3000 MWHt	53,670,000

The salt working capacity does not include salt required to fill the piping and other components in the system. These components include the hot salt storage tank heel, cold salt storage tank heel, receiver and heat exchangers. The total salt inventory was estimated based on previous studies. (Saguaro Solar Power Plant Design). The total salt inventory required for each plant size is listed below:

PLANT SIZE	WORKING SALT CAPACITY(LBS)	TOTAL INVENTORY (LBS)
150 MWHt	2,682,000	3,394,000
1200 MWHt	22,658,000	28,680,000
3000 MWHt	53,670,000	67,934,000

Several methods are available for delivery and storage of the nitrate salts prior to introduction into the thermal storage system. The salt could be shipped via railroad hopper cars (100 Ton capacity), hopper truck (20 Ton capacity), or in bags. For the quantities required in a solar power plant, bulk delivery would be required. The table below compares the number of trucks and railcars required for each plant size.

PLANT SIZE	TRUCKS(20 TON)	RAILCARS (100 TON)
150 MWHt	85	17
1200 MWHt	717	144
3000 MWHt	1699	340

This table clearly indicates that railcars are the most logical choice for delivery, although truck delivery could be an option for the 150 MWHt storage system. The standard 100 Ton gravity feed hopper car is the most abundant and simplest to operate. This type of car offers a high level of assurance that the product will not become contaminated, and that unloading operations will not be complicated.

Railcar delivery also offers another potential advantage. It is expected that the initial salt melt and plant start-up would occur over several months. The delivery of salt to the plant site could be scheduled as salt is required over this period. This would eliminate the need for large amounts of bulk salt storage.

The initial salt charging step can occur before the entire plant is ready for operation. The salt inventory would be melted in a two-phase procedure. The initial charge of salt would be melted with a fossil fired salt melter. (See Figure 1) It is expected that this initial melt would involve approximately 30% of the entire salt inventory. This amount of salt melt would allow for start-up of the central receiver and other equipment. The solar tower could then supply the heat required to melt the balance of the salt inventory. This would be accomplished by mixing hot (1050°F) salt with granular salt in a special mix tank. (See Figure 2) This mix tank can also be used for adding salt to the system as required during operation. The basic equipment required for the initial melt and the total inventory melt is shown in Table 5.

The time required to melt the initial salt charge is given in the table below.

PLANT SIZE	MELTER SIZE(MMBTU/HR)	MINIMUM MELTTIME(DAYS)
150MWHt	2.0	6
1200MWHt	5.0	21
3000MWHt	10.0	25

The time given is based on operation of the melter continuously once the unit is started up. Hence, actual melt time is expected to be somewhat longer depending upon operational problems. A detailed operational procedure for this equipment is given in Section 3.2.3.

3.2.2. Salt Maintenance

Nitrate salts, including sodium/potassium mixtures, degrade at very high temperatures. While the maximum temperature that the salt is expected to see in the solar central receiver systems is well below the temperature at which the rate of salt decomposition would be unacceptable, some degradation does take place continually at temperatures above the melting point.

The main decomposition products are nitrites, carbonates, oxides and hydroxides. Nitrites are formed in the reversible reaction of nitrate to nitrite plus oxygen:

$$NaNO_3 \quad ---> \quad NaNO_2 + 1/2\ O_2$$

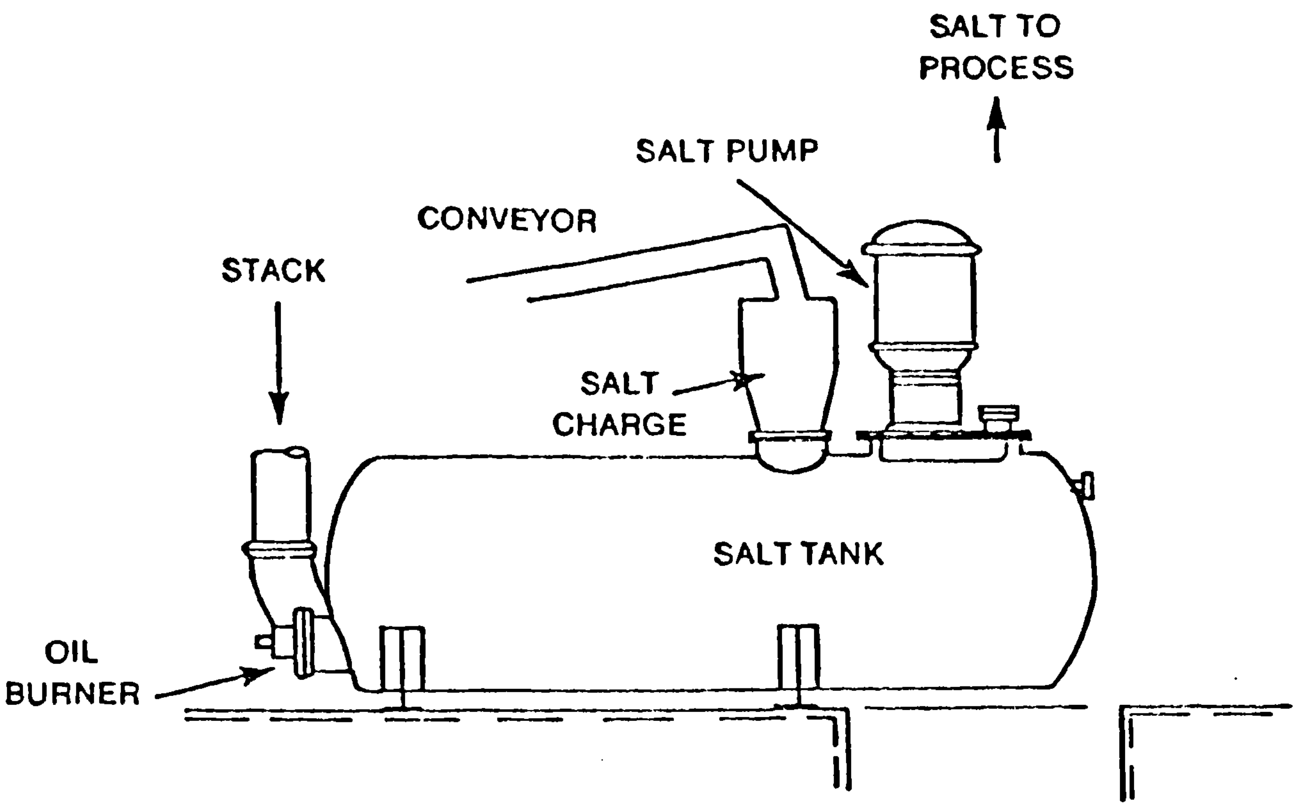
The decomposition reaction of nitrate to nitrite can be minimized by using air as a padding gas in the cold and hot storage tanks. Previous studies have found that air is nearly optimal from the standpoint of nitrate stability. Other cover gases, such as nitrogen, oxygen or inert gases, should not be used because they

092688

FIGURE 1

SALT CHARGING

(INITIAL MELT)



FOSSIL FIRED SALT MELTER

FIGURE 2

SALT CHARGING

(INVENTORY MELT)

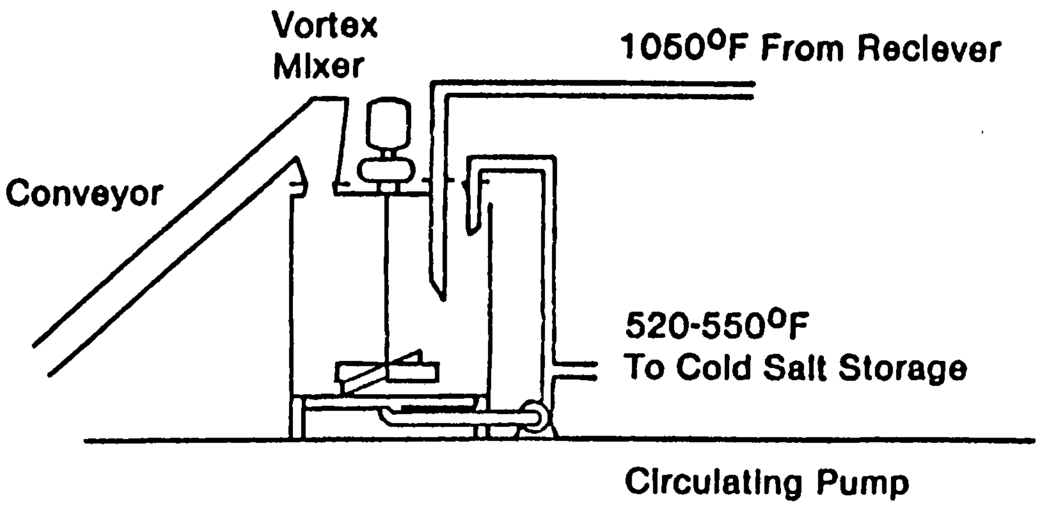


TABLE 5

EQUIPMENT REQUIREMENTS FOR SALT CHARGING

ITEM	PLANT SIZE 150MWHT	1200MWHT	3000MWHT
Salt Unloading & Initial Melt			
Enclosed feed conveyor (- 60 FT)	$75FT^3$/HR	$200FT^3$/HR	$375FT^3$/HR
Feed Hopper	$30FT^3$	$75FT^3$	$150FT^3$
Salt Melter (includes mixers, gas burner & temperature controls	2MM BTU/HR	5MM BTU/HR	10MM BTU/HR
Salt Pump	10 GPM	25 GPM	50 GPM
Total Salt Inventory Melt			
Enclosed Transfer Conveyor (-40 FT)	$75FT^3$/HR	$200FT^3$/HR	$375FT^3$/HR
Feed Hopper	$30FT^3$	$75FT^3$	$150FT^3$
Mix Tank (including Mixer)	1000 GAL	2500 GAL	5000 GAL
Salt Pump	20 GPM	50 GPM	100 GPM

would promote the decomposition of the nitrate ion.

Carbonates are formed when hot (1050°F) salt comes in contact with carbon dioxide. There are three ways carbon dioxide can react to form carbonate.[6] The first involves reaction with metal oxide or hydroxide formed from salt decomposition.

$$O^{2-} + CO_2 \quad ---> \quad CO_3^{2-}$$

$$2OH^- + CO_2 \quad ---> \quad CO_3^{2-} + H_2O \qquad (1)$$

The second reaction is with nitrate itself

$$2NO_3^- + CO_2 \quad ---> \quad 2NO_2 + 1/2 + CO_3^{2-} \qquad (2)$$

The third reaction involves the nitrite ion

$$2NO_2^- + CO_2 \quad ---> \quad NO_2 + NO + CO_3^{2-} \qquad (3)$$

According to thermodynamic calculations[6], reaction (1) is most favored. But the other reactions are certainly possible. In fact, the reverse of reaction (2) and (3) is known to occur when salt is sparged with NO_2. This method has been studied as a possible salt regeneration method.

Carbonates are very soluble at high temperatures: 33,000 ppm at 1050°F. However, at the low operating temperature of 550°F, the solubility is somewhere in the range of 3000 to 5000 ppm. If the carbonate level is allowed to exceed this range a precipitate will form on the cooler heat exchange surfaces. The best method to control carbonate formation is to eliminate any contact of carbon dioxide with the molten salt, especially at high temperatures.

Hydroxides are formed when the hot salt comes in contact with water vapor. The hydroxides are formed from the reaction of oxides and water. The oxides are decomposition products of the nitrate salt.

$$NO_3^- \quad ---> \quad NO_2^- + 1/2\ O_2$$

$$2\ NO_2^- \quad ---> \quad O^{2-} + 3/2\ O_2 + N_2$$

$$O^{2-} + H_2O \quad ---> \quad 2OH^-$$

Because the hydroxide ion is very soluble in the melt, (20%), it should pose no precipitation/fouling problems. However, hydroxides can cause significant corrosion. The hydroxide ion is known to react with oxygen in the air to form the highly corrosive peroxide ion.[7]

$$2OH^- + 1/2\ O_2 \quad ---> \quad O_2^{2-} + H_2O$$

The peroxide ion corrodes chromium containing stainless steels such as 304 and 316 by oxidizing the metallic chromium or chromium surface oxides. Experiments conducted by Olin Corporation in previous work showed the rate of corrosion appeared much worse at the air-salt interface. This discussion indicates the need for a moisture free padding gas system.

Oxides in the system, formed from the decomposition reaction of nitrates, may pose a precipitation problem if allowed to exceed its solubility. The solubility of oxides is about 2300 ppm at 550°F. (Some studies[6] have shown this solubility to be higher).

Other salt contaminants which occur in the system are the corrosion products of the containment vessels, pipes and other equipment. These include chromium, iron, nickel, molybdenum and magnesium. Based on experience at MSEE, we do not expect iron, nickel, molybdenum and magnesium to build-up in the salt system. However, chromium has slowly increased during the operation at MSEE and could present future problems. Although the solubility of chromium is quite high (2000 ppm), the environmental implications are noteworthy. If the level of chromium in the salt is above 5 ppm, the salt is judged to be "hazardous" according to EPA regulations and can only be disposed of in a secure landfill. For large quantities of salt this could be prohibitively expensive. Some experiments have been performed with the objective of precipitating the chromium and thus greatly reducing the amount of material to be landfilled. Salt spills are discussed in more detail in Section 3.2.3.

It is difficult to accurately predict rates of formation and build-up of these contaminants in a Solar Central Receiver Facility. The best available information are the results obtained from the Molten Salt Electric Experiment (MSEE). Data obtained over the first 1 1/2 years of operation showed oxide level increasing at a rate of 9 ppm/year and the chromium level increasing at a rate of 8 ppm/year. The carbonate level did not increase over the course of the experiment, but was increasing at a rate of 67 ppm/year for the last several months (See Figures 3,4,5).

It should be noted that the MSEE system is different from the proposed design in several key areas:

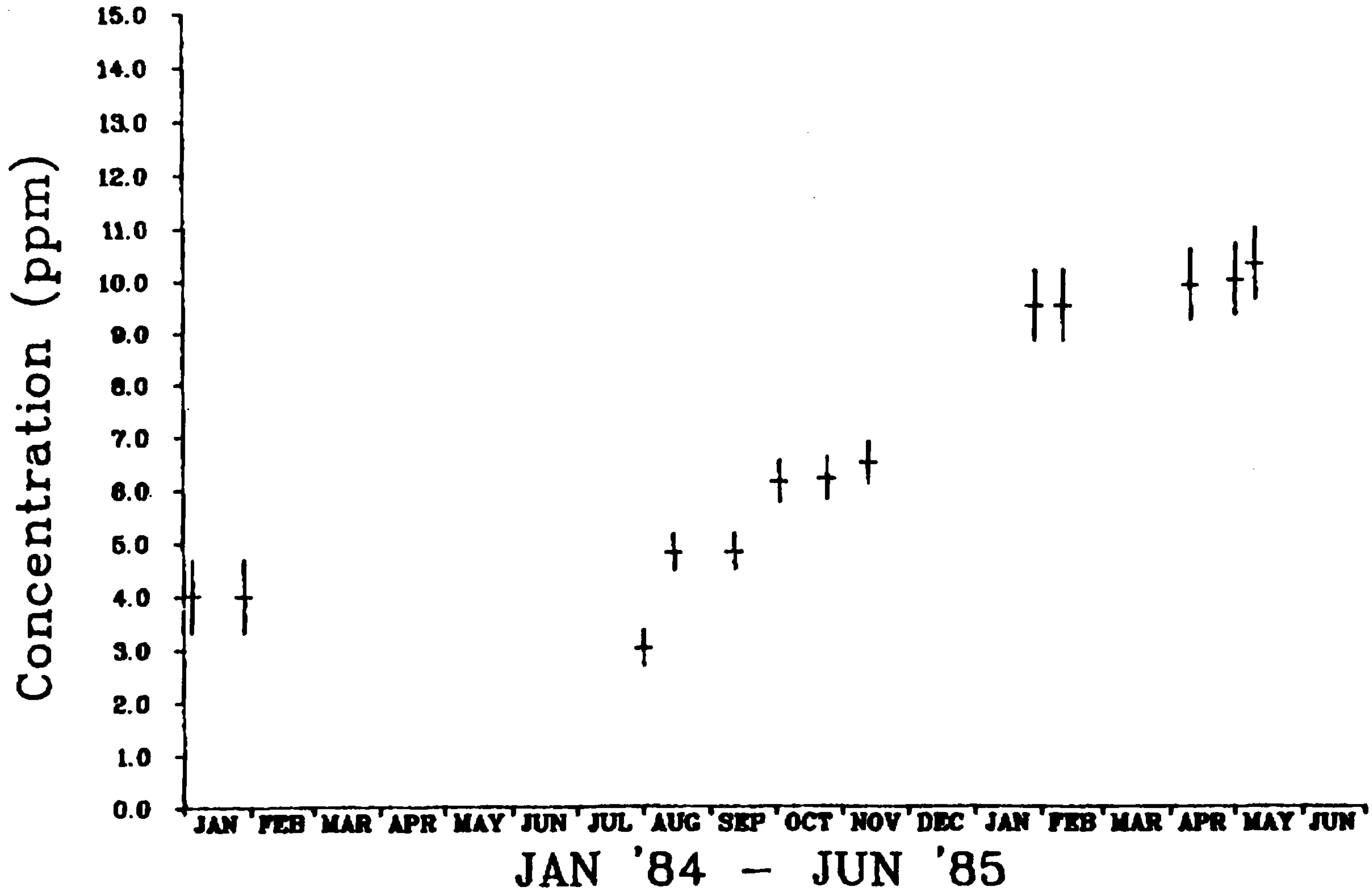
1) MSEE has no provisions for treating the air pad on the tanks.
2) MSEE tanks have a lower salt volume to surface area ratio.
3) Operation at MSEE was intermittent.
4) Hot salt temperatures at MSEE were lower when contaminant data were obtained.

The first two factors would give a lower contaminant formation rate for the present design when compared to MSEE. The last two factors have the opposite effect.

We can estimate the effect of increased salt exposure time and salt volume to surface area ratio. We have assumed, for this estimate, that MSEE operated about 2 months/year. Therefore, operation on a continuous basis would increase the rate of formation by a factor of six:

FIGURE 3

MSEE CHROMIUM ANALYSIS
95% Confidence Interval

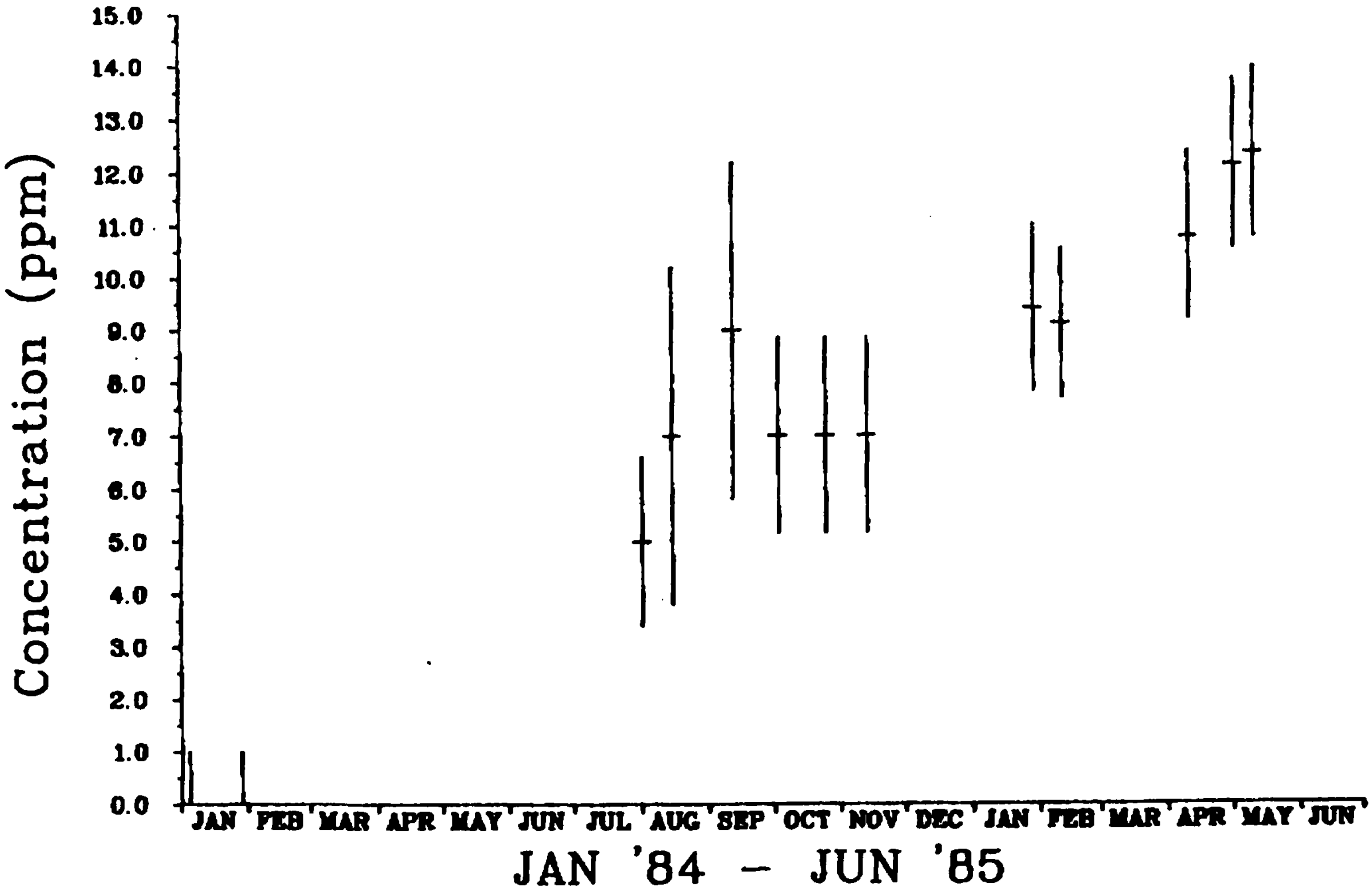


092688

FIGURE 4

MSEE OXIDE ANALYSIS

95% Confidence Interval

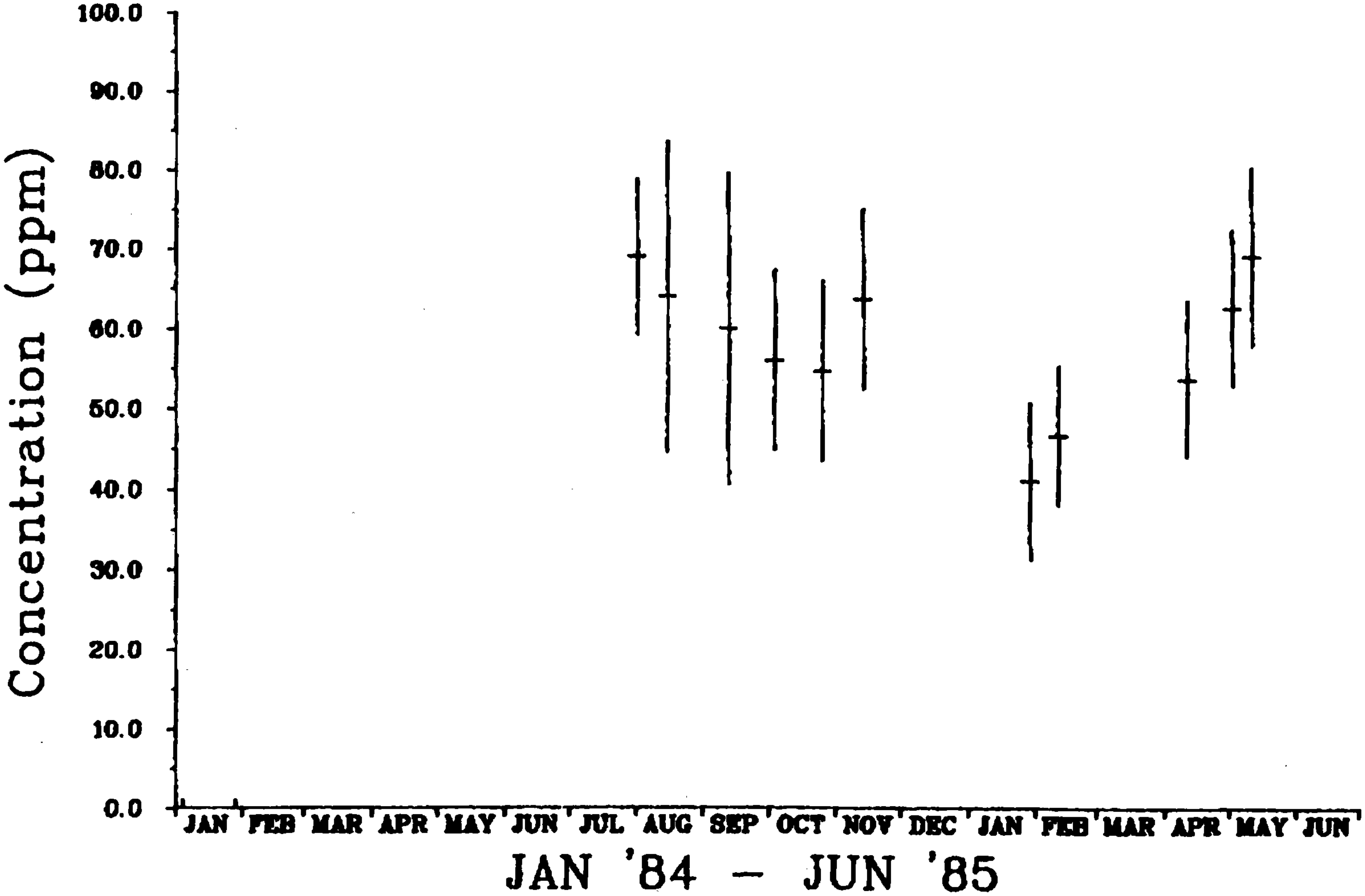


092688

092688

FIGURE 5

MSEE CARBONATE ANALYSIS
95% Confidence Interval



CONTAMINANT	MSEE BUILD-UP RATE	BUILD-UP RATE FOR CONTINUOUS OPER.
Carbonate	67 ppm/year	402 ppm/year
Oxide	9 ppm/year	54 ppm/year
Chromium	8 ppm/year	48 ppm/year

Since carbonates are formed when hot salt comes in contact with carbon dioxide in the air, the volume to surface area ratio for the hot salt tank is an important factor. The table below compares this ratio for the MSEE tanks and the proposed design.

	MSEE	150MWHt	1200MWHt	3000MWHt
Volume/SA	16.34	19.39	40.70	45.91
Factor	- -	0.84	0.40	0.36

Hence, the expected carbonate build-up rate can be estimated from these factors:

PLANT SIZE	ESTIMATED CARBONATE BUILD-UP RATE
150MWHt	338 ppm/year
1200MWHt	161 ppm/year
3000MWHt	145 ppm/year

Using these estimated build-up rates for carbonates, oxides and chromium, we can estimate the time required to reach solubility. These are shown in the table below:

YEARS TO REACH SOLUBILITY

	SOLUBILITY @550°F	150MWHt	1200MWHt	3000MWHt
Carbonates	3000ppm	9	19	21
Oxides	2300ppm	43	43	43
Chromium	2000ppm	42	42	42

As is shown in this table, the worst case is for carbonates in the 150 MWHt storage system. These estimates are based on a facility with no maintenance system. With proper preventative maintenance, these build-up rates should be greatly reduced. As was previously mentioned, carbonates can only be formed when the salt reacts with carbon dioxide. If the carbon dioxide is removed from the padding gas, carbonate formation should be eliminated.

Because of these reasons, we do not feel that a salt maintenance system should be included in the design. However, it is appropriate to discuss existing methods of salt regeneration to remove contaminants. One method to regenerate the salt if levels of carbonates and oxides are high is by reacting the contaminants with nitrogen dioxide. In this process, gaseous NO_2 is bubbled through the molten salt:

$$CO_3^{2-} + NO_2 + 1/2\ O_2 \ \text{- - ->}\ 2\ NO_3^- + CO_2$$

This technique is reported to be slow and has a chemical efficiency of only 18%[5]. Also, NO_2 is relatively expensive, hazardous, and a primary air pollutant.

Another method uses calcium nitrate to remove carbonate and hydroxide. The reactions are:

$$CO_3^{2-} + Ca(NO_3)_2 \ \text{--->}\ 2NO_3^- + CaCO_3$$

$$2OH^- + Ca(NO_3)_2 \ \text{- - ->}\ 2NO_3^- + Ca(OH)_2$$

Calcium carbonate and calcium hydroxide have very low solubilities in molten salt. These components could be removed from the molten salt by filtration. At this time, the use of calcium nitrate is the preferred salt treatment method.

Because of the inherent problems of salt regeneration, the best salt maintenance system is a preventative maintenance program. The most important part of this program is to prevent contact of the hot, molten salt with water and carbon dioxide. This can be accomplished by proper treatment of the air which is used to pad the storage tanks. One method to remove CO_2 and H_2O is the use of molecular sieves. Molecular sieves are synthetically produced zeolites characterized by pores and chrystalline cavities of extremely uniform size. Other commercial absorbents have pore sizes which can vary widely on the same particle. Molecular sieves are available over a range of sizes. Type 5A (5 angstroms) is typically used to remove carbon dioxide. Molecular sieves can be regenerated by raising the temperature to 260C. Molecular sieves are thermally stable to 540C. Table 6 shows the equipment required to treat the air used for padding the gas. Figure 6 shows the process flow diagram for this system.

When salt is removed from the cold tank and is eventually added to the hot tank, make-up air is required because of the density differences of air at 288°C and 566°C. This air is passed through the molecular sieve to remove CO_2 and water. When salt is removed from the hot tank and eventually added to the cold tank, excess air is vented from the system. This air is used to regenerate the molecular sieve by raising the temperature to desorb the trapped contaminant molecules.

Another important part of salt maintenance is continual observation of the salt properties. We recommend that the salt be sampled

TABLE 6

EQUIPMENT LIST AND SIZES

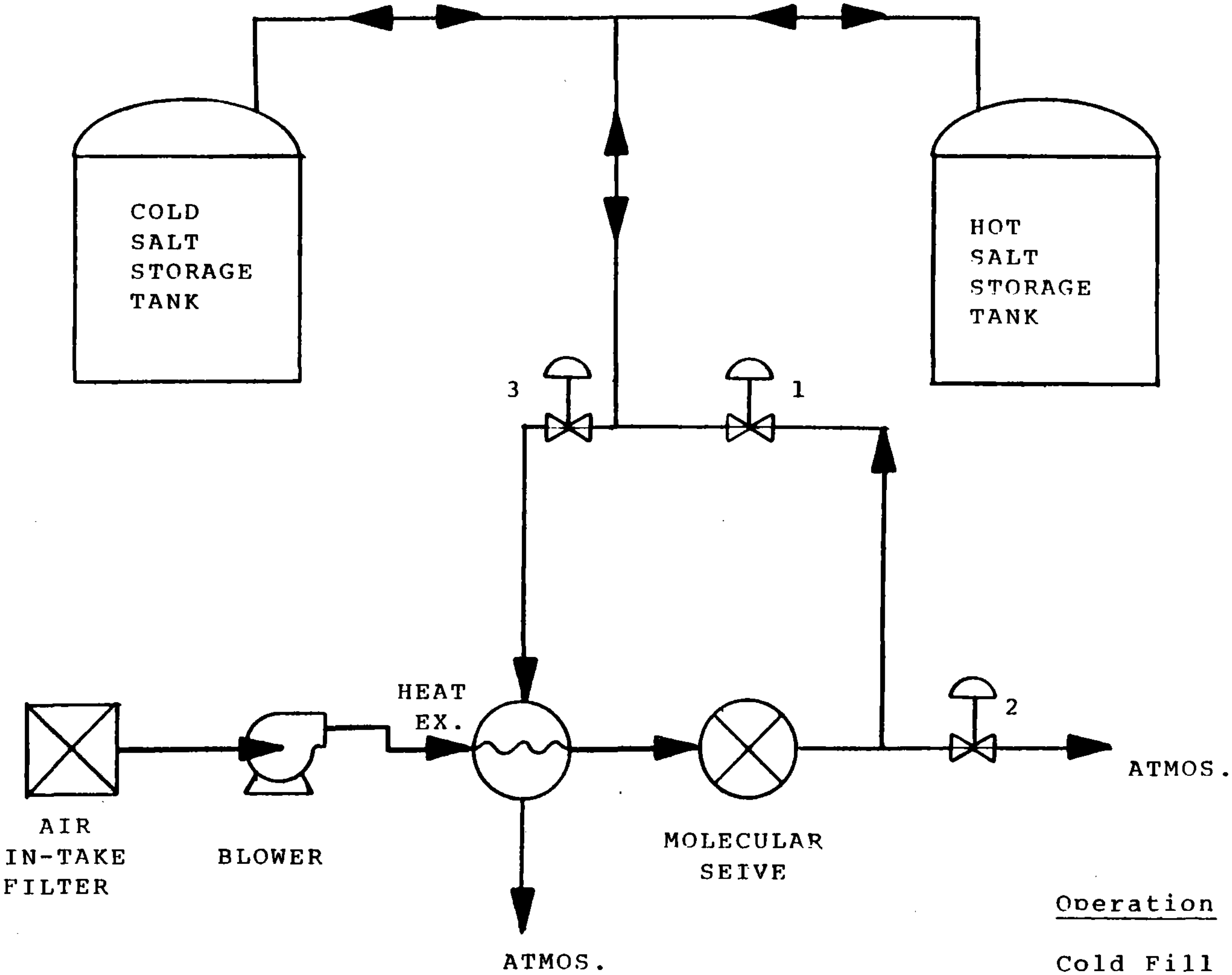
ULLAGE SYSTEM

ITEM	150MWHt	1200MWHt	3000MWHt
Air Blower	10 CFM	85 CFM	180 CFM
Air to Air Heat Exchanger	5000Btu/hr	42500Btu/hr	90000Btu/hr
Molecular Seive*	20 lbs	175 lbs	375 lbs

* Basis: 5 year life

FIGURE 6

ULLAGE SYSTEM



Operation	Valve Position 1	2	3
Cold Fill	C	O	O
Hot Fill	O	C	C

periodically and analyzed for the follow components:

CO_3^{2-}, O^{2-}, NO_2^-, NO_3^-, SO_4^{2-}, Cl^-, SiO_2,
Na, K, Ca, Cr, Ni, Fe, Mo, Mg, and Al

The analysis[12] should be performed at least monthly during the first two years of operation. After a good data base is obtained, analysis of most components could be done on a quarterly basis. But more important contaminants, such as carbonates, oxides and chromium, should be monitored more frequently. If a thermal excursion occurs in the facility, the salt should be sampled and analyzed as soon as possible.

3.2.3 Operating Procedures

This section includes conceptual operating procedures in the following key areas: initial salt melt, inventory salt melt, infrequent salt make-up, ullage system, and salt spills.

Initial Salt Melt

A fossil fired salt melter will be employed to melt the initial 30% of the total salt inventory. This quantity of molten salt would be enough to allow start-up of the balance of the solar facility including the receiver. The typical method of charging salt melters has been to add the mixed nitrate salt to an aqueous slurry of salt in contact with the gas or oil fired heater tubes. It has been demonstrated for other heat transfer salts that an increase in moisture reduces the melting point of the salt. The same should hold for 60% $NaNO_3$ and 40% KNO_3.

After the slurry is in place, the burners are activated to supply heat to the slurry. As the temperature rises the water is slowly driven off resulting in a fairly dry melt. The initial melt batch is allowed to "cook" for a few hours at about 550F in order to drive off any residual moisture which might be trapped in the melt. It is important to always keep the level of the melt above the heating elements. A step by step procedure is listed below:

1. The process tank and equipment which will receive the molten salt are preheated to about 550F.

2. The melting unit is filled with water untill the burner tubes are covered. The water can now be heated.

3. The dry salt is unloaded from railcars and conveyed to the salt melter.

4. The salt is gradually added to the melter and dissolves in the water. The heat from the burners constantly drives off water during this initial melt.

5. Care must be taken to insure the salt solution never falls below the burner tubes. Uncovered tubes will be severely damaged.

6. The melting unit must be adequately vented to a safe place to allow the steam to escape freely.

7. Before the rapid evolution of steam subsides, a dry air purge should be turned on to the melter.

8. Once the melter is filled and most of the water is driven off, the charge is held at 550F for about 5 hours in order to drive off any residual water.

9. The salt storage tanks should be purged with dry air.

10. The first batch of molten salt can then be pumped forward to the salt storage tanks. Enough salt must be left in the salt melter to insure the burner tubes are covered.

11. Additional granular is added to the salt melter and allowed to melt. When completely melted, the salt could be pumped to the salt storage tanks. This procedure is repeated untill the amount of salt required is melted.

12. When charging the salt storage tanks for the first time, it may be advantageous to charge the tanks with a heel of granular, unmelted nitrate salt. This salt would act as insulator to the bottom of the tank and could help lessen the shock of the molten salt when it first enters the storage vessel.

Inventory Salt Melt

When the initial charge of salt is melted, other equipment in the facility can become operational. This quantity of salt is estimated to be approximately 30% of the total salt inventory. When the receiver comes on line and begins to heat the molten salt, this energy can be used to melt the remaining salt charge. A special mix tank would be used for this purpose. Hot salt from the solar central receiver would be sent to the mix tank with granular nitrate salt from the incoming railcars. These materials would be mixed to form a fully melted salt at 550F. A basic step by step procedure follows.

1. The process equipment which will receive the hot nitrate salts should be preheated to the operating temperature.

2. The mix tank should first be charged with molten salt at 550F. The tank should be filled to about the 50% level. The agitator and recirculation pump could then be turned on.

3. Hot salt from the receiver would slowly be added to the mix tank to increase the temperature of the melt.

4. When the temperature reached an appropriate level, granular salt would then be added and allowed to mix with the hot salt.

5. Granular salt and hot salt feed rates would be slowly increased to a predetermined rate.

6. Temperature and level control are envisioned for the mix tank. Granular salt would be added to the mix tank a predetermined rate. Hot molten salt would be added to the tank in order to maintain a proper melt temperature (550F). Melted salt would be pumped out of the tank to the cold storage tank at a rate to maintain a constant level in the mix tank.

7. This procedure would continue untill all the salt is melted or untill the source of hot salt is depleted. Care should be taken not to let the salt temperature in the mix tank drop near its freezing point. A temperature interlock should shut down the granular salt feed if the temperature in the mix tank drops too low.

proceed to break up the solid salt into chunks for easier handling and disposal.

Spilled salt can be treated to remove most physical contaminants (sand, debris,etc.) and returned to the system. Alternately the salt could be resold for use in an application where heavy metal contamination is not a concern. Treatment to remove the physical impurities would invlove remelting and filtering the salt.

The selection of a method to dispose of spilled salt is dependent on the level of contaminants in the salt. In the solar application, the major chemical contaminant of environmental concern is chromium, primarily in its hexavalent state. While it is true that other toxic heavy metals (Ni, Cu, and Mo) are present in the materials of construction used in the solar facility, it appears that their rate of build-up in the molten salt is insignificant. Chromium, however, does build-up in the system at a slow but measurable rate. If the level of chromium in the salt is above 5ppm, it is considered to hazardous according to EPA regulations and could only be disposed of in a secure landfill. Landfilling large quantities of molten salt would very expensive. Some previous work has been done to reduce the hexavalent chromium to trivalent chromium[5] . The trivalent chromium could then be treated to precipitate Cr^{+3} hydroxides from aqueous solutions of the salt. Once the level of Cr is reduced below 5ppm, or if the chrome is present as only Cr^{+3}, the salt would be considered non-hazardous.

In the case of any major molten salt spill, the proper environmental agencies should be notified. The above discussion is only an overview the steps to be taken in the event of a salt spill. Before a solar facility is actually built and commissioned a comprehensive plan should be made in regards to salt spills. This plan should include any regulations specific to the plant location.

Infrequent Salt Make-up

It is expected that adding salt to the system would not normally be required. However over the course of 30 years of plant operation, a situation may occur to nessitate the addition of fresh salt to the system. A salt spill or salt contamination could require the need for additional salt to the system. The procedure for adding salt to the system would be the same as described above under Inventory Salt Melt.

Salt Spill

In this section it is necesary to distinguish so-called "virgin" salt from salt that is "in-process". Virgin salt has not been used in the solar central receiver facility and is presumed to be uncontaminated. In-process salt has been used, and in the case of a spill should be assumed that it is contaminated unless proven otherwise.

For virgin salt spills, the following procedure can be used for clean-up. For small, dry spills, shovel the material into a container and cover. Move the container and flush the area with water. If a molten salt spill occurs, dike the fluid with sand or earth and allow to cool. When the salt has solidified, it should be transfered to secure containers and disposed of properly. If the salt has not been contaminated with heavy metals, the salt may have use as a fertilizer.

A spill of in-process salt would pose additional problems. An in-process spill would most likely involve molten salt. The area involved in the spill should be immeadiately cleared of all personnel. After the situation has been assessed and it is determined that it is safe to reenter the area, properly protected personnel should dike the area, if required, and remove any combustible material. If a fire has resulted from the contact of molten salt with combustable material, it can be estinguished with sand, water fog, or dry chemical. The molten salt should be allowed to solidify and cool. Once this has occurred, properly protected personnel can

4.0 Recommendations

The following is a list of recommendations as a result of this study:

* Do not include a salt regeneration system as part of the baseline design. Our studies indicate that with a proper preventative maintenance program, the salt will maintain its performance characteristics over the life of the solar facility. It should be noted, however, that methods do exist to remove contaminants from the salt.

* Use an air pad on the hot and cold salt storage tanks. Air has been shown to be nearly ideal from the standpoint of salt stability.

* Remove carbon dioxide and water from the air pad used on the hot and cold salt storage tanks. Both water and carbon dioxide react with salt constituents to form unwanted contaminants. A molecular sieve can be used for this purpose.

* The molten nitrate salt should be carefully monitored throughout the life of the plant. All constituents should be monitored at least monthly during the first several years of operation. After a good data base has been established, the salt could be checked less often. However, the more important contaminants (carbonates, hydroxides, and chromium) should be checked frquently.

* Our check of the salt properties used in the Project Guidelines revealed that the thermal conductivity data had a reported uncertainty of +/-20%. If this is an important parameter in the design of any equipment in facility, further work would be required to produce more accurate data.

* During our review of available corrosion data, we found only one report which studied the effect of molten salt flowing in a pipe. This particular study assessed only one velocity (11fps). It would advantageous from the standpoint of receiver design to expand on this limited study.

5.0 Bibliography

1. Progress Report: Molten Nitrate Salt Technology Development, R. W. Mar, et. al., SAND82-8220, April 1982

2. Physical Properties Data Compilations Relevant to Energy Storage, Part II Molten Salts, NSRDS-NBS 61, Part II.

3. Olin Corporation internal memo.

4. Martin Marietta Corporation, Sandia National Laboratories, RFQ 21881

5. Manufacture, Distribution and Handling of Nitrate Salts for Solar Thermal Applications, Olin Corporation, SAND 81-8186, November 1982.

6. Olin Corporation internal report.

7. A. Rahmel, Molten Salt Technology, Ed. D.G. Lovering, Plenum PressNew York, 1982, pp. 274-275.

8. Martin Marietta Corporation, Alternate Central Receiver Power System, Phase II, Volume III - Molten Salt Materials Tests, SAND 81-8192/3, UC-62d May 1981.

9. R. W. Carling, C. M. Kramer, R. W. Bradshaw, D. A. Nissen, S. H. Goods, R. W. Mar, J. W. Munford, M. M. Karnowsky, R. N. Biefield, N. J. Norem. Report Sand 80-8052, Sandia National Laboratories.

10. A. B. Quakenbush, MSEE Salt Sampling 1984 Status Report, Olin Corporation, 1985.

11. R. A. Chihoski, F. M. Kustas, M. Nance, Electrochemical Society Proceedings, 83-1, 431, 1983.

12. Olin Corporation, Analytical Methods, (internal Report)

MSEE SALT SAMPLING

1985 STATUS REPORT

This report summarizes the analytical results of the MSEE salt sampling for 1985. The analytical results show the salt to be in good condition. The salt shows no major composition changes through May, 1985.

All samples reported here were taken from the cold sump. Since the cold sump was shut off, there have been no samples taken for the latter half of 1985. We do not expect there has been any change in composition since mid-year because the salt has not been operated at high temperatures.

The results of our analysis for 1985 are shown as Table 1. Immediately below each component average is a value for one side of the 95% confidence interval for precision. Table 2 is the results of 1984 sample analysis and is included for historical reference. Graphs for selected ionic species are also attached to show the historical trends.

The melting/freezing characteristics of the salt have not changed since the ratio of sodium to potassium has not changed. The other major components, nitrate and nitrite, are at expected concentrations for a thermally cycled system. All other cation and anion species, except chromium and oxides, continued to maintain the expected and somewhat "inert" concentrations.

Chromium and oxide (i.e., hydroxide/oxide) concentrations continue to increase in the salt. Chromium is increasing in the salt at about 8 ppm per year. The rate of chromium increase is expected to decrease as surfaces of the MSEE are passivated. The current levels of chromium are considered good and are well below the solubility limit. Oxide is increasing in concentration at about 9 ppm per year. At the current rate of accumulation, there should be no problems associated with oxide buildup for a 30 year plant life cycle. The oxide buildup is affected by several factors related to plant operation including salt exposure to atmospheric water vapor and high temperatures; therefore, the 9 ppm per year accumulation represents a minimum rate since the MSEE was operated intermittently relative to a future commercial solar facility.

In summary, the analytical results to date show the MSEE salt is performing very well. All chemical species are at acceptable levels. Although oxide and chromium concentrations in the salt are increasing, the current rate is not considered a problem. We do recommend because of unknown variables related to operation that the salt, especially the oxide component, continue to be analyzed periodically.

TABLE 1

1985 SAMPLE ANALYSIS

Sample Average and 95% Confidence Interval

		Jan. 29	Feb. 11	April 11	May 2	May 11
CO_3^{2-}	(ppm)	41.0 9.8	46.6 8.8	53.7 9.8	62.6 9.8	69.1 11.3
O^{2-}	(ppm)	9.4 1.6	9.1 1.4	10.8 1.6	12.1 1.6	12.3 1.6
NO_2^-	(%)	0.95 0.10	0.90 0.10	1.06 0.10	1.10 0.10	1.03 0.10
NO_3^-	(%)	67.0 2.0	67.0 2.0	67.5 2.0	66.7 2.0	66.8 2.0
SO_4^{2-}	(ppm)	1600 154	1600 154	1800 154	4400 154	3000 154
Cl^-	(ppm)	25.0 5.2	20.2 5.2	18.2 5.2	14.8 5.2	15.5 5.2
SiO_2	(ppm)	90 8.7	70 8.7	106 8.7	70 8.7	70 8.7
Na	(%)	16.4 0.8	16.6 0.8	16.3 0.8	16.6 0.8	16.5 0.8
K	(%)	15.2 1.1	15.0 1.1	15.3 1.1	15.0 1.1	15.2 1.1
Ca	(ppm)	4.8 0.8	5.1 0.8	8.6 0.8	6.5 0.8	5.6 0.8
Cr	(ppm)	9.5 0.7	9.5 0.7	9.9 0.7	10.0 0.7	10.3 0.7
Ni	(ppm)	3.2 0.7	3.3 0.7	3.5 0.7	3.3 0.7	3.4 0.7
Fe	(ppm)	1.5 0.7	1.6 0.7	2.6 0.7	3.5 0.7	3.0 0.7
Mo	(ppm)	3.5 0.3	2.8 0.3	3.6 0.3	3.0 0.3	2.8 0.3
Mg	(ppm)	0.5 1.4	0.6 1.4	1.6 1.4	2.2 1.4	1.6 1.4
Al	(ppm)	<5	<5	<5	<5	<5

Example: Take May 2 analysis for Mg. The value is 2.2 $\pm$ 1.4 ppm. That is, we are 95% confident the value was greater than 0.8 ppm and less than 3.6 ppm.

092688

TABLE 2

1984 SAMPLE ANALYSIS

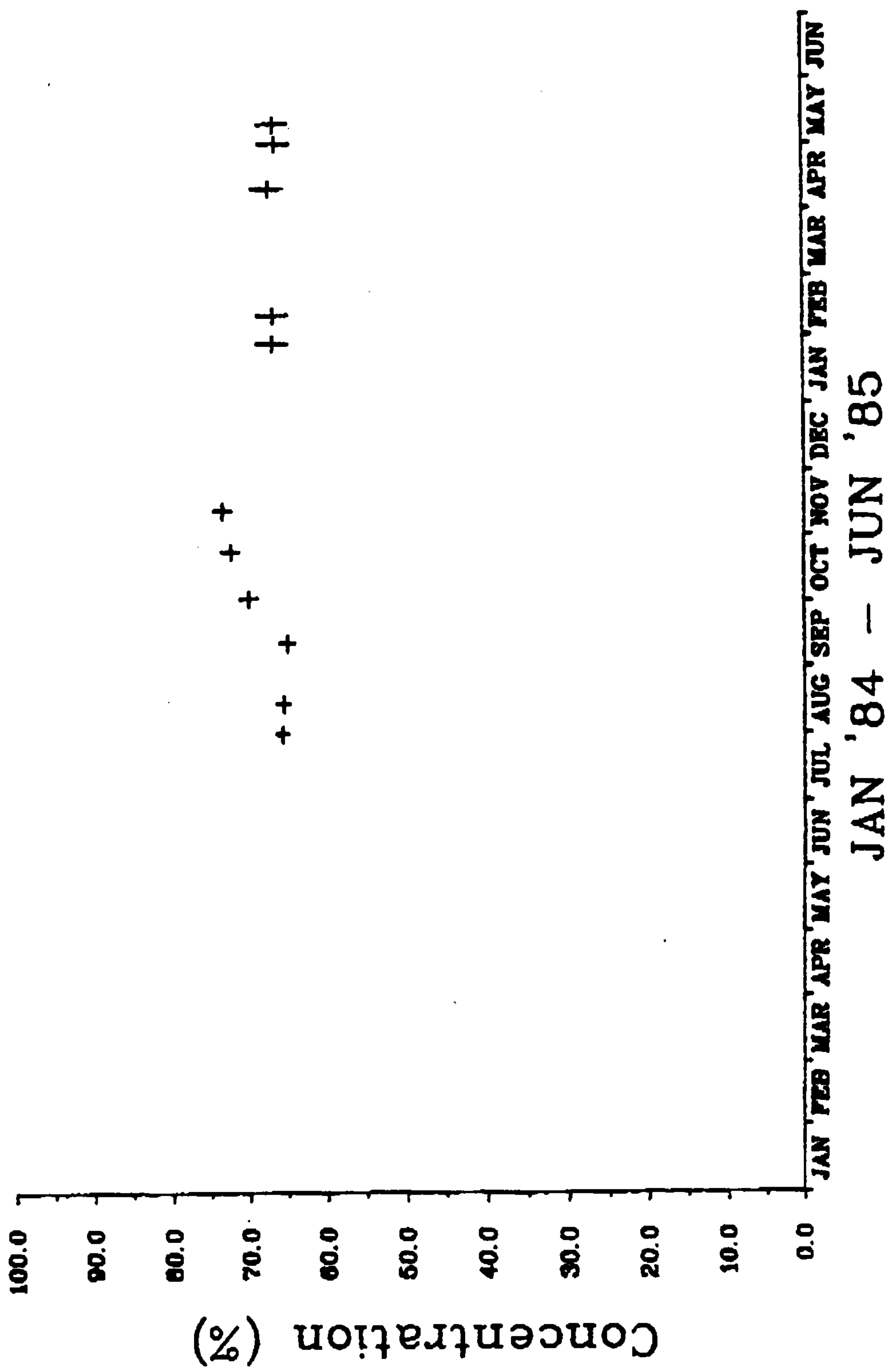
Sample Average and 95% Confidence Interval

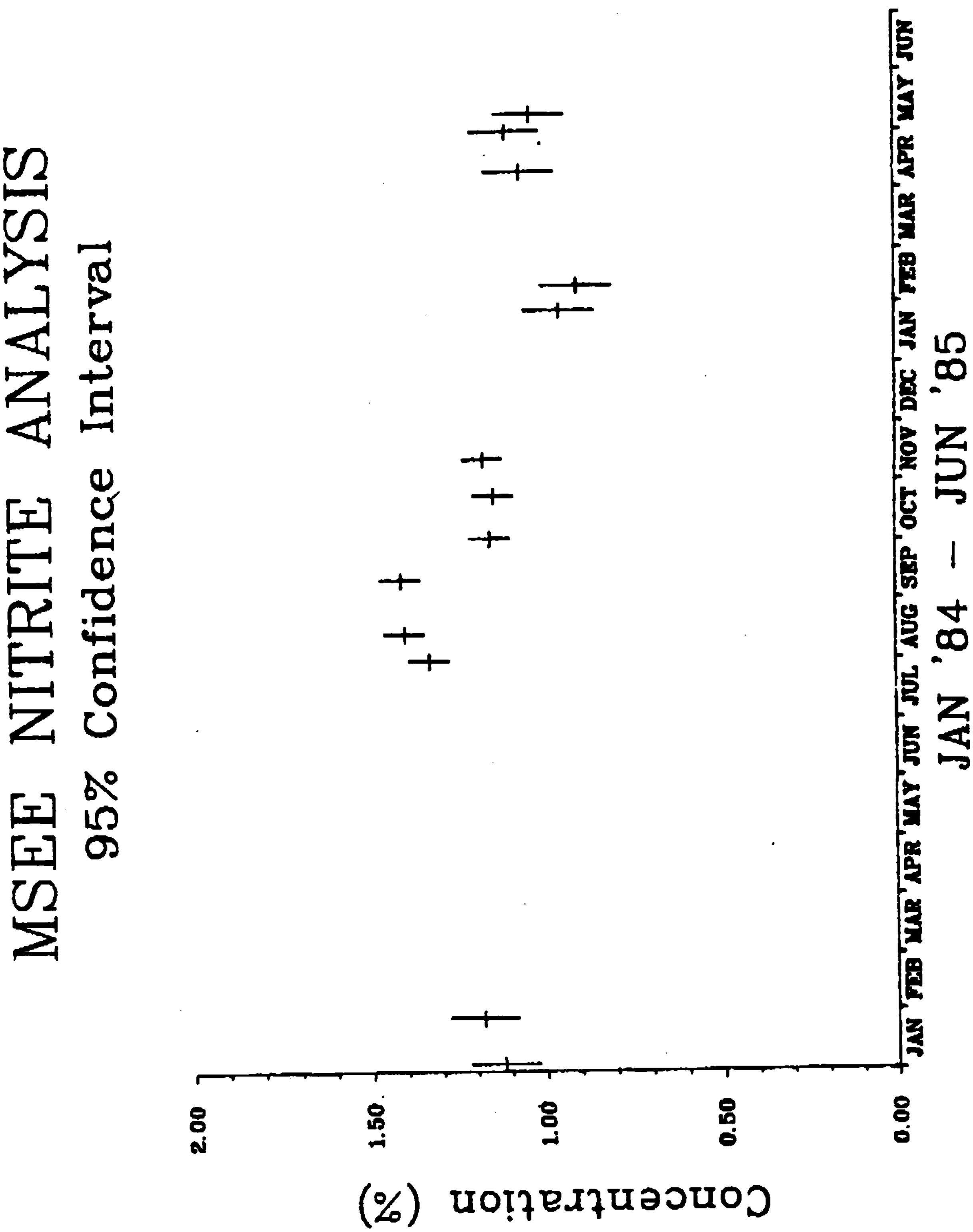
	Jan. 5	Jan. 29	Aug. 1	Aug. 15	Sept. 12	Oct. 3	Oct. 25	Nov. 13
CO_3^{2-} (ppm)	<1	<1	69.0 9.6	64.0 19.3	60.0 19.2	56.0 11.1	54.7 11.1	63.7 11.1
O^{2-} (ppm)	<1	<1	5.0 1.9	7.0 3.9	9.0 3.9	7.0 2.2	7.0 2.2	9.0 2.2
NO_2^- (%)	1.12 0.10	1.18 0.10	1.33 0.06	1.40 0.06	1.41 0.06	1.15 0.06	1.14 0.06	1.17 0.06
NO_3^- (%)			65.9 1.2	65.8 1.4	65.3 1.5	70.3 1.7	72.6 1.7	73.6 1.7
SO_4^{2-} (ppm)			1601 89	1754 89	660 89	676 89	651 89	779 89
Cl^- (ppm)	25.0 4.96	<25.0	33.0 2.9	29.3 2.9	15.0 3.5	40.7 2.9	38.0 2.9	40.0 2.9
SiO_2 (ppm)			67.5 5.1	41.2 4.4	60.0 4.4	57.7 5.1	59.7 5.1	58.7 5.1
Na (%)	15.27 0.67	14.60 0.67	16.13 0.44	16.77 0.44	16.33 0.44	16.49 0.44	15.98 0.44	16.23 0.44
K (%)	16.52 1.22	14.98 1.22	14.98 0.70	15.03 0.70	15.52 0.70	14.73 0.70	14.67 0.70	14.92 0.70
Ca (ppm)	25.0 0.84	31.0 0.84	7.00 0.42	8.00 0.42	6.61 0.42	5.28 0.48	4.58 0.48	6.76 0.48

Table 2
1984 Sample Analysis (Cont'd)

	Jan. 5	Jan. 29	Aug. 1	Aug. 15	Sept. 12	Oct. 3	Oct. 25	Nov. 13
Cr (ppm)	4.00	4.00	3.00	4.80	4.81	6.12	6.18	6.48
	0.69	0.69	0.35	0.35	0.35	0.40	0.40	0.40
Ni (ppm)	3.50	3.50	5.00	3.48	3.41	3.35	3.73	3.89
	0.65	0.65	0.33	0.33	0.33	0.38	0.38	0.38
Fe (ppm)	37.5	12.5	5.00	4.00	3.31	4.09	2.50	4.17
	0.65	0.65	0.33	0.33	0.33	0.38	0.38	0.38
Mo (ppm)	<1.3	<1.3	1.58	1.60	1.65	1.44	1.39	1.29
			0.13	0.13	0.13	0.15	0.15	0.15
Mg (ppm)	4.00	6.00	8.00	8.00	8.26	7.21	2.55	7.90
	1.37	1.37	0.68	0.68	0.68	0.79	0.79	0.79
Al (ppm)			<1	<1	<1	<1	<1	<1

MSEE NITRATE ANALYSIS
95% Confidence Interval

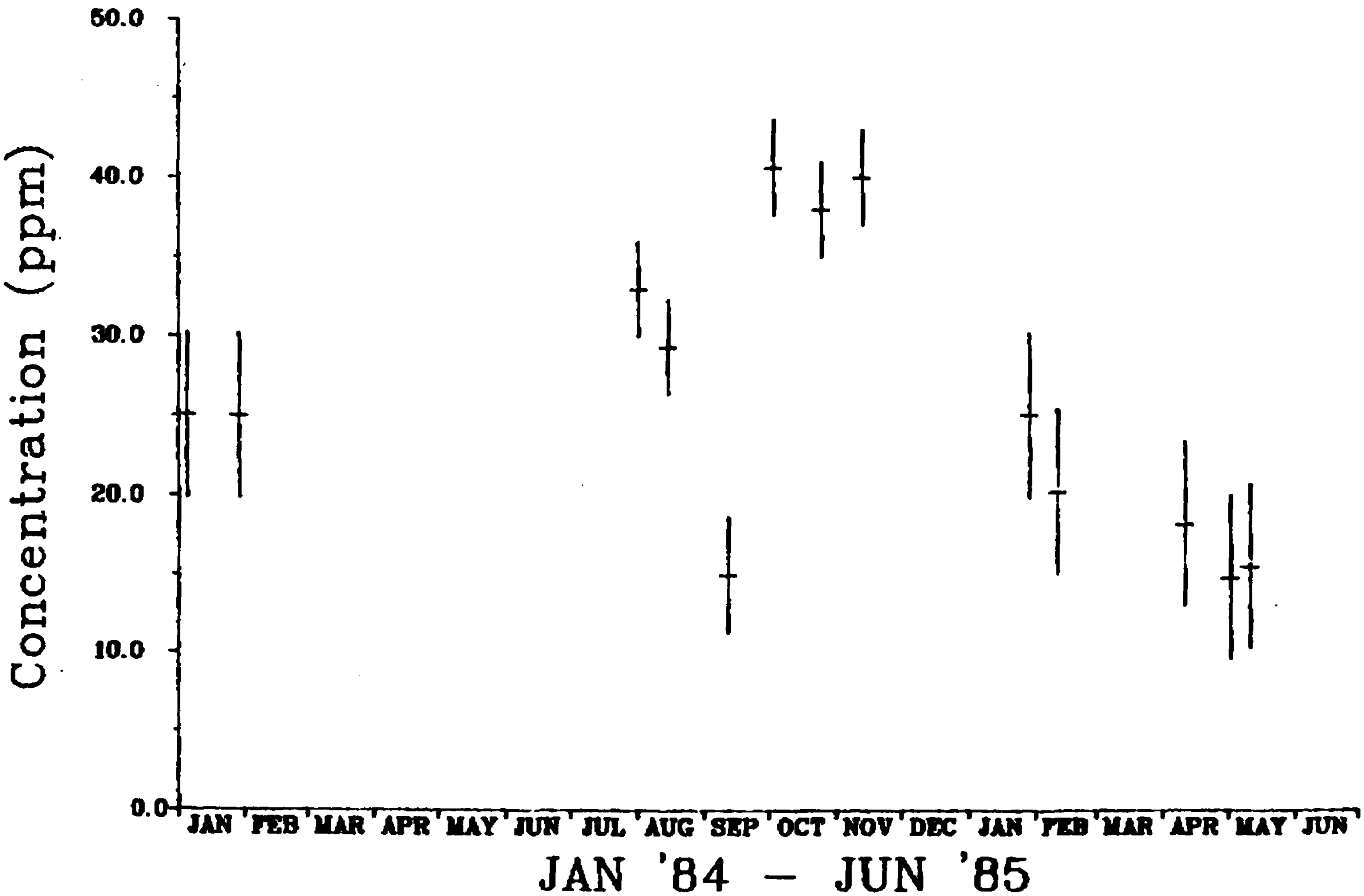



MSEE NITRITE ANALYSIS
95% Confidence Interval
Concentration (%)
0.00
0.50
1.00
1.50
2.00
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 - JUN '85

092688

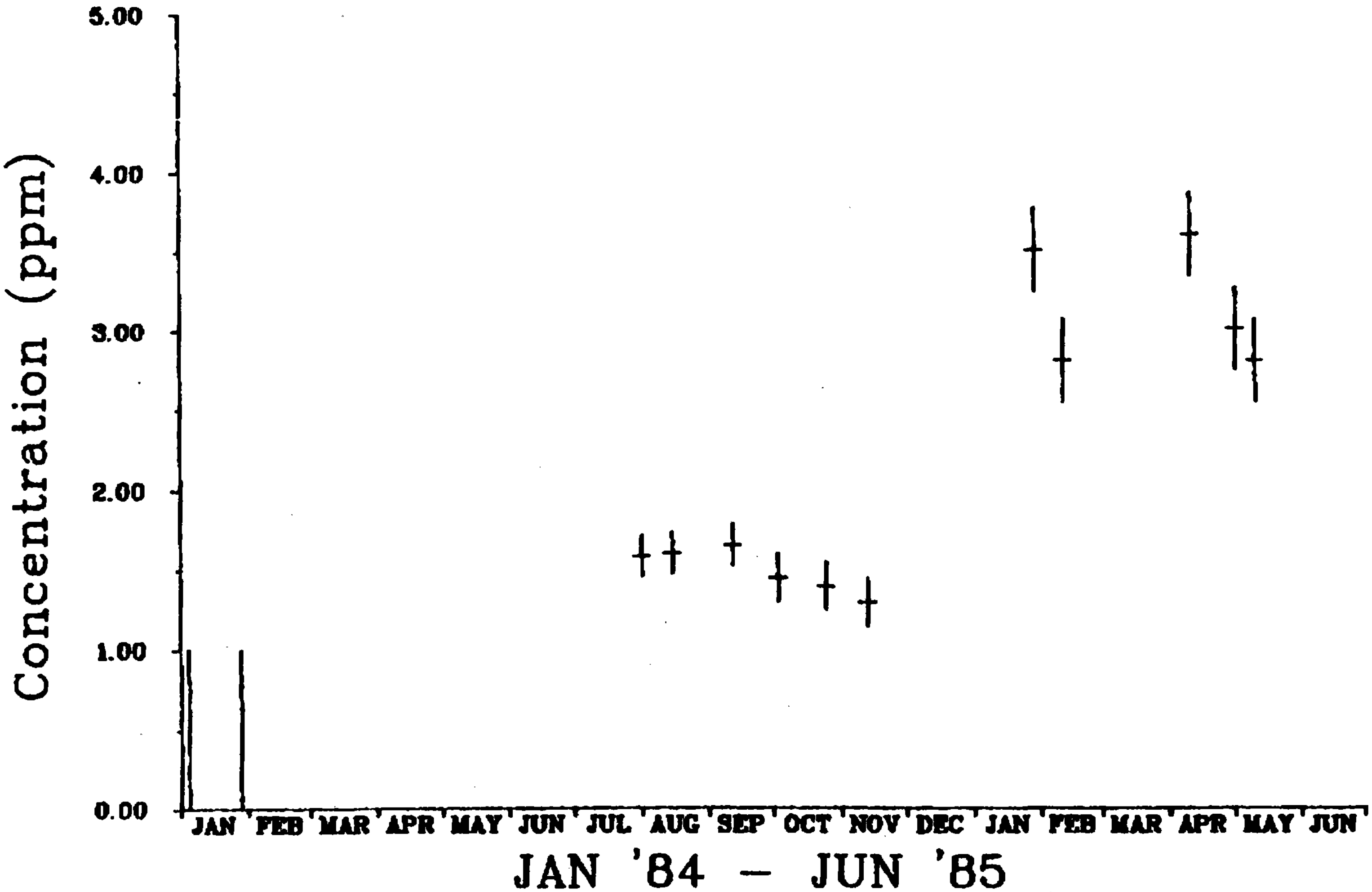
MSEE CHLORIDE ANALYSIS

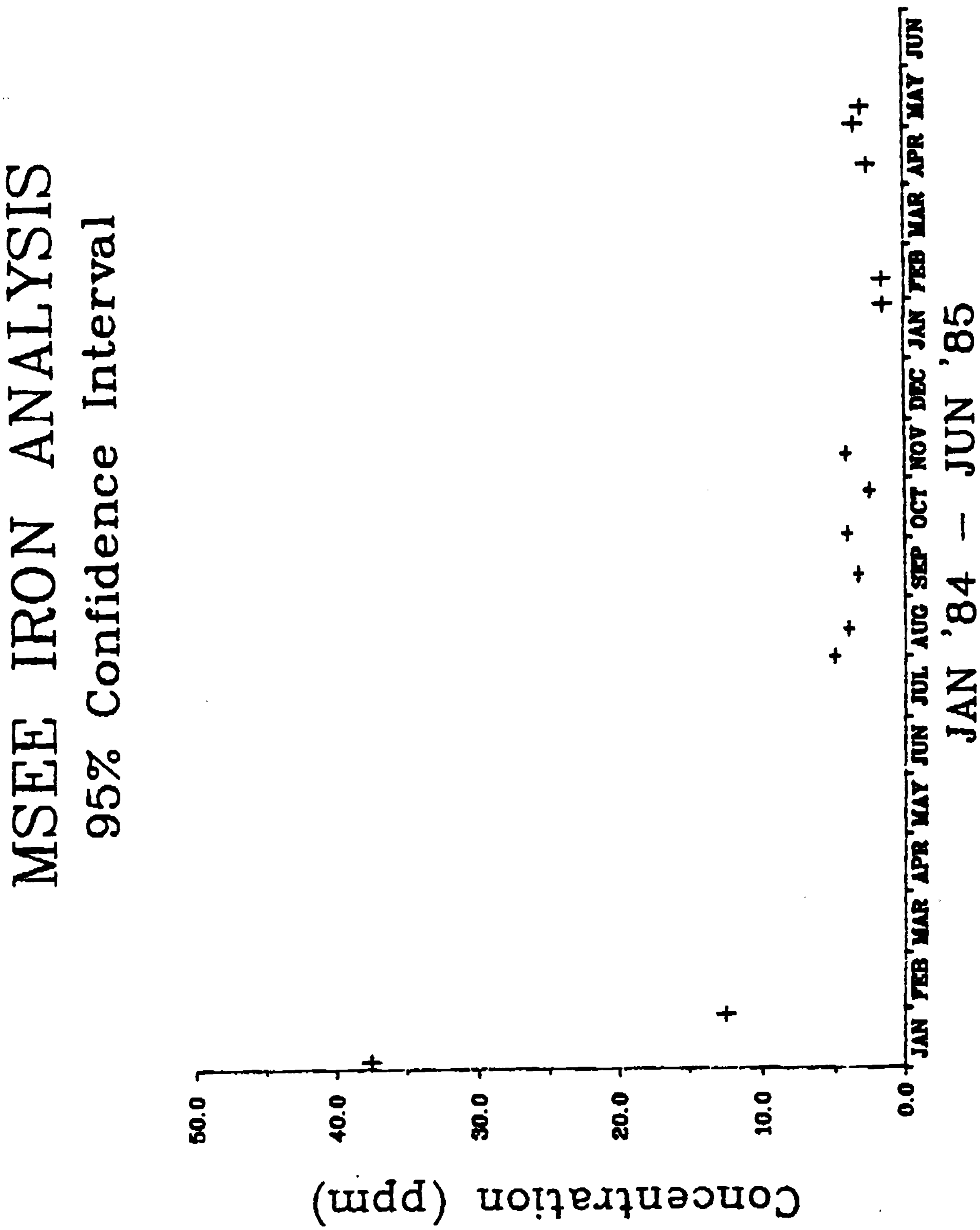
95% Confidence Interval



MSEE MOLYBDENUM ANALYSIS

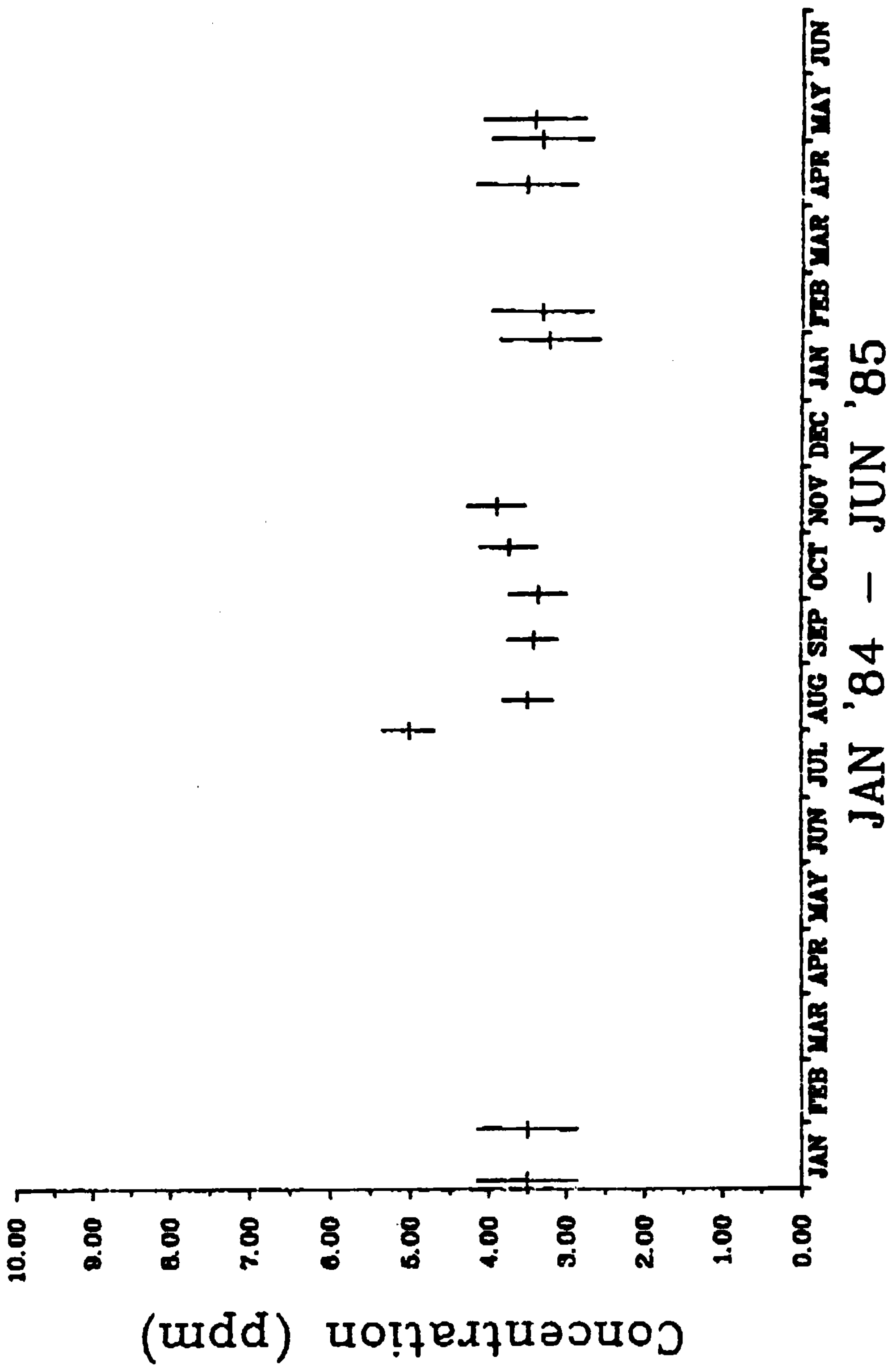
95% Confidence Interval

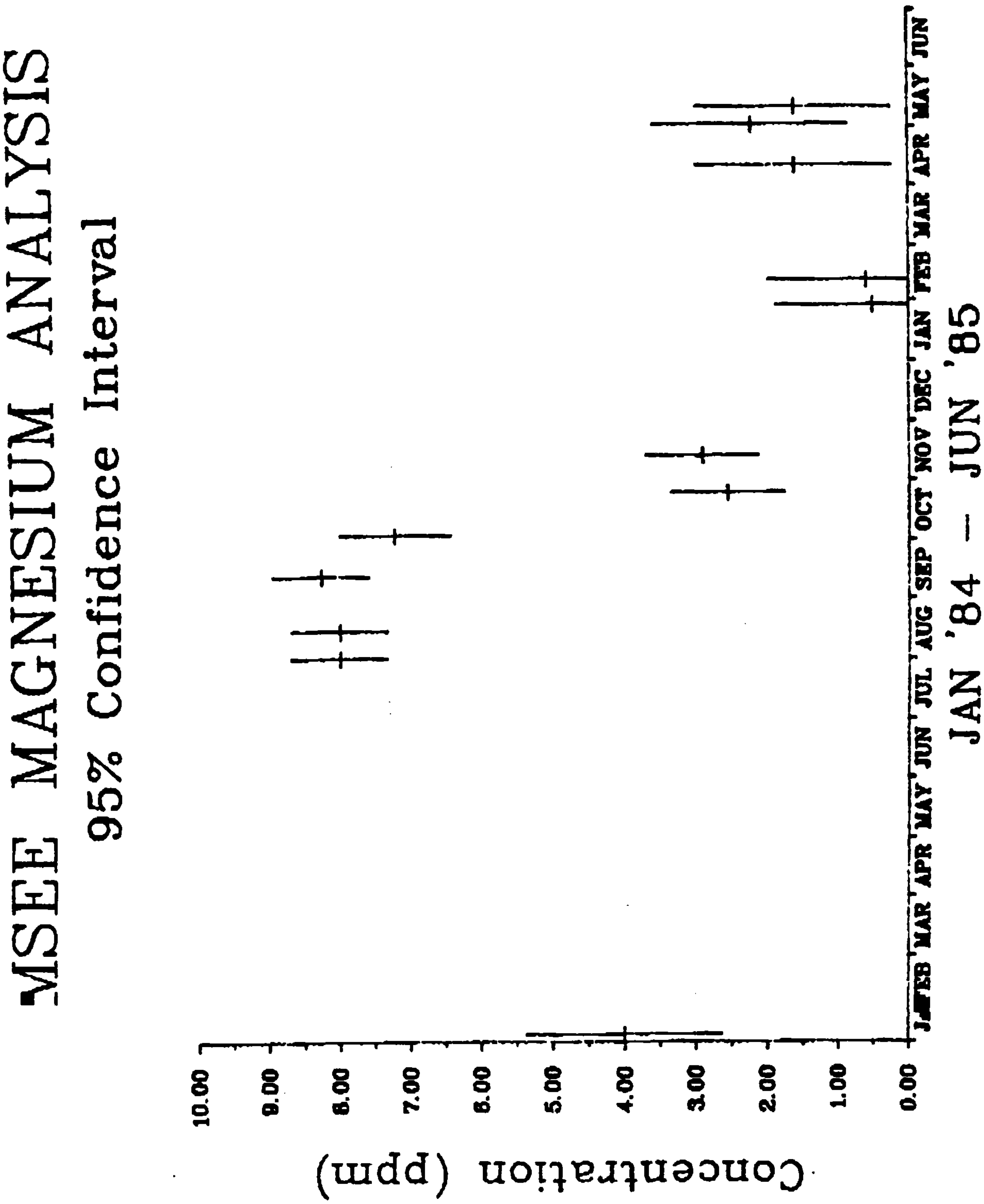



MSEE IRON ANALYSIS
95% Confidence Interval
Concentration (ppm)
50.0
40.0
30.0
20.0
10.0
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 — JUN '85

MSEE NICKEL ANALYSIS

95% Confidence Interval

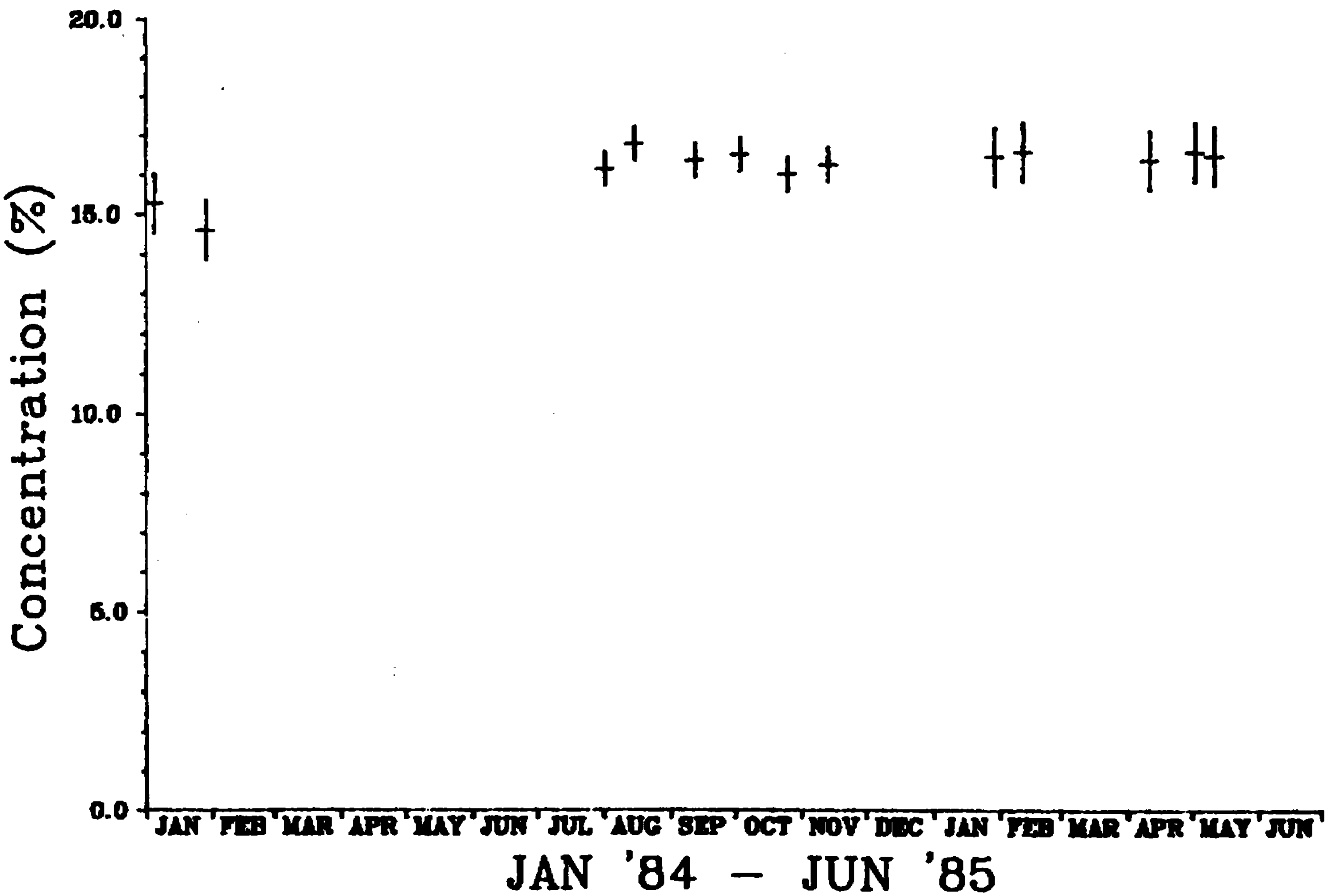



MSEE MAGNESIUM ANALYSIS
95% Confidence Interval
Concentration (ppm)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 – JUN '85

092688

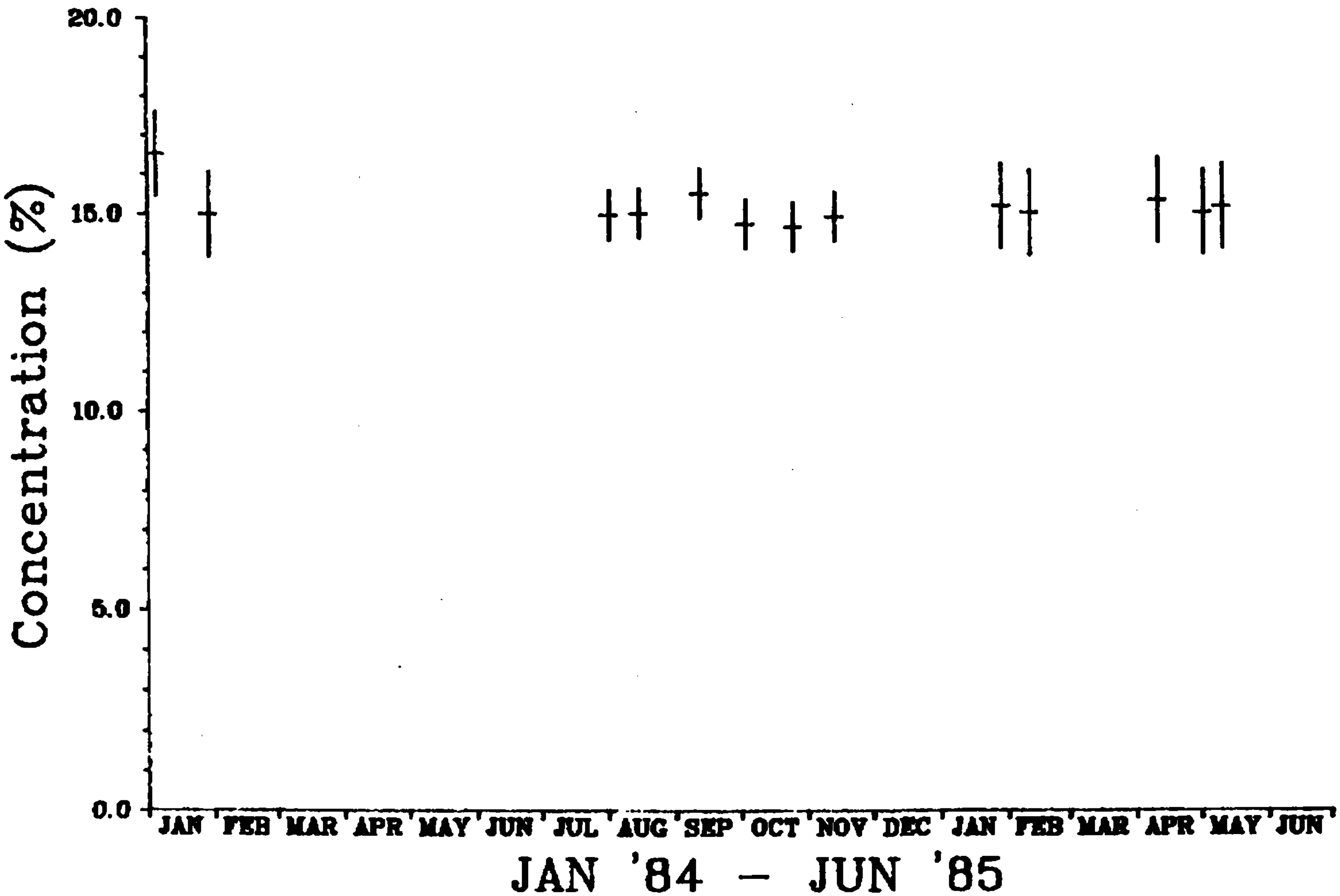
MSEE SODIUM ANALYSIS

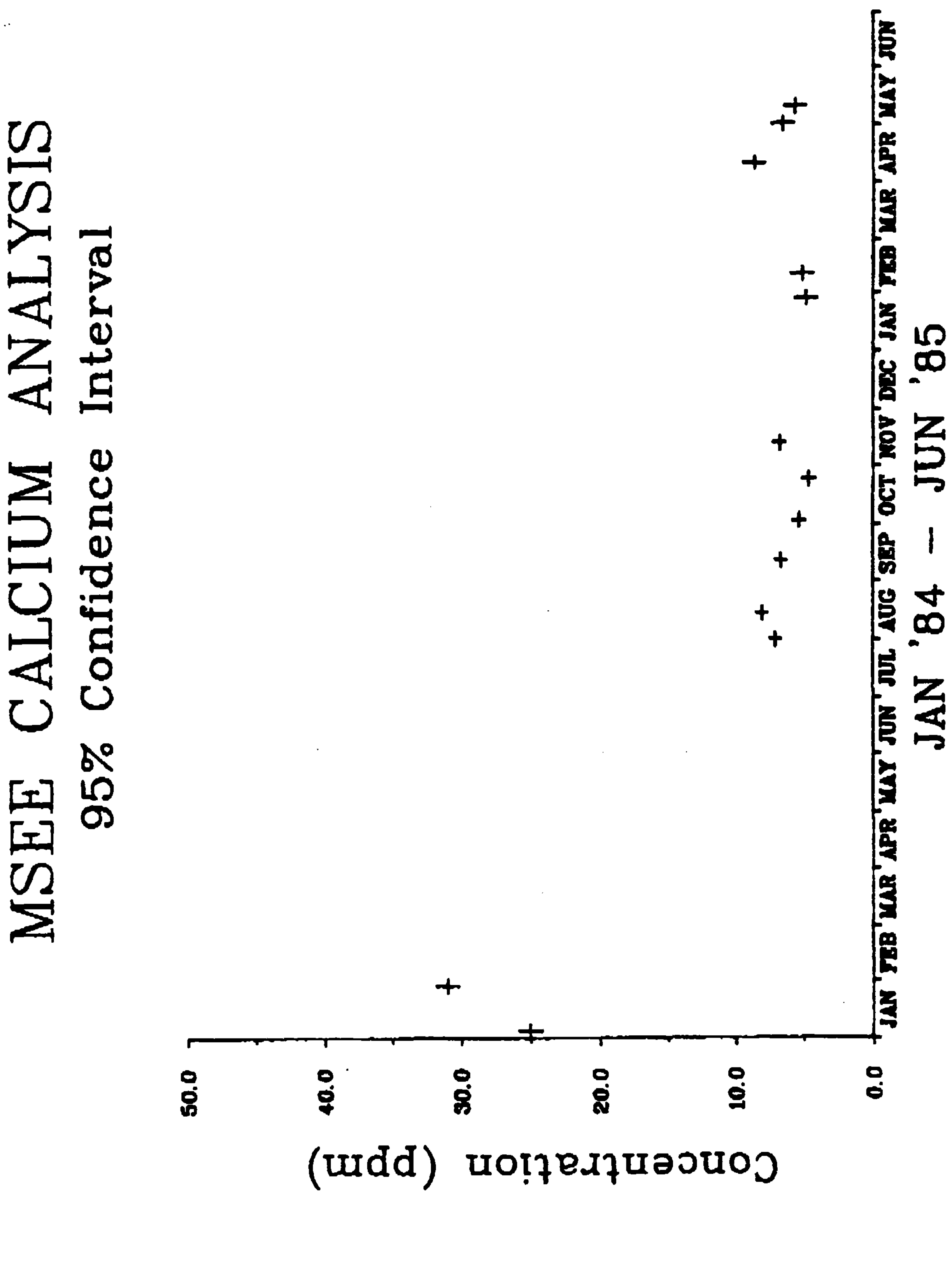
95% Confidence Interval



MSEE POTASSIUM ANALYSIS

95% Confidence Interval

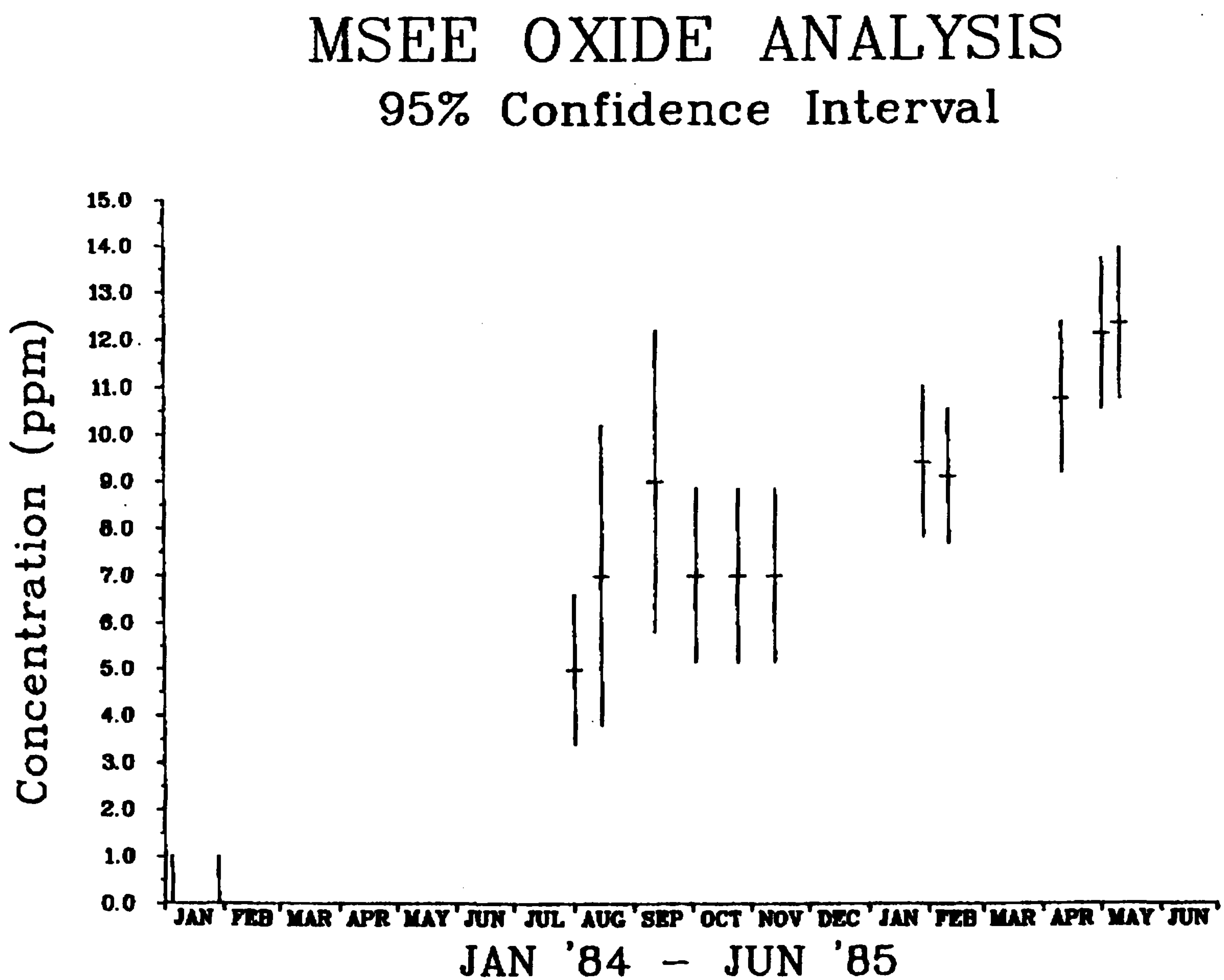


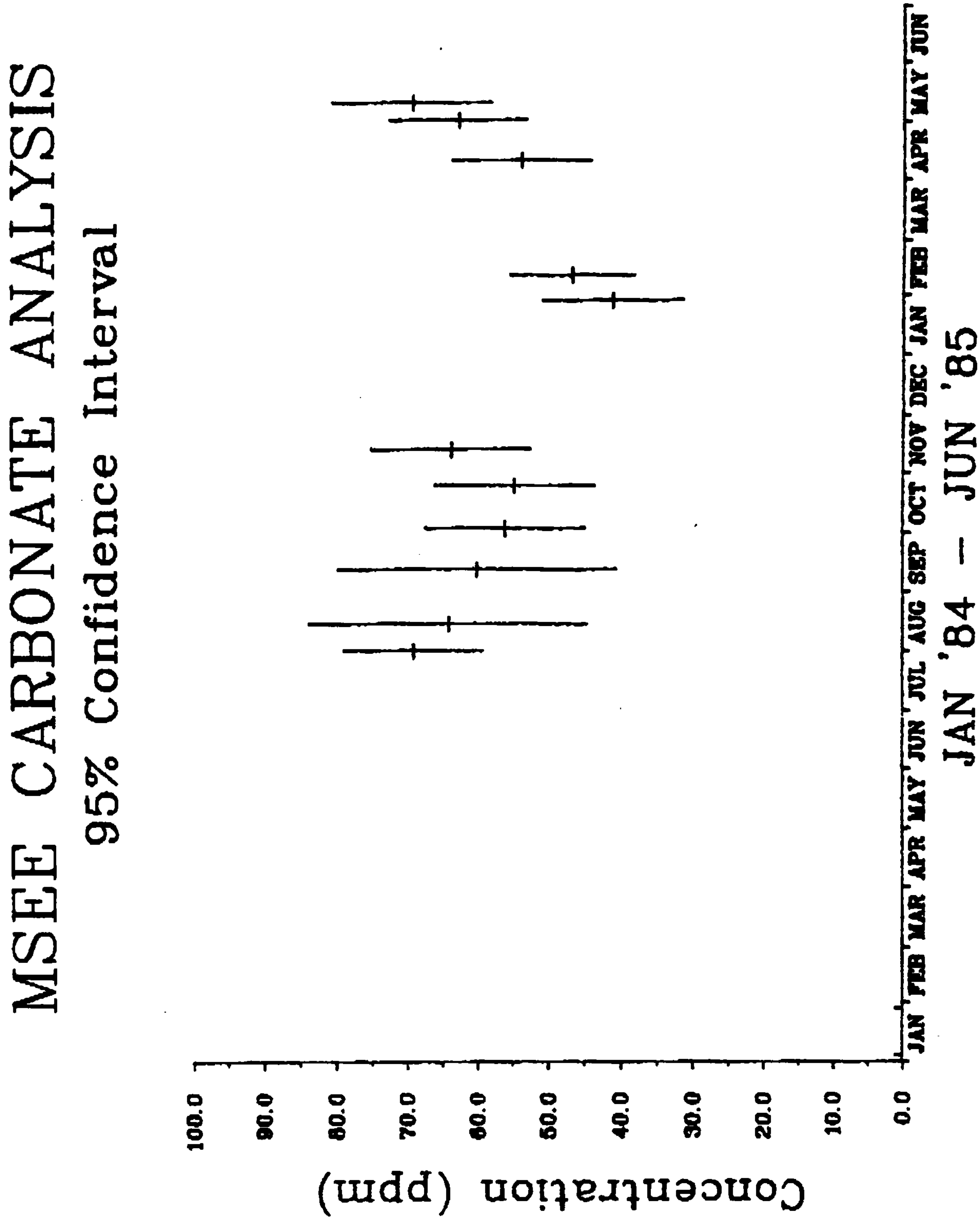


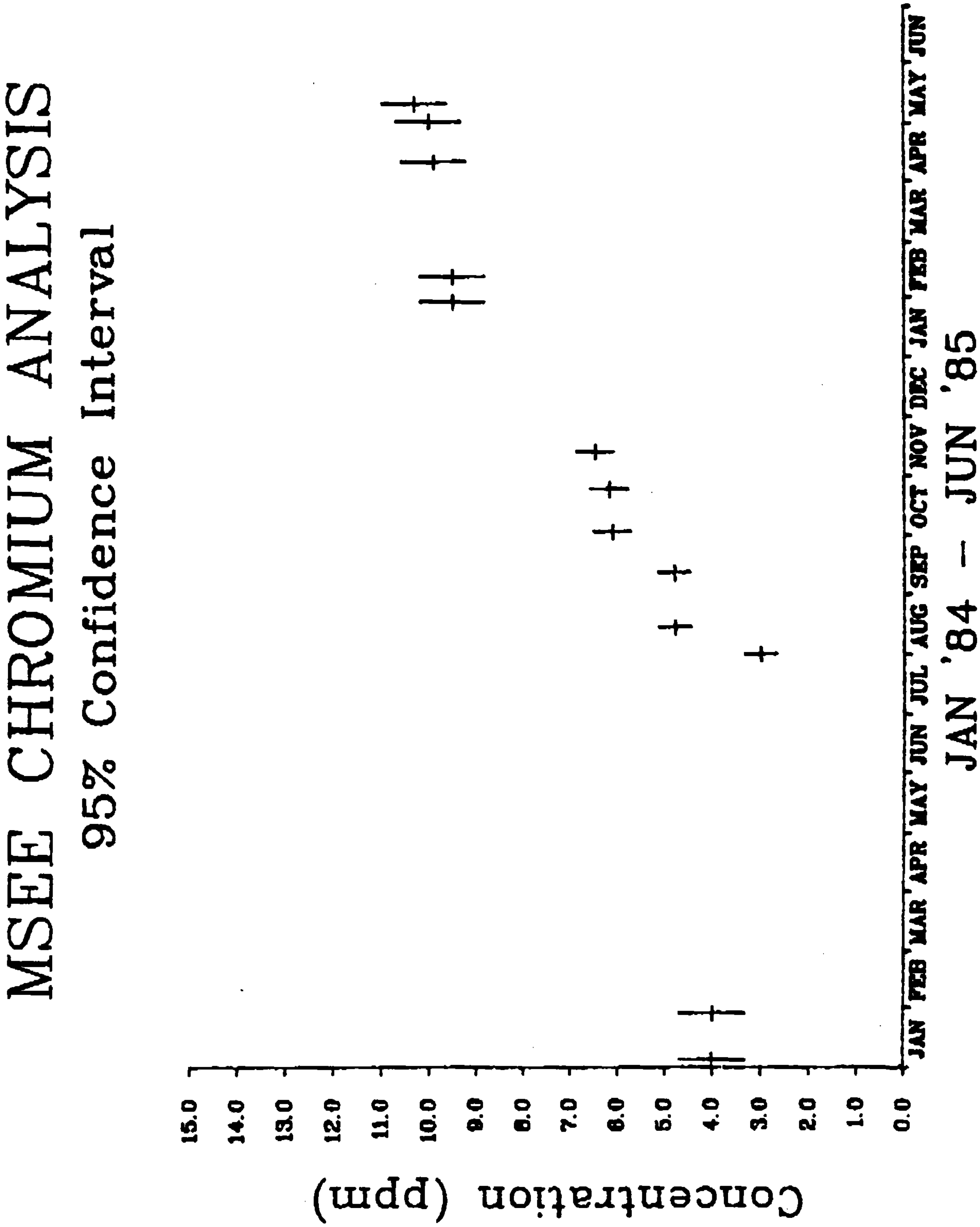
MSEE CALCIUM ANALYSIS
95% Confidence Interval
Concentration (ppm)
50.0
40.0
30.0
20.0
10.0
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 – JUN '85

092688

D-56


MSEE OXIDE ANALYSIS
95% Confidence Interval
Concentration (ppm)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 – JUN '85


MSEE CARBONATE ANALYSIS
95% Confidence Interval
Concentration (ppm)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 — JUN '85


MSEE CHROMIUM ANALYSIS
95% Confidence Interval
Concentration (ppm)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
JAN '84 – JUN '85