AEC
RESEARCH
and
DEVELOPMENT
REPORT

BNWL-308
/-

FAST FLUX TEST FACILITY

A D O P T

PROGRAM FOR STEADY-STATE PROCESS DESIGN
AND COST OPTIMIZATION OF FFTF HEAT REMOVAL
SYSTEMS USING HEAT DUMPS TO AIR

C. L. GOSS

And

H. G. JOHNSON

FILE NO.	FILE DATE
WRM-1000	DEC 27 1966
MR. Compton	32260 MATH APR 23 1968

SEPTEMBER, 1966

BATTELLE-NORTHWEST

BATTELLE MEMORIAL INSTITUTE / PACIFIC NORTHWEST LABORATORY

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

PACIFIC NORTHWEST LABORATORY

RICHLAND, WASHINGTON

operated by

BATTELLE MEMORIAL INSTITUTE

for the

UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

PRINTED BY/ FOR THE U. S. ATOMIC ENERGY COMMISSION

FAST FLUX TEST FACILITY

A D O P T

PROGRAM FOR STEADY-STATE PROCESS DESIGN AND
COST OPTIMIZATION OF FFTF HEAT REMOVAL
SYSTEMS USING HEAT DUMPS TO AIR

C. L. Goss

And

H. G. Johnson

September 1966

FIRST INTERIM REPORT
PRESENTED TO THE
1966

PACIFIC NORTHWEST LABORATORY

Richland, Washington

Operated By

Battelle Memorial Institute

For The

U.S. Atomic Energy Commission Under Contract No. AT(45-1)-1830

Printed in USA. Price \$6.00. Available from the
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards
U.S. Department of Commerce
Springfield, Virginia

ABSTRACT

ADOPT, a computer program, has been developed to provide process design and cost optimization data for the Fast Flux Test Facility's heat removal systems using an air heat dump. Complete sizing and cost data are calculated for the intermediate heat exchanger, dump heat exchanger complex, primary loops and secondary loops for a given set of input process and basic equipment design data.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. PURPOSE.	1
III. SUMMARY.	2
IV. DISCUSSION	4
A. Process Concept	4
1. Primary Loops	4
2. Intermediate Heat Exchangers (IHX)	6
3. Secondary Loops	6
4. Dump Heat Exchanger (DHX)	7
B. Process Design	7
1. IHX Design	8
a. Heat Transfer	8
b. Pressure Loss	12
c. Space Requirements	13
2. DHX Design	15
a. Heat Transfer	15
b. Pressure Loss for Heat Exchanger Section	18
c. Miscellaneous DHX Pressure Losses	19
d. Exhaust Stack Sizing	19
e. Fan Selection	20
f. DHX Shell Size	24
g. Sodium Manifold Sizing	26
h. Sizing of Miscellaneous DHX Auxiliaries	26
3. Piping Design	27
a. Primary and Secondary Loops	28
b. Containment Pipe for Primary Loops	29
4. Pump Design	30
5. Primary Loop And Reactor Tank Operating Pressures	31
6. Secondary Loop Operating Pressures	31

	<u>Page</u>
7. Secondary Loop Surge Tank	33
8. High Design Pressure Penalty	33
9. Instrumentation	34
10. Initial And Ultimate Design Conditions	34
11. Program Limits	34
C. Cost Information	35
1. Basic Equipment Cost Data	35
a. IHX	35
b. DHX	36
c. Primary And Secondary Pumps	39
d. Loop Piping	39
e. Sodium To Fill	40
f. Secondary System Surge Tank	41
g. Incremental IHX Building Cost	41
h. Incremental Instrumentation Cost	41
i. Spare Equipment	41
2. Optimization Criteria	42
D. Program.	43
1. Program Code And Machine Application	43
2. Program Techniques	43
a. Interpolation Routines	43
b. Selection Routines	44
c. Engineering Data Routines.	44
d. Cost Data Routines	45
3. Program Organization	45
a. Input And Derived Data	47
b. Heat Exchanger Selection	47
c. Primary Loop Section	49
d. Secondary Loop Section	50
e. Dump Heat Exchanger	52
f. Fan Selection.	54

	<u>Page</u>
4. Program Timing	56
E. Input Organization	56
F. Program Applications	60
1. General Applications	61
2. Optimum DHX Exhaust Air Temperature--An Illustrative Example	63
G. Program Status.	64
H. Nomenclature	104
APPENDIX A - PROGRAMMED ENGINEERING DATA	107
1. Thermal Properties	107
2. Heat Exchanger Data	107
3. Pipe And Fitting Data	108
4. Pump Data	108
5. Fan Data	108
6. Motor Data	109
7. Miscellaneous Data	109
8. Cost Data	109
APPENDIX B - PROGRAM EXAMPLE	151

LIST OF FIGURES

<u>Figure Nos.</u>		<u>Page</u>
Figure 1.	Arrangement Of A Heat Removal System	5
Figure 2.	Value Of $[\epsilon_M/\nu]_{\max}$ For Fully Established Turbulent Flow Of Liquid Metals Through Circular Tubes, And Rod Bundles With Equilateral Spacing	10
Figure 3.	Cross Section Of Vertical IHX Arranged With Remotely Removable Tube Bundle	14
Figure 4.	Fan Performance Of A Typical 84-Inch Axial Flow Fan At 1170 RPM	23
Figure 5.	DHX Arrangement	25
Figure 6.	Friction Factor As A Function Of Reynolds Number With Relative Roughness As A Parameter	28
Figure 7.	Main Program Logic	46
Figure 8.	Heat Exchanger Logic	48
Figure 9.	Primary Loop Logic	51
Figure 10.	Secondary Loop Logic	53
Figure 11.	Dump Heat Exchanger Logic	55
Figure 12.	Fan Selection Logic	57
Figure 13.	Typical Selection Of Optimum Number Of DHX Tube Passes For Each Given Exhaust Air Temperature	65
Figure 14.	Typical Selection Of The Optimum DHX Exhaust Air Temperature And Best Even Number Of Tube Passes	66
Figure 15.	Typical Optimization Of Primary Loop Pipe Diameters	67
Figure 16.	Typical Optimization Of Secondary Loop	68
Figure 17.	Reactor Tank Pressure As A Function Of Primary Loop Pipe Diameter.	69
Figure A-1	Thermal Properties Of Liquid Sodium	116
Figure A-2	Vapor Pressure Of Liquid Sodium	117
Figure A-3	Thermal Properties Of Air.	118
Figure A-4	Thermal Conductivity Of Aluminum And Steel	119
Figure A-5	Log-Mean-Temperature Difference Corrector For A One- Shell Pass, Two Or More Tube Passes Heat Exchanger	120

<u>Figure Nos.</u>		<u>Page</u>
Figure A-6.	Log-Mean-Temperature Difference Corrector For A Two-Shell Passes, Four Or More Tube Passes Heat Exchanger	121
Figure A-7.	Log-Mean-Temperature Difference Corrector For A One-Shell Pass (Cross Flow), Two-Tube Passes Heat Exchanger	122
Figure A-8.	Efficiency Of Annular Fins Of Constant Thickness	123
Figure A-9.	Transverse-Fin Heat Transfer And Pressure Drop	124
Figure A-10.	Nusselt Number For Laminar Flow Through Rod Bundles	125
Figure A-11.	Maximum Eddy Reynolds Number Corrector Function	126
Figure A-12.	Shell Side Friction Factors For Bundles With 25 Percent Cut Segmented Baffles.	127
Figure A-13.	Cavitation Parameter For 80 Percent Pump Efficiency	128
Figure A-14.	Fan Selection Diagram	129
Figure A-15.	Efficiency Of 84-E Fan At 870 RPM	130
Figure A-16.	Efficiency Of 84-E Fan At 1170 RPM	131
Figure A-17.	Efficiency Of 72-E Fan At 870 RPM	132
Figure A-18.	Efficiency Of 72-E Fan At 1170 RPM	133
Figure A-19.	Efficiency Of 48-B Fan At 1750 RPM	134
Figure A-20.	Efficiency Of 48-D Fan At 1750 RPM	135
Figure A-21.	Efficiency Of 38-A Fan At 1750 RPM	136
Figure A-22.	Efficiency Of 38-C Fan At 1750 RPM	137
Figure A-23.	Efficiency Of 33-A Fan At 1750 RPM	138
Figure A-24.	Efficiency Of 33-C Fan At 1750 RPM	139
Figure A-25.	Cost Of Horizontal Squirrel Cage Induction Motor	140
Figure A-26.	Cost Of Horizontal Wound-Rotor Induction Motor	141
Figure A-27.	Cost Of Vertical Squirrel-Cage Induction Motor	142
Figure A-28.	Cost Of Vertical Wound-Rotor Induction Motor	143
Figure A-29.	Cost Of Equipment Which Is Dependent Upon Fan Size	144
Figure A-30.	Cost Of Auxiliary Furnace	145
Figure A-31.	Cost Of Off Gas Stack	146
Figure A-32.	Cost Of Butterfly Valve-In Sodium Application. . .	147
Figure A-33.	Cost Of Check Valve In Sodium Application	148
Figure A-34.	Cost Of Gate Valve In Sodium Application	149
Figure A-35.	Cost Of Globe Valve In Sodium Application	150

LIST OF TABLES

<u>Table Nos.</u>		<u>Page</u>
Table I.	Partial Listing Of Subroutine Input	70-97
Table II.	Input Data For Illustrative Example On The Optimi- zation Of DHX Exhaust Air Temperature	98
Table A-1.	Plenum Heights Associated With Dump Exchanger Fan size	111
Table A-2.	Straight-Pipe Data	111
Table A-3.	Velocity Head Factors Of Pipe Fittings	112
Table A-4.	Weight Of Standard Weight Pipe Fittings	112
Table A-5.	Axial Flow Fan Selection	113
Table A-6.	Standard Motor Horsepower Ratings	114
Table A-7.	Miscellaneous Programmed Engineering Data	114
Table A-8.	Axial Flow Fan Costs	115
Table B-1.	Basic Process And IHX Input Data	152
Table B-2.	Dump Heat Exchanger Input Data	153
Table B-3.	Primary Loop Input Parameters.	154
Table B-4.	Secondary Loop Input Parameters	155
Table B-5.	IHX Data At Initial Conditions	156
Table B-6.	IHX Data At Ultimate Conditions	157
Table B-7.	DHX Data At 300F Exhaust Air Temperature	158
Table B-8.	DHX Data At 350F Exhaust Air Temperature	160
Table B-9.	DHX Data At 400F Exhaust Air Temperature	162
Table B-10.	DHX Data At 450F Exhaust Air Temperature	164
Table B-11.	DHX Data At 500F Exhaust Air Temperature	166
Table B-12.	DHX Data At 559F Exhaust Air Temperature	168
Table B-13.	DHX Data At 600F Exhaust Air Temperature	170
Table B-14.	Selection Of The Optimum DHX Exhaust Air Temperature And Reference Data For The Primary And Secondary Loops Designs, Which Follow	174
Table B-15.	Primary Loop Design And Cost With 14 And 16-Inch Pipe	175
Table B-16.	Primary Loop Design And Cost With 14 And 18-Inch Pipe	176
Table B-17.	Primary Loop Design And Cost With 14 And 20-Inch Pipe	177

<u>Table Nos.</u>	<u>Page</u>
Table B-18. Primary Loop Design And Cost With 14 And 24-Inch Pipe	178
Table B-19. Primary Loop Design And Cost With 14 And 30-Inch Pipe	179
Table B-20. Primary Loop Design And Cost With 14 And 36-Inch Pipe	180
Table B-21. Primary Loop Design And Cost With 16-Inch Pipe . .	181
Table B-22. Primary Loop Design And Cost With 16 And 18-Inch Pipe	182
Table B-23. Primary Loop Design And Cost With 16 And 20-Inch Pipe	183
Table B-24. Primary Loop Design And Cost With 16 And 24-Inch Pipe	184
Table B-25. Primary Loop Design And Cost With 16 And 30-Inch Pipe	185
Table B-26. Primary Loop Design And Cost With 16 And 36-Inch Pipe	186
Table B-27. Primary Loop Design And Cost With 18-Inch Pipe . .	187
Table B-28. Primary Loop Design And Cost With 18 And 20-Inch Pipe	188
Table B-29. Primary Loop Design And Cost With 18 And 24-Inch Pipe	189
Table B-30. Primary Loop Design And Cost With 18 And 30-Inch Pipe	190
Table B-31. Primary Loop Design And Cost With 18 And 36-Inch Pipe	191
Table B-32. Primary Loop Design And Cost With 20-Inch Pipe . .	192
Table B-33. Primary Loop Design And Cost With 20 And 24-Inch Pipe	193
Table B-34. Primary Loop Design And Cost With 20 And 30-Inch Pipe	194
Table B-35. Primary Loop Design And Cost With 20 And 36-Inch Pipe	195
Table B-36. Primary Loop Design And Cost With 24-Inch Pipe . .	196
Table B-37. Primary Loop Design And Cost With 24 And 30-Inch Pipe	197
Table B-38. Primary Loop Design And Cost With 24 And 36-Inch Pipe	198
Table B-39. Primary Loop Design And Cost With 30-Inch Pipe . .	199
Table B-40. Primary Loop Design And Cost With 30 And 36-Inch Pipe	200
Table B-41. Primary Loop Design And Cost With 36-Inch Pipe . .	201
Table B-42. Secondary Loop Design And Cost With 14-Inch Pipe. .	202
Table B-43. Secondary Loop Design And Cost With 16-Inch Pipe. .	203
Table B-44. Secondary Loop Design And Cost With 18-Inch Pipe. .	204
Table B-45. Secondary Loop Design And Cost With 20-Inch Pipe. .	205
Table B-46. Secondary Loop Design And Cost With 24-Inch Pipe. .	206
Table B-47. Secondary Loop Design And Cost With 30-Inch Pipe. .	207
Table B-48. Selection Of Optimum Primary And Secondary Loop . . Designs	208

ADOPT

PROGRAM FOR STEADY STATE PROCESS DESIGN AND COST OPTIMIZATION OF
FFTF HEAT REMOVAL SYSTEMS USING HEAT DUMPS TO AIR

I. INTRODUCTION

Heat generated in the fast flux test reactor is to be dissipated by dumping the heat to air or water with an intermediate secondary sodium system between the primary loop and heat dump system⁽¹⁾. With the air heat dump concept, heat is transferred from the primary coolant to the secondary coolant in an intermediate heat exchanger and the secondary coolant in turn loses its heat to ambient air in a dump heat exchanger. Two concepts of heat dumps to water are possible. One is to dump the heat from the secondary coolant directly to river water in a liquid/liquid heat exchanger; whereas, in the other concept, the secondary heat is transferred to a tertiary steam loop which in turn loses its heat to river water in a condenser. The concept of dumping heat directly to river water has been rejected⁽²⁾, but detailed studies are being made for the air and steam/water concepts, both of which appear to be feasible. Both of these concepts permit the use of multiple, parallel cooling circuits. The selection of the best heat dump method and the selection of the number of parallel cooling circuits depends on cost, safety, and reliability. This work is concerned with the process design and project costs associated with the air heat dump concept. The safety and reliability aspects of the heat removal system designs are undergoing detailed analysis in related studies for which this work provides a basis.

II. PURPOSE

The work, which is reported here, provides a computer program for steady-state process design and cost optimization of heat removal systems using an air heat dump. The computer program is required to provide acceptable in-depth analysis of the large number of variables associated with these systems, which are complex and costly. The program is arranged such that comparisons may be made between various numbers of parallel cooling circuits, and the program is general enough so that it can be used for design and optimization of the large main heat removal system as well as the small test loop systems. Such optimizations are planned and will be reported subsequently.

- (1) Memorandum, Milton Shaw to D. G. Williams, "Fast Flux Test Facility--Program Direction," Attachment B, p. 3, January 23, 1966.
- (2) BNWL-CC-691, "Water Heat Sink For FFTF's Main Heat Removal System," H. G. Johnson, June 10, 1966.

The program is a useful tool to be utilized for conceptual, preliminary and final phases of design. The work was done under Work Plan 129⁽³⁾. Work started February 1966 and was completed in August 1966.

III. SUMMARY

A machine program has been developed for providing steady-state process design data and cost optimizations for a reactor heat removal system concept which includes an intermediate secondary loop between a primary loop and air heat dump equipment. Each primary loop has its own intermediate heat exchanger for transfer of heat to a secondary loop, primary coolant recirculation pump, secondary loop, and air heat dump equipment. In those cases where there are parallel cooling circuits, the cooling circuits are independent of each other, except for common connections at the reactor tank. The program is general enough so that it can be applied to the rather large main heat removal systems as well as the relatively small test loop systems. The program is named ADOPT*.

The program is arranged to provide comprehensive steady-state process design data and cost optimization for key variables for the entire heat removal system and its major components. Main iterations are performed on the log-mean-temperature difference of the intermediate heat exchanger and the exhaust air temperature of the dump heat exchanger to establish the optimum system conditions for fixed process requirements and a given set of basic equipment design data. Basic equipment design data may be varied in successive program runs to establish optimum equipment data. The basic FFTF process data, including reactor power, primary coolant temperatures, and reactor tank pressure loss, may be varied to establish their impact on heat removal system design and cost. Optimum alternates and cases are selected based on minimum direct construction cost except in studies involving pumps and fans, wherein an alternate selection method is available. In the latter cases, the worth of an incremental added investment is balanced against the operational power cost saving due to lower equipment power requirements. The alternate with the best payout period, less than an input specified maximum value, is selected.

* Air Dump Optimization And Process Data

(3) FastFlux Test Facility Work Plan No. 129, Main And Closed Loop Coolant Systems Analysis April 20 1966

Input data for each case to be studied consists of basic process conditions, basic equipment design data, and program logic information. Process conditions required are reactor power input to the heat removal system, primary coolant hot and cold leg temperatures, ratio of temperature rise of secondary coolant to primary coolant temperature rise, reactor tank pressure loss, ambient air temperature, and atmospheric pressure. If there is an ultimate design phase with conditions different than the initial phase, process data are specified for both phases (except for the atmospheric conditions). It is assumed that initial phase conditions dictate heat exchanger sizes and costs while ultimate phase conditions dictate pipe and pump sizes and costs. Equipment input design data include such things as tube diameters, pitch, and length, type of heat exchanger, number of passes, and so forth. All told, there are up to 221 possible input variables to be specified. One-hundred-four of these inputs are set aside to specify the piping layouts for the primary and secondary loops, 26 are unit cost data, and 10 fall in the category of program logic data.

Program output includes sizing and cost data for all major system components, including the intermediate heat exchanger, primary and secondary loops' pipes and pumps, secondary loop surge tank, dump heat exchanger (including all auxiliary components such as fans and stacks, etc.) and sodium to fill systems. The more important calculated process data, such as heat transfer coefficients and surfaces, pumps' specific speeds and cavitation parameters, friction factors, pressure losses, fan size, system pressures, and brake horsepower, are included in output listings. Component costs are listed as direct construction, which includes material and installation costs.

The program is quite general and can be used in a variety of ways. It is basically a tool for determining steady-state process data and to optimize on these computed process data. One of the more important applications here will be concerned with the number of parallel cooling circuits for the main FFTF heat removal system. In addition, the program can be used to determine how the so-called proven components can

be incorporated in a design, and the program has virtually unlimited application for parametric studies by varying process or equipment design values one (or more) at a time. Another worthwhile use is for determining operational flexibility for a given system design.

The program is written for the UNIVAC 1107 computer using the FORTRAN IV programming code. The program can be readily adapted to any computer with a FORTRAN IV compiler provided the computer systems have the option of subscripted variables of four dimensions.

The program has many options. The main combinations of input parameters have been checked out by the authors, and are (to the best of their knowledge) free of defects; however, all possible combinations of input parameters have not been through the debug process. It may happen that some combinations of input parameters will cause ADOPT to experience difficulties; such difficulties will be corrected as they are discovered and/or reported.

IV. DISCUSSION

A. Process Concept

The program is written for process design and cost optimization of a heat removal system made up of one or more primary loops, each with its own independent secondary loop and air heat dump equipment. The arrangement is as shown in Figure 1. The primary coolant is heated by the reactor. This heat is then transferred to the intermediate secondary loops via the intermediate heat exchangers, and in turn, the heat is dissipated to the atmosphere in air cooled heat exchangers.

1. Primary Loops

Each primary loop contains a recirculation pump, the shell or tube side of an intermediate heat exchanger (IHX), and connecting piping. The reactor tank is common to all primary loops. All of the primary loops, in the case of the main heat removal system, enter the reactor tank's inlet plenum for a combined flow of coolant through the tank. The reactor tank serves as the surge and pressurizer vessel for all primary loops.

NOTES:

1. Pumps may be in the Hot or Cold Leg
2. Primary Coolant may be on the Shell or Tube Side of the Intermediate Heat Exchanger

FIGURE 1

Arrangement of a Heat Removal System

Alternate primary loop concepts are available. The primary coolant may be on the shell or tube side of the intermediate heat exchanger (IHX); the recirculation pump may be in the cold or hot leg; the loop may or may not be placed within a containment pipe; and the primary coolant pressure in the IHX may be greater than or less than the secondary coolant pressure. In addition, check, gate, control and butterfly valves may be specified at any loop position.

All primary loop components are assumed to be made of types 304 or 316 stainless steel. The primary coolant is sodium.

2. Intermediate Heat Exchangers (IHX)

The IHX is a vertical, shell and tube-type heat exchanger fabricated of types 304 or 316 stainless steel. The shell side is assumed to be unbaffled.

Alternate arrangements are available. Primary coolant may be on either the shell or tube side. Also, the exchanger may be a counter-flow type with one shell and one tube pass; the exchanger may have one shell and two or more tube passes, or it may have two shell and four or more tube passes.

3. Secondary Loops

Each secondary loop contains a recirculation pump, the shell or tube side of an IHX, a surge tank, the tube side of an air dump heat exchanger, and connecting piping. The secondary loops are independent of each other, and each has its own surge tank and heat dump exchanger. The pump is assumed to be placed in the surge tank.

Alternate secondary loop arrangements are available. The recirculation pumps may be in the cold or hot legs; the materials of construction may be stainless steel or carbon steel; check, gate, control and butterfly valves may be specified for any loop location; and the volume of the surge tank may be any fraction of the volume of secondary coolant contained in the loop.

The secondary coolant is sodium.

4. Dump Heat Exchanger (DHX)

The DHX is a forced circulation, extended surface, cross flow, tubular-type, air-cooled heat exchanger. A modular type of construction is assumed with two or more modules per DHX. The extended surface fins are transverse type of uniform thickness.

Ambient air enters inlet plenums below the heat exchange section, flows upward across the tubes, collects in a plenum above the tubes, and is exhausted to atmosphere via an input-specified-number of steel stacks. Axial flow-type air fans are assumed, with one fan per module.

Auxiliaries which may be specified for each module include inlet air filters, air butterfly valves, sound attenuators, variable inlet vanes, and sodium side isolation valves.

Alternate arrangements are available. The base heat exchanger tube may be carbon steel or stainless steel and the fins may be carbon steel, stainless steel, or aluminum.

B. Process Design*

Process designs are required to provide equipment sizing data in order to establish the following items of cost which are included in the cost optimizations:

1. IHX
2. Sodium to fill the IHX.
3. Incremental building cost for housing the IHX.
4. DHX.
 - a. Heat exchanger section
 - b. Supply fans with drive motors
 - c. Variable inlet vanes
 - d. Air filters
 - e. Sound attenuators
 - f. Air valves
 - g. DHX shell and foundation
 - h. Exhaust stacks
 - i. Air duct work
 - j. Auxiliary furnace

*Symbols used in this and subsequent sections are defined in paragraph H, pages 104-106.

- k. Sodium to fill tubes and pipes
- l. Manifolds and associated secondary loop piping
- m. Sodium valves at manifolds
- 5. Primary loop piping and valves.
- 6. Primary loop containment.
- 7. Primary pumps with drives.
- 8. Sodium to fill primary loops.
- 9. Secondary loop piping and valves.
- 10. Secondary pumps with drive.
- 11. Secondary loop surge tank.
- 12. Sodium to fill secondary loops and surge tanks.
- 13. Incremental instrumentation cost.
- 14. Extra costs due to high secondary system design pressure.

Conventional design procedures are generally used in the program. The more significant process design methods are highlighted below.

1. IHX Design

a. Heat Transfer

The exchanger is sized from the equation,

$$q = U_o A_o \Delta T_M F$$

The duty, q , is determined from the specified total amount of reactor heat to be dissipated and the specified number of parallel cooling circuits. The log-mean-temperature difference is determined by the primary and secondary coolant temperatures entering and leaving the tube bundle, and the log mean temperature correction, F , is obtained from tabulated data based on the standard curves shown in Figures A-5 and A-6; F is equal to one for the true counterflow exchangers. The overall heat transfer coefficient, U_o , is calculated from,

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{D_o}{h_i D_i} + R_w + R_{fouling}$$

The outside film coefficient is calculated using Maresca and Dwyer's correlation⁽⁴⁾,

$$\text{Nu}_o = 6.66 + 3.126 (p/D_o) + 1.184 (p/D_o)^2 + .0155 (\bar{\psi}_o \text{Pe}_o)^{.86}$$

while the inside film coefficient is calculated from,

$$\text{Nu}_i = \alpha + .025 (\bar{\psi}_i \text{Pe}_i)^{.8}$$

The Nusselt numbers are defined as follows:

$$\text{Nu}_o = \frac{h_o D_e}{k_o}$$

$$\text{Nu}_i = \frac{h_i D_i}{k_i}$$

The $\bar{\psi}$ terms are evaluated as functions of the Reynolds numbers by the method of Dwyer⁽⁵⁾. The $\bar{\psi}_o$ term is also a function of tube pitch. By Dwyer's definition,

$$\bar{\psi} = 1 - \frac{1.82}{\text{Pr}(\epsilon_M/\nu)_{\max}^{1.4}}$$

where $(\epsilon_M/\nu)_{\max}$ is a function of Reynolds number as shown in Figure 2 for fully established flow inside and outside of circular tubes with equilateral triangular pitch.

The α term in the inside film Nusselt equation is a constant and is specified as an input quantity. Some references show that data correlate well if α is seven while other experimental data are correlated better by setting α equal to five. Because of this uncertainty, the equation is used in the general form. A value of five should be used for conservative sizing of the exchanger.

The equivalent diameter for use in the outside film Nusselt, Peclet, and Reynolds numbers is determined from the usual definition of four times the flow area divided by the wetted perimeter. D_e is then a function of tube pitch and tube outside diameter for the assumed triangular pitch.

(4) M. W. Maresca and O. E. Dwyer, "Heat Transfer to Mercury Flowing In-Line Through a Bundle of Circular Rods," J. Heat Transfer, 86, 180, 1964.

(5) O. E. Dwyer, "Eddy Transport in Liquid Metal Heat Transfer," J. A.ICh.E.,

FIGURE 2

Value of $(\frac{\epsilon_M}{\nu})_{\max}$ for Fully Established Turbulent Flow of Liquid Metals Through Circular Tubes, and Rod Bundles with Equilateral Spacing

$$D_e = \frac{4\pi[r_m^2 - (D_o/2)^2]}{\pi D_o}$$

r_m is related to tube pitch by,

$$r_m = .526 p$$

The coolant physical properties for use in the Nusselt, Prandtl, Peclet, and Reynolds numbers are evaluated at the average of the inlet and outlet temperatures.

Coolant velocities correspond to the average temperatures. Flow area for the shell side coolant is obtained from,

$$A_{f,o} = \pi [r_m^2 - (D_o/2)^2] N_t/N_{p,o},$$

and the flow area for the tube side coolant is defined by,

$$A_{f,i} = \pi (D_i/2)^2 N_t/N_{p,i}$$

The tube wall resistance to heat transfer, R_w , is approximated as follows for thin-walled tubes:

$$R_w = \frac{D_o (D_o - D_i)}{k_w (D_o + D_i)}$$

The wall thermal conductivity is evaluated at the average metal temperature which is approximated by the average of the coolants' inlet and outlet temperatures,

$$\bar{T} = \frac{T_{p,h} + T_{p,c} + T_{s,h} + T_{s,c}}{4}$$

The fouling resistance, $R_{fouling}$, is an input value and most likely will be set equal to zero. Liquid metal systems, which are continuously purified, do not tend to foul.

The heat transfer equations selected appear to correlate recent experimental data to within a deviation of less than 10 percent over the range of interest. For conservative work, one might want to reduce the calculated Nusselt values to correspond to the scatter of points which fall below the correlation curves. Hence, arbitrary correlation factors can be specified as inputs to alter the values determined by the Nu_o and Nu_i equations above. These correlation factors are linear multipliers and should not exceed a value of one.

Shell and tube side bypassing will tend to reduce the overall heat transfer coefficient because the film heat transfer correlations are written for an average tube receiving an average flow. If flow distribution is such that some of the coolant bypasses the tube bundle, the film coefficients will be changed due to lower coolant velocities and different coolant temperatures. In addition, the log-mean-temperature difference for the coolants actually flowing through the tube bundle will be less than that computed for the heat exchanger inlet and outlet conditions at the nozzles. The net effect is that bypassing results in greater required heat transfer surface. Shell side bypassing occurs in any tube bundle, but it is a serious problem in a heat exchanger with a remotely removable tube bundle, which can result in both tube and shell side bypassing.

The program is arranged to account for tube and shell side bypassing because heat exchangers with remotely removable tube bundles are a definite possibility for the FFTF. The maximum allowable bypassing is specified as program inputs for the primary and secondary coolants in which bypassing is expressed as a fraction of total coolant flow. It is assumed that the bypassing coolants flow isothermally around the tube bundle; therefore, mass and heat balances yield actual bundle exit coolant temperatures which are used to compute the actual bundle log-mean-temperature difference, log-mean-temperature correction (if any), and film coefficients. Film coefficients are also based on the flow exclusive of the bypassing coolant.

b. Pressure Loss

Tube side pressure loss is calculated as the loss due to skin friction in the straight tube, plus return losses:

$$\Delta P_i = \left[\frac{fL V_i^2}{2g_c D_i} + 4 \frac{V_i^2}{2g_c} \right] N_{p,i} \frac{\bar{\rho}}{144}, \text{ psi.}$$

The actual tube length and the coolant density based on the average temperature are used. The Moody friction factor, f , is assumed constant and programmed as 0.015.

The shell side tube bundle is assumed to be unbaffled. Shell side pressure loss in the tube bundle is calculated as the sum of two resistances in series:

- . Flow across tubes at inlet and outlet.
- . Parallel flow along the tubes.

The first loss is calculated by:

$$\Delta P_1 = \frac{2f G^2 D_s}{2g_c \rho D_e}, \text{ psi}$$

in which the shell side friction factor, f , follows the relationship described by Figure A-12 for combined cross and parallel flow in a bundle of tubes. The mass velocity, G , is assumed to be the same as the velocity of coolant flowing in line with the tubes, and the shell diameter, D_s , is approximated as follows:

$$D_s = \sqrt{4 r_m^2 N_t + D_{cd}^2} + D_o,$$

where D_{cd} is the central downcomer OD, and D_o is the clearance allowance between the outer tube row and shell.

The equivalent diameter is the same as the one used for heat transfer calculations.

The second loss is calculated by,

$$\Delta P_2 = \frac{.015 L V_o^2 \rho}{288 g_c D_e}, \text{ psi}$$

where the velocity, V_o , is the same as the velocity used in heat transfer calculations. The total shell side pressure drop is then,

$$\Delta P_o = \Delta P_1 + \Delta P_2.$$

c. Space Requirements

The physical size of the IHX influences to some extent the building size. Therefore, it is important that an incremental building cost be estimated for each IHX alternate.

FIGURE 3

Cross Section of Vertical IHX Arranged with Remotely Removable Tube Bundle

The cross-sectional area of the vertical heat exchanger is determined by assuming a central downcomer for the tube side fluid, a shroud around the tube bundle, an allowance of nine inches for wall thicknesses and clearance between the shroud (which is a permanent part of the primary loop), and a six-inch allowance for wall thicknesses, insulation and a gap between the main shell and a containment shell. The cross-sectional arrangement is shown in Figure 3.

The downcomer diameter is based on an inside coolant velocity of 15 ft/sec, but the pipe size is rounded upward to the nearest standard size. The shroud diameter includes a clearance allowance of one tube diameter between the tube bundle and shroud. Thus, the shroud diameter is,

$$D = \sqrt{\frac{N_t \pi r_m^2 + A_{cd}}{\pi/4}} + D_o$$

where A_{cd} denotes the area occupied by the central downcomer and D_o denotes the tube OD.

The overall IHX diameter, with the assumed clearances, walls, and insulation is then $(D + 2.5)$ feet, but the required building floor space area is assumed to be two times the IHX total cross-sectional area. The incremental building volume to house the IHX is then given by the product of the total cross-sectional area times the building height at the IHX location. Thus, IHX incremental building volume is,

$$\text{Volume} = 2 \left[\frac{\pi}{4} (D + 2.5)^2 \right] \times (\text{building height}), \text{ cu ft,}$$

where building height is an input value.

2. DHX Design

a. Heat Transfer

The heat exchange surface is determined by the rate equation,

$$q = U_o A_o \Delta T_m F.$$

The duty, q , is determined from the specified total amount of reactor heat to be dissipated and the specified number of parallel cooling circuits. The log-mean-temperature is calculated in the usual way using the inlet and outlet secondary coolant and air temperatures. The log-mean-temperature correction, F , is necessary for configurations in which flows are not truly countercurrent. The DHX most likely will be arranged for cross-flow of air with two or more tube passes, shell fluid (air), mixed, and tube fluid (sodium), unmixed. The "F" correction for such a two-pass unit is shown in Figure A-7. This correction is used regardless of the number of passes. Use of these data with three or more tube passes leads to conservative exchanger sizing because a true counter-current exchanger is approached as the number of passes is increased. The program actually uses tabulated data based on the curves in Figure A-7.

The overall coefficient is based on an inside film coefficient for secondary coolant calculated by

$$Nu_i = \alpha + .025 (\bar{\psi}_i Pe_i)^{.8},$$

and an outside air film coefficient calculated using the data of Jameson⁽⁶⁾. Refer to the IHX process design for a discussion of the inside film coefficient.

Kern has arranged Jameson's data in the form of a Sieder-Tate heat transfer factor as shown in Figure A-9. The so-called "j" factor is a function of Reynolds number and is defined by:

$$j = \frac{h_{o,c} D_e}{k_o Pr^{1/3}}$$

where $h_{o,c}$ represents the clean-air film coefficient.

The equivalent diameter defined in Jameson's correlation is calculated as follows:

(6) S. L. Jameson, "Tube Spacing In Finned-Tube Banks," Tr. ASME, 67, 633 (1945) and D. Kern, Process Heat Transfer, McGraw-Hill, First Ed., 1950, p. 555.

$$A_1 = \text{Fin surface/unit length} = \frac{2\pi}{4} (D_{\text{fin}}^2 - D_o^2) N_{\text{fins}}$$

$$A_2 = \text{Bare tube surface/unit length} \\ = \pi D_o - \pi D_o N_{\text{fins}} X_{\text{fins}}$$

where N_{fins} is number fins/unit length, and X_{fins} is fin thickness. Transverse fins of uniform thickness are assumed.

$$A_o' = \text{Outside surface/unit length} = A_1 + A_2, \text{ sq ft/ft}$$

$$X_1 = \text{Projected perimeter} = \frac{2(D_{\text{fin}} - D_o)}{2} \times 2N_{\text{fins}} \\ + 2(1 - N_{\text{fins}} X_{\text{fins}}), \text{ ft/ft}$$

$$D_e = \frac{2(A_1 + A_2)}{\pi X_1}$$

The mass velocity, G_o , is determined from the free-flow area for a single bank of tubes at right angles to the air flow in the case of the cross-flow exchanger.

The Reynolds number is defined as

$$\text{Re} = \frac{D_e G_o}{\mu}$$

The clean-air film coefficient is calculated from the "j" factor obtained from Figure A-9 as a function of the Reynolds number, and is then degraded by whatever fouling is specified by input data:

$$h_{o,d} = \frac{h_o/R_{\text{foul}}}{h_o + 1/R_{\text{foul}}}$$

The actual outside film coefficient, h_o , based on the inside surface is then determined using fin efficiency data shown in Figure A-8 for annular fins of constant thickness; the program uses tabulated data based on these curves.

$$h_o = (\Omega A_1 + A_2) \frac{h_{o,d}}{A_{s,i}}$$

The overall heat transfer coefficient based on the inside surface is then,

$$U_i = \frac{h_o h_i}{h_o + h_i}.$$

The inside coefficient may be fouled if a fouling factor is specified by input. Contact and bond resistance can be accounted for by including it in the fouling resistance in the case of bimetallic tubes.

The overall coefficient based on the outside surface is then,

$$U_o = \frac{U_i \pi D_i}{A_1 + A_2}$$

Fluid properties are determined at the average fluid temperatures for use in the Prandtl and Reynolds numbers.

b. Pressure Loss for Heat Exchanger Section

Tube side pressure drop consists of three separate losses:

- Frictional losses along straight tube.
- Tube inlet, outlet and return losses.
- Inlet and exit manifold losses.

The first loss is calculated using a Moody friction factor of .015:

$$\Delta P_1 = \frac{.015 L V_i^2 \bar{\rho}}{288 g_c D_i} \times (\text{no. tube passes})$$

The second loss is taken as four velocity heads for each tube pass.

$$\Delta P_2 = 4 \frac{V_i^2 \bar{\rho}}{288 g_c} \times (\text{no. tube passes})$$

The third loss is taken as three velocity heads based on the velocity of coolant in the manifolds at a point where there is full flow.

$$\Delta P_3 = 3 \frac{V^2 \bar{\rho}}{288 g_c}$$

Total tube side pressure drop is then,

$$\Delta P_i = \Delta P_1 + \Delta P_2 + \Delta P_3.$$

The shell side pressure loss is calculated using the Gunter and Shaw correlation for pressure drop in cross-flow⁽⁷⁾,

$$\Delta P = \frac{f G^2 L (D'_e/p)^4}{2g_c \bar{\rho} D'_e \phi}, \text{ psi},$$

where L is the length of the flow path through the tube array and p is the tube pitch. The friction factor is obtained from the curve shown in Figure A-9. The Reynolds number used in this case is based on an equivalent diameter defined as,

$$D'_e = \frac{4 \times \text{net free volume}}{\text{frictional surface}}$$

$$= \frac{4[.867 p^2 - \pi D_o^2/4 - \pi(D_{fin}^2 - D_o^2) X_{fin} N_{fin}/4]}{A_1 + A_2}$$

Physical properties are determined at the average air temperature, except for the viscosity of air at the fin surface (for ϕ) which is approximated by using the air viscosity corresponding to the average secondary coolant temperature.

c. Miscellaneous DHX Pressure Losses

System pressure losses in addition to the heat exchanger section loss are inlet filter, air duct, butterfly valve, and exhaust stack losses. Filter and duct losses are specified as input values, along with an allowable net exhaust stack pressure loss. The butterfly valve loss is calculated by,

$$\Delta P = \frac{W^2(460 + T)}{124^2 C_v^2 D^4 P_{atm}}, \text{ psi}$$

where the valve coefficient, C_v , is specified by input.

d. Exhaust Stack Sizing

A steel stack is assumed. The frictional loss for the stack is given by

$$\Delta P = f W^2 \times \frac{\pi D H}{(\pi D^2/4)^3}, \text{ in. water},$$

(7) A. Y. Gunter and W. A. Shaw, "A General Correlation of Friction Factors for Various Types of Surfaces In Crossflow," Tr. ASME, 67, 643, (1945), and D. Q. Kern, op. cit.

where steel stack friction factors are used (.0011 at 350 F to .0015 at 600 F); W is the weight flow rate of exhaust air per second⁽⁸⁾. Height, H, is an input value.

The natural draft of the stack is given by⁽⁸⁾,

$$Dr = .52 P_{atm} H \left[\frac{1}{460 + T_{atm}} - \frac{1}{460 + T_h} \right], \text{ in. water.}$$

These two equations are equated by the input net allowable stack pressure loss:

$$\text{Net allowable loss} = \Delta P - Dr.$$

Thus, the required stack diameter can be calculated directly. However, the stack diameters are rounded up to the nearest half foot and the actual net stack loss is calculated for the rounded stack size for use in the fan selection which follows.

e. Fan Selection

Fan selection is based on the air rate and required fan pressure as diagrammed in Table A-5, and illustrated in Figure A-14. The air rate per fan is determined by an internal program optimization on the number of DHX modules to share equally the total amount of air passing through the heat exchanger. It is assumed that at least two modules are required for reliability, and that each module has its own fan and other auxiliaries.

The air flow rate for fan selection is determined by a total energy balance for the tertiary air system downstream of the fans.

$$Z_1 (g/gc) + \frac{V_1^2}{2g_c} + Jc_1 (T_1 - 32) + JQ =$$

$$Z_2 (g/gc) + \frac{V_2^2}{2g_c} + Jc_2 (T_2 - 32)$$

where J is the mechanical equivalent of heat and Q is heat received from the secondary loop less heat losses to the surroundings per pound of air. The elevation and kinetic energy terms are minor in a gas system and are neglected. A trial

(8) L. S. March, Mech. Engineer's Handbook, McGraw-Hill, Fourth Ed., 1941, p. 1186-1187.

and error solution of the tertiary air system is avoided if the temperature rise of compression in the fans is neglected; so for program simplicity, the assumption of zero temperature rise is made. (An increase of less than 5 F will occur for an adiabatic compression of air at a total pressure rise of 10 inches of water for worst-case FFTF inlet temperature and pressure conditions; the 10-inch pressure rise is very close to the upper limit for axial flow fans.) The heat losses from the DHX shell are neglected to offset the assumption of no temperature increase during compression. The net effect is a conservatively high air flow rate for the practical axial flow fan applications. The total air rate per DHX is then given as,

$$3600W = \frac{q}{c (T_o - T_{atm})}$$

wherein an average specific heat is used.

The total fan pressure rise for fan selection is based on the mechanical energy balance equation:

$$Z_1 (g/g_c) + V_1^2/2g_c + \int_2^1 v dP + W_e = Z_2 (g/g_c) + V_2^2/2g_c$$

+ Frictional losses,

where W_e is external work added.

Isothermal expansion is assumed for the tertiary air system, the perfect gas law is assumed to apply, and frictional losses are assumed to be proportional to the square of an average air specific volume over short sections of the system. Thus, for sections of the system which do not include a fan,

$$RT \int_2^1 \frac{dP}{\rho} = (g/g_c)(Z_2 - Z_1) + (1/2g_c)(V_2^2 - V_1^2) + m\bar{v}^2$$

where m is a constant for a given air flow rate, temperature, and system physical dimensions, and is of the form,

$$m = \left(\frac{fL}{D} + K \right) \frac{W|W|}{2g_c A^2}$$

Integration yields,

$$RT \ln \frac{P_1}{P_2} = (g/g_c)(Z_2 - Z_1) + (1/2g_c)(V_2^2 - V_1^2) + m\bar{v}^2$$

This equation may be applied to the DHX heat exchanger by dividing the heat exchanger into one or more constant temperature zones arranged in series.

The required total pressure rise through the fan is determined by integration of the energy equation over the following four sections:

- . Filter inlet to fan inlet.
- . DHX heat exchanger outlet to the top of the exhaust stack.
- . Across the DHX heat exchanger section. Hand calculations show that there is no real gain in accuracy by using more than one node in this application where the pressure loss is small relative to the absolute pressure at the inlet or outlet of the section.
- . Fan Discharge to the DHX heat exchanger inlet.

In performing the above integrations, the elevations of the filters, fans, butterfly valves and DHX heat exchanger inlet and outlet are taken at the datum plane; the diameters of the fan's inlet and outlet areas are assumed to be the same as the nominal fan size, and the flow areas at the inlet and outlet of the DHX heat exchange section are assumed to be large enough to give insignificant kinetic energy terms.

The total pressure rise through the fan is the difference in the sums of the static pressure and kinetic energy terms between the fans' discharge and inlet. The total pressure rise is corrected for deviations of the input atmospheric conditions from standard conditions to conform with the fan selection charts. The correction, C, is

$$C = \left(\frac{530}{460 + T_{atm}} \right) \left(\frac{P_{atm}}{14.7} \right), \text{ and}$$

equivalent fan pressure is given by dividing the actual total fan pressure rise by the correction, C.

FIGURE 4

Fan Performance of a Typical 84 in. Axial Flow Fan at 1170 RPM

Fan efficiency data are available in tabulated form as a function of fan air rate and equivalent fan pressure. The efficiency data were obtained from typical axial flow fan performance curves for the sizes, types, and speeds used in the program. Shown in Figure 4 is one such set of performance data for the 84-inch fan at 1170 rpm.

The fan brake horsepower is computed from the rate, actual total pressure rise, and efficiency data. A standard size drive motor is then selected for this particular application in which an overload factor of five percent is assumed. The motor options available are rated speed, fixed or variable speed types, and horizontal or vertical position.

Process conditions which fall outside the range of the axial flow fans may be impractical in many cases, but the program is allowed to continue, such that the cost of the special compressors, or blowers, can be determined as a function of the required brake horsepower. Experience with the program has shown that these special cases are always rejected on a cost basis because they are not competitive with applications allowing the selection of axial flow fans.

f. DHX Shell Size

The DHX shell is assumed to be box-shaped, as shown in Figure 5. The box length is a function of the number of tubes, number of tube rows per pass, number of tube passes, tube pitch, and a clearance allowance. The box height depends on the number of tube passes, number of tube rows per pass, tube pitch, and the heights of the air inlet and outlet plenums. These latter heights are assumed to be a function of the fan size as given in Table A-1. The box width is based on the length of finned tubing per pass plus a two-foot allowance for return bends and shell to tube clearance.

The length, X_1 , is then given as,

$$X_1 = p \times (\text{no. of tubes/row} + 1).$$

The height, X_h , is

$$X_h = \sin 60^\circ \times p \times (\text{no. tube passes}) \times (\text{no. tube rows/pass}) \\ + X_i + X_o$$

Typical Layout for
One Row Tubes per
Tube Pass, an Even
No. of Tube Passes,
4 Modules, and 3
Exhaust Stacks,

FIGURE 5

DHX Arrangement

where X_i is the inlet plenum height, and X_o is the outlet plenum height.

The width, X_w , is

$X_w = L + 2$, and the total box volume, v , is

$v = X_i X_h X_w$, cu ft.

g. Sodium Manifold Sizing

In most cases, there will be one inlet and one outlet manifold per DHX module. Each manifold is assumed to be joined to the secondary loop by two lines of the same size as the manifold proper. These manifold-to-loop connections are sized for a 12-ft/sec ultimate phase coolant velocity and ultimate phase hot-leg coolant density, but the calculated diameters are then rounded to the nearest standard pipe size. However, the rounded size is first checked against lower and upper limits before final acceptance of the size. The manifold nominal size must be at least three times as great as the base DHX heat exchanger tube O.D. and no greater than a nominal 10 inches. The manifold size is increased to the next standard pipe larger than three times the DHX tube O.D. if the calculated manifold size is less than the minimum. The manifold size is fixed at a nominal 10-inch and the number of manifolds increased to give an approximate 12 ft/sec coolant velocity if the calculated size exceeds the nominal 10-inch size.

h. Sizing of Miscellaneous DHX Auxiliaries

The use of inlet air filters, sound attenuators, butterfly valves, variable inlet vanes, and sodium valves may be specified by arrangement of input data. The filters are simply rated by the air flow rate required.

Sound attenuators, butterfly valves, and inlet vanes are sized in accordance with the fan size, as follows (in inches):

<u>Fan Size</u>	<u>Butterfly Valve Size</u>	<u>Sound Attenuator Size</u>	<u>Inlet Vane Size</u>
33	36	33	33
38	42	38	38
48	48	48	48
72	72	72	72
84	84	84	84

Sodium manifold valves for isolation are always line size. Valves may be specified in pairs (two in series) or as a single valve for each of the four locations which are required for complete isolation of a DHX module. Recall that each hot and cold manifold has two separate lines joining it to the secondary loop.

3. Piping Design

a. Primary and Secondary Loops

The optimum combination of pipe diameters and pumps is determined for each loop based on fixed input pipe lengths and numbers and types of pipe fittings and valves.

The piping losses consist of the frictional losses in straight runs of pipe, plus fitting losses. The former is calculated using Moody friction factors which are functions of Reynolds number and pipe roughness. The friction factors are computed from the following equation:

$$\frac{1}{\sqrt{f}} = -2 \log_{10} \left[\frac{\epsilon/D_i}{3.7} + \frac{2.51}{\text{Re}\sqrt{f}} \right]$$

which describes the family of curves shown in Figure 6. The roughness value is specified by input.

The pressure loss is calculated as,

$$\Delta P = \frac{f L V_i^2 \rho}{288 g_c D_i}, \text{ psi}$$

Fitting losses are calculated based on the velocity head factors for welded fittings,

$$\Delta P = \frac{K V_i^2 \rho}{288 g_c}, \text{ psi/fitting, and}$$

$$\Sigma \Delta P = \frac{\Sigma K V_i^2 \rho}{288 g_c}, \text{ psi/pipe run with coolant at constant}$$

density. The fitting factors used are listed in Table A-3.

Calculations can be made for up to four separate pipe runs in a loop. Thus, pressure losses can be computed for the runs upstream and downstream of the loop pump in either

FIGURE 6

Friction Factor as a Function of Reynolds Number with Relative Roughness as a Parameter

the cold leg or hot leg locations. The length of straight pipe and type and number of fittings are specified by input for each run.

The pressure losses for other components in a loop, including the IHX and reactor tank for the primary loop and IHX and DHX for the secondary loop, are added to the piping losses for purposes of determining the pump sizes and power requirements. The IHX and DHX pressure losses are computed in the program, but the reactor tank pressure drop is an input value.

The best combination of pipe diameters and pump sizes is determined by an iterative procedure in which the array of standard pipe diameters is examined from the smallest size pipe, which corresponds to an input-specified maximum allowable coolant velocity, to the largest size to be considered. Input can be specified to discontinue the iteration at any desired pipe size, up to the largest pipe programmed which is 42 inches.

Pipe and fitting data built into the program are listed in Tables A-2, A-3, and A-4. Program recompilation will be needed if the combination of design pressure and temperature requires pipe wall thicknesses greater than the values given, but the program should be suitable as is for primary loop design temperatures up to 1100 F.

Pipe material may be either carbon or stainless steel as reflected in the unit cost input data.

Valves are always line size.

b. Containment Pipe for Primary Loop

The containment pipe may be specified by arrangement of input data. If containment is desired, the annulus width between the main pipe and containment pipe and containment pipe wall thickness are specified as inputs. The sizing

is done only to provide data so that the cost of the containment pipe installation can be estimated from the weight of containment pipe to do the job. The program assumes that the entire primary loop is contained when containment is specified.

Containment pipes are not standard sizes. The containment pipe material may be either carbon or stainless steel as reflected in the input unit cost data. A density of pipe material of 500 lb/cu.ft. is locked into the program.

4. Pump Design

The pump head is determined by summing the individual component pressure losses around the loop. Brake horsepower is then computed for this head, the flow rate of coolant per loop, and an input efficiency value. The pump motor is then selected by picking the standard motor which meets this application. An overload factor of five percent is allowed such that the motor size is the next standard size above the BHP divided by 1.05.

Specified as input are pump speed and efficiency, motor type (fixed speed or variable speed), and motor position (horizontal or vertical). Direct drive is assumed.

The cavitation constant is calculated as a function of specific speed for the pump using the data shown in Figure A-13. The correlation is for an 80-percent efficiency which appears to give slightly high NPSH values for liquid metal mechanical type pumps. The cavitation constant, σ , is used to establish the minimum required pump suction pressure for the specified input conditions:

$$H_{\text{suction}} = \sigma (\text{TDH}) - \frac{V^2}{2g_c} + \text{vapor pressure} - P_{\text{atm}}$$

in consistent units of ft./fluid.

The pump shaft length has an important influence on the pressure in the system's surge tank. For this reason, the

vertical distance between the pump impeller and coolant level in the surge tank, or reactor tank in the case of the primary loop, is described by input data.

5. Primary Loop And Reactor Tank Operating Pressures

A maximum allowable reactor tank pressure is specified by input. The program then iterates on pipe sizes, rejecting cases in which the allowable tank pressure is exceeded, for the input specified pump speed, elevation data, and number of parallel cooling circuits.

The reactor tank pressure is computed by a mechanical energy balance between the pump suction and reactor tank. For the pump in the cold leg,

$$P_{\text{tank}} = P_{\text{suction}} + \Delta P + \frac{V_c^2 \rho_c}{288g_c} - \frac{Z_h \rho_h g}{144g_c} - \frac{Z_c \rho_c g}{144g_c}, \text{ psig}$$

where ΔP is the piping and IHX pressure losses between the points of interest, Z_h is elevation from thermal centerline of the IHX to the coolant level in the reactor tank, and Z_c is the elevation from the pump impeller to the thermal centerline of the IHX.

When the pump is in the hot leg,

$$P_{\text{tank}} = P_{\text{suction}} + \Delta P + \frac{V_h^2 \rho_h}{288g_c} - \frac{Z_h \rho_h g}{144g_c}, \text{ psig},$$

where ΔP is the piping pressure loss between the reactor tank and pump, and Z_h is the elevation from the pump impeller to the level of coolant in the reactor tank. The minimum required pump suction pressure computed from the cavitation constant is used as a base pressure in both pump location cases. The tank pressure is set to zero gauge pressure whenever a negative tank pressure is calculated from the minimum required pump suction pressure, and the pump suction is increased accordingly

6. Secondary Loop Operating Pressures

The difference in secondary loop pressure and primary loop pressure in the IHX is fixed by input, which sets a minimum required secondary coolant pressure in the IHX if the ratio of secondary to primary pressure is to be greater than one or sets a ~~maximum~~ secondary pressure at the IHX if the ratio is less

than one. In addition, the pressure at the secondary pump suction must be great enough to prevent cavitation, and it is possible that a maximum pump discharge pressure might be desired to limit the system design pressure.

The program contains internal checks to reject cases when any limit is exceeded. The base secondary loop pressure is the pressure in the IHX to satisfy the specified differential between the primary and secondary systems, but this base pressure depends on the primary loop's required pump suction and reactor tank pressures, which are calculated first. The secondary base pressure is then used to arrive at a secondary pump suction pressure which is compared against the minimum required to prevent cavitation. If the calculated suction pressure is sufficient, the pump discharge pressure is calculated and checked against the maximum allowable design pressure. If the calculated pump suction is less than the minimum required pressure, the pump suction pressure is set equal to the minimum allowable value and the pressure in the IHX increased accordingly. This can lead to impossible situations if the secondary system is to be run at a lower pressure than the primary and if the primary system pressure is limited to a low reactor tank pressure. When the allowable design pressure is exceeded, the case is rejected and the iterations continue by going to the next larger pipe size.

Mechanical energy balances are made to establish loop pressures of primary coolant in the IHX and at the secondary pump suction.

The pressure of secondary coolant in the IHX is simply the primary pressure there, plus the desired pressure differential between the two loops. The differential can be positive or negative. The secondary pump discharge pressure is simply the sum of the suction pressure and total loop frictional loss.

The surge tank vapor space pressure is the sum of the pump suction pressure and static head above the pump to the coolant level in the tank. The amount of pump submergence is an input value.

7. Secondary Loop Surge Tank

A surge tank is provided for each secondary loop. The tank working volume is based on an input-specified fraction of the total coolant volume contained in the secondary loop outside of the surge tank. Tank freeboard is set as 25 percent of the actual tank volume; hence,

$$\text{total volume} = \text{volume coolant} \times \text{input fraction} / .75.$$

8. High Design Pressure Penalty

In any cost optimization study, many cases are studied which may or may not be obviously uneconomical due to one or more extreme design conditions. Such cases should not be rejected on the basis of an apparent unusual design value because the design may be feasible, even though costly. Any feasible case should be given due consideration through an economic comparison with the more typical cases, and rejection of a case should be made only on the basis of unfavorable cost.

One such example in this program is the pressure loss on the tube side of the DHX which is reflected in the design pressure of the IHX and secondary loop and secondary pump head and power. Some DHX configurations give high tube side pressure losses which would result in relatively high secondary loop and IHX design pressures. The straightforward way of optimizing would be to arrange the program with system and equipment design pressures as calculated variables and with cost data given as a function of design pressure as well as size data. However, to do so would increase the size and complexity of the program, which is already massive. An alternate approach, and the approach taken, is to determine a so-called DHX design penalty cost which accounts for higher IHX and secondary loop costs due to high secondary loop design pressure resulting from high DHX tube side pressure loss. The penalty is derived from the secondary pump discharge pressure in excess of 150 psig, which is used as the reference pressure because input cost data for the IHX and secondary loop are usually based on this design pressure. A 150 psig design pressure is probably adequate for most reasonable cases.

9. Instrumentation

Instrumentation costs can be an important variable in some optimization studies, such as one which optimizes on the number of parallel cooling circuits. It is assumed that there will be a certain amount of instrumentation which is common to all parallel cooling circuits and that the cost of this instrumentation is independent of the number of parallel cooling circuits. It is further assumed that the instrumentation cost per loop can be based on the required number of controller and/or recorder applications per loop. This then leads to an incremental instrumentation cost which is useful in comparisons involving varying numbers of cooling circuits. The number of applications per loop is specified as input and therefore is the subject of a separate process study which must be done outside of this program.

10. Initial And Ultimate Design Conditions

Occasionally, a plant must be designed to meet operating conditions for an initial phase of operation as well as for an ultimate phase. For example, this was done in the FFTF conceptual study reported in BNWL-CC-400⁽⁹⁾. The program recognizes this possibility and is arranged so that equipment sizing is done in a way that will satisfy both conditions. The assumption is made that initial phase conditions will dictate heat exchanger sizes while ultimate phase conditions will dictate pipe and pump sizes.

The program can be used if only one set of basic design conditions is specified.

11. Program Limits

The program recognizes the possibility of limiting conditions beyond which a design is not feasible. However, these limits are not computed within the program. Rather, the limits must be anticipated by out-of-program studies and then fed into the program as input data.

Here are some typical examples. The IHX log mean temperature difference probably has an upper limit which is dependent on mechanical design considerations. Hence, there would be no

(9) BNWL-CC-400, "Progress Report, Fast Flux Test Facility," February, 1960.

point in making process studies beyond the limiting mechanical design value, and so the program is provided with an upper limit stop on the IHX log-mean-temperature difference. Another example is on the temperature of the exhaust air from the DHX. It is possible that an upper limit exists because of safety, material selection, or mechanical design. In this case, the program is provided with an upper limit stop on the exhaust air temperature. A third example is on the coolant velocities in the primary and secondary systems. No doubt there is an upper velocity limit due to effects other than pressure loss considerations, so the program is provided with input maximum allowable coolant velocities for each of the loops.

C. Cost Information

1. Basic Equipment Cost Data

The real heart of the program is the cost data supplied as inputs since the optimization can be no better than the basic cost data.

All major components are included in the cost optimizations, and the cost formulas are intended to be general enough such that the full range of equipment sizes is covered. The general method of costing is discussed here. Refer to the section on input (IV., E) for specific data and locations of data within the program.

All of the basic unit cost data include material and installation costs only and therefore all of the calculated component and system costs are direct construction costs. Electric motor drive costs include the material and installation costs for electrical controls as well as the motor itself.

a. IAHX

The IAHX cost is based on actual required surface. Cost is assumed to be a straight-line relationship with surface on a log/log plot, which is the way heat exchanger costs are typically presented. Thus, the IAHX cost formula is,

$$\text{cost} = \text{reference cost} \left(\frac{\text{calculated surface}}{\text{reference surface}} \right)^y$$

where the reference cost, reference surface and exponent are inputs.

b. DHX

The DHX cost is broken down into the individual costs of the several components which make up the DHX. These components are the tubular heat exchanger section, fans, variable inlet vanes, sound attenuators, air filters, air butterfly valves, heat exchanger box (or shell), exhaust stacks, air ducts, auxiliary furnace, sodium (to fill), sodium manifolds, secondary loop piping associated with the length of the DHX, and sodium valves in the manifolds. In addition, the high design pressure penalty due to high DHX tube side pressure losses is added whenever the secondary pump's discharge pressure exceeds 150 psig.

- Tubular Heat Exchanger Section: Cost is based on the weight of finned and unfinned tubing. Weight is determined from the calculated surface and input tube arrangement data. Cost is then given by,

$$\text{cost} = \text{cost/lb. unfinned tubing} \times \text{weight unfinned tubing} \\ + \text{cost/lb. finned tubing} \times \text{weight finned tubing.}$$

- Supply Fans: Supply fan costs include the fan and motor driver, which are costed separately. Fan costs are a direct function of the selected nominal size, type, and speed. Motor drive costs are based on the power rating of the selected standard motors. Tabulated motor unit cost data are arranged to give the cost as a function of motor speed (970, 1170, or 1750 rpm), type (fixed speed squirrel cage induction or variable speed wound rotor induction), and position (horizontal or vertical).
- Variable Inlet Vanes And Sound Attenuators: Cost of variable inlet vanes for flow control and sound attenuators are direct functions of the nominal fan size.
- Air Filters: Cost of the inlet air filters is based on the calculated total volumetric air flow rate. Thus,

$$\text{cost} = \text{cost/cfm} \times \text{total air rate for the DHX.}$$
 Simply set the input unit cost to zero, if air filters are not desired for the design.

- Air Butterfly Valves: Butterfly valve costs are a direct function of the valve size.
- Heat Exchanger Shell: The cost of the heat exchanger shell is based on a cost-per-unit volume and the calculated total volume. Thus,

$$\text{cost} = (\text{cost/cu ft})(\text{total volume in cubic feet})$$
- Exhaust Stack: The exhaust stack costs are a function of stack height, which is input, and calculated stack diameter:

$$\text{cost} = f(\text{height, diameter}).$$
- Air Ducts: Air duct costs are assumed to be directly proportional to the heat exchanger shell volume, and hence, shell costs:

$$\text{cost} = (\text{input duct cost fraction})(\text{cost of shell})$$
- Auxiliary Furnace: The cost of an auxiliary furnace is based on its rated duty, which is always taken as an input-specified fraction of the calculated loop duty. The cost of furnaces versus rating is assumed to be a straight-line on a log/log plot. Furnace costs built into the program are \$14,000 for for a 1×10^6 Btu/hr rating and \$50,000 for a 10×10^6 Btu/hr rating.
- Sodium: Sodium costs to fill the DHX tubes, manifolds, and secondary loop piping associated with the DHX length are based on the total sodium weight. The weight is calculated from the volume to fill a system and the density of sodium at its melting point. Cost then is,

$$\text{cost} = (\text{cost sodium/lb})(\text{total weight sodium})$$
- DHX Manifolds and Loop Piping: The cost of sodium manifolds and the secondary loop pipe associated with the DHX shell length is based on weight, which in turn is a function of pipe diameter and length. The unit weight of pipes is obtained from data listed in Table A-2. The pipe diameter for the last half of the pipe run of secondary piping alongside the DHX is reduced to give one-half the flow area

so three unit weights and three lengths are involved. The unit cost of installing the manifolds may be different than the unit cost for installing the secondary piping. Thus, the total piping cost for the DHX is,

$$\text{cost} = (\text{cost/lb})_m (\text{weight of manifolds}) + (\text{cost/lb}) (\text{weight of large secondary loop pipe associated with DHX length} + \text{weight of reduced size loop pipe}),$$

where $(\text{cost/lb})_m$ denotes manifold pipe unit cost and (cost/lb) denotes the secondary loop unit cost.

- DHX Sodium Valves: Sodium valve costs are a function of type and size. Tabulated data are included for gate, globe (or control), butterfly, and check-type valves. cost is given as,

$$\text{cost} = (\text{number of valves})(\text{unit cost/valve})$$

Valves are always manifold line size.

- High Design Pressure Penalty: The DHX high design pressure penalty assumes that the cost of the IHX and secondary loop will be increased above that calculated within the program using the input cost and process data. These added IHX and secondary loop costs are charged to the DHX because the added costs are due primarily to the DHX tube side pressure losses. The ratio of the costs relative to design pressure are estimated as follows:

<u>Design Pressure</u> Psig	<u>Cost</u> <u>Ratio</u>
150	1.0
300	1.59
950	1.95
600	2.43

The data are sufficiently linear so that the design pressure penalty is given as,

$$\text{penalty in dollars} = (\text{computed cost of IHX} + \text{computed cost of secondary loop})(.00318) (\text{secondary pump discharge pressure} - 150)$$

A calculated negative penalty for secondary pump discharge pressures less than 150 psig is rejected.

It is assumed that non-standard design pressures could be justified for the IHX and secondary loop components should the need arise. Therefore, the calculated pump discharge pressures are not rounded up to standard design pressures. (The TEMA standards, for example, specify standard design pressures of 75, 150, 300, 450, 600 psig, with intermediate pressures considered only in special circumstances.)

c. Primary And Secondary Pumps

The cost of a pump includes the basic pump cost plus its motor drive. These are costed separately. The cost of the basic pump without drive is assumed to vary with brake horsepower as a straight line on a log/log plot. The drive cost is the cost of a standard motor selected for the brake horsepower using a five-percent overload factor. Motor costs in the program are a function of speed (970, 1170 or 1750 rpm), type (fixed speed squirrel cage induction or variable speed wound rotor induction), position (horizontal or vertical), and power rating.

The basic pump cost is given by:

$$\text{basic pump cost} = \text{reference cost} \left(\frac{\text{calculated BHP}}{\text{reference BHP}} \right)^y$$

where the reference cost, reference BHP and exponent, y, are inputs. These inputs must be based on a pump-type typical of those being studied in the program.

Pump shaft length can be a significant cost parameter, but it is fixed for a given program run because shaft length has an important affect on reactor tank pressure. Thus, the affect of shaft length on pump cost must be reflected in the input cost data.

d. Loop Piping

. Primary and Secondary Piping: The cost of these pipes is based on input costs/unit weight in which separate unit

costs are used for the primary and secondary piping.

Weight is a function of the input lengths of straight pipe and numbers and types of fittings plus the pipe diameters determined internally in the program. The unit weights of pipe used in the program are listed in Table A-2, and the fitting weights are listed in Table A-4. These weight data are applicable to either carbon or stainless steel systems.

Piping cost is given as,

$$\text{cost} = (\text{cost/lb})(\text{weight straight pipe} + \text{weight fittings}).$$

The piping auxiliaries such as insulation, electrical heating, supports, etc., are included in the input unit cost figure where applicable.

• Primary Containment Pipe: The containment pipe cost is also based on weight (which is a function of the primary loop input lengths), diameter calculated internally within the program and a containment pipe unit cost. Total containment piping cost is then,

$$\text{cost} = (\text{cost/lb})(\text{weight in lbs.})$$

The containment pipe unit cost input data may contain insulation and electrical heating charges; when so included, these extras are not included in the primary pipe unit cost in those cases where primary loop containment is specified.

• Loop Valves: Valve costs are a function of size, service, (primary or secondary), type (gate, globe or control, butterfly, or check), and in the case of secondary service, of material (carbon or stainless steel). These data are tabulated against the nominal valve size. Hence, total cost for any one type valve = (cost/valve)(number) and, the total valve cost is the summation of these terms.

Valve pressure ratings are reflected in the unit cost input data.

e. Sodium To Fill

Sodium costs to fill the various systems are based on the total sodium weight required. The weight is determined

from the system volume and the density of sodium at its melting point (208 F). Sodium cost is then,

$$\text{cost} = (\text{cost/sodium/lb})(\text{total weight of sodium in lbs}).$$

f. Secondary System Surge Tank

The surge tank cost is based on the calculated tank volume. The cost is assumed to be a straight-line relationship with actual tank volume on a log/log plot. Cost is given by,

$$\text{cost} = \text{reference cost} \left(\frac{\text{calculated volume}}{\text{reference volume}} \right)^y$$

where reference cost, reference volume, and exponent, y, are input data.

g. Incremental IHX Building Cost

Building cost is based on a constant cost per unit volume. The incremental cost is then,

$$\text{cost} = (\text{building cost/cu ft})(\text{building volume required for the IHX})$$

h. Incremental Instrumentation Cost

Instrumentation costs are based on an input number of controller and/or recorder applications per heat removal circuit and a unit instrumentation cost. Thus, this cost is given by,

$$\text{cost} = (\text{cost/each installation})(\text{number of installations})$$

i. Spare Equipment

Cost of spare equipment is not included in the program. Such costs will have to be added outside of the program to the installed equipment costs generated within the program. The program does give an easy way to calculate the cost of spares since the material-only cost of a given spare is some fraction of the installed direct construction cost calculated in the program for the component in question.

In general, the material-only cost of a component, such as a heat exchanger or pump, is about 90 percent of the program's installed direct construction cost. Some typical program data are listed below for reference:

<u>Component</u>	<u>Material Cost As A Percent Of The Installed Cost</u>
IHX	93
Pump Without Drive	89
DHX Fan Without Drive	50
800 Horsepower Motor	97
200 Horsepower Motor	91

2. Optimization Criteria

In general, the alternate selected, whenever two or more alternates are being compared, is the one with the least direct construction cost. However, if the selection involves equipment which consumes significant amounts of electrical power, an additional method of selection is available in routines which size the primary and secondary pumps and DHX fans, and if used, it must be used for all three selections.

With the option, the worth of an added incremental investment is determined by comparing power savings against the added investment. Power savings are based on an input-specified plant time operating efficiency defined as the integrated power per year (MWH) divided by rated power times hours per year. The alternate which gives the best payout period, less than an input-specified maximum value, is selected with this option.

For example, in the primary loop pipe-pump optimization, the pipe size could be increased over that size which yields the least direct construction cost, and by so doing, pump power would be reduced. Hence, the savings in power could be balanced against the added cost due to a larger pipe size, and the alternate arrangement with the least payout period would be selected provided it does not exceed the maximum allowable value.

The incremental investment is determined by escalating the direct construction costs, which are determined for each alternate, to total project-type costs by an input-specified ratio, Hence,

total investment = (direct construction cost)(ratio of
the total project cost to total direct
construction cost).

The incremental investment is simply the difference of the total investment of an alternate and total investment of the least project cost case.

If the optimization is to be based on the least project cost, the maximum allowable payout period of an incremental investment is made zero.

The program contains iterations on variables which affect the whole design as well as several subiterations which affect only parts of the design. The above optimization criteria apply in both cases.

D. Program

1. Program Code And Machine Application

The ADOPT Program is coded in FORTRAN IV machine language. The authors selected the UNIVAC 1107 computer for program application because of storage and permissible subscript size; large quantities of programmed engineering data required large storage capability and the use of four-dimensional, subscripted arrays facilitated the handling of such data.

2. Program Techniques

In addition to the usual library functions, some special functions were constructed and/or utilized to perform repetitive calculations. Most of the functions utilized the feature that a function whose arguments are arranged as a subscripted array can be called with the array name and size provided a suitable dimension statement is included within the function routine.

This feature not only permits compact notation, it also eliminates much of the bookkeeping required in the common statements.

a. Interpolation Routines

General interpolation routines to search two-dimensional and three-dimensional tables and perform second-order interpolation are utilized.

- A binomial interpolation routine, FIND, is used to search a two-dimensional array of size $n \times m$ to return the interpolated value which corresponds to a one-dimensional argument of any column or any row. FIND can be called with any row (or column) argument provided the specified row (or column) is single valued, and will return the interpolated value from any requested row (or column). If the argument is outside the array, FIND returns the boundary value.

FIND also assumes that a mirror image (or opposite quadrant image) of the data exists when the argument is less than zero.

- A binomial routine, SEEK, is used to search a three-dimensional array of size $j \times n \times m$, to return the interpolated value which corresponds to a two-dimensional argument. The array must be constructed in a special way so that the argument ranges are included. Seek utilizes another function, SET, to provide subscripts of rows which bracket the arguments.

b. Selection Routines

An integer function, KMIN, searches an array of data to return the subscript of the minimum value.

c. Engineering Routines

- Function FITWT finds the weights of a group of pipe fittings (described by an array which lists the types of fittings, the quantity of each type, and the nominal size) and returns the total weight of the group.

- Function FIXLMT searches the heat exchanger log-mean-temperature corrector tables (depicted by Figures A-5 through A-7) to return the LMTD corrector which corresponds to the argument R, P parameters.

- Function FRICTF returns the Moody friction factor calculated for the argument coolant Reynolds number, pipe material roughness, and pipe diameter. The friction factor is obtained by trial and comparison, and the solution criteria are that successive values agree to within .1 percent.

- Function PHIF returns a maximum eddy Reynolds number corrector function (from which the $\bar{\psi}$ corrector is derived) for arguments of coolant Reynolds number and heat exchanger pitch-to-diameter ratio. The function uses binomial interpolation on tabulated data depicted by Figure A-11.

d. Cost Data Routines

- Function DRIVE returns the cost and size of an induction motor which will drive the load specified by the argument; the argument also includes identification of motor type and speed. A motor overload factor of 1.05 is included.
- Function VLVCST returns the cost of all valves in a group of fittings (described by an array which lists the types of fittings, the quantity of each type, and the nominal fitting size and location of the group of fittings).

3. Program Organization

The program constructs the optimization in three basic cycles: first, data for a case is read in and the input process and equipment data are used to calculate derived data which will be used throughout the optimization (such as thermal-hydraulic properties, loop heat duty, equivalent diameters, tube flow areas, etc.). Next a series of iterations on heat exchanger temperatures (i.e., IHX log-mean-temperature difference and DHX exhaust air temperature) is performed with the end result that optimum IHX and DHX heat exchanger surfaces are selected. Finally, primary and secondary loops are sized and costed. Throughout the cycles, engineering and cost data are written out when applicable. Many suboptimizations are performed during the intermediate cycle, and each selection of a suboptimum is followed immediately by a recalculation of the optimum case so that all parameters in the program will be updated to the optimum condition. Figure 7 shows the basic program logic path.

Figure 7. MAIN PROGRAM LOGIC

a. Input And Derived Data

After the data for a case is read in, the primary coolant's thermal properties are determined. Next, the geometry dependent properties of flow areas, heat transfer areas, and equivalent diameters are calculated on a per tube basis for later use throughout the program. Input data are used to construct the logic limits for the intermediate heat exchanger cases: logic is arranged to study a range of IHX designs based on a minimum, maximum, and incremental log-mean-temperature difference.

b. Heat Exchanger Selection

For a given IHX log-mean-temperature difference (LMTD), the set of energy balance, rate, heat transfer coefficient, and secondary coolant physical property equations which describe IHX performance are solved simultaneously to give IHX heat transfer surface, secondary coolant temperatures, and primary and secondary coolant flow rates. The amount of IHX shell and tube side bypassing, type of IHX exchanger, and location of primary and secondary coolants are taken into account in the solution of the equations. IHX size is determined based on initial process conditions, and the IHX is costed. Next, the heat exchanger performance is calculated at ultimate process conditions for the calculated heat transfer area. At ultimate conditions, some estimates of primary loop pressure drops are made for the next program phase of DHX and secondary loop evaluation. An optimum dump heat exchanger with an associated optimum secondary loop is selected (described in Item e) and the costs of both heat exchangers and the secondary loop are totaled.

The process is repeated for each IHX LMTD described by the logic construction. Total costs are next compared, and the LMTD which results in the least total cost is determined.

Some data are constructed at the least cost case conditions (such as sodium pressure drops in heat exchangers at ultimate conditions) to be used in sizing and costing the loops.

Figure 8 depicts the IHX section logic path.

Figure 8. HEAT EXCHANGER LOGIC

c. Primary Loop Section

The primary loop section sizes and costs the primary pipes and pump. A maximum primary coolant velocity, a maximum primary loop pipe diameter, and a maximum allowable reactor tank pressure are program input constraints.

The smallest pipe size considered is based on maximum coolant velocity at ultimate conditions and using hot-leg density; the minimum pipe size is rounded to the next standard size below the calculated size. All loop piping is set to the minimum size and the loop pressure profile is determined based upon pump location. Pump head and flow determine horsepower (i.e., size).

The minimum required pump suction to satisfy NPSH requirements is determined and the reactor tank pressure is then calculated to give this required pump suction pressure, taking into account the system elevations, pump speed, etc. Cases are rejected whenever the calculated tank pressure exceeds the input-specified maximum allowable value and negative tank pressures are rejected by increasing the pump suction above the minimum required as needed to give zero gauge pressure in the tank. The pipe and pump are costed. All pipe except discharge pipe is increased to the next larger standard size and the loop pressure calculations, pump sizing, and cost evaluations are repeated. The latter step is repeated until all pipe sizes, up to the maximum specified, have been studied, with the pump discharge piping size unchanged. Whenever loop constraints are exceeded, the case is rejected and the case with the next larger pipe size is studied. The optimum configuration is selected, based on lowest construction cost case or the best power savings case, which is consistent with the input maximum allowable payout period.

The pump discharge piping is next increased to the next standard size and the above process is repeated. This is continued until all cases of pump discharge pipe up to the

largest allowed size are covered. At this stage, there is a series of suboptimums which correspond to each pump discharge pipe size. The optimum among these is selected, again based on either the lowest construction cost case or the best power savings case.

Some data are constructed at the final optimum conditions (such as loop pressure drops at ultimate conditions) to be used in sizing and costing the secondary loop.

Provision is made through input control integers to design to an input-specified pipe size if the loop size is constructed externally to the program.

Figure 9 depicts the primary loop section logic path.

d. Secondary Loop Section

The secondary loop section sizes and costs the secondary pipe, pump, and surge tank. A maximum secondary coolant velocity, a maximum allowable secondary pump discharge pressure, a maximum allowable standard pipe size, and a minimum pressure difference between primary and secondary coolants in the IHX are input constraints.

The smallest pipe size considered is based upon the maximum allowable coolant velocity using the ultimate condition hot-leg density, but the pipe size is rounded to the next smaller standard size. All loop piping cases of standard size from the minimum calculated size to the input maximum size are considered.

For each case, the pressure profile is first determined. The base pressure for the secondary loop is the pressure in the IHX to satisfy the input differential between primary and secondary system pressures. If the pump discharge pressure constraint is exceeded, the case is rejected and the next larger pipe size case is considered. Minimum suction pressure is calculated based on pump cavitation considerations; if the actual suction pressure is less than the calculated minimum, the suction pressure is set equal to the

Figure 9. PRIMARY LOOP LOGIC

minimum calculated and the loop pressure profile is recalculated. If the surge tank pressure is subatmospheric, the surge tank pressure is set equal to atmospheric pressure, and the loop pressure profile is recalculated. A high design pressure penalty is calculated where necessary. Pump head and flow determine pump horsepower (i.e., size). The pipe and pump are costed.

When all cases have been sized and costed, the optimum secondary loop is selected based upon minimum project cost or best acceptable power savings.

If the secondary loop sizing is done subsequent to the heat exchanger optimizations, the ADOPT case is now completed. If the secondary loop sizing is done as the optimum secondary loop associated with a dump heat exchanger case, the optimum secondary loop sizing and costing are repeated to assure proper inputs to the heat exchanger optimizations.

Provision is made through input control integers to design to an input-specified pipe size if the loop size is constructed externally to the program. Also, by input control integers, each case can have either all secondary pipe the same size, or have the cold-leg pipe be one standard size smaller than the hot-leg pipe.

Figure 10 depicts the secondary loop section logic path.

e. Dump Heat Exchanger

This section studies cases identified by a range of air exhaust temperatures to select the optimum DHX design. For each case, an optimum secondary loop is selected so that loop dependence upon DHX sodium side pressure drop is taken into account.

The input data contain DHX logic parameters of:

- Difference between ambient air and minimum air exhaust temperature.
- Incremental exhaust air temperatures.

Figure 10. SECONDARY LOOP LOGIC

. Difference between secondary coolant hot-leg temperature and maximum exhaust temperature.

These parameters describe the range of exhaust air temperatures considered.

For a given exhaust air temperature, the DHX LMTD and LMTD correction for cross flow at initial conditions are computed. For a series of tube pass configurations, the DHX is sized (the heat transfer coefficient is calculated); an optimum number of fan modules is selected (see Section f); the DHX is costed; and an optimum secondary loop is selected and costed. The optimum number of tube passes is selected, and the case with the optimum number is reconstructed.

When all exhaust air temperatures have been considered, the optimum case is selected, based either on construction cost or power savings. Finally, this optimum case is reconstructed, and some DHX parameters (such as sodium side pressure drop and sodium volume) are calculated at ultimate conditions for later use in loop sizing.

Tube passes are considered in groups of four; if an optimum is reached within a given group, the optimum is selected. However, if the optimum configuration is the largest number of tube passes in the group, the next group of tube passes is studied to assure that a true optimum rather than a boundary optimum is reached.

Figure 11 depicts the DHX section logic path.

f. Fan Selection

The optimum fan size and quantity is selected based on either cost or power savings. At a given DHX design, air flow, and air temperature profile, the tertiary loop is sized for from two to eight fan modules. For each number of modules, the tertiary loop pressure profile is calculated and the fan head is determined. Fan size is selected based on air flow rate, and fan type is selected based on both

Figure 11. DUMP HEAT EXCHANGER LOGIC

air flow rate and fan pressure differential. An appropriate motor is selected to drive the fan, and the size-dependent loop components of fan, motor, valves, inlet vane assemblies, air filters, and ducts are costed. The quantity of fans which yields the optimum from a construction cost or power savings standpoint is selected; the tertiary loop is then reconstructed for this optimum configuration.

Figure 12 depicts the fan selection program logic.

4. Program Timing

The machine time required to run a case is dependent not only upon the programmed complexity but also upon the size of the case as dictated by input. Approximately 45 seconds of machine time are required to run each IHX LMTD case with an average number of DHX iterations; less than ten seconds is consumed by the subsequent piping routines. Thus, total machine costs will be essentially a function of the number of IHX LMTD cases the program is instructed to consider; a rule of thumb for estimation would be two minutes for each LMTD.

E. Input Organization

Every effort was made to organize the program input so that the program could be used readily by a large cross-section of personnel.

The basic philosophy of input organization is to identify an input parameter by a numbered label and have each parameter read in by separate data card. The first card in any data list identifies the total number of parameters for the case; the machine expects exactly that many cards to follow the first card. Subsequent cases are stacked sequentially, with each section headed by a card which specifies the number of parameters or data cards which belong to that case. The program is terminated when a blank data card is encountered; thus, the data cards should have exactly one blank card per machine application. The blank card is at the end of the data cards and is not included in any card count.

Figure 12. FAN SELECTION LOGIC

Each data card is constructed in a format of (2I5, F10.4, 2I5). The parameter identification integer is always the first integer; this integer must be punched so that its last digit is in Column 5 of an 80-80 card. The second integer field is used only if the parameter is an integer quantity; in this instance, the integer must be punched so that its last digit is in Column 10 of the 80-80 card. If the parameter is a floating point number (a number with a decimal), the parameter is punched in the space constructed by Columns 11 through 20 of the 80-80 card. The last two integer formats are used only in the instance when the parameter is a piping fitting.

A list of the input routine is reproduced in part in Table I. Note that when an integer input is required, the parameter is set equal to JVALUE; when a decimal input is required, the parameter is set equal to VALUE. In Table I, the parameter descriptions precede the identification command, and each description starts with a letter "C". Also, the numerical value at the right-hand side of each description is the program initial value input; if the parameter is not read in as an input, the program will select this initial value as the parameter value for the first case considered. (Initial values are included to permit the user to avoid repetitious punching of data cards when data is not changed.) When successive cases are run, the program will use for any parameter which is not read in, the parameter's value in the preceding case.

The program input can be considered in eleven basic groups of data:

- Process Conditions (Initial - Ultimate)
- System Design Data
- IHX Design Data
- DHX Design Data
- Common IHX and DHX Design Data
- Primary Loop Design Data
- Confinement Design Data

- . Secondary Loop Design Data
- . Program Limits Data
- . Cost Data
- . Program Logic Data

The input descriptions are listed under the above categories in Table I. It is felt that most descriptions are self-explanatory with the exceptions of ultimate phase process conditions, primary loop elevation terms ZPC and ZPH, and pipe fitting factors (in the primary and secondary loop design data).

The ultimate phase design data will be handled as any other data when entered on a data card. If none of the five ultimate phase data are read in for a case, the program will set the ultimate conditions equal to the initial phase conditions for the specific case. If one or more of the five data are read in, the program will use the read-in data for a given case. If some (but not all) of the ultimate phase data are read in, the remaining ultimate phase parameters will assume their value from the preceding case.

The primary loop elevation terms ZPH and ZPC (respective identification integers 86 and 87) have different definitions dependent upon the location of the primary pump; for consistency, the construction of input for a case must take this into account.

- . When the primary pump is in the cold leg, ZPH is the height of the reactor vessel above the IHX thermal centerline and ZPC is the height of the IHX thermal centerline above the primary pump impeller.
- . When the primary pump is in the hot leg, ZPH is the height of the reactor vessel coolant above the primary pump impeller and ZPC is zero. The program automatically equates ZPC to zero when the primary pump is in the hot leg.

Pipe straight-pipe lengths and pipe fitting factors all have the same identification integer for a given loop (84 for primary pipe and 104 for secondary pipe). The input routine keeps a tally of fitting types, quantity of each type, and number of distinct

types; this information is necessary for later evaluation of fitting weights and cost for different loop sizes. The input routine also keeps a running tally of total velocity head "K" factors for a given loop zone for later program pressure drop calculations.

The pipe fitting input section basically is concerned with three decisions:

- . Does the data card describe a length of straight pipe or a fitting.
- . In what loop zone is the pipe or fitting to be placed.
- . If a fitting, has the loop zone received any other fittings.

The data card format contains as usual the identification integer (84 or 104) in the first I5 field, the zone location in the second I5 field, the fitting type identification integer in the third I5 field, and the number of such fittings in the zone in the fourth I5 field.

If the data card describes straight pipe, the fitting type is set equal to one (in the third I5 field) and the length of the pipe is listed in the floating point field between the second and third integer fields.

The program has an initial pipe fitting configuration for each zone of each loop. If the configuration in a zone is to be changed for a given case, the program will erase all of the information from the preceding case for that zone. To remove all fittings from a zone when no different fittings are to be included, simply add a data card which calls for zero quantity of some type fitting.

Table II of Section F depicts an input layout for a specific program application. Particular note should be taken of the Item 84 and 104 inputs.

F. Program Applications

The program provides steady-state process data and a method for cost optimization of system components as well as cost optimization of the system itself. This section of the report discusses possible general applications and concludes with results of a specific application. Remarks in general apply to the main heat removal system and the small test loops.

1. General Applications

The program is quite general and can be used in a variety of ways, some of which are listed below:

- a. The optimum IHX log-mean-temperature difference and DHX exhaust air temperature can be determined for a given number of parallel cooling circuits and other fixed input data. Complete process design and cost data are then provided for these optimum temperatures.
- b. The optimum number of parallel cooling circuits for a given set of design data can be determined by a series of runs in which the number of circuits is varied over the range of interest while holding all other input data constant. In this case, additional calculations are required outside the program. For example, the individual costs calculated in the program for the optimum IHX, DHX, primary loop and secondary loop must be totaled for each cooling circuit case and to these totals must be added the cost of spare equipment. The cost of spare equipment can be estimated from the program's component installed cost data by factoring out installation costs as discussed in Section IV.C.1.i.
- c. The optimum combination of loop pipe and pump sizes can be determined for a given set of input data.
- d. Optimizations can be performed on individual components by a series of runs in which all inputs are held constant except the design value(s) being studied. A partial listing of such cases is as follows:
 - Ratio of heat exchanger tube length-to-tube diameter.
 - Heat exchanger tube pitch.
 - DHX fin tube arrangement (but recall that the program is locked in on transverse fins of uniform thickness).
 - Primary and/or secondary pumps' speeds.
- e. The effect of specified design values on process performance can be evaluated. Examples are as follows:

- The effect of primary pump shaft length and pump speed on the required reactor tank vapor space pressure can be determined for a given set of process and design conditions.
 - The comparison of hot-leg and cold-leg pump locations can be made for a given set of input data.
 - The comparison of primary sodium on the shell side and on the tube side of the IHX can be made.
 - Comparisons can be made between secondary loop pressures in the IHX greater than and less than primary loop pressures.
 - Comparisons of various loop piping layouts can be made for a given set of process conditions and a given IHX log-mean-temperature difference.
- f. The program can be used for making parametric studies on the basic process conditions. Studies on the reactor tank pressure loss, which consists mainly of the core pressure loss, temperature rise of primary coolant, primary coolant hot-leg temperature, and reactor power should be of interest. Included here could be studies on circulation of "excess" primary coolant as a way to achieve 1200 F (or higher) core outlet temperatures while holding the primary coolant hot leg to lower temperatures which are compatible with a stainless steel construction material for the primary system.
- g. Heat exchanger operational flexibility can be determined for a given set of equipment design data over the full range of process conditions. The program was not written specifically for this type of application which may result in a rather inefficient program use. However, it is probably better to use the program inefficiently than to write a new program or perform hand calculations to do the same job.

Program iterations on the IHX log-mean-temperature difference are performed until known IHX and DHX exchange surfaces are bracketed. The number of iterations will depend on the desired precision of agreement between calculated surfaces and known surfaces.

2. Optimum DHX Exhaust Air Temperature--An Illustrative Example

Use of the program is illustrated by the following specific application.

The optimum DHX exhaust air temperature is determined for an FFTF main heat removal system which meets a set of initial design conditions as well as a set of ultimate design conditions, for a system made up of three parallel cooling circuits, and for a given initial phase IHX log-mean-temperature difference of 100 F.

The basic data for the run are listed in Table II, and repeated in Tables B-1 through B-4 of Appendix B (which are copies of the actual program input listings).

The program results are shown in Tables B-5 through B-48, which are copies of actual program output listings. Table B-5 gives IHX data for the initial design phase; Table B-6 gives the IHX data for the ultimate design phase; Tables B-7 through B-13 give the DHX data for the range of DHX exhaust air temperatures studied; Table B-14 reports on the optimum DHX design for the given IHX log-mean-temperature difference; Tables B-15 through B-41 report the primary loop data for the range of pipe sizes; Tables B-42 through B-47 report the secondary loop data for the range of pipe sizes; and Table B-48 specifies the optimum primary and secondary loop cases.

The program results can be plotted in a variety of ways. Some typical examples are shown in Figures 13-17. The cost of the DHX and secondary loop is plotted in Figure 13, versus the number of tube side passes for the optimum exhaust air temperature. Also shown are the tube and shell side pressure losses. The exhaust air optimization data are shown in Figure 14. The primary loop construction cost and annual pump power cost data are plotted versus pipe size in Figure 15. As shown, the optimum case is for 16-inch cold-leg and hot-leg pipes, wherein the payout period on the added investment over

and above the minimum project cost case is 8.3 years. The optimum secondary loop pipe size is shown to be 16-inches in Figure 16.

A family of curves of reactor tank pressure versus primary loop pipe size is shown in Figure 17. It should be noted that tank pressure data for the 14-inch cold-leg and 14-inch hot-leg pipe sizes case are available even though the case was automatically rejected due to the calculated pressures being greater than the maximum allowable value of 5.0 psig, which was specified by input.

G. Program Status

Two points need to be made. The first is that unit cost data will require a continuous review. This is true of the data which are fed in as input for each run as well as the cost data which are built into the program. The second point is concerned with the many options built into the program. It is safe to say that it would be impractical to make debug runs for all possible combinations of options. The program may encounter difficulties as different combinations are tried. These faults will be removed as they are discovered. Other than this, the program is considered to be complete.

FIGURE 13

Typical Selection of Optimum Number of DHX Tube Passes for each Given Exhaust Air Temperature

FIGURE 14

Typical Selection of the Optimum DHX Exhaust Air Temperature and Best Even Number of Tube Passes

FIGURE 15

Typical Optimization of Primary Loop Pipe Diameters

FIGURE 16

Typical Optimization of Secondary Loop

FIGURE 17

Reactor Tank Pressure as a Function of Primary Loop Pipe Diameter

TABLE I. PARTIAL LISTING OF SUBROUTINE INPUT

INITIAL
VALUEIDENTIFICATION
INTEGER

SUBROUTINE INPUT

SUBROUTINE INPUT READS INPUT DATA FOR EACH CASE.

IF NEW DATA IS NOT READ IN, SUBROUTINE INPUT WILL
INITIALIZE ON THE VALUES LISTED TO THE EXTREME RIGHT
OF EACH SYMBOL DEFINITION.

UNLESS CHANGED, PARAMETERS WILL BE THE SAME FOR EACH
SUBSEQUENT CASE.

SPARE DENOTES SPARE INPUT VALUE FOR FUTURE CHANGES.

```

200 FORMAT(2I5,F10.4,2I5)
201 FORMAT(1H1/5X55HEND OF DATA. EXIT WILL BE CALLED FROM SUBROUTINE I
    INPUT.)
202 FORMAT(1H0/99H INCONSISTENT DATA FOR PRIMARY LOOP FITTINGS. THE
    1FOLLOWING HARDWARE WILL BE IGNORED IN THIS CASE/
    25X15,9H OF TYPE 15,22H IN PRIMARY LOOP ZONE 15/
    347H THE INPUT CARD HAS A FIXED POINT VALUE OF E15.7)
203 FORMAT(1H0/99H INCONSISTENT DATA FOR SECONDARY LOOP FITTINGS. THE
    1FOLLOWING HARDWARE WILL BE IGNORED IN THIS CASE/
    25X15,9H OF TYPE 15,24H IN SECONDARY LOOP ZONE 15/
    347H THE INPUT CARD HAS A FIXED POINT VALUE OF E15.7)
    KLUB=0
    KLOBHA=0
    KLOBHB=0
    KLOBCA=0
    KLOBCB=0
    KLOB1=0
    KLOB2=0
    KLOB3=0
    KLOB4=0

```

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
1101 READ (2,200) INPUTS	
IF (INPUTS) 1102,1102,1103	
1102 WRITE (3,201)	
CALL EXIT	
1103 DO 1104 I=1,INPUTS	
READ(2,200) NO,JVALUE,VALUE,KVALUE,NVALUE	
GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,	
23,24,25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,	
42,43,44,45,46,47,48,49,50,51,52,53,54,55,56,57,58,59,60,	
61,62,63,64,65,66,67,68,69,70,71,72,73,74,75,76,77,78,79,	
80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95,96,97,98,	
99,100,101,102,103,104,105,106,107,108,109,110,111,112,113,	
114,115,116,117,118,119,120,121,122,123,124,125,126,127,	
128,129,130,131,132,133,134,135,136,137,138,139,140,141,	
142,143,144,145,146,147,148,149,150,151,152,153,154,155,	
156,157,158,159,160,161,162,163,164,165,166,167,168,169,	
170,171,172,173,174,175),NO	
1 PROCESS CONDITIONS.	
INITIAL PHASE.	
W IS TOTAL DUTY FOR MAIN HEAT REMOVAL SYSTEM AT STARTUP, MW.	300.
Q IS HEAT DUTY CONVERTED TO BTU/HR.	
1 W=VALUE	
Q=3.413E6*W	
GO TO 1104	
TPH IS STARTUP PRIMARY COOLANT HOT LEG TEMPERATURE, DEG.F.	775.
2 TPH=VALUE	
GO TO 1104	
TPC IS STARTUP PRIMARY COOLANT COLD LEG TEMPERATURE, DEG.F.	500.
3 TPC=VALUE	
GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	FX IS RATIO OF IHX TEMPERATURE DROPS, SECONDARY TO PRIMARY AT STARTUP OR INITIAL CONDITIONS.	1.
C	4 FX=VALUE GO TO 1104	
C	PCORE IS REACTOR TANK PRESSURE DROP AT STARTUP CONDITIONS, PSI.	100.
C	5 PCORE=VALUE GO TO 1104	
C	6 SPARE=0. GO TO 1104	
C	7 SPARE=0. GO TO 1104	
C	ULTIMATE PHASE.	
C	WU IS DUTY FOR MAIN HEAT REMOVAL SYSTEM AT ULTIMATE CONDITIONS, MW. UNLESS SPECIFIC PROGRAM INPUT, TO BE SET EQUAL TO W.	
C	8 WU=VALUE QU=3.413E6*WU GO TO 504	
C	TPHU IS PRIMARY COOLANT HOT LEG TEMPERATURE AT ULTIMATE CONDITIONS, DEG.F. UNLESS SPECIFIC PROGRAM INPUT, TO BE SET EQUAL TO TPH.	
C	9 TPHU=VALUE GO TO 504	
C	TPCU IS PRIMARY COOLANT COLD LEG TEMPERATURE AT ULTIMATE CONDITIONS, DEG.F. UNLESS SPECIFIC PROGRAM INPUT, TO BE SET EQUAL TO TPC.	
C	10 TPCU=VALUE GO TO 504	
C	FXU IS RATIO OF IHX TEMPERATURE DROPS, SECONDARY TO PRIMARY, FOR ULTIMATE CONDITIONS. UNLESS SPECIFIC PROGRAM INPUT, TO BE SET EQUAL TO FX.	
C	11 FXU=VALUE GO TO 504	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	PTANKU IS REACTOR TANK PRESSURE DROP AT ULTIMATE CONDITIONS, PSI.	
C	UNLESS SPECIFIC PROGRAM INPUT, TO BE SET EQUAL TO PCORE.	
	12 PTANKU=VALUE	
	GO TO 504	
	13 SPARE=0.	
	GO TO 504	
	14 SPARE=0.	
	GO TO 504	
C	PROCESS DESIGN DATA COMMON TO BOTH PHASES.	
C	TTC IS AMBIENT AIR TEMPERATURE, DEG.F.	100.
C	TTC=VALUE	
C	GO TO 1104	
C	PATM IS ATMOSPHERIC PRESSURE, PSIA	13.7
C	PATM=VALUE	
	GO TO 1104	
	17 SPARE=0.	
	GO TO 1104	
	18 SPARE=0.	
	GO TO 1104	
C	II SYSTEM DESIGN DATA.	
C	N IS NUMBER OF PARALLEL COOLING CIRCUITS.	3
C	N=JVALUE	
C	GO TO 1104	
C	YEAR IS ACCEPTABLE PAYOUT PERIOD ON INCREMENTAL BASIS, YEARS.	5.
C	YEAR=VALUE	
	YEARS=VALUE	
	GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
C EO IS PRIMARY LOOP TIME OPERATING EFFICIENCY. C EOS IS SECONDARY LOOP TIME OPERATING EFFICIENCY. C EOF IS FAN TIME OPERATING EFFICIENCY	.75 .75 .75
21 EO=VALUE EOS=EO EOF=EO GO TO 1104	
C NCONT IS NUMBER OF CONTROLLER AND RECORDER APPLICATIONS.	10
22 NCONT=JVALUE GO TO 1104	
C ZBLDGX IS HEIGHT OF IHX BUILDING, FT.	60.
23 ZBLDGX=VALUE GO TO 1104	
C PRMAX IS THE MAXIMUM ALLOWABLE REACTOR VESSEL PRESSURE, PSIG.	15.
24 PRMAX=VALUE GO TO 1104	
25 SPARE=0. GO TO 1104	
26 SPARE=0. GO TO 1104	
27 SPARE=0. GO TO 1104	
28 SPARE=0. GO TO 1104	
29 SPARE=0. GO TO 1104	
C C III IHX DESIGN DATA.	
C IX IS CONTROL INTEGER TO DETERMINE TYPE OF IHX. C IX=0, TYPICAL COUNTERFLOW EXCHANGER. C IX=1, 1 SHELL PASS AND 2 TUBE PASSES. C IX=2, 2 SHELL PASSES AND 4 TUBE PASSES. C IX=3, 1 SHELL CROSS FLOW AND 2 TUBE PASSES.	0
30 IX=JVALUE	

-74-

BNWL-308

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
C SET UP NUMBER OF PASSES FOR PROPER HEAT EXCHANGER.	
IF(IX) 503,503,500	
500 GO TO (501,502,1104),IX	
501 NSPX=1	
NTPX=2	
GO TO 1104	
502 NSPX=2	
NTPX=4	
GO TO 1104	
503 NSPX=1	
NTPX=1	
GO TO 1104	
C DOX IS IHX OUTSIDE TUBE DIAMETER, FT.	.08333
31 DOX=VALUE	
GO TO 1104	
C DIX IS IHX INSIDE TUBE DIAMETER, FT. .	.07517
32 DIX=VALUE	
GO TO 1104	
C PX IS IHX TUBE PITCH, FT.	.1146
33 PX=VALUE	
GO TO 1104	
C LAX IS IHX ACTUAL LENGTH PER TUBE, FT.	20.
34 LAX=VALUE	
GO TO 1104	
C LX IS IHX EFFECTIVE HEAT TRANSFER LENGTH PER TUBE, FT.	16.
35 LX=VALUE	
GO TO 1104	
C NSPX IS NUMBER OF IHX SHELL SIDE PASSES.	1
36 NSPX=JVALUE	
GO TO 1104	
C NTPX IS NUMBER OF IHX TUBE SIDE PASSES.	1
37 NTPX=JVALUE	
GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	RFX IS IHX COMBINED SHELL AND TUBE SIDE FOULING FACTOR, HR.SQ.FT.DEG.F./BTU.	1E-5
C	38 RFX=VALUE GO TO 1104	
C	IXCODE IS CONTROL INTEGER WHICH DENOTES LOCATION OF SECONDARY COOLANT IN THE IHX.	1
C	IXCODE=1, SECONDARY COOLANT IN TUBES.	
C	IXCODE=2, SECONDARY COOLANT IN SHELL.	
C	39 IXCODE=JVALUE GO TO 1104	
C	FRPX IS FRACTION OF PRIMARY COOLANT WHICH BYPASSES THE IHX.	.05
C	40 FRPX=VALUE GO TO 1104	
C	FRSX IS FRACTION OF SECONDARY COOLANT WHICH BYPASSES THE IHX.	.025
C	41 FRSX=VALUE GO TO 1104	
C	42 SPARE=0. GO TO 1104	
C	43 SPARE=0. GO TO 1104	
C	44 SPARE=0. GO TO 1104	
C	45 SPARE=0. GO TO 1104	
C	46 SPARE=0. GO TO 1104	
C	IV DHX DESIGN DATA.	
C	DOY IS OUTSIDE TUBE DIAMETER OF DHX, FT.	.0833333
C	47 DOY=VALUE GO TO 1104	
C	DIY IS INSIDE TUBE DIAMETER OF DHX, FT.	.075167
C	48 DIY=VALUE GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	49 DFY IS OUTSIDE DIAMETER OF DHX FINS, FT. DFY=VALUE GO TO 1104	.1875
C	50 PY IS DHX TUBE PITCH, FT. PY=VALUE GO TO 1104	.2292
C	51 NRY IS NUMBER OF ROWS OF TUBES PER PASS ON THE TUBE SIDE OF THE DHX. 2 NRY=JVALUE GO TO 1104	
C	52 ZFY IS DHX FIN THICKNESS, FT. ZFY=VALUE GO TO 1104	.002917
C	53 NFY IS NUMBER OF FINS PER FOOT OF FINNED LENGTH OF THE DHX TUBES. 96 NFY=JVALUE GO TO 1104	
C	54 LAY IS DHX ACTUAL LENGTH PER TUBE, FT. LAY=VALUE GO TO 1104	18.
C	55 LY IS DHX EFFECTIVE HEAT TRANSFER LENGTH PER TUBE, FT. LY=VALUE GO TO 1104	15.
C	56 RFIY IS FOULING FACTOR ON THE TUBE (SODIUM) SIDE OF THE DHX, HR.SQ.FT.DEG.F./BTU. RFIY=VALUE GO TO 1104	1.E-5
C	57 RFOY IS FOULING FACTOR ON THE SHELL (AIR) SIDE OF THE DHX, HR.SQ.FT.DEG.F./BTU. RFOY=VALUE GO TO 1104	.003
C	58 IVT IS CONTROL INTEGER TO DENOTE MATERIALS OF DHX BARE TUBES. 1 IVT=0 FOR CARBON STEEL. IVT=1 FOR STAINLESS STEEL.	
C	59 IVT=JVALUE GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
C IF IS CONTROL INTEGER WHICH DENOTES MATERIAL OF CONSTRUCTION OF C DHX FINS. C IF=1 FOR ALUMINUM. C IF=2 FOR STAINLESS STEEL. C IF=3 FOR MILD STEEL.	3
59 IF=JVALUE GO TO 1104	
C KVT IS CONTROL INTEGER TO DENOTE NUMBER OF SODIUM VALVES C USED IN SERIES FOR SHUTOFF AT THE DHX. C KVT=1 FOR ONE VALVE. C KVT=2 FOR TWO VALVES IN SERIES.	1
60 KVT=JVALUE GO TO 1104	
C CBVT IS AIR BUTTERFLY VALVE FLOW COEFFICIENT.	1.95
61 CBVT=VALUE GO TO 1104	
C PSMAX IS MAXIMUM ALLOWABLE NET STACK PRESSURE LOSS, IN.H2O	.50
62 PSMAX=VALUE GO TO 1104	
63 SPARE=0. GO TO 1104	
C PAFT IS DHX AIR FILTER PRESSURE LOSS, IN.H2O	0.4
64 PAFT=VALUE GO TO 1104	
C PDWT IS DHX AIR DUCT WORK PRESSURE LOSS, IN. H2O	0.1
65 PDWT=VALUE GO TO 1104	
C HST IS DHX STACK HEIGHT, FT.	100.
66 HST=VALUE GO TO 1104	
C NST IS NUMBER OF STACKS PER DHX.	3
67 NST=JVALUE GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	KFAN IS CONTROL INTEGER WHICH DENOTES TYPE OF FAN MOTOR DRIVE.	1
C	KFAN=1 FOR VERTICAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	KFAN=2 FOR VERTICAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
C	KFAN=3 FOR HORIZONTAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	KFAN=4 FOR HORIZONTAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
68	KFAN=JVALUE GO TO 1104	
C	KVANE IS CONTROL INTEGER TO DENOTE STATUS OF FAN INLET VANE.	2
C	KVANE=1, INLET VANE ASSEMBLY IS NOT IN SYSTEM.	
C	KVANE=2, INLET VANE ASSEMBLY IS IN SYSTEM.	
69	KVANE=JVALUE GO TO 1104	
C	ITPY IS CONTROL INTEGER WHICH DENOTES WHETHER THE	
C	NUMBER OF DHX TUBE PASSES IS ODD OR EVEN.	2
C	ITPY=1 FOR ODD NUMBER OF TUBE PASSES.	
C	ITPY=2 FOR EVEN NUMBER OF TUBE PASSES.	
70	ITPY=JVALUE GO TO 1104	
C	RATET(9) IS RATING OF AUXILIARY FURNACE, FRACTION OF LOOP HEAT DUTY .01	
71	RATET(9)=VALUE GO TO 1104	
72	SPARE=0. GO TO 1104	
73	SPARE=0. GO TO 1104	
74	SPARE=0. GO TO 1104	
75	SPARE=0. GO TO 1104	
76	SPARE=0. GO TO 1104	

INITIAL
VALUE

```
C
C
C
C
C
C
V COMMON IHX AND DHX DESIGN DATA.
C
C      CNUSS IS THE CONSTANT COEFFICIENT IN THE CORRELATION OF
C      THE NUSSELT NUMBER OF THE COOLANT IN THE TUBES.
C
77 CNUSS=VALUE
GO TO 1104
C
78 FRYSY IS CORRELATION COEFFICIENT FOR NUSSELT NUMBER DATA.
C
78 FRYSY=VALUE
GO TO 1104
79 SPARE=0.
GO TO 1104
80 SPARE=0.
GO TO 1104
81 SPARE=0.
GO TO 1104
82 SPARE=0.
GO TO 1104
C
VI PRIMARY LOOP DESIGN DATA.
C
C      KP IS CONTROL INTEGER WHICH DENOTES THE LOCATION OF PRIMARY PUMPS.
C      KP=1 FOR PRIMARY PUMP IN THE PRIMARY LOOP COLD LEG.
C      KP=2 FOR PRIMARY PUMP IN THE PRIMARY LOOP HOT LEG.
C
83 KP=JVALUE
GO TO 1104
C
C      KVALUE IS CONTROL INTEGER WHICH DESCRIBES PRIMARY PIPE AND FITTINGS.
C      KVALUE=1 FOR STRAIGHT PIPE.
C      KVALUE FROM 2 TO 12 FOR FITTING TYPE.
C
C      JVALUE DENOTES PRIMARY LOOP ZONE.
C      ZONE 1 IS REACTOR VESSEL TO HOT LEG PUMP LOCATION.
C      ZONE 2 IS HOT LEG PUMP LOCATION TO IHX.
C      ZONE 3 IS IHX TO COLD LEG PUMP LOCATION.
C      ZONE 4 IS COLD LEG PUMP LOCATION TO REACTOR VESSEL.
C
84 IF(KVALUE-1) 300,300,305
```

TABLE I. CONTINUED

IDENTIFICATION
INTEGER

PRIMARY LOOP STRAIGHT PIPE

300	GO TO (301,302,303,304),JVALUE	
	LPHA IS	
	LENGTH OF ZONE 1, FT.	40.
301	LPHA=VALUE	
	GO TO 1104	
302	LPHB IS	
	LENGTH OF ZONE 2, FT.	0.
	LPHB=VALUE	
	GO TO 1104	
303	LPCA IS	
	LENGTH OF ZONE 3, FT.	40.
	LPCA=VALUE	
	GO TO 1104	
304	LPCB IS	
	LENGTH OF ZONE 4, FT.	60.
	LPCB=VALUE	
	GO TO 1104	

PRIMARY LOOP FITTINGS

THE PROGRAM INITIAL VALUES ASSUME THE FOLLOWING PRIMARY LOOP HARDWARE

TYPE	ZONE 1	ZONE 2	ZONE 3	ZONE 4
2	90 DEG. L.R. ELBOW	3	0	2
3	90 DEG. S.R. ELBOW	0	0	0
4	45 DEG. FLOW	0	0	0
5	N X N REDUCER	0	0	0
6	THRU FLOW TEE	0	0	0
7	BRANCH FLOW TEE	0	0	0
8	OPEN CHECK VALVE	0	0	1
9	OPEN GATE VALVE	0	0	0
10	OPEN GLOBE VALVE	0	0	0
11	SUDDEN EXPANSION	1	0	1
12	SUDDEN CONTRACTION	1	0	0
13	OPEN BUTTERFLY VALVE	0	0	0
14	5.5 D RADIUS BEND	0	0	0

INITIAL
VALUE

TABLE I. CONTINUED

IDENTIFICATION INTEGER		
305	IF(KVALUE-13)	600,601,250
600	MVALUE=KVALUE	
	GO TO 602	
250	MVALUE=2	
	GO TO 602	
601	MVALUE=1	
602	GO TO (306,312,317,322),JVALUE	
306	IF(KLOBHA) 307,307,308	
307	KLOBHA=1	
	BKPHA=0.	
	JHA=0	
308	BKPHA=BKPHA+FLOAT(NVALUE)*VLOSS(MVALUE)	
	IF(KVALUE-7) 309,349,309	
349	KVALUE=6	
309	JHA=JHA+1	
	IF(JHA-25) 311,311,310	
310	WRITE (3,202) NVALUE,JVALUE,KVALUE,VALUE	
	GO TO 1104	
311	KHA(JHA)=KVALUE	
	NHA(JHA)=NVALUE	
	GO TO 1104	
312	IF(KLOBHB) 313,313,314	
313	KLOBHB=1	
	BKPHB=0.	
	JHB=0	
314	BKPHB=BKPHB+FLOAT(NVALUE)*VLOSS(MVALUE)	
	IF(KVALUE-7) 315,335,315	
335	KVALUE=6	
315	JHB=JHB+1	
	IF(JHB-25) 316,316,310	
316	KHB(JHB)=KVALUE	
	NHB(JHB)=NVALUE	
	GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
317 IF(KLOBCA) 318,318,319	
318 KLOBCA=1	
BKPCA=0.	
JCA=0	
319 BKPCA=BKPCA+FLOAT(NVALUE)*VLOSS(MVALUE)	
IF(KVALUE-7) 320,340,320	
340 KVALUE=6	
320 JCA=JCA+1	
IF(JCA-25) 321,321,310	
321 KCA(JCA)=KVALUE	
NCA(JCA)=NVALUE	
GO TO 1104	
322 IF(KLOBCB) 323,323,324	
323 KLOBCB=1	
BKPCB=0.	
JCB=0	
324 BKPCB=BKPCB+FLOAT(NVALUE)*VLOSS(MVALUE)	
IF(KVALUE-7) 325,345,325	
345 KVALUE=6	
325 JCB=JCB+1	
IF(JCB-25) 326,326,310	
326 KCB(JCB)=KVALUE	
NCB(JCB)=NVALUE	
GO TO 1104	
C EP IS ABSOLUTE ROUGHNESS OF PRIMARY PIPE, FT.	.00015
85 EP=VALUE	
GO TO 1104	
C ZPH IS PRIMARY LOOP ELEVATION DESCRIPTION, FT.	18.
C WHEN KP=1, ZPH IS HEIGHT OF REACTOR VESSEL COOLANT ABOVE	
C IXH THERMAL CENTERLINE.	
C WHEN KP=2, ZPH IS HEIGHT OF REACTOR VESSEL COOLANT ABOVE	
C PRIMARY PUMP IMPELLER.	
86 ZPH=VALUE	
GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	ZPC IS PRIMARY LOOP ELEVATION DESCRIPTION, FT.	-4.
C	WHEN KP=1, ZPC IS HEIGHT OF IHX THERMAL CENTERLINE ABOVE PRIMARY PUMP IMPELLER.	
C	WHEN KP=2, ZPC IS ZERO.	
87	ZPC=VALUE	
	GO TO 1104	
C	VMAX IS MAXIMUM ALLOWABLE PRIMARY COOLANT VELOCITY, FT./SEC.	35.
88	VMAX=VALUE	
	GO TO 1104	
C	DPMAX IS MAXIMUM ALLOWABLE STANDARD PRIMARY PIPE SIZE, NOM.IN.	42.
89	DPMAX=VALUE	
	GO TO 1104	
C	RPMP IS PRIMARY PUMP SPEED, RPM.	1170.
90	RPMP=VALUE	
	GO TO 1104	
C	PEP IS PRIMARY PUMP EFFICIENCY.	.75
91	PEP=VALUE	
	GO TO 1104	
C	KPUMP IS CONTROL INTEGER WHICH DENOTES TYPE OF PRIMARY PUMP DRIVE. 2	
C	KPUMP=1 FOR VERTICAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	KPUMP=2 FOR VERTICAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
C	KPUMP=3 FOR HORIZONTAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	KPUMP=4 FOR HORIZONTAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
92	KPUMP=JVALUE	
	GO TO 1104	
93	SPARE=U.	
	GO TO 1104	
94	SPARE=0.	
	GO TO 1104	
95	SPARE=0.	
	GO TO 1104	
96	SPARE=0.	
	GO TO 1104	

TABLE 1. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
97 SPARE=0. GO TO 1104	
C C VII CONFINEMENT PIPE DESIGN DATA. C	
C XAN IS ANNULUS WIDTH BETWEEN PRIMARY PIPE AND CONFINER PIPE, IN.	2.0
98 XAN=VALUE GO TO 1104	
C XCP IS THICKNESS OF CONFINER PIPE WALL, IN.	.375
99 XCP=VALUE GO TO 1104	
100 SPARE=0. GO TO 1104	
101 SPARE=0. GO TO 1104	
102 SPARE=0. GO TO 1104	
C C VIII SECONDARY LOOP DESIGN DATA. C	
C KS IS CONTROL INTEGER WHICH DENOTES LOCATION OF SECONDARY PUMP.	1
C KS=1, PUMP IS IN COLD LEG.	
C KS=2, PUMP IS IN HOT LEG.	
103 KS=JVALUE GO TO 1104	
C KVALUE IS CONTROL INTEGER WHICH DESCRIBES SECONDARY PIPE AND FITTINGS.	
C KVALUE=1 FOR STRAIGHT PIPE.	
C KVALUE FROM 2 TO 12 FOR FITTING TYPE.	
C JVALUE DENOTES SECONDARY LOOP ZONE.	
C ZONE 1 IS IHX TO HOT LEG PUMP LOCATION.	
C ZONE 2 IS HOT LEG PUMP LOCATION TO DHX.	
C ZONE 3 IS DHX TO COLD LEG PUMP LOCATION.	
C ZONE 4 IS COLD LEG PUMP LOCATION TO IHX.	
104 IF(KVALUE-1) 400,400,405	

TABLE I. CONTINUED

IDENTIFICATION
INTEGER

INITIAL
VALUE

C
C SECONDARY LOOP STRAIGHT PIPE.

C	400	GO TO (401,402,403,404),JVALUE	
		LS1 IS LENGTH OF ZONE 1, FT.	190.
	401	LS1=VALUE	
		GO TO 1104	
C		LS2 IS LENGTH OF ZONE 2, FT.	0.
	402	LS2=VALUE	
		GO TO 1104	
C		LS3 IS LENGTH OF ZONE 3, FT.	115.
	403	LS3=VALUE	
		GO TO 1104	
C		LS4 IS LENGTH OF ZONE 4, FT.	94.
	404	LS4=VALUE	
		GO TO 1104	

C
C SECONDARY LOOP FITTINGS.

C THE PROGRAM INITIAL VALUES ASSUME THE FOLLOWING SECONDARY LOOP HARDWARE

C	TYPE	ZONE 1	ZONE 2	ZONE 3	ZONE 4
C 2	90 DEG. L.R. ELBOW	2	0	2	5
C 3	90 DEG. S.R. ELBOW	0	0	0	0
C 4	45 DEG. ELBOW	0	0	0	0
C 5	N X N REDUCER	0	0	0	0
C 6	THRU FLOW TEE	2	0	2	0
C 7	BRANCH FLOW TEE	0	0	0	0
C 8	OPEN CHECK VALVE	0	0	0	0
C 9	OPEN GATE VALVE	0	0	0	0
C 10	OPEN GLOBE VALVE	0	0	0	0
C 11	SUDDEN EXPANSION	1	0	1	1
C 12	SUDDEN CONTRACTION	1	0	1	0
C 13	OPEN BUTTERFLY VALVE	0	0	0	0
C 14	5.5 D RADIUS BEND	0	0	0	0

TABLE I. CONTINUED

IDENTIFICATION
INTEGER

INITIAL
VALUE

```

405 IF(KVALUE-13) 603,604,251
603 MVALUE=KVALUE
    GO TO 605
251 MVALUE=2
    GO TO 605
604 MVALUE=1
605 GO TO (406,412,417,422),JVALUE
406 IF(KLOB1) 407,407,408
407 KLOB1=1
    BKS1=0.
    JS1=0
408 BKS1=BKS1+FLOAT(NVALUE)*VLOSS(MVALUE)
    IF(KVALUE-7) 409,439,409
439 KVALUE=6
409 JS1=JS1+1
    IF(JS1-25) 411,411,410
410 WRITE (3,203) NVALUE,JVALUE,KVALUE,VALUE
    GO TO 1104
411 KS1(JS1)=KVALUE
    NS1(JS1)=NVALUE
    GO TO 1104
412 IF(KLOB2) 413,413,414
413 KLOB2=1
    BKS2=0.
    JS2=0
414 BKS2=BKS2+FLOAT(NVALUE)*VLOSS(MVALUE)
    IF(KVALUE-7) 415,435,415
435 KVALUE=6
415 JS2=JS2+1
    IF(JS2-25) 416,416,410
416 KS2(JS2)=KVALUE
    NS2(JS2)=NVALUE
    GO TO 1104

```

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
417 IF(KLOB3) 418,418,419	
418 KLOB3=1	
BKS3=0.	
JS3=0	
419 BKS3=BKS3+FLOAT(NVALUE)*VLOSS(MVALUE)	
IF(KVALUE-7) 420,430,420	
430 KVALUE=6	
420 JS3=JS3+1	
IF(JS3-25) 421,421,410	
421 KS3(JS3)=KVALUE	
NS3(JS3)=NVALUE	
GO TO 1104	
422 IF(KLOB4) 423,423,424	
423 KLOB4=1	
BKS4=0.	
JS4=0	
424 BKS4=BKS4+FLOAT(NVALUE)*VLOSS(MVALUE)	
IF(KVALUE-7) 425,436,425	
436 KVALUE=6	
425 JS4=JS4+1	
IF(JS4-25) 426,426,410	
426 KS4(JS4)=KVALUE	
NS4(JS4)=NVALUE	
GO TO 1104	
C MATLS IS CONTROL INTEGER TO DENOTE SECONDARY LOOP MATERIALS	2
C OF CONSTRUCTION.	
C MATLS=1, SECONDARY LOOP MATERIAL IS CARBON STEEL.	
C MATLS=2, SECONDARY LOOP MATERIAL IS STAINLESS STEEL.	
105 MATLS=JVALUE	
GO TO 1104	
C ES IS ABSOLUTE ROUGHNESS OF SECONDARY PIPE, FT.	.00015
106 ES=VALUE	
GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	ZSC IS HEIGHT OF SECONDARY PUMP DISCHARGE ABOVE LEVEL OF	20.
C	PRIMARY COOLANT IN THE IHX, FT.	
107	ZSC=VALUE	
	GO TO 1104	
C	ZS IS HEIGHT OF SODIUM IN SURGE TANK ABOVE SECONDARY PUMP	5.
C	IMPELLER, FT.	
108	ZS=VALUE	
	GO TO 1104	
C	PMAXS IS MAXIMUM ALLOWABLE PRESSURE AT SECONDARY PUMP	300.
C	DISCHARGE, PSIG.	
109	PMAXS=VALUE	
	GO TO 1104	
C	VMAXS IS MAXIMUM ALLOWABLE SECONDARY COOLANT VELOCITY, FT./SEC.	25.
110	VMAXS=VALUE	
	GO TO 1104	
C	DMAXS IS MAXIMUM ALLOWABLE SECONDARY LOOP PIPE SIZE, NOM.IN.	42.
111	DMAXS=VALUE	
	GO TO 1104	
C	PMIN IS MINIMUM PRESSURE DIFFERENCE BETWEEN SECONDARY SYSTEM AND	25.
C	PRIMARY SYSTEM IN THE IHX, PSI.	
112	PMIN=VALUE	
	GO TO 1104	
C	RPMS IS SPEED OF SECONDARY SYSTEM PUMPS, RPM.	1170.
113	RPMS=VALUE	
	GO TO 1104	
C	ESP IS EFFICIENCY OF SECONDARY SYSTEM PUMPS.	.75
114	ESP=VALUE	
	GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	CPUMPS IS CONTROL INTEGER WHICH DENOTES TYPE OF SECONDARY PUMP MOTOR DRIVE.	2
C	CPUMPS=1 FOR VERTICAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	CPUMPS=2 FOR VERTICAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
C	CPUMPS=3 FOR HORIZONTAL SQUIRREL CAGE INDUCTION MOTOR DRIVES.	
C	CPUMPS=4 FOR HORIZONTAL WOUND-ROTOR INDUCTION MOTOR DRIVES.	
115	CPUMPS=JVALUE	
	GO TO 1104	
C	FTANK IS RATIO OF SECONDARY SURGE TANK VOLUME TO LOOP VOLUME.	.25
116	FTANK=VALUE	
	GO TO 1104	
C	KODE IS CONTROL INTEGER WHICH RELATES SIZE OF SECONDARY SYSWEM HOT AND COLD LEG PIPING.	1
C	KODE=1 WHEN ALL SECONDARY SYSTEM PIPE HAS THE SAME DIAMETER.	
C	KODE=2 WHEN SECONDARY SYSTEM COLD LEG PIPE IS ONE STANDARD SIZE SMALLER THAN THE HOT LEG PIPE.	
117	KODE=JVALUE	
	GO TO 1104	
118	SPARE=0.	
	GO TO 1104	
119	SPARE=0.	
	GO TO 1104	
120	SPARE=0.	
	GO TO 1104	
121	SPARE=0.	
	GO TO 1104	
122	SPARE=0.	
	GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
C C IX PROGRAM LIMITS DATA. C	
C TMXMIN IS MINIMUM IHX LOG MEAN TEMPERATURE DIFFERENCE TO BE C CONSIDERED, DEG.F.	25.
123 TMXMIN=VALUE GO TO 1104	
C DELTMX IS IHX LMTD INCREMENT, DEG.F.	25.
124 DELTMX=VALUE GO TO 1104	
C TMXMAX IS MAXIMUM IHX LOG MEAN TEMPERATURE DIFFERENCE TO BE C CONSIDERED, DEG.F.	175.
125 TMXMAX=VALUE GO TO 1104	
C TLOWER IS DIFFERENCE BETWEEN TERTIARY COOLANT HOT LEG C TEMPERATURE LOWER LIMIT AND AMBIENT TEMPERATURE, DEG.F.	75.
126 TLOWER=VALUE GO TO 1104	
C TDELTA IS INCREMENTAL TERTIARY COOLANT HOT LEG C TEMPERATURE, DEG.F.	25.
127 TDELTA=VALUE GO TO 1104	
C TUPPER IS DIFFERENCE BETWEEN SECONDARY COOLANT HOT LEG C TEMPERATURE AND UPPER LIMIT ON TERTIARY COOLANT HOT C LEG TEMPERATURE, DEG.F.	50.
128 TUPPER=VALUE GO TO 1104	
129 SPARE=0. GO TO 1104	
130 SPARE=0. GO TO 1104	
131 SPARE=0. GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
132 SPARE=0. GO TO 1104	
133 SPARE=0. GO TO 1104	
C C X COST DATA. C	
C HX1 IS REFERENCE IHX COST, DOLLARS PER SQ. FT.	3.6E5
134 HX1=VALUE GO TO 1104	
C HX2 IS REFERENCE IHX HEAT TRANSFER AREA, SQ. FT.	3000.
135 HX2=VALUE GO TO 1104	
C HX3 IS REFERENCE IHX COST EXPRESSION EXPONENT.	0.75
136 HX3=VALUE GO TO 1104	
C RATE(10) IS COST OF SODIUM, DOLLARS PER LB.	.22
137 RATE(10)=VALUE GO TO 1104	
C RATE(12) IS COST OF INSTALLED IHX BUILDING, DOLLARS PER CU. FT.	3.0
138 RATE(12)=VALUE GO TO 1104	
C CSTCNT IS INSTRUMENT COST, DOLLARS PER ITEM.	1500.
139 CSTCNT=VALUE GO TO 1104	
C RATE(1) IS COST OF DHX FINNED TUBING, DOLLARS PER LB.	1.3
140 RATE(1)=VALUE GO TO 1104	
C RATE(2) IS COST OF DHX UNFINNED TUBING, DOLLARS PER LB.	1.0
141 RATE(2)=VALUE GO TO 1104	
C RATE(3) IS COST OF INLET AIR FILTERS, DOLLARS PER 1000 CFM.	42.5
142 RATE(3)=VALUE GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	RATET(6) IS COST OF DHX HOUSING, DOLLARS PER CU. FT.	1.5
143	RATET(6)=VALUE GO TO 1104	
C	RATET(8) IS COST FACTOR FOR DHX DUCT WORK, FRACTION OF DHX HOUSING.	.1
144	RATET(8)=VALUE GO TO 1104	
C	RATET(11) IS COST OF INSTALLED SODIUM MANIFOLDS, DOLLARS PER LB.	9.82
145	RATET(11)=VALUE GO TO 1104	
C	PIPER IS UNIT COST OF INSTALLED PRIMARY PIPE, DOLLARS PER LB.	8.98
146	PIPER=VALUE GO TO 1104	
C	CPIPER IS UNIT COST OF INSTALLED CONFINER PIPE, DOLLARS PER LB. (INCLUDING HEATING AND INSULATION.)	12.1
147	CPIPER=VALUE GO TO 1104	
C	SPIPER IS UNIT COST OF INSTALLED SECONDARY PIPE, DOLLARS PER LB.	9.82
148	SPIPER=VALUE GO TO 1104	
C	PP1 IS REFERENCE PRIMARY PUMP COST, DOLLARS.	2.50E5
149	PP1=VALUE GO TO 1104	
C	PP2 IS REFERENCE PRIMARY PUMP HORSEPOWER, HP.	2000.
150	PP2=VALUE GO TO 1104	
C	PP3 IS PRIMARY PUMP COST EXPRESSION EXPONENT.	.57
151	PP3=VALUE GO TO 1104	
C	SP1 IS REFERENCE SECONDARY PUMP COST, DOLLARS.	1.75E5
152	SP1=VALUE GO TO 1104	
C	SP2 IS REFERENCE SECONDARY PUMP HORSEPOWER, HP.	1250.
153	SP2=VALUE GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
C SP3 IS SECONDARY PUMP COST EXPRESSION EXPONENT.	.57
154 SP3=VALUE	
GO TO 1104	
C SURGE1 IS REFERENCE SURGE TANK COST, DOLLARS.	4500.
155 SURGE1=VALUE	
GO TO 1104	
C SURGE2 IS REFERENCE SURGE TANK VOLUME, CU. FT.	133.67
156 SURGE2=VALUE	
GO TO 1104	
C SURGE3 IS REFERENCE SURGE TANK COST EXPRESSION EXPONENT.	.6
157 SURGE3=VALUE	
GO TO 1104	
C POWER IS ELECTRICAL POWER COST, DOLLARS PER KILOWATT-HOUR.	.0027
158 POWER=VALUE	
GO TO 1104	
C CI IS COST FACTOR TO CONVERT DIRECT CONSTRUCTION COST TO CAPITAL	1.65
C COST FOR DETERMINING IF ADDITIONAL INVESTMENT IS WORTHWHILE.	
159 CI=VALUE	
GO TO 1104	
160 SPARE=0.	
GO TO 1104	
161 SPARE=0.	
GO TO 1104	
162 SPARE=0.	
GO TO 1104	
163 SPARE=0.	
GO TO 1104	
164 SPARE=0.	
GO TO 1104	

TABLE 1. CONTINUED

IDENTIFICATION INTEGER		INITIAL VALUE
C	X1 PROGRAM LOGIC DATA.	
C	KASE IS CONTROL INTEGER WHICH PERMITS SPECIFIC PRIMARY LOOP PIPE SIZES TO BE COSTED.	0
C	KASE=0, PROGRAM WILL SIZE PIPE BASED ON OPTIMUM COST.	
C	KASE=1, PROGRAM WILL COST PIPE FOR ONE SIZE. PIPING DIAMETERS SHOULD BE SPECIFIED AS ITEM 49, WITH ZONE DESIGNATED AS KVALUE.	
165	KASE=JVALUE	
	IF(KVALUE) 1104,1104,327	
327	GO TO (328,329,330,331),KVALUE	
C	DIPHA IS NOMINAL DIAMETER OF ZONE 1 PIPE, IN.	20.
328	DIPHA=VALUE	
	GO TO 1104	
C	DIPHB IS NOMINAL DIAMETER OF ZONE 2 PIPE, IN.	20.
329	DIPHB=VALUE	
	GO TO 1104	
C	DIPCA IS NOMINAL DIAMETER OF ZONE 3 PIPE, IN.	20.
330	DIPCA=VALUE	
	GO TO 1104	
C	DIPCB IS NOMINAL DIAMETER OF ZONE 4 PIPE, IN.	20.
331	DIPCB=VALUE	
	GO TO 1104	
C	KASES IS CONTROL INTEGER WHICH PERMITS SPECIFIC SECONDARY LOOP PIPE SIZES TO BE COSTED.	0
C	KASES=0, PROGRAM WILL SIZE PIPE BASED ON OPTIMUM COST.	
C	KASES=1, PROGRAM WILL COST PIPE FOR ONE SIZE. PIPING DIAMETERS SHOULD BE SPECIFIED AS ITEM 73, WITH ZONE DESIGNATED AS KVALUE.	
166	KASES=JVALUE	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
IF(KVALUE) 1104,1104,450	
450 GO TO (451,452,453,454),KVALUE	
C D1, IS NOMINAL DIAMETER OF ZONE 1 PIPE, IN.	20.
451 D1=VALUE	
GO TO 1104	
C D2, IS NOMINAL DIAMETER OF ZONE 2 PIPE, IN.	20.
452 D2=VALUE	
GO TO 1104	
C D3, IS NOMINAL DIAMETER OF ZONE 3 PIPE, IN.	20.
453 D3=VALUE	
GO TO 1104	
C D4, IS NOMINAL DIAMETER OF ZONE 4 PIPE, IN.	20.
454 D4=VALUE	
GO TO 1104	
C LIMIT IS CONTROL INTEGER TO EXCLUDE LOOP SIZING ROUTINES.	0
C LIMIT=0, LOOP PIPES WILL BE SIZED AND COST ESTIMATED.	
C LIMIT=1, LOOP SIZING ROUTINES ARE BY-PASSED.	
167 LIMIT=JVALUE	
GO TO 1104	
C IDEBUG IS CONTROL INTEGER FOR DEBUG PRINTOUT OF PIPE SIZING ROUTINES.	0
C IDEBUG=0 FOR NO PRINTOUT.	
C IDEBUG=1 FOR DEBUG PRINTOUT.	
168 IDEBUG=JVALUE	
GO TO 1104	
169 SPARE=0.	
GO TO 1104	
170 SPARE=0.	
GO TO 1104	
171 SPARE=0.	
GO TO 1104	
172 SPARE=C.	
GO TO 1104	
173 SPARE=0.	
GO TO 1104	

TABLE I. CONTINUED

IDENTIFICATION INTEGER	INITIAL VALUE
174 SPARE=0. GO TO 1104	
175 SPARE=0. GO TO 1104	
504 KLUB=1	
1104 CONTINUE IF(KLUB) 1105,1105,1106	
C C C	
SET UP ULTIMATE CONDITIONS IF NOT SPECIFIED AS INPUT.	
1105 TPCU=TPC TPHU=TPH QU=Q FXU=FX PTANKU=PCORE	
1106 CONTINUE GO TO (1108,1107),KP	
1107 ZPC=0.	
1108 CONTINUE RETURN END	

TABLE I. INPUT DATA FOR ILLUSTRATIVE EXAMPLE ON THE OPTIMIZATION OF DIX EXHAUST AIR TEMPERATURE

INPUT VARIABLE		PROGRAM INPUT (1), (2)		No. IBM Card Column	
<u>PROCESS CONDITIONS</u>					
Initial Design Phase:					
Reactor Power to System, MW		300.		1	500.
Primary Coolant Temperature:					
Hot Leg, °F		775.		2	775.
Cold Leg, °F		500.		3	500.
Ratio Temperature Rise Secondary to Primary Coolants		1.0		4	1.
Reactor Tank Pressure Loss, psi		75.0		5	75.
Ultimate Design Phase:					
Reactor Power to System, MW		400.		6	400.
Primary Coolant Temperature:					
Hot Leg, °F		975.		7	975.
Cold Leg, °F		700.		8	700.
Ratio Temperature Rise Secondary to Primary Coolants		1.0		9	1.
Reactor Tank Pressure Loss, psi		100.		10	100.
Process Data Common to Both Phases:					
Ambient Air Temperature, °F		100.		11	100.
Atmospheric Pressure, psia		13.7		12	13.7
<u>SYSTEM DESIGN DATA</u>					
Number Parallel Cooling Circuits		3, 1		13	3
Maximum Acceptable Payout Period, yrs		10.		14	10.
Time Operating Efficiency, Fraction		.75		15	.75
Number Instrument Controllers and/or Recorders Per Loop		10, 1		16	10
Building Height at IHX Location, ft		60.		17	60.
Maximum Allowable Reactor Tank Vapor Space Pressure, psig		5.		18	5.
<u>IHX DESIGN DATA</u>					
Type Exchanger		Counter Flow CI=0		19	
Tube OD, ft		0.0833 (1 in.)		20	0.0833
Tube ID, ft		0.07517 (.902 in.)		21	0.07517
Tube Pitch, ft		0.1146 (1.375 in.)		22	0.1146
Actual Tube Length Per Pass, ft		20.		23	20.
Effective Tube Length For Heat Transfer, ft		16.		24	16.
(1) Numbers in Parenthesis are Equivalent Values in More Common Units, But These Values Must not be Used as Inputs. (2) CI Denotes Control Integer and I Denotes Integer Input.					

TABLE 1. INPUT DATA FOR ILLUSTRATIVE EXAMPLE ON THE OPTIMIZATION OF DHX EXHAUST AIR TEMPERATURE - CONTINUED

TABLE I. INPUT DATA FOR ILLUSTRATIVE EXAMPLE ON THE OPTIMIZATION OF DHX EXHAUST AIR TEMPERATURE - CONTINUED																										
INPUT VARIABLE	PROGRAM INPUT (1), (2)	No. IBM Card Column																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
<u>IHX DESIGN DATA (CONTINUED)</u>																										
Number of Shell Side Passes	1, I	36																								
Number of Tube Side Passes	1, I	37																								
Combined Shell and Tube Side Fouling, hr-sq ft-°F/Btu	0.	38																								
Location of Secondary Coolant	Tube Side CI = 1	39																								
Fraction of Primary Coolant Bypassing Bundle	0.05	40																								
Fraction of Secondary Coolant Bypassing Bundle	0.025	41																								
<u>DHX DESIGN DATA</u>																										
Base Tube OD, ft	0.0833 (1 in.)	47																								
Base Tube ID, ft	0.07517 (0.902in.)	48																								
Fin OD, ft	0.1875 (2.25in.)	49																								
Tube Pitch, ft	0.2292 (2.75in.)	50																								
Number of Tube Rows/Tube Pass	2, I	51																								
Fin Thickness, ft	0.002917(0.035in.)	52																								
Number of Fins/Unit Length, per ft	96, I	53																								
Base Tube Length Per Pass, ft	18.	54																								
Finned Length Per Pass, ft	15.	55																								
Tube Side Fouling Factor, hr-sq ft-°F/Btu	0.	56																								
Shell Side Fouling Factor, hr-sq ft-°F/Btu	0.003	57																								
Base Tube Material	SS CI = 1	58																								
Fin Material	CS CI = 3	59																								
Number of Sodium Valves in Series at Manifolds for Isolation	2, I	60																								
Butterfly Valve Flow Coefficient	1.95	61																								
Maximum Allowable Net Stack Pressure Loss, in. Water	0.5	62																								
Air Filter Pressure Loss Allowance, in. Water	0.4	64																								
Air Duct Pressure Loss Allowance, in. Water	0.1	65																								
Exhaust Stack Height, ft	100.	66																								
Number of Exhaust Stacks Per DHX	3, I	67																								
Type Fan Motor	Horizontal Squirrel Cage Induct CI=3	68																								
Are Fan Inlet Vanes Used?	Yes CI = 2	69																								
Even or Odd Number of Tube Passes	Even CI = 2	70																								
Auxiliary Furnace Duty as Fraction of DHX Duty	0.01	71																								

(1) Numbers in Parenthesis are Equivalent Values in More Common Units, But These Values Must not be Used as Inputs.

(2) CI Penotes Control Integer and I Denotes Integer Input.

- (1) Numbers in Parenthesis are Equivalent Values in More Common Units, But These Values Must Not be Used as Inputs.
 (2) CI Denotes Control Integer and I Denotes Integer Input.

TABLE I. INPUT DATA FOR ILLUSTRATIVE EXAMPLE ON THE OPTIMIZATION OF DHX EXHAUST AIR TEMPERATURE - CONTINUED

INPUT VARIABLE		No. IBM Card Column									
PROGRAM INPUT (1), (2)		1	2	3	4	5	6	7	8	9	10
COMMON IHX AND DHX DESIGN DATA											
Constant α For Inside Film Correlation Correlation Coefficient to Account for Scatter of Experimental Data, Deviation Fraction		5.									
		.1									
PRIMARY LOOP DESIGN DATA											
Pump Location											
Straight Pipe Lengths, ft											
Hot Leg A											
Hot Leg B											
Cold Leg A											
Cold Leg B											
Type and Number of Fittings in Hot Leg A:											
90° Long Radius Ells											
Sudden Contractions											
Type and Number Fittings in Hot Leg B:											
90° Long Radius Ells											
90° Short Radius Ells											
Check Valves											
Sudden Expansions											
Type and Number Fittings in Cold Leg A:											
90° Long Radius Ells											
45° Ells											
Sudden Expansions											
Sudden Contractions											
Type and Number Fittings in Cold Leg B:											
None											
Absolute Pipe Roughness, ft											
Height Reactor Coolant Level Above Pump Impeller, ft											
Height Reactor Coolant Level Above IHX											
Thermal Centerline, ft											
Height IHX Thermal Centerline Above Pump Impeller, ft											
Maximum Allowable Coolant Velocity, ft/sec											
Maximum Allowable Pipe Size, in. Nominal											
Pump Speed, rpm											
Pump Efficiency, Fraction											
Type Pump Motor											

(1) Numbers in Parenthesis are Equivalent Values in More Common Units, But These Values Must not be Used as Inputs.
 (2) CI Denotes Control Integer and I Denotes Integer Input.

TABLE I. INPUT DATA FOR ILLUSTRATIVE EXAMPLE ON THE OPTIMIZATION OF DHX EXHAUST AIR TEMPERATURE - CONTINUED

INPUT VARIABLE		PROGRAM INPUT (1), (2)	No. IBM Card Column									
CONFINEMENT PIPE DATA												
Annulus Between Primary Pipe and Confinement Pipe, in.		2.										
Confinement Pipe Wall Thickness, in.		0.375										
SECONDARY LOOP DESIGN DATA												
Pump Location												
Straight Pipe Lengths, ft												
Hot Leg A												
Hot Leg B												
Cold Leg A												
Cold Leg B												
Type and Number Fittings in Hot Leg A:												
90° Long Radius Ells												
90° Short Radius Ells												
45° Ells												
Open Gate												
Sudden Contractions												
Type and Number Fittings in Hot Leg B:												
None												
Type and Number Fittings in Cold Leg A:												
90° Long Radius Ells												
90° Short Radius Ells												
45° Ells												
Sudden Expansions												
Type and Number Fittings in Cold Leg B:												
90° Long Radius Ells												
45° Ells												
Open Gate Valves												
Sudden Expansions												
Materials of Construction												
Absolute Pipe Roughness, ft												
Height of Pump Discharge Above Level of Primary Coolant in the IHX, ft												
Height of Coolant Level in Surge Tank Above Pump Impeller, ft												
Maximum Allowable Pump Discharge Pressure, psig												
Maximum Allowable Coolant Velocity, ft/sec												
Maximum Allowable Pipe Size, In. Nominal												
Minimum Difference of Secondary System Pressure Above Primary												
System Pressure in the IHX, psi												
Pump Speed, rpm												

(1) Numbers in Parenthesis are Equivalent Values in More Common Units, But These Values Must not be Used as Inputs.
 (2) CI Denotes Control Integer and I Denotes Integer Input.

H. Nomenclature

		Units
A	Surface or flow area	sq ft
b	A constant	
c	Specific heat	Btu/(lb)(°F)
C_v	Valve coefficient	
D	Diameter	ft
f	Moody friction factor	
F	Log-mean-temperature correction	
g	Gravity	ft/sec ²
g_c	Dimensional constant	ft/sec ²
G	Mass velocity	lb/(sec)(sq ft)
h	Film coefficient for heat transfer	Btu/(hr)(sq ft)(°F)
j	Sieder and Tate heat transfer factor	
J	Mechanical equivalent of heat	ft-lb/Btu
k	Thermal conductivity	Btu/(hr)(sq ft)(°F/ft)
K	Pipe fitting velocity head factor	
L	Length	
m	A constant	ft
N	Number of tubes or tube passes	
Nu	Nusselt number, hD/k	
p	Pitch	ft
P	Pressure	psig or psia
Pe	Peclet number, $DV \rho c/k$	
Pr	Prandtl number, $c \mu/k$	
Δp	Pressure loss or drop	psi
q	Heat duty	Btu/hr
r_m	Radius of circle of same cross-sectional area as a hexagon circumscribed about one tube of an infinite array of tubes on equilateral triangular pitch in which the hexagon represents the flow cross section assignable to that particular tube	ft

		Units
R	Heat Transfer resistance or Gas constant	hr-sq ft-°F/Btu or ft/°Rankine
Re	Reynolds number, $DV\rho/\mu$	
T	Temperature	°F or Degrees Absolute
TDH	Pump total dynamic heat	ft
U	Overall heat transfer coefficient	Btu/(hr)(sq ft)(°F)
v	Volume	cu ft
V	Velocity	ft/sec
W	Weight flow rate	lb/sec
W_e	External work added to a system	ft-lb(force)/lb
X	Distance or length	ft
Z	Elevation	ft
<u>Greek Letters</u>		
α	A constant	
δ	A constant	
Δ	A difference	
ϵ	Absolute roughness of pipe	ft
ϵ_M	Eddy diffusivity for momentum transfer	sq ft/hr
η	Pump specific speed	$\frac{\text{lb(mass)}}{\text{or lb(mass)}}/(\text{ft})(\text{hr})$ $\frac{\text{lb(mass)}}{\text{lb(mass)}}/(\text{ft})(\text{sec})$
μ	Viscosity	sq ft/hr lb/cu ft
ν	Kinematic viscosity	
ρ	Density	
σ	Pump cavitation parameter	
ϕ	$(\mu/\mu_w)^{1/4}$	
$\bar{\psi}$	Average value of ratio of diffusivity for heat transfer to diffusivity for momentum transfer.	
Ω	Fin efficiency factor	
<u>Subscripts</u>		
c	Cold or clean	
e	Equivalent diameter	
f	Flow	

Units

h Hot
i Inside or Inlet
M Mean
o Outside or Outlet
p Passes or Primary
s Surface or Secondary
t Tube
w Wall

APPENDIX A
PROGRAMMED ENGINEERING DATA

Various engineering and cost data are locked into the program in the sense that these values cannot be changed by manipulation of input, but require a recompilation of a source routine in order to make a change. Most of the data are incorporated as tabular functions in the program, although in some instances an algebraic relationship is used. This appendix sets forth all such data and references both the sources of the data and the specific routine in ADOPT where the data are located. Where feasible, the data are presented graphically in this appendix even though they are utilized as a tabular function in ADOPT.

1. Thermal Properties

The thermal properties of both sodium and air (at atmospheric pressure) and the thermal conductivity of some fin materials are located in Block Data Routine PROPS.

Figure A-1. Thermal Properties of Liquid Sodium

Figure A-2. Vapor Pressure of Liquid Sodium

Figure A-3. Thermal Properties of Air

Figure A-4. Thermal Conductivity of Aluminum and Steel

2. Heat Exchanger Data

Most properties which are dependent upon the geometry of a heat exchanger are located in Block Data Routine XDATA. The thermal conductivity of stainless steel (Fig. A-4) is used in equation form in the main ADOPT routine and in subroutine FINALS. The Jameson and Gunter and Shaw relationships for transverse fins (Fig. A-9) are used in equation form in subroutine UYCOEF. The shell-side friction factor is used in equation form in subroutines FINALS and XVALUE. The plenum height data are located in subroutine FVALUE. One precaution must be noted if the log-mean-temperature difference correctors are changed: not only must the tabular values be changed in XDATA, but in addition, any change in the temperature drop ratio parameter R must also be included in function PHIF.

Figure A-5	Log-Mean-Temperature Difference Corrector for a One-Shell Pass, Two or More-Tube-Passes Heat Exchanger
Figure A-6	Log-Mean-Temperature Difference Corrector for a Two-Shell Pass, Four or More-Tube-Passes Heat Exchanger
Figure A-7	Log-Mean-Temperature Difference Corrector for a One-Shell Pass (Crossflow), Two-Tube-Passes Heat Exchanger
Figure A-8	Efficiency of Annular Fins of Constant Thickness
Figure A-9	Transverse-Fin Heat Transfer and Pressure Drop
Figure A-10	Nusselt Number for Laminar Flow Through Rod Bundles
Figure A-11	Maximum Eddy Reynolds Number Corrector Function
Figure A-12	Shell-Side Friction Factors for Bundles with 25-Percent Cut Segmented Baffles
Table A-1	Plenum Heights Associated with Dump Heat Exchanger Fan Size

3. Pipe And Fitting Data

Data for straight pipe and fittings is located in Block Data Routine PIPE.

Table A-2	Straight Pipe Data
Table A-3	Velocity Head Factors of Pipe Fittings
Table A-4	Weight of Standard Weight Pipe Fittings

4. Pump Data

The specific speed for primary and secondary pumps are used in equation form in subroutines PVALUE and SVALUE.

Figure A-13. Cavitation Parameter for 80-Percent Pump Efficiency

5. Fan Data

Fan data consists of selection parameters and fan efficiency curves for fans which range in size from 33-inches to 84-inches. The fan size selection data are used in equation form in subroutine FVALUE. The fan-type selection data and the efficiency data are located in function FCOST.

Table A-5	Axial Flow Fan Selection
Figure A-14	Fan Selection Diagram
Figure A-15	Efficiency of 84-E Fan at 870 RPM
Figure A-16	Efficiency of 84-E Fan at 1170 RPM
Figure A-17	Efficiency of 72-E Fan at 870 RPM
Figure A-18	Efficiency of 72-E Fan at 1170 RPM
Figure A-19	Efficiency of 48-B Fan at 1750 RPM
Figure A-20	Efficiency of 48-D Fan at 1750 RPM
Figure A-21	Efficiency of 38-A Fan at 1750 RPM
Figure A-22	Efficiency of 38-C Fan at 1750 RPM
Figure A-23	Efficiency of 38-A Fan at 1750 RPM
Figure A-24	Efficiency of 33-C Fan at 1750 RPM

6. Motor Data

Standard motor power rating data are located in function DRIVE.

Table A-6	Standard Motor Power Ratings
-----------	------------------------------

7. Miscellaneous Data

Some miscellaneous pressure drop data and densities are scattered throughout the program; these data and their locations are referenced in Table A-7.

Table A-7	Miscellaneous Programmed Engineering Data
-----------	---

8. Cost Data

Effort was made to have all cost data as input parameters to expedite rate changes; however, some data are locked into an array of fixed size and were more readily included as tabular functions. Fan costs occur in function FCOST, as do costs of equipment which are dependent upon fan size; motor costs occur in function DRIVE; auxiliary furnace costs are located in function TVALUE in equation form; off-gas stack costs are located in block data routine PRICES; and valve costs occur in function VLV CST.

Table A-8	Axial Flow Fan Costs
Figure A-25	Cost of Horizontal Squirrel Cage Induction Motor
Figure A-26	Cost of Horizontal Wound-Rotor Induction Motor
Figure A-27	Cost of Vertical Squirrel Cage Induction Motor

- Figure A-28 Cost of Vertical Wound-Rotor Induction Motor
- Figure A-29 Cost of Equipment Which is Dependent Upon Fan Size
- Figure A-30 Cost of Auxiliary Furnace
- Figure A-31 Cost of Off-Gas Stack
- Figure A-32 Cost of Butterfly Valve in Sodium Application
- Figure A-33 Cost of Check Valve in Sodium Application
- Figure A-34 Cost of Gate Valve in Sodium Application
- Figure A-35 Cost of Globe Valve in Sodium Application

TABLE A-1
Plenum Heights Associated With Dump Heat Exchanger Fan Size

<u>Fan Size, Inches</u>	<u>Lower Plenum Height, Ft.</u>	<u>Upper Plenum Height, Ft.</u>
33	7	4
38	7	4
48	8	5
72	9	6
84	10	7

TABLE A-2
Straight-Pipe Data

<u>Nominal Size, In.</u>	<u>Flow Area, Sq. Ft.</u>	<u>Wall Thickness Ft.</u>	<u>Inside Diameter, Ft.</u>	<u>Unit Weight Lbs./Ft.</u>
1	.0060	.0111	.0874	1.679
1.5	.0141	.0121	.1342	2.718
2	.0233	.0128	.1722	3.653
3	.0513	.0180	.2557	7.580
4	.0884	.0197	.3355	10.79
6	.2007	.0233	.5054	18.98
8	.3472	.0268	.6651	28.56
10	.5479	.0304	.8350	40.50
12	.7854	.0338	1.000	49.60
14	.9546	.0312	1.104	54.60
16	1.269	.0312	1.271	62.60
18	1.623	.0312	1.437	70.60
20	2.021	.0312	1.604	78.60
24	2.951	.0312	1.937	94.60
30	4.667	.0312	2.437	118.7
36	6.681	.0417	2.917	189.6
42	9.164	.0417	3.417	226.3

TABLE A-3
Velocity Head Factors Of Pipe Fittings

<u>Fitting</u>	<u>Factor</u>
90° Long Radius Elbow or 5.5 x D Bend	0.315
90° Short Radius Elbow	0.455
45° Elbow	0.208
Reducer (N x N One Size)	0.040
Through Flow Tee	0.377
Branch Flow Tee	1.360
Open Check Valve	2.320
Open Gate Valve	0.208
Open Globe Valve	9.550
Open Butterfly Valve	0.263
Sudden Contraction	1.000
Sudden Expansion	0.500

Ref: Tube Turn, Piping Engineering, 1951, p. 24.

TABLE A-4
Weight Of Standard Weight Pipe Fittings

(Weights given in pounds.)

<u>Nominal Size, Inches</u>	<u>90° Long Radius Elbow</u>	<u>90° Short Radius Elbow</u>	<u>45° Elbow</u>	<u>NxN-1 Reducer</u>	<u>Tee</u>	<u>5.5D Radius Bend</u>
1	0.40	0.25	0.25	0.40	0.75	1.33
1.5	0.90	0.56	0.40	0.62	2.00	3.23
2	1.60	1.00	0.81	0.90	3.50	5.80
3	5.00	3.00	2.63	1.80	7.00	18.0
4	9.00	6.25	4.50	3.38	12.0	34.2
6	24.5	18.0	12.0	8.50	34.0	90.2
8	50.0	34.0	23.0	13.25	55.0	181.0
10	88.0	58.0	43.0	22.0	85.0	321.0
12	125.0	80.0	62.0	28.0	120.0	473.0*
14	160.0	105.0	80.0	60.0	165.0	608.0*
16	206.0	132.0	100.0	71.0	195.0	792.0*
18	260.0	167.0	126.0	85.0	200.0	1128.0*
20	320.0	210.0	160.0	124.0	250.0	1248.0*
24	460.0	298.0	238.0	150.0	360.0	1804.0*
30	700.0	464.0	240.0	220.0	560.0	2816.0*
36	1350.0	890.0	450.0	450.0	1070.0	5434.0*
42	1900.0	1250.0	630.0	640.0	1900.0	7513.0*

*These data may be impractical, but are necessary to complete table for programming purposes.

TABLE A-5
Axial Flow Fan Selection

<u>Air Rate Per Fan cfm</u>	<u>Fan Size In.</u>	<u>Equivalent Fan Pressure In. Water</u>	<u>Fan Speed rpm</u>	<u>Fan Type</u>
0 to 20,000	33	≤ 4	1750	A-Low Pressure
		4-6	1750	C-High Pressure
20,000 to 40,000	38	≤ 4	1750	A-Low Pressure
		4-8	1750	C-High Pressure
40,000 to 90,000	48	≤ 5	1750	B-Low Pressure
		5-11	1750	D-High Pressure
90,000 to 160,000	72	≤ 4	870	E
		4-9	1170	E
160,000 to *	84	≤ 3	870	E
		3-5	870 or 1170**	E
		5-*	1170	E

* Refer to Figure A-14 for upper limits.

**In this pressure range, both speeds are considered and selection is made based on least system cost.

TABLE A-6
Standard Motor Horsepower Ratings

5.0	150.	1250.
7.5	200.	1500.
10.	250.	1750.
15.	300.	2000.
20.	350.	2250.
25.	400.	2500.
30.	450.	3000.
40.	500.	3500.
50.	600.	4000.
60.	700.	4500.
75	800.	5000.
100.	900.	5500.
125.	1000.	6000.

TABLE A-7
Miscellaneous Programmed Engineering Data

<u>Name</u>	<u>Definition</u>	<u>Location</u>
FOURF	Moody Friction Factor	FINALS, TVALUE, XVALUE
FREEZE	Density of Sodium at Freezing Point	INVEST, SCOST, THERMY, TVALUE, XVALUE
RHOMY	Density of DHX Fins	THERMY

TABLE A-8
Axial Flow Fan Costs

<u>Fan Type</u>	<u>Fan Speed</u> rpm	<u>Fan Cost</u> Dollars
84-E	870	9300
84-E	1170	9300
72-E	870	6010
72-E	1170	6010
48-B	1750	1968
48-D	1750	2490
38-A	1750	1043
38-C	1750	1350
33-A	1750	865
33-C	1750	1171

FIGURE A-1

Thermal Properties of Liquid Sodium

FIGURE A-2

Vapor Pressure of Liquid Sodium

FIGURE A-3
Thermal Properties of Air

FIGURE A-4

Thermal Conductivity of Aluminum and Steel

Ref. Standards of Tubular Exchanger Manufacturers
Association; 4th. Ed; 1959, p. 66

FIGURE A-5

Log-Mean-Temperature-Difference Corrector for a 1 Shell Pass, 2 or More Tube Passes
Heat Exchanger

Ref. Standards of Tubular Exchanger Manufacturers Association; 4th Ed; 1959; p. 68

FIGURE A-6

Log-Mean-Temperature-Difference Corrector for a 2 Shell Passes, 4 or More Tube Passes Heat Exchanger

FIGURE A-7

Log-Mean-Temperature-Difference Corrector for a 1 Shell Pass (Cross-Flow), 2 Tube Passes Heat Exchanger

FIGURE A-8

Efficiency of Annular Fins of Constant Thickness

$$De_v = (4) \text{ (Net Free Volume / Frictional Surface)}$$

$$De = \frac{(2) \text{ (Fin Area + Bare Tube Area)}}{(\pi) \text{ (Projected Perimeter)}}$$

$$\Delta P = \frac{(f) (G_s^2) (L)}{(5.22 \times 10^{10}) (De'_v) (S) (\phi_s)} \left(\frac{De'_v}{S_T} \right)^{0.4} \left(\frac{S_L}{S_T} \right)^{0.6}$$

FIGURE A-9

Transverse-Fin Heat Transfer and Pressure Drop

FIGURE A-10

Nusselt Number for Laminar Flow Through Rod Bundles

ϕ , Maximum Eddy Reynolds Number Corrector Function

FIGURE A-11

Maximum Eddy Reynolds Number Corrector Function

FIGURE A-12

Shell Side Friction Factors for Bundles with 25% Cut Segmented Baffles

FIGURE A-13

Cavitation Parameter for 80% Pump Efficiency

FIGURE A-14

Fan Selection Diagram

FIGURE A-15

Efficiency of 84-E Fan at 870 RPM

FIGURE A-16

Efficiency of 84-E Fan at 1170 RPM

FIGURE A-17

Efficiency of 72-E Fan at 870 RPM

FIGURE A-18

Efficiency of 72-E Fan at 1170 RPM

FIGURE A-19

Efficiency of 48-B Fan at 1750 RPM

FIGURE A-20

Efficiency of 48-D Fan at 1750 RPM

FIGURE A-21

Efficiency of 38-A Fan at 1750 RPM

FIGURE A-22

Efficiency of 38-C Fan at 1750 RPM

Air Flow Rate, 1000 cfm

FIGURE A-23

Efficiency of 33-A Fan at 1750 RPM

FIGURE A-26

Cost of Horizontal Wound-Rotor Induction Motor

FIGURE A-27

Cost of Vertical Squirrel Cage Induction Motor

FIGURE A-28

Cost of Vertical Wound-Rotor Induction Motor

FIGURE A-29

Cost of Equipment Which is Dependent upon Fan Size

Furnace Rating, MW

FIGURE A-30

Cost of Auxiliary Furnace

Stack Height, Ft.

FIGURE A-31

Cost of Off-Gas Stack

FIGURE A-32

Cost of Butterfly Valve in Sodium Application

FIGURE A-33

Cost of Check Valve in Sodium Application

FIGURE A-34

Cost of Gate Valve in Sodium Application

FIGURE A-35

Cost of Globe Valve in Sodium Application

APPENDIX B
PROGRAM EXAMPLE

The Tables in this appendix are copies of the input and calculated data for the illustrative example discussed in paragraph IV.F.2. The Tables are copies of the actual program listings except for the Table titles.

TABLE B-1. BASIC PROCESS AND IHX INPUT DATA.

AIR DUMP OPTIMIZATION AND PROCESS DATA PROGRAM - ADOPT

BASIC PROCESS INPUT DATA

AMBIENT TEMPERATURE IS .1000000+03 DEG.F. AND AMBIENT PRESSURE IS .1370000+02 PSIA.

THERE ARE 3 PARALLEL COOLING CIRCUITS AND/OR 3 INTERMEDIATE HEAT EXCHANGERS TO DIVIDE THE TOTAL HEAT LOAD.

MAIN HEAT REMOVAL SYSTEM PARAMETERS

	STARTUP	ULTIMATE
PRIMARY COOLANT HOT LEG TEMPERATURE, DEG.F. ---	.7750000+03	.9750000+03
PRIMARY COOLANT COLD LEG TEMPERATURE, DEG.F. --	.5000000+03	.7000000+03
TOTAL DUTY, BTU/HR. -----	.1024000+10	.1365200+10
RATIO OF TEMPERATURE RISE OF SECONDARY COOLANT TO TEMPERATURE RISE OF PRIMARY COOLANT --	.1000000+01	.1000000+01
REACTOR TANK PRESSURE DROP, PSI. -----	.7500000+02	.1000000+03

ACCEPTIBLE PAYOUT PERIOD ON INCREMENTAL INVESTMENT IS .1000000+02 YEARS

INTERMEDIATE HEAT EXCHANGER INPUT PARAMETERS

THE PRIMARY COOLANT IS ON THE SHELL SIDE AND THE SECONDARY COOLANT IS ON THE TUBE SIDE.

THE INTERMEDIATE HEAT EXCHANGER IS A TYPICAL COUNTERFLOW HEAT EXCHANGER.

304 S/S TUBE MATERIAL WITH .1146000+00 FT. TUBE PITCH

TUBE LENGTH IS .2000000+02 FT. WITH EFFECTIVE HEAT TRANSFER LENGTH OF .1600000+02 FT.

INSIDE TUBE DIAMETER IS .7517000-01 FT., OUTSIDE TUBE DIAMETER IS .8333000-01 FT.

1 SHELL SIDE AND 1 TUBE SIDE PASSES

EQUIVALENT DIAMETER IS .9109122-01 FT. FOR HEAT TRANSFER AREA AND .9109122-01 FT. FOR PRESSURE DROP CALCULATIONS.

TUBE SIDE FLOW AREA IS .4437911-02 SQ. FT. PER TUBE AND SHELL SIDE FLOW AREA IS .5961663-02 SQ. FT. PER TUBE.

THE COMBINED SHELL AND TUBE SIDE FOULING FACTOR IS .0000000

THE FRACTION OF PRIMARY COOLANT WHICH IS BYPASSED IS .5000000-01

THE FRACTION OF SECONDARY COOLANT WHICH IS BYPASSED IS .2500000-01

THE IHX BUILDING HEIGHT IS .6000000+02 FT.

TABLE B-2. DUMP HEAT EXCHANGER INPUT DATA.

TUBE MATERIAL IS STAINLESS STEEL. THERE ARE 2 ROWS OF TUBES PER PASS ON THE TUBE SIDE.
 FIN MATERIAL IS MILD STEEL. THERE ARE 96 FINS PER FOOT OF TUBE LENGTH
 FIN DIAMETER IS .1875000-00 AND FIN THICKNESS IS .2917000-02 FT.
 TUBE LENGTH IS .1800000+02 FT. WITH EFFECTIVE HEAT TRANSFER LENGTH OF .1500000+02 FT.
 INSIDE TUBE DIAMETER IS .7517000-01 FT., OUTSIDE TUBE DIAMETER IS .8333300-01 FT.
 EQUIVALENT DIAMETER IS .1319185-00 FT. FOR HEAT TRANSFER AREA AND .3050995-01 FT. FOR PRESSURE DROP CALCULATIONS.
 TUBE SIDE FLOW AREA IS .4437911-02 SQ.FT./TUBE AND SHELL SIDE FLOW AREA IS .1750454+01 SQ.FT./TUBE
 TUBE PITCH IS .2292000-00 FT.
 HEAT TRANSFER SURFACE IS .3542300+01 SQ. FT. PER TUBE ON THE TUBE SIDE AND .4442731+01 SQ.FT/FT ON THE SHELL SIDE
 TUBE SIDE FOULING FACTOR IS .0000000 AND SHELL SIDE FOULING FACTOR IS .3000000-02
 THERE ARE 3 STACKS OF HEIGHT .1000000+03 FT. AND 2 SODIUM VALVES PER EACH DUMP HEAT EXCHANGER
 BUTTERFLY VALVE COEFFICIENT IS .1950000+01
 MAXIMUM ALLOWABLE NET STACK PRESSURE IS .5000000-00 IN.
 PRESSURE LOSS AT STANDARD CONDITIONS THROUGH DUCT WORK IS .1000000+00 IN. AND THROUGH AIR FILTERS, .4000000-00 IN.
 FAN SIZE, INCHES DHX UPPER PLENUM HEIGHT, FT. DHX LOWER PLENUM HEIGHT, FT.

84	7.	10.
72	6.	9.
48	5.	8.
38	4.	7.
33	4.	7.

THE CORRELATION COEFFICIENT FOR THE HEAT TRANSFER COEFFICIENT IS .1000000+00 FOR BOTH THE IHX AND THE DHX.
 THE CONSTANT COEFFICIENT FOR THE CORRELATION OF THE NUSSLETT NUMBER OF THE COOLANT IN THE TUBES IS .500000+01 FOR BOTH IHX AND DHX
 THE FANS ARE DRIVEN BY HORIZONTAL SQUIRREL CAGE MOTORS.
 FAN INLET VANE ASSEMBLY IS IN SYSTEM.

TABLE B-3. PRIMARY LOOP INPUT PARAMETERS.

PRIMARY PIPE CONFIGURATION

ZONE	HA	HB	CA	CB
LENGTH OF STRAIGHT PIPE, FT.	.3000000+02	.5000000+02	.6000000+02	.0000000
FITTING FACTORS, -----	.1445000+01	.4405000+01	.2338000+01	.0000000

PRIMARY LOOP CONSTRAINTS

MAXIMUM ALLOWABLE REACTOR VESSEL PRESSURE	.5000000+01 PSIG
MAXIMUM ALLOWABLE COOLANT VELOCITY -----	.3500000+02 FT/SEC
MAXIMUM ALLOWABLE STANDARD PIPE SIZE -----	.3600000+02 IN.
REACTOR TANK PRESSURE DROP, ULTIMATE COND.	.1000000+03 PSI.
PRIMARY PIPE ABSOLUTE ROUGHNESS -----	.1500000-03 FT.

PRIMARY PUMP DATA

THE PRIMARY PUMP IS IN THE HOT LEG

PUMP SPEED -----	.1170000+04 RPM
PUMP EFFICIENCY ---	.7500000-00
LOOP T.O.E. -----	.7500000-00

PRIMARY LOOP GEOMETRY

HEIGHT OF REACTOR VESSEL COOLANT LEVEL ABOVE PUMP IMPELLER -----	.1500000+02 FT.
CONFINER PIPE WALL THICKNESS -----	.3750000-00 IN.
ANNULUS WIDTH BETWEEN PRIMARY AND CONFINER PIPE	.2000000+01 IN.

THE PRIMARY PUMPS ARE DRIVEN BY VERTICAL WOUND ROTOR INDUCTION MOTORS.

TABLE B-4. SECONDARY LOOP INPUT PARAMETERS.

SECONDARY PIPE CONFIGURATION

ZONE	HA	HB	CA	CB
LENGTH OF STRAIGHT PIPE, FT.	.2000000+03	.0000000	.1250000+03	.1000000+03
FITTING FACTORS, -----	.4204000+01	.0000000	.3063000+01	.3199000+01

SECONDARY LOOP CONSTRAINTS

MAXIMUM ALLOWABLE PUMP DISCHARGE PRESSURE	.2000000+03 PSIG
MAXIMUM ALLOWABLE COOLANT VELOCITY -----	.3500000+02 FT/SEC
MAXIMUM ALLOWABLE STANDARD PIPE SIZE -----	.3000000+02 IN.
MINIMUM PRESSURE DIFFERENCE BETWEEN PRIMARY AND SECONDARY COOLANTS IN THE INTERMEDIATE HEAT EXCHANGER -----	.2500000+02 PSI.
SECONDARY PIPE ABSOLUTE ROUGHNESS -----	.1500000-03 FT.
WORKING VOLUME RATIO FOR SECONDARY LOOP SURGE TANK -----	.2500000-00

SECONDARY PUMP DATA

THE SECONDARY PUMP IS IN THE COLD LEG

PUMP SPEED -----	.1170000+04 RPM
PUMP EFFICIENCY ---	.7500000-00
LOOP T.O.E. -----	.7500000-00

SECONDARY LOOP GEOMETRY

HEIGHT OF SECONDARY PUMP DISCHARGE ABOVE LEVEL OF PRIMARY COOLANT IN THE IHX -----	.2000000+02 FT.
HEIGHT OF SODIUM IN SURGE TANK ABOVE IMPELLER -	.5000000+01 FT.

THE SECONDARY PUMPS ARE DRIVEN BY VERTICAL WOUND ROTOR INDUCTION MOTORS.

IN SIZING THE SECONDARY PIPE, THE COLD LEG PIPE WILL BE THE SAME SIZE AS THE HOT LEG PIPE.

TABLE B-5. IHX DATA AT INITIAL CONDITIONS.

INTERMEDIATE HEAT EXCHANGER CASE NO. 1 THE IHX LOG MEAN TEMPERATURE DIFFERENCE IS .1000000+03 DEG.F.

STARTUP CONDITIONS

THE TUBE BUNDLE LOG MEAN TEMPERATURE DIFFERENCE IS .8918606+02 DEG.F.

	SHELL SIDE	TUBE SIDE
NUMBER OF PASSES	1	1
TUBE BUNDLE COLD LEG TEMPERATURE, DEG.F.	.4855263+03	.4000000+03
TUBE BUNDLE BULK TEMPERATURE, DEG.F.	.6302632+03	.5375000+03
TUBE BUNDLE HOT LEG TEMPERATURE, DEG.F.	.7750000+03	.6820513+03
TUBE BUNDLE FLOW RATE, LB./HR.	.3811662+07	.3864968+07
PRESSURE DROP, PSI	.2158102+01	.1773810+01
VELOCITY, FT./SEC.	.4530623+01	.6078836+01
REYNOLDS NUMBER	.1097884+06	.1091828+06
NUSSELT NUMBER	.1435556+02	.8959047+01
PECLET MODULUS	.5903367+03	.6420349+03
PRANDTL NUMBER	.5377043-02	.5880368-02
FILM COEFFICIENT BTU/HR/SQ.FT./DEG.F.	.6127857+04	.4789737+04
VOLUME OCCUPIED BY SODIUM, CU.FT.	.3017142+03	.1631896+03

THE WALL RESISTANCE IS .3876339-03 HR.-SQ.FT.-DEG.F./BTU AND THE FOULING FACTOR IS .0000000 HR.-SQ.FT.-DEG.F./BTU

THE HEAT TRANSFER AREA IS .2996819+04 SQ.FT. AND THE HEAT TRANSFER COEFFICIENT IS .1277089+04 BTU/HR/SQ.FT./DEG.F.

THE EFFECTIVE OVERALL HEAT TRANSFER COEFFICIENT IS .1138985+04 BTU/HR/SQ.FT./DEG.F.

THERE ARE 715 TUBES.

CENTRAL DOWNCOMER DIAMETER IS .1600000+02 IN. AND THE SHROUD DIAMETER IS .3572743+01 FT.

THE LOG MEAN TEMPERATURE CORRECTOR IS .1000000+01

HEAT EXCHANGER COST ---- .4252453+06 DOLLARS.

SODIUM COST ----- .5993539+04 DOLLARS.

BUILDING COST ----- .1042696+05 DOLLARS.

HEAT EXCHANGER COMPLEX = .4416658+06 DOLLARS.

TABLE B-6. IHX DATA AT ULTIMATE CONDITIONS.

IHX DATA AT ULTIMATE CONDITIONS. THE IHX LOG MEAN TEMPERATURE DIFFERENCE IS .1122805+03 DEG.F.
 THE TUBE BUNDLE LOG MEAN TEMPERATURE DIFFERENCE IS .1014727+03 DEG.F.

	SHELL SIDE	TUBE SIDE
NUMBER OF PASSES	1	1
TUBE BUNDLE COLD LEG TEMPERATURE, DEG.F.	.6855263+03	.5877196+03
TUBE BUNDLE BULK TEMPERATURE, DEG.F.	.8302632+03	.7287452+03
TUBE BUNDLE HOT LEG TEMPERATURE, DEG.F.	.9750000+03	.8697708+03
TUBE BUNDLE FLOW RATE, LB./HR.	.5179258+07	.5271653+07
BULK FLOW RATE, LB./HR.	.5451851+07	.5406823+07
PRESSURE DROP, PSI	.3794151+01	.3402489+01
VELOCITY, FT./SEC.	.6358729+01	.8548876+01
REYNOLDS NUMBER	.1846630+06	.1877622+06
NUSSLETT NUMBER	.1656753+02	.1056463+02
PECLET MODULUS	.8377925+03	.9153658+03
PRANDTL NUMBER	.4536874+02	.4875132+02
FILM COEFFICIENT BTU/HR/SQ.FT./DEG.F.	.6563813+04	.5279653+04

THE WALL RESISTANCE IS .3770760-03 HR.-SQ.FT.-DEG.F./BTU AND THE FOULING FACTOR IS .0000000 HR.-SQ.FT.-DEG.F./BTU
 THE HEAT TRANSFER AREA IS .2996819+04 SQ.FT. AND THE HEAT TRANSFER COEFFICIENT IS .1496460+04 BTU/HR/SQ.FT./DEG.F.

THE LOG MEAN TEMPERATURE CORRECTOR IS .1000000+01

THE EFFECTIVE OVERALL HEAT TRANSFER COEFFICIENT IS .1352459+04 BTU/HR/SQ.FT./DEG.F.

PUMP PENALTY DATA.

	PRIMARY SIDE	SECONDARY SIDE
IHX PRESSURE DROP, PSI. -----	.3794151+01	.3402489+01
LOOP BRAKE HORSEPOWER REQUIREMENTS	.1174044+04	.6371725+03
IHX BRAKE HORSEPOWER REQUIREMENTS	.2093062+02	.3150236+02
PUMP PENALTY, DOLLARS -----	.1868064+04	.0000000

TABLE B-7. DHX DATA AT 300F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SUBCASE NO. 1 PARAMETERS.										PAGE 1
INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY										
TPH 775. DEG.F.	TPC 500. DEG.F.	WP .4012276+07 LB./HR.	ISH 675. DEG.F.	TSC 400. DEG.F.	WS .3964069+07 LB./HR.					
TTH 300. DEG.F.	TTC 100. DEG.F.	WT .5668172+07 LB./HR.	TMX 100. DEG.F.	TMY 336. DEG.F.						
NUMBER OF TUBE PASSES --						8	6	4	2	
DUMP HEAT EXCHANGER THERMAL DESIGN										
HEAT TRANSFER SURFACE AREA, SQ.FT.						4082069+05	4905456+05	6063674+05	9732753+05	
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F.						2487834+02	2070248+02	1674811+02	1043437+02	
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F.						4808033+03	4018849+03	3273484+03	2046749+03	
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F.						1704603+05	1248487+05	8544034+04	4799878+04	
AIR FLOW RATE, LB./HR./SQ.FT.						1002473+06	6244912+05	3356296+05	1043670+05	
AIR PRESSURE DROP IN DHX, INCHES OF H2O						4903679+03	1520379+03	3180943+02	1797657+01	
SODIUM VELOCITY, FT./SEC.						5865543+02	3653945+02	1972483+02	6106593+01	
SODIUM PRESSURE DROP IN DHX, PSI						1258167+04	3682751+03	7391479+02	4212966+01	
DUMP HEAT EXCHANGER MECHANICAL DESIGN										
NUMBER OF TUBES PER PASS / PER ROW						76/ 38	122/ 61	226/ 113	730/ 365	
HEAT EXCHANGER BOX LENGTH, FT.						8938800+01	1421040+02	2612880+02	8388720+02	
HEAT EXCHANGER BOX VOLUME, CU.FT.						3065922+04	4682224+04	8256575+04	2537568+05	
MANIFOLD INSIDE DIAMETER, INCHES						1082000+02	1002000+02	1002000+02	7981000+01	
SECONDARY LOOP PIPING I.D., INCHES						1325000+02	1325000+02	1725000+02	1725000+02	
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT						9077583+02	1162351+03	1873297+03	3907854+03	
WEIGHT OF UNFINNED TUBING, LB.						9267604+03	1115771+04	1377946+04	2225444+04	
WEIGHT OF FINNED TUBING, LB.						3292749+05	3964297+05	4895798+05	7906931+05	
TERTIARY LOOP DESIGN										
NUMBER OF FAN MODULES						2	2	2	6	
FAN AIR FLOW RATE, CFM						8386622+06	8386622+06	8386622+06	2795541+06	
FAN SPEED, RPM						1170000+04	1170000+04	1170000+04	1170000+04	
FAN SIZE, INCHES						8400000+02	8400000+02	8400000+02	8400000+02	
FAN PRESSURE, INCHES OF WATER						1019829+04	2026875+03	4464371+02	6026364+01	
EQUIVALENT FAN PRESSURE, INCHES OF WATER						1156222+04	2297952+03	5061442+02	6832338+01	
FAN EFFICIENCY						7100000+00	7100000+00	7100000+00	7976141+00	
FAN BRAKE HORSEPOWER						1903325+06	3782794+05	8331940+04	3337224+03	
FAN MOTOR HORSEPOWER						3000000+04	3000000+04	3000000+04	3500000+03	
STACK DIAMETER, FT.						1250000+02	1250000+02	1250000+02	1250000+02	
STACK FRICTION DROP, INCHES OF WATER						6966191+00	6966191+00	6966191+00	6966191+00	
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O						1905114+01	4616559+01	6322914+01	7599290+00	
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.						1373478+04	5563366+03	39A2928+03	3820539+03	
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.						3536491+03	3536491+03	3536491+03	3760276+03	

-158-

BNWL-308

TABLE B-7 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY							PAGE 2	
TPM 975. DEG.F.	TPC 700. DEG.F.	HP	.5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS	.5406824+07 LB./HR.	
TMX 112. DEG.F.	NUMBER OF TUBE PASSES --						2	
SECONDARY LOOP DESIGN								
COLD LEG PIPE DIAMETER, INCHES	----	----	1400000+02	1400000+02	1800000+02	1800000+02	1800000+02	
HOT LEG PIPE DIAMETER, INCHES	----	----	1400000+02	1400000+02	1800000+02	1800000+02	1800000+02	
SURGE TANK VOLUME, CU.FT.	----	----	1619903+03	1664622+03	2440469+03	2597590+03	2597590+03	
SURGE TANK GAS SPACE PRESSURE, PSIG	----	----	0000000	0000000	1687212+01	1128479+03	1128479+03	
PUMP HEAD, FT.	----	----	6496982+04	2047448+04	4412614+03	9274661+02	9274661+02	
PUMP FLOW RATE, GPM	----	----	1220996+05	1220996+05	1220996+05	1220996+05	1220996+05	
PUMP DISCHARGE PRESSURE, PSIG	----	----	2492984+04	7869479+03	1727924+03	1503258+03	1503258+03	
PUMP SUCTION PRESSURE, PSIG	----	----	1917053+01	1917091+01	3604308+01	1147649+03	1147649+03	
PUMP SPECIFIC SPEED	----	----	1786526+03	4247500+03	1342830+04	4325830+04	4325830+04	
PUMP CAVITATION PARAMETER	----	----	7826033+02	2454853+01	1121701+00	5254134+00	5254134+00	
PUMP BRAKE HORSEPOWER	----	----	2365524+05	7454674+04	1606615+04	3376866+03	3376866+03	
PUMP MOTOR SIZE, HORSEPOWER	----	----	3000000+04	3000000+04	1750000+04	3500000+03	3500000+03	
PRESSURE DROP, SECONDARY SIDE OF IHX	----	----	3402491+01	3402491+01	3402491+01	3402491+01	3402491+01	
PRESSURE DROP, SECONDARY SIDE OF DHX	----	----	2412067+04	7060302+03	1417040+03	8076792+01	8076792+01	
COST DATA, DOLLARS								
HEAT EXCHANGER SECTION								
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY	----	----	4373250+05	5265163+05	6502332+05	1050155+06	1050155+06	
INLET AIR FILTERS	----	----	1541943+08	4686293+07	1599334+07	1477200+06	1477200+06	
SOUND ATTENUATORS	----	----	7500000+04	7500000+04	7500000+04	2250000+05	2250000+05	
AIR SIDE BUTTERFLY VALVES	----	----	6200000+05	6200000+05	6200000+05	1860000+06	1860000+06	
HEAT EXCHANGER BOX	----	----	4598884+04	7023336+04	1238486+05	3806351+05	3806351+05	
OFF GAS STACK	----	----	1012500+06	1012500+06	1012500+06	1012500+06	1012500+06	
DUCT WORK	----	----	4598884+03	7023336+03	1238486+04	3806351+04	3806351+04	
AUXILIARY FURNACE	----	----	2759882+05	2759882+05	2759882+05	2759882+05	2759882+05	
SODIUM IN DUMP HEAT EXCHANGER	----	----	1170282+04	1498503+04	2415054+04	5038005+04	5038005+04	
DHX AND ASSOCIATED PIPE	----	----	2102960+05	2928792+05	5390365+05	1341744+06	1341744+06	
SODIUM VALVES IN DHX MANIFOLDS	----	----	4800000+05	4800000+05	4800000+05	1176000+06	1176000+06	
TOTAL DHX AND TERTIARY LOOP COST	----	----	1580805+08	5095092+07	2052534+07	9600529+06	9600529+06	
SODIUM IN SECONDARY LOOP								
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS	----	----	5244912+04	5244912+04	8886150+04	8886150+04	8886150+04	
SECONDARY PIPE	----	----	1053272+07	6022656+06	2819152+06	1019951+06	1019951+06	
SECONDARY LOOP VALVES	----	----	2568421+06	2568421+06	3413137+06	3413137+06	3413137+06	
SECONDARY LOOP SURGE TANK	----	----	1000000+05	1000000+05	1600000+05	1600000+05	1600000+05	
HIGH DESIGN PRESSURE COST PENALTY	----	----	5042467+04	5125533+04	6448127+04	6694097+04	6694097+04	
TOTAL SECONDARY LOOP COST	----	----	1320312+08	2675969+07	7945446+05	9495186+03	9495186+03	
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST	----	----	1453353+08	3555447+07	7340177+06	4758385+06	4758385+06	
THE OPTIMUM NUMBER OF TUBE PASSES IS 2								

-159-

BNWL-308

TABLE B-8. DHX DATA AT 350F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SUBCASE NO. 2 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F.	TPC 500. DEG.F.	WP .4012276+07 LB./HR.	TSH 675. DEG.F.	TSC 400. DEG.F.	WS .3964069+07 LB./HR.
TTH 350. DEG.F.	TYC 100. DEG.F.	WT .5328823+07 LB./HR.	TMX 100. DEG.F.	TMY 312. DEG.F.	

NUMBER OF TUBE PASSES --

— **E**

--L

3

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.5296650+05	.6136381+05	.7688637+05	.1361874+06
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. -	.2077476+02	.1793184+02	.1431159+02	.8079794+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. -	.4020335+03	.3481870+03	.2793288+03	.1578238+03
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.1427413+05	.1084237+05	.7473496+04	.4153704+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.6150005+05	.3979415+05	.2114064+05	.5963276+04
AIR PRESSURE DROP IN DHX, INCHES OF H2O --	.2047322+03	.6813856+02	.1395082+02	.6572553+00
SODIUM VELOCITY, FT./SEC. -----	.4548789+02	.2932772+02	.1547852+02	.4370405+01
SODIUM PRESSURE DROP IN DHX, PSI -----	.7578540+03	.2382953+03	.4664559+02	.3568434+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW -----	98/ 49	152/ 76	288/ 144	1020/ 510
HEAT EXCHANGER BOX LENGTH, FT. -----	.1146000+02	.1764840+02	.3323400+02	.1171212+03
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.3930670+04	.5815020+04	.1050178+05	.3542888+05
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.1002000+02	.7981000+01
SECONDARY LOOP PIPING I.D., INCHES -----	.1325000+02	.1325000+02	.1525000+02	.1725000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT -----	.1167398+03	.1445884+03	.2207710+03	.5457313+03
WEIGHT OF UNFINISHED TUBING, LB. -----	.1195033+04	.1390141+04	.1755967+04	.3109525+04
WEIGHT OF FINNED TUBING, LB. -----	.4245913+05	.4939124+05	.6238893+05	.1104804+06

TERTIARY LOOP DESIGN

	2	2	2	4
NUMBER OF FAN MODULES -----				
FAN AIR FLOW RATE, CFM -----	.6702111+06	.6702111+06	.6702111+06	.3351056+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.1170000+04
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.2836628+03	.8452780+02	.2267112+02	.5497630+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER -	.3216003+03	.9583267+02	.2570319+02	.6232891+01
FAN EFFICIENCY -----	.7100000-00	.7100000-00	.7100000-00	.7679384-00
FAN BRAKE HORSEPOWER -----	.4230705+05	.1260695+05	.3381297+04	.3790425+03
FAN MOTOR HORSEPOWER -----	.3000000+04	.3000000+04	.3000000+04	.4000000+03
STACK DIAMETER, FT. -----	.1100000+02	.1100000+02	.1100000+02	.1100000+02
STACK FRICTION DROP, INCHES OF WATER -----	.8822164-00	.8822164-00	.8822164-00	.8822164-00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.2567731+01	.3669675+01	.4228129+01	.1094412+01
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.6462444+03	.4471094+03	.3852527+03	.3802673+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3625816+03	.3625816+03	.3625816+03	.3747696+03

-160-

BMW-L-308

TABLE B-8 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY								PAGE 2
TPH 975. DEG.F.	TPC 700. DEG.F.	WP	.5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS	.5406824+07 LR./HR.	
TMX 112. DEG.F.	NUMBER OF TUBE PASSES --		8	6	4	2		
SECONDARY LOOP DESIGN								
COLD LEG PIPE DIAMETER, INCHES			.1400000+02	.1400000+02	.1600000+02	.1800000+02		
HOT LEG PIPE DIAMETER, INCHES			.1400000+02	.1400000+02	.1600000+02	.1800000+02		
SURGE TANK VOLUME, CU.FT.			.1675760+03	.1723161+03	.2149887+03	.2782693+03		
SURGE TANK GAS SPACE PRESSURE, PSIG			.0000000	.0000000	.1931122+02	.1140835+03		
PUMP HEAD, FT.			.3995374+04	.1397538+04	.3490200+03	.8952389+02		
PUMP FLOW RATE, GPM			.1220996+05	.1220996+05	.1220996+05	.1220996+05		
PUMP DISCHARGE PRESSURE, PSIG			.1533820+04	.5377601+03	.1550040+03	.1503258+03		
PUMP SUCTION PRESSURE, PSIG			.1917068+01	.1917091+01	.2122831+02	.1160006+03		
PUMP SPECIFIC SPEED			.2572616+03	.5656140+03	.1601457+04	.4442105+04		
PUMP CAVITATION PARAMETER			.1266439+01	.3582746+01	.1415304+00	.5441349+00		
PUMP BRAKE HORSEPOWER			.1454699+05	.5088380+04	.1270338+00	.3259528+03		
PUMP MOTOR SIZE, HORSEPOWER			.3000000+04	.3000000+04	.1250000+04	.3500000+03		
PRESSURE DROP, SECONDARY SIDE OF IHX			.3402491+01	.3402491+01	.3402491+01	.3402491+01		
PRESSURE DROP, SECONDARY SIDE OF DHX			.1452902+04	.4568424+03	.8942552+02	.6841142+01		
COST DATA, DOLLARS								
HEAT EXCHANGER SECTION			.5639191+05	.6559875+05	.8286158+05	.1467340+06		
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY			.5084558+07	.2132679+07	.8810331+06	.1099600+06		
INLET AIR FILTERS			.5696794+05	.5696794+05	.5696794+05	.5696794+05		
SOUND ATTENUATORS			.7500000+04	.7500000+04	.7500000+04	.1500000+05		
AIR SIDE BUTTERFLY VALVES			.6200000+05	.6200000+05	.6200000+05	.1240000+06		
HEAT EXCHANGER BOX			.5896005+04	.8722531+04	.1575268+05	.5314332+05		
OFF GAS STACK			.8910000+05	.8910000+05	.8910000+05	.8910000+05		
DUCT WORK			.5896004+03	.8722531+03	.1575268+04	.5314332+04		
AUXILIARY FURNACE			.2759882+05	.2759882+05	.2759882+05	.2759882+05		
SODIUM IN DUMP HEAT EXCHANGER			.1505009+04	.1864034+04	.2846179+04	.7035568+04		
DHX AND ASSOCIATED PIPE			.2696103+05	.3637371+05	.6302402+05	.1873309+06		
SODIUM VALVES IN DHX MANIFOLDS			.4800000+05	.4800000+05	.4800000+05	.7840000+05		
TOTAL DHX AND TERTIARY LOOP COST			.5467068+07	.2537277+07	.1339160+07	.9005849+06		
SODIUM IN SECONDARY LOOP			.5244912+04	.5244912+04	.6951703+04	.8886150+04		
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS			.8268920+06	.5075379+06	.2386173+06	.1003388+06		
SECONDARY PIPE			.2568421+06	.2568421+06	.2982236+06	.3413137+06		
SECONDARY LOOP VALVES			.1000000+05	.1000000+05	.1320000+05	.1600000+05		
SECONDARY LOOP SURGE TANK			.5146082+04	.5232932+04	.5975840+04	.6976358+04		
HIGH DESIGN PRESSURE COST PENALTY			.6802327+07	.1512398+07	.1598662+05	.9480952+03		
TOTAL SECONDARY LOOP COST			.7906452+07	.2297256+07	.5789551+06	.4744631+06		
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST			.1337352+08	.4834533+07	.1918115+07	.1375048+07		
THE OPTIMUM NUMBER OF TUBE PASSES IS 2								

161

BWNL-308

BWL-308

161-

TABLE B-9. DHX DATA AT 400F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SURCASE NO. 3 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F. TPC 500. DEG.F. WP .4012276+07 LB./HR. TSH 675. DEG.F. TSC 400. DEG.F. WS .3964069+07 LB./HR.
 TTH 400. DEG.F. TTC 100. DEG.F. WT .4433476+07 LB./HR. TMX 100. DEG.F. TMY 287. DEG.F.

NUMBER OF TUBE PASSES -- 8 6 4 2

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.6693973+05	.7807517+05	.1040170+06	.2031357+06
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. ---	.1820443+02	.1560803+02	.1171539+02	.5998946+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. -	.3519971+03	.3028907+03	.2284589+03	.1164486+03
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.1229776+05	.9346536+04	.6389645+04	.3660627+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.4052413+05	.2597701+05	.1298850+05	.3323830+04
AIR PRESSURE DROP IN DHX, INCHES OF H2O ---	.9754023+02	.3190048+02	.5832619+01	.2291255+00
SODIUM VELOCITY, FT./SEC. -----	.3595010+02	.2297842+02	.1143029+02	.2925074+01
SODIUM PRESSURE DROP IN DHX, PSI -----	.4744668+03	.1474201+03	.2677388+02	.2606674+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW -----	124/ 62	194/ 97	390/ 195	1524/ 762
HEAT EXCHANGER BOX LENGTH, FT. -----	.1443960+02	.2246160+02	.4492320+02	.1748796+03
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.4952644+04	.7400935+04	.1419551+05	.5290066+05
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.1002000+02	.7981000+01
SECONDARY LOOP PIPING I.D., INCHES -----	.1325000+02	.1325000+02	.1525000+02	.1725000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT	.1474244+03	.1842830+03	.2986462+03	.8150167+03
WEIGHT OF UNFINNED TUBING, LB. -----	.1512083+04	.1774258+04	.2377872+04	.4645996+04
WEIGHT OF FINNED TUBING, LB. -----	.5372380+05	.6303882+05	.8448501+05	.1650707+06

TERTIARY LOOP DESIGN

NUMBER OF FAN MODULES -----	2	2	2	4
FAN AIR FLOW RATE, CFM -----	.5576025+06	.5576025+06	.5576025+06	.2788012+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.8700000+03
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.1193091+03	.4027755+02	.1235942+02	.4337698+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER -	.1352656+03	.4566432+02	.1401239+02	.4917828+01
FAN EFFICIENCY -----	.7100000+00	.7100000+00	.7100000+00	.7291056+00
FAN BRAKE HORSEPOWER -----	.1480461+05	.4997887+04	.1533633+04	.2620720+03
FAN MOTOR HORSEPOWER -----	.3000000+04	.3000000+04	.1500000+04	.2500000+03
STACK DIAMETER, FT. -----	.1050000+02	.1050000+02	.1050000+02	.1050000+02
STACK FRICTION DROP, INCHES OF WATER -----	.8048289+00	.8048289+00	.8048289+00	.8048289+00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.2353960+01	.2795094+01	.2992414+01	.7591541+00
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.4868441+03	.4078125+03	.3798944+03	.3803808+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3675350+03	.3675350+03	.3675350+03	.3760431+03

TABLE B-9 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY					PAGE 2
TPH 975. DEG.F.	TPC 700. DEG.F.	WP .5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS .5406824+07 LB./HR.
TMX 112. DEG.F.					
NUMBER OF TUBE PASSES --	8	6	4	2	
SECONDARY LOOP DESIGN					
COLD LEG PIPE DIAMETER, INCHES -----	.1400000+02	.1400000+02	.1600000+02	.1800000+02	
HOT LEG PIPE DIAMETER, INCHES -----	.1400000+02	.1400000+02	.1600000+02	.1800000+02	
SURGE TANK VOLUME, CU.FT. -----	.1741773+03	.1805114+03	.2288975+03	.3104388+03	
SURGE TANK GAS SPACE PRESSURE, PSIG -----	.0000000	.0000000	.5740781+02	.1159273+03	
PUMP HEAD, FT. -----	.2578415+04	.9431549+03	.2495419+03	.8471501+02	
PUMP FLOW RATE, GPM -----	.1220996+05	.1220996+05	.1220996+05	.1220996+05	
PUMP DISCHARGE PRESSURE, PSIG -----	.9905308+03	.3635408+03	.1550040+03	.1503258+03	
PUMP SUCTION PRESSURE, PSIG -----	.1917091+01	.1917095+01	.5932490+02	.1178444+03	
PUMP SPECIFIC SPEED -----	.3572962+03	.7596364+03	.2059138+04	.4629912+04	
PUMP CAVITATION PARAMETER -----	.1953831-01	.5287970-01	.1972214-00	.5747055-00	
PUMP BRAKE HORSEPOWER -----	.9387903+04	.3433988+04	.9085718+03	.3084439+03	
PUMP MOTOR SIZE, HORSEPOWER -----	.3000000+04	.3000000+04	.9000000+03	.3000000+03	
PRESSURE DROP, SECONDARY SIDE OF IHX -----	.3402491+01	.3402491+01	.3402491+01	.3402491+01	
PRESSURE DROP, SECONDARY SIDE OF DHX -----	.9096131+03	.2826231+03	.5132893+02	.4997325+01	
COST DATA, DOLLARS					
HEAT EXCHANGER SECTION -----	.7135303+05	.8372472+05	.1122084+06	.2192379+06	
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY -	.2388236+07	.1134264+07	.4999458+06	.9232000+05	
INLET AIR FILTERS -----	.4739621+05	.4739621+05	.4739621+05	.4739621+05	
SOUND ATTENUATORS -----	.7500000+04	.7500000+04	.7500000+04	.1500000+05	
AIR SIDE BUTTERFLY VALVES -----	.6200000+05	.6200000+05	.6200000+05	.1240000+06	
HEAT EXCHANGER BOX -----	.7428966+04	.1110140+05	.2129327+05	.7935099+05	
OFF GAS STACK -----	.8505000+05	.8505000+05	.8505000+05	.8505000+05	
DUCT WORK -----	.7428966+03	.1110140+04	.2129327+04	.7935098+04	
AUXILIARY FURNACE -----	.2759882+05	.2759882+05	.2759882+05	.2759882+05	
SODIUM IN DUMP HEAT EXCHANGER -----	.1900595+04	.2375777+04	.3850147+04	.1050719+05	
DHX AND ASSOCIATED PIPE -----	.3397089+05	.4629381+05	.8640764+05	.2797132+06	
SODIUM VALVES IN DHX MANIFOLDS -----	.4800000+05	.4800000+05	.4800000+05	.7840000+05	
TOTAL DHX AND TERTIARY LOOP COST -----	.2781178+07	.1556415+07	.1003380+07	.1066509+07	
SODIUM IN SECONDARY LOOP -----	.5244912+04	.5244912+04	.6951703+04	.8886150+04	
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS --	.6702852+06	.4293183+06	.1949030+06	.9531879+05	
SECONDARY PIPE -----	.2568421+06	.2568421+06	.2982236+06	.3413137+06	
SECONDARY LOOP VALVES -----	.1000000+05	.1000000+05	.1320000+05	.1600000+05	
SECONDARY LOOP SURGE TANK -----	.5265772+04	.5380869+04	.6204892+04	.7449639+04	
HIGH DESIGN PRESSURE COST PENALTY -----	.3713456+07	.7798674+06	.1529464+05	.9433850+03	
TOTAL SECONDARY LOOP COST -----	.4661095+07	.1486653+07	.5347778+06	.4699117+06	
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST	.7442272+07	.3043069+07	.1538157+07	.1536421+07	
THE OPTIMUM NUMBER OF TUBE PASSES IS 2					

-163-

BNWL-308

TABLE B-10. DHX DATA AT 450F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SUBCASE NO. 4 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F. TPC 500. DEG.F. WP .4012276+07 LB./HR. TSH 675. DEG.F. TSC 400. DEG.F. WS .3964069+07 LB./HR.
 TTH 450. DEG.F. TTC 100. DEG.F. WT .3793963+07 LB./HR. TMX 100. DEG.F. TMY 261. DEG.F.

NUMBER OF TUBE PASSES -- 8 6 4 2

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.8346553+05	.9976309+05	.1381317+06	.3128896+06
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. -----	.1609050+02	.1346192+02	.9722623+01	.4292256+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.3117333+03	.2615902+03	.1891093+03	.8288469+02
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.1071251+05	.8102348+04	.5653093+04	.3064114+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.2778739+05	.1740897+05	.8368405+04	.1846968+04
AIR PRESSURE DROP IN DHX, INCHES OF H2O --	.4999377+02	.1566601+02	.2661390+01	.7931914+01
SODIUM VELOCITY, FT./SEC. -----	.2857572+02	.1797505+02	.8605816+01	.1900176+01
SODIUM PRESSURE DROP IN DHX, PSI -----	.3008607+03	.9135147+02	.1533641+02	.1636106+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW -----	156/ 78	248/ 124	518/ 259	2346/ 1173
HEAT EXCHANGER BOX LENGTH, FT. -----	.1810660+02	.2865000+02	.5959200+02	.2690808+03
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.6210458+04	.9439968+04	.1883079+05	.8139629+05
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.7981000+01	.1002000+02
SECONDARY LOOP PIPING I.D., INCHES -----	.1325000+02	.1925000+02	.1525000+02	.1725000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT	.1851901+03	.2810250+03	.3534256+03	.1383488+04
WEIGHT OF UNFINNED TUBING, LB. -----	.1902298+04	.2268124+04	.3158302+04	.7151908+04
WEIGHT OF FINNED TUBING, LB. -----	.6758801+05	.8058571+05	.1122134+06	.2541049+06

TERTIARY LOOP DESIGN

NUMBER OF FAN MODULES -----	2	2	4	3
FAN AIR FLOW RATE, CFM -----	.4771703+06	.4771703+06	.2385851+06	.3181135+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.8700000+03
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.5950297+02	.2158988+02	.6378002+01	.4212884+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER --	.6746098+02	.2447734+02	.7231005+01	.4776321+01
FAN EFFICIENCY -----	.7100000+00	.7100000+00	.9306640+00	.7045053+00
FAN BRAKE HORSEPOWER -----	.6318453+04	.2292569+04	.2894408+03	.3005622+03
FAN MOTOR HORSEPOWER -----	.3000000+04	.2250000+04	.3000000+03	.3000000+03
STACK DIAMETER, FT. -----	.1000000+02	.1000000+02	.1000000+02	.1000000+02
STACK FRICTION DROP, INCHES OF WATER -----	.7842339+00	.7842339+00	.7842339+00	.7842339+00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.1953137+01	.2136810+01	.5527046+00	.9892511+00
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.4300523+03	.3921392+03	.3831898+03	.3793910+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3705493+03	.3705493+03	.3768118+03	.3751781+03

-161-

BMT-308

TABLE B-10 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY					PAGE 2
TPH 975. DEG.F.	TPC 700. DEG.F.	WP .5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS .5406824+07 LB./HR.
TMX 112. DEG.F.	NUMBER OF TUBE PASSES --				
	8	6	4	2	
SECONDARY LOOP DESIGN					
COLD LEG PIPE DIAMETER, INCHES -----	.1400000+02	.2000000+02	.1600000+02	.1800000+02	
HOT LEG PIPE DIAMETER, INCHES -----	.1400000+02	.2000000+02	.1600000+02	.1800000+02	
SURGE TANK VOLUME, CU.FT. -----	.1823019+03	.3040379+03	.2356150+03	.3952258+03	
SURGE TANK GAS SPACE PRESSURE, PSIG -----	.0000000	.2307177+01	.7933488+02	.1177880+03	
PUMP HEAD, FT. -----	.1710370+04	.5049016+03	.1923536+03	.7986210+02	
PUMP FLOW RATE, GPM -----	.1220996+05	.1220996+05	.1220996+05	.1220996+05	
PUMP DISCHARGE PRESSURE, PSIG -----	.6577059+03	.1978132+03	.1550040+03	.1503258+03	
PUMP SUCTION PRESSURE, PSIG -----	.1917091+01	.4224273+01	.8125198+02	.1197051+03	
PUMP SPECIFIC SPEED -----	.4860998+03	.1213774+04	.2503040+04	.4839355+04	
PUMP CAVITATION PARAMETER -----	.2933370-01	.9816382-01	.2551918-00	.6092687-00	
PUMP BRAKE HORSEPOWER -----	.6227388+04	.1838326+04	.7003517+03	.2907746+03	
PUMP MOTOR SIZE, HORSEPOWER -----	.3000000+04	.2000000+04	.7000000+03	.3000000+03	
PRESSURE DROP, SECONDARY SIDE OF IHX -----	.3402491+01	.3402491+01	.3402491+01	.3402491+01	
PRESSURE DROP, SECONDARY SIDE OF DHX -----	.5767882+03	.1751324+03	.2940186+02	.3136624+01	165+
COST DATA, DOLLARS					
HEAT EXCHANGER SECTION -----	.8976671+05	.1070295+06	.1490358+06	.3374883+06	
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY --	.1325914+07	.6709330+06	.9476000+05	.7425000+05	
INLET AIR FILTERS -----	.4055947+05	.4055947+05	.4055947+05	.4055947+05	
SOUND ATTENUATORS -----	.7500000+04	.7500000+04	.1500000+05	.1125000+05	
AIR SIDE BUTTERFLY VALVES -----	.6200000+05	.6200000+05	.1240000+06	.9300000+05	
HEAT EXCHANGER BOX -----	.9315687+04	.1415995+05	.2824618+05	.1220944+06	
OFF GAS STACK -----	.8100000+05	.8100000+05	.8100000+05	.8100000+05	
DUCT WORK -----	.9315687+03	.1415995+04	.2824618+04	.1220944+05	
AUXILIARY FURNACE -----	.2759882+05	.2759882+05	.2759882+05	.2759882+05	
SODIUM IN DUMP HEAT EXCHANGER -----	.2387471+04	.3622974+04	.4556363+04	.1783593+05	
DHX AND ASSOCIATED PIPE -----	.4259842+05	.7130172+05	.9925337+05	.4766491+06	
SODIUM VALVES IN DHX MANIFOLDS -----	.4800000+05	.4800000+05	.7840000+05	.7200000+05	
TOTAL DHX AND TERTIARY LOOP COST -----	.1737572+07	.1135121+07	.7452346+06	.1365935+07	
SODIUM IN SECONDARY LOOP -----	.5244912+04	.1107156+05	.6951703+04	.8886150+04	
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS --	.5550727+06	.3050320+06	.1667852+06	.9271256+05	
SECONDARY PIPE -----	.2568421+06	.3859751+06	.2922236+06	.3413137+06	
SECONDARY LOOP VALVES -----	.1000000+05	.2100000+05	.1320000+05	.1600000+05	
SECONDARY LOOP SURGE TANK -----	.5412829+04	.7357093+04	.6313517+04	.8611063+04	BWVL-308
HIGH DESIGN PRESSURE COST PENALTY -----	.2057264+07	.1782134+06	.1448494+05	.9418882+03	
TOTAL SECONDARY LOOP COST -----	.2889836+07	.9086491+06	.5063229+06	.4684654+06	
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST	.4627408+07	.2043771+07	.1251557+07	.1834401+07	
THE OPTIMUM NUMBER OF TUBE PASSES IS 4					

TABLE B-11. DHX DATA AT 500F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SURCASE NO. 5 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F. TPC 500. DEG.F. WP .4012276+07 LB./HR. TSH 675. DEG.F. TSC 400. DEG.F. WS .3964069+07 LB./HR.
 TTH 500. DEG.F. TTC 100. DEG.F. WT .3314345+07 LB./HR. TMX 100. DEG.F. TMY 232. DEG.F.

NUMBER OF TUBE PASSES -- 8 6 4 2

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.1032009+06	.1289039+06	.1845788+06	.4739287+06
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. -----	.1426169+02	.1141796+02	.7973938+01	.3105572+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. -	.2761691+03	.2216724+03	.1547406+03	.5973662+02
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.9404619+04	.7041365+04	.4921608+04	.2673128+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.1962094+05	.1176038+05	.5472314+04	.1065215+04
AIR PRESSURE DROP IN DHX, INCHES OF H2O --	.2703408+02	.7799645+01	.1247015+01	.2939874-01
SODIUM VELOCITY, FT./SEC. -----	.2321777+02	.1384414+02	.6441926+01	.1254309+01
SODIUM PRESSURE DROP IN DHX, PSI -----	.1996143+03	.5538463+02	.8876974+01	.1450276+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW -----	192/ 96	322/ 161	692/ 346	3554/ 1777
HEAT EXCHANGER BOX LENGTH, FT. -----	.2223240+02	.3713040+02	.7953240+02	.4075176+03
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.7625499+04	.1223420+05	.2513186+05	.1232731+06
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.1002000+02	.1002000+02
SECONDARY LOOP PIPING I.D., INCHES -----	.1325000+02	.1725000+02	.1725000+02	.1725000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT	.2276765+03	.3423170+03	.5715113+03	.2095430+04
WEIGHT OF UNFINNED TUBING, LB. -----	.2341290+04	.2944903+04	.4219199+04	.1083456+05
WEIGHT OF FINNED TUBING, LB. -----	.8318524+05	.1046314+06	.1499067+06	.3849484+06

TERTIARY LOOP DESIGN

NUMBER OF FAN MODULES -----	2	2	3	3
FAN AIR FLOW RATE, CFM -----	.4168483+06	.4168483+06	.2778989+06	.2778989+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.8700000+03
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.3308468+02	.1273212+02	.5074436+01	.3848503+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER -	.3750947+02	.1443493+02	.5753098+01	.4363207+01
FAN EFFICIENCY -----	.7100000-00	.7100000-00	.7831854-00	.7456491-00
FAN BRAKE HORSEPOWER -----	.3069048+04	.1181075+04	.2844900+03	.2266215+03
FAN MOTOR HORSEPOWER -----	.3000000+04	.1250000+04	.3000000+03	.2500000+03
STACK DIAMETER, FT. -----	.9500000+01	.9500000+01	.9500000+01	.9500000+01
STACK FRICTION DROP, INCHES OF WATER -----	.8050280-00	.8050280-00	.8050280-00	.8050280-00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.1583184+01	.1664972+01	.7527951-00	.7551993-00
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.4056004+03	.3852478+03	.3811361+03	.3799101+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3725157+03	.3725157+03	.3760616+03	.3760616+03

TABLE B-11 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY										PAGE 2
TPH 975, DEG.F.	TPC 700, DEG.F.	WP	.5451851+07 LB./HR.	TSH 863, DEG.F.	TSC 588, DEG.F.	WS	.5406824+07 LB./HR.			
TMX 112, DEG.F.										
NUMBER OF TUBE PASSES --										2
										4
										6
										8
SECONDARY LOOP DESIGN										
COLD LEG PIPE DIAMETER, INCHES			.1400000+02	.1800000+02	.1800000+02		.1800000+02		.1800000+02	
HOT LEG PIPE DIAMETER, INCHES			.1400000+02	.1800000+02	.1800000+02		.1800000+02		.1800000+02	
SURGE TANK VOLUME, CU.FT.			.1914421+03	.2760981+03	.3075908+03		.4889585+03		.4889585+03	
SURGE TANK GAS SPACE PRESSURE, PSIG			.0000000	.1474527+02	.1039064+03		.1181443+03		.1181443+03	
PUMP HEAD, FT.			.1204130+04	.3486091+03	.1160670+03		.7893293+02		.7893293+02	
PUMP FLOW RATE, GPM			.1220996+05	.1220996+05	.1220996+05		.1220996+05		.1220996+05	
PUMP DISCHARGE PRESSURE, PSIG			.4636037+03	.1503258+03	.1503258+03		.1503258+03		.1503258+03	
PUMP SUCTION PRESSURE, PSIG			.1917091+01	.1666236+02	.1058235+03		.1200614+03		.1200614+03	
PUMP SPECIFIC SPEED			.6324671+03	.1602467+04	.3656044+04		.4882018+04		.4882018+04	
PUMP CAVITATION PARAMETER			.4152021+01	.1416481+00	.4207890+00		.6163686+00		.6163686+00	
PUMP BRAKE HORSEPOWER			.4384188+04	.1269271+04	.4225953+03		.2873916+03		.2873916+03	
PUMP MOTOR SIZE, HORSEPOWER			.3000000+04	.1250000+04	.4500000+03		.3000000+03		.3000000+03	
PRESSURE DROP, SECONDARY SIDE OF IHX			.3402491+01	.3402491+01	.3402491+01		.3402491+01		.3402491+01	
PRESSURE DROP, SECONDARY SIDE OF DHX			.3826660+03	.1061794+03	.1701829+02		.2780363+01		.2780363+01	
COST DATA, DOLLARS										-167-
HEAT EXCHANGER SECTION			.1104821+06	.1389658+06	.1909980+06		.5112675+06		.5112675+06	
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY			.6289109+06	.4174736+06	.7107000+05		.6924000+05		.6924000+05	
INLET AIR FILTERS			.3543210+05	.3543210+05	.3543210+05		.3543210+05		.3543210+05	
SOUND ATTENUATORS			.7500000+04	.7500000+04	.1125000+05		.1125000+05		.1125000+05	
AIR SIDE BUTTERFLY VALVES			.6200000+05	.6200000+05	.9300000+05		.9300000+05		.9300000+05	
HEAT EXCHANGER BOX			.1143825+05	.1835130+05	.3769778+05		.1849096+06		.1849096+06	
OFF-GAS STACK			.7695000+05	.7695000+05	.7695000+05		.7695000+05		.7695000+05	
DUCT WORK			.1143825+04	.1835130+04	.3769778+04		.1849096+05		.1849096+05	
AUXILIARY FURNACE			.2759882+05	.2759882+05	.2759882+05		.2759882+05		.2759882+05	
SODIUM IN DUMP HEAT EXCHANGER			.2935206+04	.4413151+04	.7367924+04		.2701428+05		.2701428+05	
DHX AND ASSOCIATED PIPE			.5230439+05	.8742715+05	.1640752+06		.7218757+06		.7218757+06	
SODIUM VALVES IN DHX MANIFOLDS			.4800000+05	.4800000+05	.7200000+05		.7200000+05		.7200000+05	
TOTAL DHX AND TERTIARY LOOP COST			.1264695+07	.9259470+06	.7993095+06		.1849029+07		.1849029+07	
SODIUM IN SECONDARY LOOP			.5244912+04	.8886150+04	.8886150+04		.8886150+04		.8886150+04	
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS			.4758295+06	.2385328+06	.1248140+06		.9220586+05		.9220586+05	
SECONDARY PIPE			.2568421+06	.3413137+06	.3413137+06		.3413137+06		.3413137+06	
SECONDARY LOOP VALVES			.1000000+05	.1600000+05	.1600000+05		.1600000+05		.1600000+05	
SECONDARY LOOP SURGE TANK			.5574066+04	.6943648+04	.7408558+04		.9783919+04		.9783919+04	
HIGH DESIGN PRESSURE COST PENALTY			.1191881+07	.1091225+04	.9738985+03		.9425783+03		.9425783+03	
TOTAL SECONDARY LOOP COST			.1945372+07	.6127675+06	.4993964+06		.4691322+06		.4691322+06	
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST			.3210067+07	.1538715+07	.1298706+07		.2318161+07		.2318161+07	
THE OPTIMUM NUMBER OF TUBE PASSES IS 4										

BNWL-308

TABLE B-12. DHX DATA AT 550F EXHAUST AIR TEMPERATURE.

-168-

BNWL-30

JUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SUBCASE NO. 6 PARAMETERS. PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F. IPC 500. DEG.F. WP .4012276+07 LB./HR. TSH 675. DEG.F. TSC 400. DEG.F. WS .3964069+07 LB./HR.
 TTH 530. DEG.F. TTC 100. DEG.F. WT .2941324+07 LB./HR. TMX 100. DEG.F. TMY 200. DEG.F.

NUMBER OF TUBE PASSES --

8

6

4

2

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. ----- .1608566+06 .2060529+06 .3267010+06 .9045695+06
 HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. ----- .1124691+02 .8779973+01 .5537598+01 .2000000+01
 OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. ----- .2180439+03 .1701556+03 .1070078+03 .3653457+02
 INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. ----- .7297574+04 .5668544+04 .3931169+04 .2673128+04
 AIR FLOW RATE, LB./HR./SQ.FT. ----- .1116492+05 .6525519+04 .2743381+04 .4952317+03
 AIR PRESSURE DROP IN DHX, INCHES OF H2O ----- .9760703+01 .2686717+01 .3554270+00 .7279365+02
 SODIUM VELOCITY, FT./SEC. ----- .1485938+02 .8672788+01 .3642004+01 .6569132+00
 SODIUM PRESSURE DROP IN DHX, PSI ----- .8349793+02 .2188863+02 .5359916+01 .2979604+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW ----- 300/ 150 514/ 257 1224/ 612 6786/ 3393
 HEAT EXCHANGER BOX LENGTH, FT. ----- .3460920+02 .5913360+02 .1404996+03 .7779048+03
 HEAT EXCHANGER BOX VOLUME, CU.FT. ----- .1187062+05 .1948409+05 .4439720+05 .2353143+06
 MANIFOLD INSIDE DIAMETER, INCHES ----- .1002000+02 .1002000+02 .1002000+02 .1002000+02
 SECONDARY LOOP PIPING I.D., INCHES ----- .1725000+02 .1525000+02 .1725000+02 .1725000+02
 SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT. ----- .3896793+03 .5142938+03 .1010105+04 .4000228+04
 WEIGHT OF UNFINNED TUBING, LB. ----- .3558265+04 .4700870+04 .7462860+04 .2068749+05
 WEIGHT OF FINNED TUBING, LB. ----- .1299769+06 .1670204+06 .2651530+06 .7350196+06

TERTIARY LOOP DESIGN

NUMBER OF FAN MODULES ----- 2 3 2 2
 FAN AIR FLOW RATE, CFM ----- .3699331+06 .2466221+06 .3699331+06 .3699331+06
 FAN SPEED, RPM ----- .1170000+04 .1170000+04 .1170000+04 .1170000+04
 FAN SIZE, INCHES ----- .8400000+02 .8400000+02 .8400000+02 .8400000+02
 FAN PRESSURE, INCHES OF WATER ----- .1440573+02 .6391121+01 .4748299+01 .4436747+01
 EQUIVALENT FAN PRESSURE, INCHES OF WATER ----- .1633237+02 .7245879+01 .5428693+01 .5030123+01
 FAN EFFICIENCY ----- .7260942+00 .8465644+00 .7343370+00 .7144940+00
 FAN BRAKE HORSEPOWER ----- .1159638+04 .2941752+03 .3811239+03 .3629496+03
 FAN MOTOR HORSEPOWER ----- .1250000+04 .3000000+03 .4000000+03 .3500000+03
 STACK DIAMETER, FT. ----- .9000000+01 .9000000+01 .9000000+01 .9000000+01
 STACK FRICTION DROP, INCHES OF WATER ----- .8634011+00 .8634011+00 .8634011+00 .8634011+00
 BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O ----- .1304440+01 .5906084+00 .1337006+01 .1338225+01
 FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS. ----- .3682733+03 .3630587+03 .3783043+03 .3783043+03
 FAN SUCTION STATIC PRESSURE, IN. H2O ABS. ----- .3738676+03 .3766676+03 .3738676+03 .3738676+03

TABLE B-12 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY										PAGE 2
TPH 975. DEG.F.	TPC 700. DEG.F.	WP .5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS .5406824+07 LR./HR.					
TMX 112. DEG.F.										
						NUMBER OF TUBE PASSES --	8	6	4	2
SECONDARY LOOP DESIGN										
COLD LEG PIPE DIAMETER, INCHES							.1800000+02	.1600000+02	.1800000+02	.1800000+02
HOT LEG PIPE DIAMETER, INCHES							.1800000+02	.1600000+02	.1800000+02	.1800000+02
SURGE TANK VOLUME, CU.FT.							.2894731+03	.2760501+03	.3801346+03	.7397402+03
SURGE TANK GAS SPACE PRESSURE, PSIG							.1706786+01	.6677345+02	.1106490+03	.1152124+03
PUMP HEAD, FT.							.4891779+03	.2251152+03	.9848145+02	.8657969+02
PUMP FLOW RATE, GPM							.1220996+05	.1220996+05	.1220996+05	.1220996+05
PUMP DISCHARGE PRESSURE, PSIG							.1911841+03	.1550040+03	.1503258+03	.1503258+03
PUMP SUCTION PRESSURE, PSIG							.3623882+01	.6869054+02	.1125661+03	.1171295+03
PUMP SPECIFIC SPEED							.1242919+04	.2224535+04	.4135492+04	.4554922+04
PUMP CAVITATION PARAMETER							.1012871+00	.2183963+00	.4951141+00	.5624505+00
PUMP BRAKE HORSEPOWER							.1781077+04	.8196354+03	.3585669+03	.3152331+03
PUMP MOTOR SIZE, HORSEPOWER							.1750000+04	.8000000+03	.3500000+03	.3500000+03
PRESSURE DROP, SECONDARY SIDE OF IHX							.3402491+01	.3402491+01	.3402491+01	.3402491+01
PRESSURE DROP, SECONDARY SIDE OF DHX							.1600761+03	.4196329+02	.1027564+02	.5712279+01
COST DATA, DOLLARS										
HEAT EXCHANGER SECTION							.1726283+06	.2218274+06	.3521617+06	.9762130+06
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY							.4128638+06	.7107000+05	.5498000+05	.4924000+05
INLET AIR FILTERS							.3144432+05	.3144432+05	.3144432+05	.3144432+05
SOUND ATTENUATORS							.7500000+04	.1125000+05	.7500000+04	.7500000+04
AIR SIDE BUTTERFLY VALVES							.6200000+05	.9300000+05	.6200000+05	.6200000+05
HEAT EXCHANGER BOX							.1780593+05	.2922614+05	.6659580+05	.3529715+06
OFF GAS STACK							.7290000+05	.7290000+05	.7290000+05	.7290000+05
DUCT WORK							.1780593+04	.2922614+04	.6659580+04	.3529715+05
AUXILIARY FURNACE							.2759882+05	.2759882+05	.2759882+05	.2759882+05
SODIUM IN DUMP HEAT EXCHANGER							.5023745+04	.6630276+04	.1302227+05	.5157094+05
DHX AND ASSOCIATED PIPE							.9158278+05	.1309840+06	.2898504+06	.1377979+07
SODIUM VALVES IN DHX MANIFOLDS							.4800000+05	.7200000+05	.4800000+05	.4800000+05
TOTAL DHX AND TERTIARY LOOP COST							.9511283+06	.7708535+06	.1032713+07	.3092714+07
SODIUM IN SECONDARY LOOP							.8886150+04	.6951703+04	.8886150+04	.8886150+04
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS							.2941354+06	.1830825+06	.1048824+06	.9880305+05
SECONDARY PIPE							.3413137+06	.2982236+06	.3413137+06	.3413137+06
SECONDARY LOOP VALVES							.1600000+05	.1320000+05	.1600000+05	.1600000+05
SECONDARY LOOP SURGE TANK							.7143558+04	.6942923+04	.8412248+04	.1254288+05
HIGH DESIGN PRESSURE COST PENALTY							.1452595+06	.1511829+05	.9542898+03	.9522710+03
TOTAL SECONDARY LOOP COST							.8127383+06	.5235190+06	.4804489+06	.4784981+06
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST							.1763866+07	.1294372+07	.1513162+07	.3571212+07
THE OPTIMUM NUMBER OF TUBE PASSES IS 6										

BNWL-308

BNWL-308

TABLE B-13. DHX DATA AT 600F EXHAUST AIR TEMPERATURE.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SURCASE NO. 7 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F.	TPC 500. DEG.F.	WP .4012276+07 LB./HR.	TSH 675. DEG.F.	TSC 400. DEG.F.	WS .3964069+07 LB./HR.
TTH 600. DEG.F.	TTC 100. DEG.F.	WT .2642922+07 LB./HR.	TMX 100. DEG.F.	TMY 162. DEG.F.	

NUMBER OF TUBE PASSES --	8	6	4	2
--------------------------	---	---	---	---

DUMP HEAT EXCHANGER THERMAL DESIGN

HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.2810002+06	.3878975+06	.7042609+06	.1164773+07
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. -----	.8290197+01	.6005573+01	.3307789+01	.2000000+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. -	.1605788+03	.1160275+03	.6358156+02	.2888532+02
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.5607326+04	.4239355+04	.2928816+04	.2673128+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.5729979+04	.3113092+04	.1143392+04	.3455429+03
AIR PRESSURE DROP IN DHX, INCHES OF H2O --	.2903458+01	.6973540-00	.7169425-01	.3841481-02
SODIUM VELOCITY, FT./SEC. -----	.8474929+01	.4595683+01	.1688565+01	.5101640-00
SODIUM PRESSURE DROP IN DHX, PSI -----	.2751140+02	.8719437+01	.3460373+01	.2963982+01

DUMP HEAT EXCHANGER MECHANICAL DESIGN

NUMBER OF TUBES PER PASS / PER ROW -----	526/ 263	970/ 485	2640/ 1320	8738/ 4369
HEAT EXCHANGER BOX LENGTH, FT. -----	.6050880+02	.1113912+03	.3027732+03	.1001604+04
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.2075394+05	.3670260+05	.9567487+05	.3029828+06
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.1002000+02	.1002000+02
SECONDARY LOOP PIPING I.D., INCHES -----	.1525000+02	.1725000+02	.1725000+02	.1725000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT	.6500730+03	.1028868+04	.2177490+04	.5150651+04
WEIGHT OF UNFINNED TUBING, LB. -----	.6414158+04	.8871292+04	.1609637+05	.2663827+05
WEIGHT OF FINNED TUBING, LB. -----	.2278929+06	.3151941+06	.5718986+06	.9464488+06

TERTIARY LOOP DESIGN

NUMBER OF FAN MODULES -----	3	2	2	2
FAN AIR FLOW RATE, CFM -----	.2216018+06	.3324027+06	.3324027+06	.3324027+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.1170000+04
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.6623515+01	.5007204+01	.4376236+01	.4307869+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER -	.7509353+01	.5676874+01	.4961520+01	.4884009+01
FAN EFFICIENCY -----	.8094286-00	.7594340-00	.7349567-00	.7311215-00
FAN BRAKE HORSEPOWER -----	.2865104+03	.3462796+03	.3127236+03	.3094529+03
FAN MOTOR HORSEPOWER -----	.3000000+03	.3500000+03	.3000000+03	.3000000+03
STACK DIAMETER, FT. -----	.8500000+01	.8500000+01	.8500000+01	.8500000+01
STACK FRICTION DROP, INCHES OF WATER -----	.9627202-00	.9627202-00	.9627202-00	.9627202-00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.4764180-00	.1078149+01	.1079916+01	.1080108+01
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.3837244+03	.3798432+03	.3792122+03	.3791438+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3771009+03	.3748360+03	.3748360+03	.3748360+03

-170-

BMT-308

TABLE B-13 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY					PAGE 2
TPH 975. DEG.F.	TPC 700. DEG.F.	WP .5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS .5406824+07 LB./HR.
TMX 112. DEG.F.					
	NUMBER OF TUBE PASSES --	8	6	4	2
SECONDARY LOOP DESIGN					
COLD LEG PIPE DIAMETER, INCHES -----	.1600000+02	.1800000+02	.1800000+02	.1800000+02	
HOT LEG PIPE DIAMETER, INCHES -----	.1600000+02	.1800000+02	.1800000+02	.1800000+02	
SURGE TANK VOLUME, CU.FT. -----	.3093407+03	.4025408+03	.5732210+03	.8912024+03	
SURGE TANK GAS SPACE PRESSURE, PSIG -----	.5599388+02	.1042084+03	.1142907+03	.1152423+03	
PUMP HEAD, FT. -----	.2532296+03	.1152793+03	.8898358+02	.8650159+02	
PUMP FLOW RATE, GPM -----	.1220996+05	.1220996+05	.1220996+05	.1220996+05	
PUMP DISCHARGE PRESSURE, PSIG -----	.1550040+03	.1503258+03	.1503258+03	.1503258+03	
PUMP SUCTION PRESSURE, PSIG -----	.5791097+02	.1061255+03	.1162078+03	.1171594+03	
PUMP SPECIFIC SPEED -----	.2036607+04	.3674764+04	.4462319+04	.4558007+04	
PUMP CAVITATION PARAMETER -----	.1943779-00	.4236354-00	.5474058-00	.5629533-00	
PUMP BRAKE HORSEPOWER -----	.9219985+03	.4197273+03	.3239856+03	.3149487+03	
PUMP MOTOR SIZE, HORSEPOWER -----	.9000000+03	.4000000+03	.3500000+03	.3000000+03	
PRESSURE DROP, SECONDARY SIDE OF IHX -----	.3402491+01	.3402491+01	.3402491+01	.3402491+01	
PRESSURE DROP, SECONDARY SIDE OF DHX -----	.5274286+02	.1671627+02	.6633975+01	.5682331+01	
COST DATA, DOLLARS					
HEAT EXCHANGER SECTION -----	.3026749+06	.4186236+06	.7593645+06	.1257022+07	
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY -	.7107000+05	.4924000+05	.4738000+05	.4738000+05	
INLET AIR FILTERS -----	.2825423+05	.2825423+05	.2825423+05	.2825423+05	
SOUND ATTENUATORS -----	.1125000+05	.7500000+04	.7500000+04	.7500000+04	
AIR SIDE BUTTERFLY VALVES -----	.9300000+05	.6200000+05	.6200000+05	.6200000+05	
HEAT EXCHANGER BOX -----	.3113090+05	.5505389+05	.1435123+06	.4544742+06	
OFF GAS STACK -----	.6885000+05	.6885000+05	.6885000+05	.6885000+05	
DUCT WORK -----	.3113090+04	.5505389+04	.1435123+05	.4544742+05	
AUXILIARY FURNACE -----	.2759882+05	.2759882+05	.2759882+05	.2759882+05	
SODIUM IN DUMP HEAT EXCHANGER -----	.8380741+04	.1326417+05	.2807220+05	.6640219+05	
DHX AND ASSOCIATED PIPE -----	.1516745+06	.2622815+06	.6246204+06	.1774239+07	
SODIUM VALVES IN DHX MANIFOLDS -----	.7200000+05	.4800000+05	.4800000+05	.4800000+05	
TOTAL DHX AND TERTIARY LOOP COST -----	.8689972+06	.1046172+07	.1859704+07	.3887167+07	
SODIUM IN SECONDARY LOOP -----	.6951703+04	.8886150+04	.8886150+04	.8886150+04	
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS --	.1961281+06	.1152487+06	.1000586+06	.9626200+05	
SECONDARY PIPE -----	.2982236+06	.3413137+06	.3413137+06	.3413137+06	
SECONDARY LOOP VALVES -----	.1320000+05	.1600000+05	.1600000+05	.1600000+05	
SECONDARY LOOP SURGE TANK -----	.7433818+04	.8706338+04	.1076324+05	.1402605+05	
HIGH DESIGN PRESSURE COST PENALTY -----	.1533369+05	.9653335+03	.9517280+03	.9511750+03	
TOTAL SECONDARY LOOP COST -----	.5372708+06	.4911202+06	.4779734+06	.4774391+06	
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST	.1406268+07	.1537292+07	.2337677+07	.4364607+07	
THE OPTIMUM NUMBER OF TUBE PASSES IS 8					

-171-

BMTL-308

TABLE B-13 CONTINUED.

DUMP HEAT EXCHANGER, SECONDARY LOOP, AND TERTIARY LOOP SURCASE NO. 7 PARAMETERS.

PAGE 1

INITIAL DESIGN CONDITIONS FOR 300. MW LOOP DUTY

TPH 775. DEG.F. TPC 500. DEG.F. WP .4012276+07 LB./HR. TSH 675. DEG.F. TSC 400. DEG.F. WS .3964069+07 LB./HR.
 TTH 600. DEG.F. TTC 100. DEG.F. WT .2642922+07 LB./HR. TMX 100. DEG.F. TMY 162. DEG.F.

NUMBER OF TUBE PASSES --	14	12	10	8
DUMP HEAT EXCHANGER THERMAL DESIGN				
HEAT TRANSFER SURFACE AREA, SQ.FT. -----	.1745572+06	.1976812+06	.2277851+06	.2810002+06
HEAT TRANSFER COEFF., BTU/HR/SQ.FT/DEG.F. -----	.1334546+02	.1178436+02	.1022695+02	.8290197+01
OUTSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.2577956+03	.2280573+03	.1978567+03	.1605788+03
INSIDE FILM COEFF., BTU/HR/SQ.FT/DEG.F. --	.9585519+04	.8139512+04	.6834943+04	.5607326+04
AIR FLOW RATE, LB./HR./SQ.FT. -----	.1614812+05	.1222550+05	.8855422+04	.5729979+04
AIR PRESSURE DROP IN DHX, INCHES OF H2O --	.3513789+02	.1791697+02	.8178621+01	.2903458+01
SODIUM VELOCITY, FT./SEC. -----	.2396673+02	.1812119+02	.1311121+02	.8474929+01
SODIUM PRESSURE DROP IN DHX, PSI -----	.3696831+03	.1826495+03	.8133764+02	.2751140+02

NUMBER OF TUBES PER PASS / PER ROW -----	186/ 93	246/ 123	340/ 170	526/ 263
DUMP HEAT EXCHANGER MECHANICAL DESIGN				
HEAT EXCHANGER BOX LENGTH, FT. -----	.2154480+02	.2842080+02	.3919320+02	.6050880+02
HEAT EXCHANGER BOX VOLUME, CU.FT. -----	.8262068+04	.1051529+05	.1397190+05	.2075394+05
MANIFOLD INSIDE DIAMETER, INCHES -----	.1002000+02	.1002000+02	.1002000+02	.1002000+02
SECONDARY LOOP PIPING I.D., INCHES -----	.1325000+02	.1325000+02	.1725000+02	.1525000+02
SODIUM VOLUME IN DUMP HEAT EXCHANGER, CU.FT	.3522154+03	.4073610+03	.5215355+03	.6500730+03
WEIGHT OF UNFINNED TUBING, LB. -----	.3969217+04	.4499666+04	.5182542+04	.6414158+04
WEIGHT OF FINNED TUBING, LB. -----	.1410250+06	.1598716+06	.1841340+06	.2278929+06

NUMBER OF FAN MODULES -----	2	2	2	3
TERTIARY LOOP DESIGN				
FAN AIR FLOW RATE, CFM -----	.3324027+06	.3324027+06	.3324027+06	.2216018+06
FAN SPEED, RPM -----	.1170000+04	.1170000+04	.1170000+04	.1170000+04
FAN SIZE, INCHES -----	.8400000+02	.8400000+02	.8400000+02	.8400000+02
FAN PRESSURE, INCHES OF WATER -----	.4135997+02	.2277878+02	.1263135+02	.6623515+01
EQUIVALENT FAN PRESSURE, INCHES OF WATER --	.4689150+02	.2582525+02	.1432068+02	.7509353+01
FAN EFFICIENCY -----	.7326071-00	.7326071-00	.7326071-00	.8094286-00
FAN BRAKE HORSEPOWER -----	.2965041+04	.1632981+04	.9055244+03	.2865104+03
FAN MOTOR HORSEPOWER -----	.3000000+04	.1750000+04	.9000000+03	.3000000+03
STACK DIAMETER, FT. -----	.8500000+01	.8500000+01	.8500000+01	.8500000+01
STACK FRICTION DROP, INCHES OF WATER -----	.9627202-00	.9627202-00	.9627202-00	.9627202-00
BUTTERFLY VALVE PRESSURE DROP, IN. OF H2O	.9852023-00	.1030630+01	.1057240+01	.4764180-00
FAN DISCHARGE STATIC PRESSURE, IN. H2O ABS.	.4161960+03	.3976148+03	.3874673+03	.3837244+03
FAN SUCTION STATIC PRESSURE, IN. H2O ABS.	.3748360+03	.3748360+03	.3748360+03	.3771009+03

-172-

BMT-308

TABLE B-13 CONTINUED.

ULTIMATE DESIGN CONDITIONS FOR 400. MW LOOP DUTY										PAGE 2	
TPH 975. DEG.F.	TPC 700. DEG.F.	WP	.5451851+07 LB./HR.	TSH 863. DEG.F.	TSC 588. DEG.F.	WS	.5406824+07 LB./HR.				
TMX 112. DEG.F.	NUMBER OF TUBE PASSES --			14	12	10	8				
SECONDARY LOOP DESIGN											
COLD LEG PIPE DIAMETER, INCHES	1400000+02							1400000+02	1800000+02		1600000+02
HOT LEG PIPE DIAMETER, INCHES	1400000+02							1400000+02	1800000+02		1600000+02
SURGE TANK VOLUME, CU.FT.	2228237+03							2341411+03	3196474+03		3093407+03
SURGE TANK GAS SPACE PRESSURE, PSIG	0000000							0000000	1702545+01		5599388+02
PUMP HEAD, FT.	2054488+04							1119305+04	4783763+03		2532296+03
PUMP FLOW RATE, GPM	1220996+05							1220996+05	1220996+05		1220996+05
PUMP DISCHARGE PRESSURE, PSIG	7896472+03							4310801+03	1870383+03		1550040+03
PUMP SUCTION PRESSURE, PSIG	1917091+01							1917091+01	3619641+01		5791097+02
PUMP SPECIFIC SPEED	4236579+03							6680850+03	1263909+04		2036607+04
PUMP CAVITATION PARAMETER	2446525-01							4063415-01	1035510+00		1943779-00
PUMP BRAKE HORSEPOWER	7480306+04							4075343+04	1741748+04		9219985+03
PUMP MOTOR SIZE, HORSEPOWER	3000000+04							3000000+04	1750000+04		9000000+03
PRESSURE DROP, SECONDARY SIDE OF IHX	3402491+01							3402491+01	3402491+01		3402491+01
PRESSURE DROP, SECONDARY SIDE OF DHX	7087295+03							3501624+03	1559346+03		5274286+02
COST DATA, DOLLARS											
HEAT EXCHANGER SECTION	1873017+06							2123328+06	2445567+06		3026749+06
SUPPLY FANS, INCL. DRIVE + VANE ASSEMBLY	8112594+06							5291063+06	3419852+06		7107000+05
INLET AIR FILTERS	2825423+05							2825423+05	2825423+05		2825423+05
SOUND ATTENUATORS	7500000+04							7500000+04	7500000+04		1125000+05
AIR SIDE BUTTERFLY VALVES	6200000+05							6200000+05	6200000+05		9300000+05
HEAT EXCHANGER BOX	1239310+05							1577293+05	2095786+05		3113090+05
OFF GAS STACK	6885000+05							6885000+05	6885000+05		6885000+05
DUCT WORK	1239310+04							1577293+04	2095786+04		3113090+04
AUXILIARY FURNACE	2759882+05							2759882+05	2759882+05		2759882+05
SODIUM IN DUMP HEAT EXCHANGER	4540761+04							5251698+04	6723636+04		8380741+04
DHX AND ASSOCIATED PIPE	6953412+05							8343835+05	1151417+06		1516745+06
SODIUM VALVES IN DHX MANIFOLD	4800000+05							4800000+05	4800000+05		7200000+05
TOTAL DHX AND TERTIARY LOOP COST	1328471+07							1089682+07	9736640+06		8689972+06
SODIUM IN SECONDARY LOOP	5244912+04							5244912+04	8886150+04		6951703+04
SEC. PUMP, INCL. DRIVE + ELEC. CONTROLS	6032141+06							4612361+06	2914273+06		1961281+06
SECONDARY PIPE	2568421+06							2568421+06	3413137+06		2982236+06
SECONDARY LOOP VALVES	1000000+05							1000000+05	1600000+05		1320000+05
SECONDARY LOOP SURGE TANK	6105574+04							6289791+04	7581450+04		7433818+04
HIGH DESIGN PRESSURE COST PENALTY	2691232+07							1055868+07	1303696+06		1533369+05
TOTAL SECONDARY LOOP COST	3572639+07							1795481+07	7955782+06		5372708+06
TOTAL DHX, SECONDARY AND TERTIARY LOOP COST	4901110+07							2885163+07	1769242+07		1406268+07
THE OPTIMUM NUMBER OF TUBE PASSES IS 8											

BWWL-308

-173-

TABLE B-14. SELECTION OF THE OPTIMUM DHX EXHAUST AIR TEMPERATURE AND REFERENCE DATA
FOR THE PRIMARY AND SECONDARY LOOPS DESIGNS, WHICH FOLLOW.

THE OPTIMUM TERTIARY LOOP IS .4500000+03 DEG.F. OUTLET AIR WITH A 4 PASS DUMP EXCHANGER.

THE TOTAL COST FOR THE IHX, DHX, SECONDARY LOOP, AND TERTIARY LOOP IS .1710091+07 DOLLARS, INCLUDING THE FOLLOWING SPECIAL COSTS.

INSTRUMENTATION ----- .1500000+05 DOLLARS.
HIGH SECONDARY LOOP DESIGN PRESSURE - .1284894+05 DOLLARS.
PRIMARY PUMP PENALTY ----- .1868064+04 DOLLARS.

174

THE OPTIMUM CASE STUDIED SO FAR IS AN INTERMEDIATE HEAT EXCHANGER WITH HEAT TRANSFER AREA OF .2996819+04 SQ.FT., WHICH CORRESPONDS TO A LOG MEAN TEMPERATURE OF .1000000+03 DEG.F. FOR STARTUP CONDITIONS AND .1122788+03 DEG.F. FOR ULTIMATE CONDITIONS. THE TOTAL COST IS .1710091+07 DOLLARS.

THE FOLLOWING HEAT EXCHANGER PARAMETERS WILL BE USED TO SIZE AND COST THE LOOPS, BASED ON ULTIMATE CONDITIONS -

SODIUM PRESSURE DROP IN PRIMARY SIDE OF THE IHX ----- .3794151+01 PSI.
SODIUM PRESSURE DROP IN SECONDARY SIDE OF THE IHX ----- .3402491+01 PSI.
SODIUM PRESSURE DROP IN SECONDARY SIDE OF THE DHX ----- .2940186+02 PSI.
VOLUME OF SODIUM IN SECONDARY SIDE OF THE IHX ----- .1631896+03 CU.FT.
VOLUME OF SODIUM IN SECONDARY SIDE OF THE DHX ----- .2400442+03 CU.FT.

TABLE B-15. PRIMARY LOOP DESIGN AND COST WITH 14 AND 16 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

WITH .1104000+01 FT. COLD LEG PIPE AND .1104000+01 FT. HOT LEG PIPE, THE .9049960+01 PSIG REACTOR TANK PRESSURE EXCEEDS THE MAXIMUM ALLOWABLE PRESSURE OF .5000000+01 PSIG.

TRIAL NO. 1 WITH 16.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1532119+04 HP
SUCTION PRESSURE ----- .2120503+01 PSIG
HEAD ----- .4173255+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1451808+04
CAVITATION PARAMETER ----- .12433396+00

-175-

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1600000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.5166744+01	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.1878000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.6180000+03	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.3155652+04	.4114179+04	.4793573+04	.0000000
SODIUM WEIGHT, LB.	.2230493+04	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.1923200+02	.1724800+02	.1724800+02	.1724800+02
REYNOLDS NUMBER	.1025676+08	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.2304551+02	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1252739-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP ----- .1848000+04 DOLLARS.
PRIMARY PUMP ----- .2147600+06 DOLLARS.
PRIMARY PIPE ----- .8375646+05 DOLLARS.
CONFINER PIPE ----- .1459672+06 DOLLARS.

TOTAL COST ----- .5609396+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .4861323+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IXH IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9255500+06 DOLLARS.

POWER COST PER YEAR ----- .2026579+05 DOLLARS PER YEAR.

BNWL-308

TABLE B-16. PRIMARY LOOP DESIGN AND COST WITH 14 AND 18 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 18.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1510889+04 HP
SUCTION PRESSURE ----- .3271513+01 PSIG
HEAD ----- .4115428+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1467081+04
CAVITATION PARAMETER - .1260691-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1800000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.3087222+01	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.2118000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.7800000+03	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.3575955+04	.4114179+04	.4793573+04	.0000000
SODIUM WEIGHT, LB.	.2851171+04	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.2124400+02	.1724800+02	.1724800+02	.1724800+02
REYNOLDS NUMBER	.9067019+07	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1801895+02	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1227774-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

-176-

COST DATA

SODIUM IN PRIMARY LOOP - .1984000+04 DOLLARS.
PRIMARY PUMP ----- .2130666+06 DOLLARS.
PRIMARY PIPE ----- .8736642+05 DOLLARS.
CONFINER PIPE ----- .1510529+06 DOLLARS.

TOTAL COST ----- .5680699+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .2779198+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9373150+06 DOLLARS.
POWER COST PER YEAR ---- .1998498+05 DOLLARS PER YEAR.

TABLE B-17. PRIMARY LOOP DESIGN AND COST WITH 14 AND 20 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 3 WITH 20.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1499332+04 HP
SUCTION PRESSURE ----- .3914414+01 PSIG
HEAD ----- .4083949+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1475554+04
CAVITATION PARAMETER - .1270311-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2000000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.1955219+01	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.2358000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.9600000+03	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4013948+04	.4114179+04	.4793573+04	.0000000
SODIUM WEIGHT, LB.	.3552372+04	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.2324800+02	.1724800+02	.1724800+02	.1724800+02
REYNOLDS NUMBER	.8127638+07	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1447044+02	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1206964-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .2139000+04 DOLLARS.
PRIMARY PUMP - .2121361+06 DOLLARS.
PRIMARY PIPE - .9113802+05 DOLLARS.
CONFINER PIPE - .1563526+06 DOLLARS.

TOTAL COST ----- .5763657+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .1645763+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9510030+06 DOLLARS.
POWER COST PER YEAR ----- .1983211+05 DOLLARS PER YEAR.

TABLE B-18. PRIMARY LOOP DESIGN AND COST WITH 14 AND 24 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 4 WITH 24.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1488488+04 HP
SUCTION PRESSURE ----- .4534446+01 PSIG
HEAD ----- .4054412+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1483609+04
CAVITATION PARAMETER - .1279472-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.8930269-00	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.2838000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.1380000+04	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4951787+04	.4114179+04	.4793573+04	.0000000
SODIUM WEIGHT, LB.	.5180468+04	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.2724400+02	.1724800+02	.1724800+02	.1724800+02
KEYNOLDS NUMBER	.6721817+07	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.9910116+01	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1175030-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

COST DATA
SODIUM IN PRIMARY LOOP - .2497000+04 DOLLARS.
PRIMARY PUMP ----- .2112602+06 DOLLARS.
PRIMARY PIPE ----- .9922002+05 DOLLARS.
CONFINER PIPE ----- .1677004+06 DOLLARS.

TOTAL COST ----- .5952777+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .5822157-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9822080+06 DOLLARS.
POWER COST PER YEAR ----- .1968868+05 DOLLARS PER YEAR.

TABLE B-19. PRIMARY LOOP DESIGN AND COST WITH 14 AND 30 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 5 WITH 30.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1482924+04 HP
 SUCTION PRESSURE ----- .4863178+01 PSIG
 HEAD ----- .4039255+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1487782+04
 CAVITATION PARAMETER - .1284225-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CR
PIPE DIAMETER, IN.	.3000000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.3479913-00	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.3561000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.4114179+04	.4793573+04	.0000000
SODIUM WEIGHT, LB.	.6200131+04	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.1724800+02	.1724800+02	.1724800+02
REYNOLDS NUMBER	.5347416+07	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1143077-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

-179-

COST DATA

SODIUM IN PRIMARY LOOP - .3161000+04 DOLLARS.
 PRIMARY PUMP ----- .2108097+06 DOLLARS.
 PRIMARY PIPE ----- .1121782+06 DOLLARS.
 CONFINER PIPE ----- .1857759+06 DOLLARS.

TOTAL COST ----- .6265247+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .3648257-01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1033765+07 DOLLARS.

POWER COST PER YEAR ----- .1961508+05 DOLLARS PER YEAR.

TABLE B-20. PRIMARY LOOP DESIGN AND COST WITH 14 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 6 WITH 36.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1481077+04 HP
 SUCTION PRESSURE ----- .4975313+01 PSIG
 HEAD ----- .4034226+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1489173+04
 CAVITATION PARAMETER - .1285810-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.1671196-00	.2599148+02	.1512179+02	.0000000
PIPING WEIGHT, LB.	.5688000+04	.2730000+04	.3276000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.4250000+03	.4000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.4114179+04	.4793573+04	.0000000
CONFINER WEIGHT, LB.	.1174851+05	.2804766+04	.3365719+04	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.1724800+02	.1724800+02	.1724800+02
REYNOLDS NUMBER	.4471171+07	.1180623+08	.9148968+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.3053963+02	.2916740+02	.0000000
FRICTION FACTOR	.1124017-01	.1283562-01	.1287112-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4360000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .3942000+04 DOLLARS.
 PRIMARY PUMP ----- .2106600+06 DOLLARS.
 PRIMARY PIPE ----- .1487896+06 DOLLARS.
 CONFINER PIPE ----- .2061760+06 DOLLARS.

TOTAL COST ----- .6841676+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1446216-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF YHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1128876+07 DOLLARS.
 POWER COST PER YEAR ----- .1959065+05 DOLLARS PER YEAR.

TABLE B-21. PRIMARY LOOP DESIGN AND COST WITH 16 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 16.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1345649+04 HP
 SUCTION PRESSURE ----- .2096302+01 PSIG
 HEAD ----- .3665339+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1600220+04
 CAVITATION PARAMETER - .1413860-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1600000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.5166744+01	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.1878000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.6180000+03	.5440000+03	.5120000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.3155652+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.2230493+04	.3717488+04	.4460986+04	.0000000
CONFINER DIAMETER, IN.	.1925200+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.1025676+08	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.2304551+02	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1252739-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .2289000+04 DOLLARS.
 PRIMARY PUMP - .1994546+06 DOLLARS.
 PRIMARY PIPE - .9373324+05 DOLLARS.
 CONFINER PIPE - .1596787+06 DOLLARS.

TOTAL COST ----- .5733955+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .4837122+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9461020+06 DOLLARS.
 POWER COST PER YEAR ----- .1779930+05 DOLLARS PER YEAR.

TABLE B-22. PRIMARY LOOP DESIGN AND COST WITH 16 AND 18 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 18.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1324419+04 HP
SUCTION PRESSURE ----- .3246953+01 PSIG
HEAD ----- .3607512+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1619420+04
CAVITATION PARAMETER - .1436296-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1800000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.3087222+01	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.2118000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.7800000+03	.5440000+03	.5120000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.3575955+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.2851171+04	.3717488+04	.4460986+04	.0000000
CONFINER DIAMETER, IN.	.2124400+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.9067019+07	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1801895+02	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1227774-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .2426000+04 DOLLARS.
PRIMARY PUMP - .1976548+06 DOLLARS.
PRIMARY PIPE - .9734320+05 DOLLARS.
CONFINER PIPE - .1647644+06 DOLLARS.

TOTAL COST ----- .5804284+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .2754638+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9577060+06 DOLLARS.
POWER COST PER YEAR ----- .1751848+05 DOLLARS PER YEAR.

TABLE B-23. PRIMARY LOOP DESIGN AND COST WITH 16 AND 20 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 3 WITH 20.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1312862+04 HP
 SUCTION PRESSURE ----- .3889653+01 PSIG
 HEAD ----- .3576033+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1630099+04
 CAVITATION PARAMETER - .1448812-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2000000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.1955219+01	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.2358000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.9600000+03	.5440000+03	.5120000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4013948+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.3552372+04	.3717488+04	.4460986+04	.0000000
CONFINER DIAMETER, IN.	.2324800+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.8127638+07	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1447044+02	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1206964-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .2580000+04 DOLLARS.
 PRIMARY PUMP ----- .1966698+06 DOLLARS.
 PRIMARY PIPE ----- .1011148+06 DOLLARS.
 CONFINER PIPE ----- .1700641+06 DOLLARS.

TOTAL COST ----- .5886688+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .1621002+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9713030+06 DOLLARS.
 POWER COST PER YEAR --- .1736562+05 DOLLARS PER YEAR.

TABLE B-24. PRIMARY LOOP DESIGN AND COST WITH 16 AND 24 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 4 WITH 24.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER -----	.1302018+04 HP				
SUCTION PRESSURE -----	.4509494+01 PSIG				
HEAD -----	.3546496+03 FT				
FLOW RATE -----	.1312680+05 GPM				
SPECIFIC SPEED -----	.1640271+04				
CAVITATION PARAMETER -	.1460757-00				
		ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.1600000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.8930269-00	.1453778+02	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.2838000+04	.3130000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.1380000+04	.5440000+03	.5440000+03	.5120000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4951787+04	.4644978+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.5180468+04	.3717488+04	.3717488+04	.4460986+04	.0000000
CONFINER DIAMETER, IN.	.2724400+02	.1925200+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.6721817+07	.1025676+08	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.9910116+01	.2304551+02	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1175030-01	.1252739-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP -	.2938000+04 DOLLARS.
PRIMARY PUMP -----	.1957422+06 DOLLARS.
PRIMARY PIPE -----	.1091968+06 DOLLARS.
CONFINER PIPE -----	.1814120+06 DOLLARS.

TOTAL COST ----- 5985290+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .5572644-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9875720+06 DOLLARS.

POWER COST PER YEAR ---- .1722218+05 DOLLARS PER YEAR.

TABLE B-25. PRIMARY LOOP DESIGN AND COST WITH 16 AND 30 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 5 WITH 30.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1296454+04 HP
 SUCTION PRESSURE ----- .4838126+01 PSIG
 HEAD ----- .3531340+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1645548+04
 CAVITATION PARAMETER - .1466964-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3000000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.3479913-00	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.3561000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.5440000+03	.5120000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.8200131+04	.3717488+04	.4460986+04	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.5347416+07	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1143077-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .3603000+04 DOLLARS.
 PRIMARY PUMP ----- .1952650+06 DOLLARS.
 PRIMARY PIPE ----- .1221549+06 DOLLARS.
 CONFINER PIPE ----- .1994874+06 DOLLARS.

TOTAL COST ----- .6297504+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .1143097-01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1039088+07 DOLLARS.
 POWER COST PER YEAR ----- .1714858+05 DOLLARS PER YEAR.

TABLE B-26. PRIMARY LOOP DESIGN AND COST WITH 16 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 6 WITH 36.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1294607+04 HP
 SUCTION PRESSURE ----- .4950229+01 PSIG
 HEAD ----- .3526310+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1647308+04
 CAVITATION PARAMETER - .1469035-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.1671196-00	.1453778+02	.8310367+01	.0000000
PIPING WEIGHT, LB.	.5688000+04	.3130000+04	.3756000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.5440000+03	.5120000+03	.0000000
CONFINEE PIPE WEIGHT, LB.	.8131585+04	.4644978+04	.5395962+04	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.3717488+04	.4460986+04	.0000000
CONFINEE DIAMETER, IN.	.3900400+02	.1925200+02	.1925200+02	.1925200+02
REYNOLDS NUMBER	.4471171+07	.1025676+08	.7948243+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.2304551+02	.2201001+02	.0000000
FRICTION FACTOR	.1124017-01	.1252739-01	.1257242-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.4724000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .4383000+04 DOLLARS.
 PRIMARY PUMP ----- .1951064+06 DOLLARS.
 PRIMARY PIPE ----- .1587664+06 DOLLARS.
 CONFINEE PIPE ----- .2198875+06 DOLLARS.

TOTAL COST ----- .6873833+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1697051-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1134182+07 DOLLARS.
 POWER COST PER YEAR ----- .1712416+05 DOLLARS PER YEAR.

TABLE B-27. PRIMARY LOOP DESIGN AND COST WITH 18 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 18.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1231156+04 HP
 SUCTION PRESSURE ----- .3233352+01 PSIG
 HEAD ----- .3353479+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1710581+04
 CAVITATION PARAMETER - .1543970-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1800000+02	.1800000+02	.1800000+02	.1800000+02
PRESSURE DROP, PSI	.3087222+01	.8768528+01	.4944350+01	.0000000
PIPING WEIGHT, LB.	.2118000+04	.3530000+04	.4236000+04	.0000000
FITTING WEIGHT, LB.	.7800000+03	.6870000+03	.6460000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.3575955+04	.5203521+04	.6024090+04	.0000000
SODIUM WEIGHT, LB.	.2851171+04	.4751952+04	.5702342+04	.0000000
CONFINER DIAMETER, IN.	.2124400+02	.2124400+02	.2124400+02	.2124400+02
REYNOLDS NUMBER	.9067019+07	.9067019+07	.7026280+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1801895+02	.1801895+02	.1720931+02	.0000000
FRICTION FACTOR	.1227774-01	.1227774-01	.1233294-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5082000+05	.0000000	.0000000

-187-

COST DATA

SODIUM IN PRIMARY LOOP - .2927000+04 DOLLARS.
 PRIMARY PUMP ----- .1895970+06 DOLLARS.
 PRIMARY PIPE ----- .1077331+06 DOLLARS.
 CONFINER PIPE ----- .1791231+06 DOLLARS.

TOTAL COST ----- .5922002+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .2741037+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9771300+06 DOLLARS.
 POWER COST PER YEAR ---- .1628487+05 DOLLARS PER YEAR.

BNWL-308

TABLE B-28. PRIMARY LOOP DESIGN AND COST WITH 18 AND 20 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 20.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1219599+04 HP
SUCTION PRESSURE ----- .3875929+01 PSIG
HEAD ----- .3322000+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1722723+04
CAVITATION PARAMETER - .1558454-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CR
PIPE DIAMETER, IN.	.2000000+02	.1800000+02	.1800000+02	.1800000+02
PRESSURE DROP, PSI	.1955219+01	.8768528+01	.4944350+01	.0000000
PIPING WEIGHT, LB.	.2358000+04	.3530000+04	.4236000+04	.0000000
FITTING WEIGHT, LB.	.9600000+03	.6870000+03	.6460000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4013948+04	.5203521+04	.6024090+04	.0000000
SODIUM WEIGHT, LB.	.3552372+04	.4751952+04	.5702342+04	.0000000
CONFINER DIAMETER, IN.	.2324800+02	.2124400+02	.2124400+02	.2124400+02
REYNOLDS NUMBER	.8127638+07	.9067019+07	.7026280+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1447044+02	.1801895+02	.1720931+02	.0000000
FRICTION FACTOR	.1206964-01	.1227774-01	.1233294-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5082000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .3081000+04 DOLLARS.
PRIMARY PUMP ----- .1885805+06 DOLLARS.
PRIMARY PIPE ----- .1115047+06 DOLLARS.
CONFINER PIPE ----- .1844229+06 DOLLARS.

TOTAL COST ----- .6004090+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .1607278+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .9906740+06 DOLLARS.
POWER COST PER YEAR ----- .1613201+05 DOLLARS PER YEAR.

TABLE B-29. PRIMARY LOOP DESIGN AND COST WITH 18 AND 24 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 3 WITH 24.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1208755+04 HP
 SUCTION PRESSURE ----- .4495653+01 PSIG
 HEAD ----- .3292463+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1734301+04
 CAVITATION PARAMETER - .1572294-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.1800000+02	.1800000+02	.1800000+02
PRESSURE DROP, PSI	.8930269-00	.8768528+01	.4944350+01	.0000000
PIPING WEIGHT, LB.	.2838000+04	.3530000+04	.4236000+04	.0000000
FITTING WEIGHT, LB.	.1380000+04	.6870000+03	.6460000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4951787+04	.5203521+04	.6024090+04	.0000000
SODIUM WEIGHT, LB.	.5180468+04	.4751952+04	.5702342+04	.0000000
CONFINER DIAMETER, IN.	.2724400+02	.2124400+02	.2124400+02	.2124400+02
REYNOLDS NUMBER	.6721817+07	.9067019+07	.7026280+07	.0000000
SODIUM VELOCITY, FT./SEC.	.9910116+01	.1801895+02	.1720931+02	.0000000
FRICTION FACTOR	.1175030-01	.1227774-01	.1233294-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5082000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .3439000+04 DOLLARS.
 PRIMARY PUMP ----- .1876229+06 DOLLARS.
 PRIMARY PIPE ----- .1195867+06 DOLLARS.
 CONFINER PIPE ----- .1957707+06 DOLLARS.

TOTAL COST ----- .6192392+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .5434226-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1021744+07 DOLLARS.
 POWER COST PER YEAR ----- .1598857+05 DOLLARS PER YEAR.

-189-

BNWL-308

TABLE B-30. PRIMARY LOOP DESIGN AND COST WITH 18 AND 30 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 4 WITH 30.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
POWER -----	.1203191+04 HP			
SUCTION PRESSURE -----	.4824224+01 PSIG			
HEAD -----	.3277307+03 FT			
FLOW RATE -----	.1312680+05 GPM			
SPECIFIC SPEED -----	.1740313+04			
CAVITATION PARAMETER -	.1579493-00			
PIPE DIAMETER, IN.	.3000000+02	.1800000+02	.1800000+02	.1800000+02
PRESSURE DROP, PSI	.3479913-00	.8768528+01	.4944350+01	.0000000
PIPING WEIGHT, LB.	.3561000+04	.3530000+04	.4236000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.6870000+03	.6460000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.5203521+04	.6024090+04	.0000000
SODIUM WEIGHT, LB.	.8200131+04	.4751952+04	.5702342+04	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.2124400+02	.2124400+02	.2124400+02
REYNOLDS NUMBER	.5347416+07	.9067019+07	.7026280+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.1801895+02	.1720931+02	.0000000
FRICTION FACTOR	.1143077-01	.1227774-01	.1233294-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5082000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP -	.4103000+04 DOLLARS.
PRIMARY PUMP -----	.1871301+06 DOLLARS.
PRIMARY PIPE -----	.1325448+06 DOLLARS.
CONFINER PIPE -----	.2138462+06 DOLLARS.

TOTAL COST ----- .6504440+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.2470978-02 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1073232+07 DOLLARS.

POWER COST PER YEAR ---- .1591497+05 DOLLARS PER YEAR.

TABLE B-31. PRIMARY LOOP DESIGN AND COST WITH 18 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 5 WITH 36.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1201344+04 HP
 SUCTION PRESSURE ----- .4936305+01 PSIG
 HEAD ----- .3272277+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1742319+04
 CAVITATION PARAMETER - .1581896-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.1800000+02	.1800000+02	.1800000+02
PRESSURE DROP, PSI	.1671196-00	.8768528+01	.4944350+01	.0000000
PIPING WEIGHT, LB.	.5688000+04	.3530000+04	.4236000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.6870000+03	.6460000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.5203521+04	.6024090+04	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.4751952+04	.5702342+04	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.2124400+02	.2124400+02	.2124400+02
REYNOLDS NUMBER	.4471171+07	.9067019+07	.7026280+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.1801895+02	.1720931+02	.0000000
FRICTION FACTOR	.1124017-01	.1227774-01	.1233294-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5082000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .4884000+04 DOLLARS.
 PRIMARY PUMP ----- .1869663+06 DOLLARS.
 PRIMARY PIPE ----- .1691563+06 DOLLARS.
 CONFINER PIPE ----- .2342463+06 DOLLARS.

TOTAL COST ----- .7080728+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1836290-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1168320+07 DOLLARS.
 POWER COST PER YEAR ---- .1589054+05 DOLLARS PER YEAR.

TABLE B-32. PRIMARY LOOP DESIGN AND COST WITH 20 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 20,000 IN. HOT LEG PIPE AND 20,000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1168584+04 HP
 SUCTION PRESSURE ----- .3867976+01 PSIG
 HEAD ----- .3183044+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1778825+04
 CAVITATION PARAMETER - .1625794-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2000000+02	.2000000+02	.2000000+02	.2000000+02
PRESSURE DROP, PSI	.1955219+01	.5595338+01	.3120525+01	.0000000
PIPING WEIGHT, LB.	.2358000+04	.3930000+04	.4716000+04	.0000000
FITTING WEIGHT, LB.	.9600000+03	.8500000+03	.8000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4013948+04	.5782602+04	.6672977+04	.0000000
SODIUM WEIGHT, LB.	.3552372+04	.5920620+04	.7104745+04	.0000000
CONFINER DIAMETER, IN.	.2324800+02	.2324800+02	.2324800+02	.2324800+02
REYNOLDS NUMBER	.8127638+07	.8127638+07	.6298327+07	.0000000
SODIUM VELOCITY, FT./SEC.	.1447044+02	.1447044+02	.1382024+02	.0000000
FRICTION FACTOR	.1206964-01	.1206964-01	.1213556-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5440000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .3647000+04 DOLLARS.
 PRIMARY PUMP ----- .1840429+06 DOLLARS.
 PRIMARY PIPE ----- .1222537+06 DOLLARS.
 CONFINER PIPE ----- .1992813+06 DOLLARS.

TOTAL COST ----- .6256249+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .1599325+01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1032281+07 DOLLARS.
 POWER COST PER YEAR ----- .1545722+05 DOLLARS PER YEAR.

TABLE B-33. PRIMARY LOOP DESIGN AND COST WITH 20 AND 24 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 24.000 IN. HOT LEG PIPE AND 20.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1157740+04 HP
 SUCTION PRESSURE ----- .4487627+01 PSIG
 HEAD ----- .3153506+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1791307+04
 CAVITATION PARAMETER - .1640869-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.2000000+02	.2000000+02	.2000000+02
PRESSURE DROP, PSI	.8930269-00	.5595338+01	.3120525+01	.0000000
PIPING WEIGHT, LB.	.2838000+04	.3930000+04	.4716000+04	.0000000
FITTING WEIGHT, LB.	.1380000+04	.8500000+03	.8000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.4951787+04	.5782602+04	.6672977+04	.0000000
SODIUM WEIGHT, LB.	.5180468+04	.5920620+04	.7104745+04	.0000000
CONFINER DIAMETER, IN.	.2724400+02	.2324800+02	.2324800+02	.2324800+02
REYNOLDS NUMBER	.6721817+07	.8127638+07	.6298327+07	.0000000
SODIUM VELOCITY, FT./SEC.	.9910116+01	.1447044+02	.1382024+02	.0000000
FRICTION FACTOR	.1175030-01	.1206964-01	.1213556-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5440000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .4005000+04 DOLLARS.
 PRIMARY PUMP ----- .1830675+06 DOLLARS.
 PRIMARY PIPE ----- .1303357+06 DOLLARS.
 CONFINER PIPE ----- .2106291+06 DOLLARS.

TOTAL COST ----- .6444374+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .5353972-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1063321+07 DOLLARS.
 POWER COST PER YEAR ----- .1531378+05 DOLLARS PER YEAR.

TABLE B-34. PRIMARY LOOP DESIGN AND COST WITH 20 AND 30 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 3 WITH 30.000 IN. HOT LEG PIPE AND 20.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1152176+04 HP
SUCTION PRESSURE ----- .4816161+01 PSIG
HEAD ----- .3138350+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1797791+04
CAVITATION PARAMETER - .1648713-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3000000+02	.2000000+02	.2000000+02	.2000000+02
PRESSURE DROP, PSI	.3479913-00	.5595338+01	.3120525+01	.0000000
PIPING WEIGHT, LB.	.3561000+04	.3930000+04	.4716000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.8500000+03	.8000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.5782602+04	.6672977+04	.0000000
SODIUM WEIGHT, LB.	.8200131+04	.5920620+04	.7104745+04	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.2324800+02	.2324800+02	.2324800+02
REYNOLDS NUMBER	.5347416+07	.8127638+07	.6298327+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.1447044+02	.1382024+02	.0000000
FRICTION FACTOR	.1143077-01	.1206964-01	.1213556-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5440000+05	.0000000	.0000000

COST DATA
SODIUM IN PRIMARY LOOP - .4669000+04 DOLLARS.
PRIMARY PUMP - .1825655+06 DOLLARS.
PRIMARY PIPE - .1432939+06 DOLLARS.
CONFINER PIPE - .2287046+06 DOLLARS.

TOTAL COST ----- .6756329+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1053453-01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1114794+07 DOLLARS.
POWER COST PER YEAR ----- .1524018+05 DOLLARS PER YEAR.

TABLE B-35. PRIMARY LOOP DESIGN AND COST WITH 20 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 4 WITH 36.000 IN. HOT LEG PIPE AND 20.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1150329+04 HP
 SUCTION PRESSURE ----- .4928230+01 PSIG
 HEAD ----- .3133320+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1799955+04
 CAVITATION PARAMETER - .1651334-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.2000000+02	.2000000+02	.2000000+02
PRESSURE DROP, PSI	.1671196-00	.5595338+01	.3120525+01	.0000000
PIPING WEIGHT, LB.	.5688000+04	.3930000+04	.4716000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.8500000+03	.8000000+03	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.5782602+04	.6672977+04	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.5920620+04	.7104745+04	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.2324800+02	.2324800+02	.2324800+02
REYNOLDS NUMBER	.4471171+07	.8127638+07	.6298327+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.1447044+02	.1382024+02	.0000000
FRICTION FACTOR	.1124017-01	.1206964-01	.1213556-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.5440000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .5450000+04 DOLLARS.
 PRIMARY PUMP ----- .1823986+06 DOLLARS.
 PRIMARY PIPE ----- .1799053+06 DOLLARS.
 CONFINER PIPE ----- .2491047+06 DOLLARS.

TOTAL COST ----- .7332586+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1917040-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1209876+07 DOLLARS.
 POWER COST PER YEAR ---- .1521575+05 DOLLARS PER YEAR.

TABLE B-36. PRIMARY LOOP DESIGN AND COST WITH 24 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 24.000 IN. HOT LEG PIPE AND 24.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1109618+04 HP
 SUCTION PRESSURE ----- .4479730+01 PSIG
 HEAD ----- .3022428+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1849261+04
 CAVITATION PARAMETER - .1711304-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.2400000+02	.2400000+02	.2400000+02
PRESSURE DROP, PSI	.8930269-00	.2584316+01	.1417870+01	.0000000
PIPING WEIGHT, LB.	.2638000+04	.4730000+04	.5676000+04	.0000000
FITTING WEIGHT, LB.	.1380000+04	.1218000+04	.1158000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.4951787+04	.6982748+04	.8022882+04	.0000000
SODIUM WEIGHT, LB.	.5180468+04	.8634113+04	.1036094+05	.0000000
CONFINER DIAMETER, IN.	.2724400+02	.2724400+02	.2724400+02	.2724400+02
REYNOLDS NUMBER	.6721817+07	.6721817+07	.5208919+07	.0000000
SODIUM VELOCITY, FT./SEC.	.9910116+01	.9910116+01	.9464828+01	.0000000
FRICTION FACTOR	.1175030-01	.1175030-01	.1183891-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.6156000+05	.0000000	.0000000

-196-

COST DATA

SODIUM IN PRIMARY LOOP - .5318000+04 DOLLARS.
 PRIMARY PUMP ----- .1786906+06 DOLLARS.
 PRIMARY PIPE ----- .1526600+06 DOLLARS.
 CONFINER PIPE ----- .2414847+06 DOLLARS.

TOTAL COST ----- .7017134+06 DOLLARS.

REACTOR VESSEL PRESSURE IS .5274996-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1157827+07 DOLLARS.
 POWER COST PER YEAR ----- .1467725+05 DOLLARS PER YEAR.

TABLE B-37. PRIMARY LOOP DESIGN AND COST WITH 24 AND 30 INCH PIPE.
PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 30.000 IN. HOT LEG PIPE AND 24.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1104054+04 HP
SUCTION PRESSURE ----- .4808224+01 PSIG
HEAD ----- .3007272+03 FT
FLOW RATE ----- .1312680+05 GPM
SPECIFIC SPEED ----- .1856247+04
CAVITATION PARAMETER - .1719842-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3000000+02	.2400000+02	.2400000+02	.2400000+02
PRESSURE DROP, PSI	.3479913-00	.2584316+01	.1417870+01	.0000000
PIPING WEIGHT, LB.	.3561000+04	.4730000+04	.5676000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.1218000+04	.1158000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.6982748+04	.8022882+04	.0000000
SODIUM WEIGHT, LB.	.8200131+04	.8634113+04	.1036094+05	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.2724400+02	.2724400+02	.2724400+02
REYNOLDS NUMBER	.5347416+07	.6721817+07	.5208919+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.9910116+01	.9464828+01	.0000000
FRICTION FACTOR	.1143077-01	.1175030-01	.1183891-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.6156000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .5982000+04 DOLLARS.
PRIMARY PUMP - .1781793+06 DOLLARS.
PRIMARY PIPE - .1656181+06 DOLLARS.
CONFINER PIPE - .2595602+06 DOLLARS.

TOTAL COST ----- .7328996+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1847101-01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF YHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1209284+07 DOLLARS.
POWER COST PER YEAR ----- .1460365+05 DOLLARS PER YEAR.

TABLE B-38, PRIMARY LOOP DESIGN AND COST WITH 24 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 3 WITH 36.000 IN. HOT LEG PIPE AND 24.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1102207+04 HP
 SUCTION PRESSURE ----- .4920280+01 PSIG
 HEAD ----- .3002243+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1858579+04
 CAVITATION PARAMETER - .1722694-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.2400000+02	.2400000+02	.2400000+02
PRESSURE DROP, PSI	.1671196-00	.2584316+01	.1417870+01	.0000000
PIPING WEIGHT, LB.	.5688000+04	.4730000+04	.5676000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.1218000+04	.1158000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.6982748+04	.8022882+04	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.8634113+04	.1036094+05	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.2724400+02	.2724400+02	.2724400+02
REYNOLDS NUMBER	.4471171+07	.6721817+07	.5208919+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.9910116+01	.9464828+01	.0000000
FRICTION FACTOR	.1124017-01	.1175030-01	.1183891-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.6156000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .6763000+04 DOLLARS.
 PRIMARY PUMP ----- .1780094+06 DOLLARS.
 PRIMARY PIPE ----- .2022296+06 DOLLARS.
 CONFINER PIPE ----- .2799603+06 DOLLARS.

TOTAL COST ----- .7905223+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.1996543-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1304361+07 DOLLARS.
 POWER COST PER YEAR ----- .1457923+05 DOLLARS PER YEAR.

TABLE B-39. PRIMARY LOOP DESIGN AND COST WITH 30 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 30.000 IN. HOT LEG PIPE AND 30.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1079201+04 HP
 SUCTION PRESSURE ----- .4803990+01 PSIG
 HEAD ----- .2939577+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1888216+04
 CAVITATION PARAMETER - .1759047-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3000000+02	.3000000+02	.3000000+02	.3000000+02
PRESSURE DROP, PSI	.3479913-00	.1018162+01	.5496537-00	.0000000
PIPING WEIGHT, LB.	.3561000+04	.5935000+04	.7122000+04	.0000000
FITTING WEIGHT, LB.	.2100000+04	.1864000+04	.1640000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.6445625+04	.8879956+04	.9976430+04	.0000000
SODIUM WEIGHT, LB.	.8200131+04	.1366689+05	.1640026+05	.0000000
CONFINER DIAMETER, IN.	.3324400+02	.3324400+02	.3324400+02	.3324400+02
REYNOLDS NUMBER	.5347416+07	.5347416+07	.4143858+07	.0000000
SODIUM VELOCITY, FT./SEC.	.6266285+01	.6266285+01	.5984724+01	.0000000
FRICTION FACTOR	.1143077-01	.1143077-01	.1155458-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.7230000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .8418000+04 DOLLARS.
 PRIMARY PUMP ----- .1758819+06 DOLLARS.
 PRIMARY PIPE ----- .1995536+06 DOLLARS.
 CONFINER PIPE ----- .3061543+06 DOLLARS.

TOTAL COST ----- .8243078+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.2270509-01 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1360107+07 DOLLARS.
 POWER COST PER YEAR ----- .1427492+05 DOLLARS PER YEAR.

TABLE B-40. PRIMARY LOOP DESIGN AND COST WITH 30 AND 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 2 WITH 36.000 IN. HOT LEG PIPE AND 30.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1077355+04 HP
 SUCTION PRESSURE ----- .4916039+01 PSIG
 HEAD ----- .2934548+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1890642+04
 CAVITATION PARAMETER - .1762032-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.3000000+02	.3000000+02	.3000000+02
PRESSURE DROP, PSI	.1671196-00	.1018162+01	.5496537-00	.0000000
PIPING WEIGHT, LB.	.5688000+04	.5935000+04	.7122000+04	.0000000
FITTING WEIGHT, LB.	.4050000+04	.1864000+04	.1640000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.8879956+04	.9976430+04	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.1366689+05	.1640026+05	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.3324400+02	.3324400+02	.3324400+02
REYNOLDS NUMBER	.4471171+07	.5347416+07	.4143858+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.6266285+01	.5984724+01	.0000000
FRICTION FACTOR	.1124017-01	.1143077-01	.1155458-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.7230000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .9199000+04 DOLLARS.
 PRIMARY PUMP ----- .1757103+06 DOLLARS.
 PRIMARY PIPE ----- .2361650+06 DOLLARS.
 CONFINER PIPE ----- .3265544+06 DOLLARS.

TOTAL COST ----- .8819288+06 DOLLARS.

REACTOR VESSEL PRESSURE IS -.2038951-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1455182+07 DOLLARS.
 POWER COST PER YEAR ----- .1425049+05 DOLLARS PER YEAR.

TABLE B-41. PRIMARY LOOP DESIGN AND COST WITH 36 INCH PIPE.

PRIMARY PUMPS ARE IN HOT LEG.

TRIAL NO. 1 WITH 36.000 IN. HOT LEG PIPE AND 36.000 IN. COLD LEG PIPE.

PUMP DATA

POWER ----- .1069061+04 HP
 SUCTION PRESSURE ----- .4914601+01 PSIG
 HEAD ----- .2911957+03 FT
 FLOW RATE ----- .1312680+05 GPM
 SPECIFIC SPEED ----- .1901632+04
 CAVITATION PARAMETER - .1775564-00

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3600000+02	.3600000+02	.3600000+02	.3600000+02
PRESSURE DROP, PSI	.1671196-00	.4923493-00	.2630961-00	.0000000
PIPING WEIGHT, LB.	.5688000+04	.9480000+04	.1137600+05	.0000000
FITTING WEIGHT, LB.	.4050000+04	.3590000+04	.3150000+04	.0000000
CONFINER PIPE WEIGHT, LB.	.8131585+04	.1091393+05	.1212974+05	.0000000
SODIUM WEIGHT, LB.	.1174851+05	.1958084+05	.2349701+05	.0000000
CONFINER DIAMETER, IN.	.3900400+02	.3900400+02	.3900400+02	.3900400+02
REYNOLDS NUMBER	.4471171+07	.4471171+07	.3464832+07	.0000000
SODIUM VELOCITY, FT./SEC.	.4377302+01	.4377302+01	.4180618+01	.0000000
FRICTION FACTOR	.1124017-01	.1124017-01	.1139747-01	.0000000
TOTAL VALVE COST, DOLLARS	.0000000	.8304000+05	.0000000	.0000000

COST DATA

SODIUM IN PRIMARY LOOP - .1206100+05 DOLLARS.
 PRIMARY PUMP ----- .1749381+06 DOLLARS.
 PRIMARY PIPE ----- .3352593+06 DOLLARS.
 CONFINER PIPE ----- .3772205+06 DOLLARS.

TOTAL COST ----- .1044519+07 DOLLARS.

REACTOR VESSEL PRESSURE IS -.2053330-00 PSIG.

SODIUM PRESSURE DROP IN PRIMARY SIDE OF IHX IS .3794151+01 PSI.

TOTAL INVESTMENT ----- .1723456+07 DOLLARS.
 POWER COST PER YEAR ---- .1414079+05 DOLLARS PER YEAR.

TABLE B-42. SECONDARY LOOP DESIGN AND COST WITH 14 INCH PIPE.

SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 1 WITH 14.000 IN. HOT LEG PIPE AND 14.000 IN. COLD LEG PIPE.

PUMP DATA

SURGE TANK DATA

PUMP POWER -----	.1029392+04 HP	SURGE TANK VOLUME -----	.2025171+03 CU.FT
MOTOR POWER -----	.1000000+04 HP	SURGE TANK GAS SPACE PRESSURE -----	.4722368+02 PSIG
DISCHARGE PRESSURE ----	.1575432+03 PSIG		
ACTUAL SUCTION PRESSURE	.4914077+02 PSIG		
MIN. SUCTION PRESSURE -	.3854982-00 PSIG		
HEAD -----	.2827255+03 FT		
FLOW RATE -----	.1220996+05 GPM	HEAT EXCHANGER DATA	
SPECIFIC SPEED-----	.1875077+04	PRESSURE DROP, SECONDARY SIDE OF IHX	.3402489+01 PSI
CAVITATION PARAMETER --	.1742909-00	PRESSURE DROP, SECONDARY SIDE OF DHX	.2940184+02 PSI

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1400000+02	.1400000+02	.1400000+02	.1400000+02
PRESSURE DROP, PSI	.3285150+02	.0000000	.2174831+02	.2099826+02
PIPING WEIGHT, LB.	.1092000+05	.0000000	.6825000+04	.5460000+04
FITTING WEIGHT, LB.	.1220000+04	.0000000	.7700000+03	.9600000+03
PIPE VOLUME, CU.FT.	.1914516+03	.0000000	.1196573+03	.9572581+02
SODIUM WEIGHT, LB.	.1121906+05	.0000000	.7011915+04	.5609532+04
REYNOLDS NUMBER	.1072868+08	.0000000	.7974935+07	.7974935+07
SODIUM VELOCITY, FT./SEC.	.2971350+02	.0000000	.2840659+02	.2840659+02
FRICTION FACTOR	.1284795-01	.0000000	.1289410-01	.1289410-01
TOTAL VALVE COST, DOLLARS	.5000000+04	.0000000	.0000000	.5000000+04

COST DATA

SODIUM IN SECONDARY LOOP ----	.5244912+04 DOLLARS.
SECONDARY PUMP -----	.1566644+06 DOLLARS.
SECONDARY PIPE -----	.2568421+06 DOLLARS.
SECONDARY LOOP VALVES -----	.1000000+05 DOLLARS.
SECONDARY LOOP SURGE TANK ---	.5765363+04 DOLLARS.
SECONDARY PUMP DRIVE -----	.5300000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	.2228856+05 DOLLARS.

TOTAL COST ----- .5098053+06 DOLLARS.

TOTAL INVESTMENT ----- .8411788+06 DOLLARS.

POWER COST PER YEAR ----- .1361670+05 DOLLARS PER YEAR.

TABLE B-43. SECONDARY LOOP DESIGN AND COST WITH 16 INCH PIPE.

SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 2 WITH 16.000 IN. HOT LEG PIPE AND 16.000 IN. COLD LEG PIPE.

PUMP DATA

SURGE TANK DATA

PUMP POWER -----	.7003510+03 HP	SURGE TANK VOLUME -----	.2356150+03 CU.FT
MOTOR POWER -----	.7000000+03 HP	SURGE TANK GAS SPACE PRESSURE -----	.7234972+02 PSIG
DISCHARGE PRESSURE ----	.1480188+03 PSIG		
ACTUAL SUCTION PRESSURE	.7426682+02 PSIG		
MIN. SUCTION PRESSURE -	.2383211+01 PSIG		
HEAD -----	.1923535+03 FT		
FLOW RATE -----	.1220996+05 GPM		
SPECIFIC SPEED-----	.2503041+04		
CAVITATION PARAMETER --	.2551920-00		

HEAT EXCHANGER DATA

PRESSURE DROP, SECONDARY SIDE OF IHX	.3402489+01 PSI
PRESSURE DROP, SECONDARY SIDE OF DHX	.2940184+02 PSI

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.1600000+02	.1600000+02	.1600000+02	.1600000+02
PRESSURE DROP, PSI	.1769352+02	.0000000	.1178024+02	.1147394+02
PIPING WEIGHT, LB.	.1252000+05	.0000000	.7825000+04	.6260000+04
FITTING WEIGHT, LB.	.1552000+04	.0000000	.9820000+03	.1230000+04
PIPE VOLUME, CU.FT.	.2537535+03	.0000000	.1585959+03	.1268767+03
SODIUM WEIGHT, LB.	.1486995+05	.0000000	.9293721+04	.7434977+04
REYNOLDS NUMBER	.9320627+07	.0000000	.6928292+07	.6928292+07
SODIUM VELOCITY, FT./SEC.	.2242210+02	.0000000	.2143589+02	.2143589+02
FRICTION FACTOR	.1254304-01	.0000000	.1260147-01	.1260147-01
TOTAL VALVE COST, DOLLARS	.6600000+04	.0000000	.0000000	.6600000+04

COST DATA

SODIUM IN SECONDARY LOOP ----	.6951703+04 DOLLARS.
SECONDARY PUMP -----	.1257851+06 DOLLARS.
SECONDARY PIPE -----	.2982236+06 DOLLARS.
SECONDARY LOOP VALVES -----	.1320000+05 DOLLARS.
SECONDARY LOOP SURGE TANK ---	.6313517+04 DOLLARS.
SECONDARY PUMP DRIVE -----	.4100000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	-.0000000 DOLLARS.

TOTAL COST ----- .4914739+06 DOLLARS.

TOTAL INVESTMENT -----	.8109320+06 DOLLARS.
POWER COST PER YEAR ----	.9264177+04 DOLLARS PER YEAR.

TABLE B-44. SECONDARY LOOP DESIGN AND COST WITH 18 INCH PIPE.
SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 3 WITH 18.000 IN. HOT LEG PIPE AND 18.000 IN. COLD LEG PIPE.

PUMP DATA		SURGE TANK DATA			
PUMP POWER	.5401894+03 HP	SURGE TANK VOLUME	-----	.2731275+03 CU.FT	
MOTOR POWER	.6000000+03 HP	SURGE TANK GAS SPACE PRESSURE	-----	.8453762+02 PSIG	
DISCHARGE PRESSURE	.1433406+03 PSIG				
ACTUAL SUCTION PRESSURE	.8645472+02 PSIG				
MIN. SUCTION PRESSURE	.3398580+01 PSIG				
HEAD	.1483646+03 FT	HEAT EXCHANGER DATA			
FLOW RATE	.1220996+05 GPM	PRESSURE DROP, SECONDARY SIDE OF IHX		.3402489+01 PSI	
SPECIFIC SPEED	.3041201+04	PRESSURE DROP, SECONDARY SIDE OF DHX		.2940184+02 PSI	
CAVITATION PARAMETER	.3299962-00				
-204-					
	ZONE HA	ZONE HB	ZONE CA	ZONE CB	
PIPE DIAMETER, IN.	.1800000+02	.1800000+02	.1800000+02	.1800000+02	
PRESSURE DROP, PSI	.1035765+02	.0000000	.6928207+01	.6795669+01	
PIPING WEIGHT, LB.	.1412000+05	.0000000	.8825000+04	.7060000+04	
FITTING WEIGHT, LB.	.1960000+04	.0000000	.1240000+04	.1552000+04	
PIPE VOLUME, CU.FT.	.3243653+03	.0000000	.2027283+03	.1621827+03	
SODIUM WEIGHT, LB.	.1900781+05	.0000000	.1187988+05	.9503904+04	
REYNOLDS NUMBER	.8239473+07	.0000000	.6124639+07	.6124639+07	
SODIUM VELOCITY, FT./SEC.	.1753151+02	.0000000	.1676041+02	.1676041+02	
FRICTION FACTOR	.1229696-01	.0000000	.1236843-01	.1236843-01	
TOTAL VALVE COST, DOLLARS	.8000000+04	.0000000	.0000000	.8000000+04	

COST DATA

SODIUM IN SECONDARY LOOP	.8886150+04 DOLLARS.
SECONDARY PUMP	.1084802+06 DOLLARS.
SECONDARY PIPE	.3413137+06 DOLLARS.
SECONDARY LOOP VALVES	.1600000+05 DOLLARS.
SECONDARY LOOP SURGE TANK	.6898726+04 DOLLARS.
SECONDARY PUMP DRIVE	.3700000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	.0000000 DOLLARS.

TOTAL COST .5185788+06 DOLLARS.

TOTAL INVESTMENT .8556551+06 DOLLARS.
POWER COST PER YEAR .7145575+04 DOLLARS PER YEAR.

TABLE B-45. SECONDARY LOOP DESIGN AND COST WITH 20 INCH PIPE.

SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 4 WITH 20.000 IN. HOT LEG PIPE AND 20.000 IN. COLD LEG PIPE.

PUMP DATA

SURGE TANK DATA

PUMP POWER -----	.4544646+03 HP	SURGE TANK VOLUME -----	.3155067+03 CU.FT
MOTOR POWER -----	.4500000+03 HP	SURGE TANK GAS SPACE PRESSURE -----	.9104247+02 PSIG
DISCHARGE PRESSURE ----	.1408180+03 PSIG		
ACTUAL SUCTION PRESSURE	.9295957+02 PSIG		
MIN. SUCTION PRESSURE -	.3960549+01 PSIG		
HEAD -----	.1248201+03 FT		
FLOW RATE -----	.1220996+05 GPM		
SPECIFIC SPEED-----	.3462021+04		
CAVITATION PARAMETER --	.3915656-00		

HEAT EXCHANGER DATA

PRESSURE DROP, SECONDARY SIDE OF IHX	.3402489+01 PSI
PRESSURE DROP, SECONDARY SIDE OF DHX	.2940184+02 PSI

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2000000+02	.2000000+02	.2000000+02	.2000000+02
PRESSURE DROP, PSI	.6449853+01	.0000000	.4331160+01	.4273076+01
PIPING WEIGHT, LB.	.1572000+05	.0000000	.9825000+04	.7860000+04
FITTING WEIGHT, LB.	.2440000+04	.0000000	.1540000+04	.1920000+04
PIPE VOLUME, CU.FT.	.4041379+03	.0000000	.2525862+03	.2020690+03
SODIUM WEIGHT, LB.	.2368248+05	.0000000	.1480155+05	.1184124+05
REYNOLDS NUMBER	.7385829+07	.0000000	.5490100+07	.5490100+07
SODIUM VELOCITY, FT./SEC.	.1407899+02	.0000000	.1345975+02	.1345975+02
FRICTION FACTOR	.1209263-01	.0000000	.1217779-01	.1217779-01
TOTAL VALVE COST, DOLLARS	.1050000+05	.0000000	.0000000	.1050000+05

COST DATA

SODIUM IN SECONDARY LOOP ----	.1107156+05 DOLLARS.
SECONDARY PUMP -----	.9830472+05 DOLLARS.
SECONDARY PIPE -----	.3859751+06 DOLLARS.
SECONDARY LOOP VALVES -----	.2100000+05 DOLLARS.
SECONDARY LOOP SURGE TANK ---	.7522372+04 DOLLARS.
SECONDARY PUMP DRIVE -----	.3050000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	-.0000000 DOLLARS.

TOTAL COST ----- .5543737+06 DOLLARS.

TOTAL INVESTMENT -----	.9147167+06 DOLLARS.
POWER COST PER YEAR ----	.6011616+04 DOLLARS PER YEAR.

TABLE B-46. SECONDARY LOOP DESIGN AND COST WITH 24 INCH PIPE.

SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 5 WITH 24.000 IN. HOT LEG PIPE AND 24.000 IN. COLD LEG PIPE.

PUMP DATA

SURGE TANK DATA

PUMP POWER -----	.3755242+03 HP	SURGE TANK VOLUME -----	.4139056+03 CU.FT
MOTOR POWER -----	.4000000+03 HP	SURGE TANK GAS SPACE PRESSURE -----	.9701309+02 PSIG
DISCHARGE PRESSURE ----	.1384756+03 PSIG		
ACTUAL SUCTION PRESSURE	.9893019+02 PSIG		
MIN. SUCTION PRESSURE -	.4498041+01 PSIG		
HEAD -----	.1031388+03 FT		
FLOW RATE -----	.1220996+05 GPM	PRESSURE DROP, SECONDARY SIDE OF YHX	.3402489+01 PSI
SPECIFIC SPEED-----	.3994628+04	PRESSURE DROP, SECONDARY SIDE OF DHX	.2940184+02 PSI
CAVITATION PARAMETER --	.4729749-00		

HEAT EXCHANGER DATA

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.2400000+02	.2400000+02	.2400000+02	.2400000+02
PRESSURE DROP, PSI	.2870817+01	.0000000	.1939572+01	.1930698+01
PIPING WEIGHT, LB.	.1892000+05	.0000000	.1182500+05	.9460000+04
FITTING WEIGHT, LB.	.3508000+04	.0000000	.2214000+04	.2776000+04
PIPE VOLUME, CU.FT.	.5893593+03	.0000000	.3683495+03	.2946796+03
SODIUM WEIGHT, LB.	.3453645+05	.0000000	.2158528+05	.1726823+05
REYNOLDS NUMBER	.6108317+07	.0000000	.4540489+07	.4540489+07
SODIUM VELOCITY, FT./SEC.	.9642036+01	.0000000	.9217943+01	.9217943+01
FRICTION FACTOR	.1178130-01	.0000000	.1189522-01	.1189522-01
TOTAL VALVE COST, DOLLARS	.1450000+05	.0000000	.0000000	.1450000+05

COST DATA

SODIUM IN SECONDARY LOOP ----	.1614579+05 DOLLARS.
SECONDARY PUMP -----	.8817449+05 DOLLARS.
SECONDARY PIPE -----	.4782634+06 DOLLARS.
SECONDARY LOOP VALVES -----	.2900000+05 DOLLARS.
SECONDARY LOOP SURGE TANK ---	.8852998+04 DOLLARS.
SECONDARY PUMP DRIVE -----	.2130000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	-.0000000 DOLLARS.

TOTAL COST ----- .6417367+06 DOLLARS.

TOTAL INVESTMENT ----- .1058866+07 DOLLARS.

POWER COST PER YEAR ---- .4967399+04 DOLLARS PER YEAR.

TABLE B-47. SECONDARY LOOP DESIGN AND COST WITH 30 INCH PIPE.

SECONDARY PUMPS ARE IN COLD LEG.

TRIAL NO. 6 WITH 30.000 IN. HOT LEG PIPE AND 30.000 IN. COLD LEG PIPE.

PUMP DATA

SURGE TANK DATA

PUMP POWER	.3359603+03 HP	SURGE TANK VOLUME	-----	.5964080+03 CU.FT
MOTOR POWER	.3500000+03 HP	SURGE TANK GAS SPACE PRESSURE	-----	.9999300+02 PSIG
DISCHARGE PRESSURE	.1372891+03 PSIG			
ACTUAL SUCTION PRESSURE	.1019101+03 PSIG			
MIN. SUCTION PRESSURE	.4781119+01 PSIG			
HEAD	.9227248+02 FT			
FLOW RATE	.1220996+05 GPM			
SPECIFIC SPEED	.4342489+04			
CAVITATION PARAMETER	.5280859-00			

HEAT EXCHANGER DATA

PRESSURE DROP, SECONDARY SIDE OF IHX	.3402489+01 PSI
PRESSURE DROP, SECONDARY SIDE OF DHX	.2940184+02 PSI

	ZONE HA	ZONE HB	ZONE CA	ZONE CB
PIPE DIAMETER, IN.	.3000000+02	.3000000+02	.3000000+02	.3000000+02
PRESSURE DROP, PSI	.1089621+01	.0000000	.7408629-00	.7442377-00
PIPING WEIGHT, LB.	.2374000+05	.0000000	.1483750+05	.1187000+05
FITTING WEIGHT, LB.	.5136000+04	.0000000	.3268000+04	.3980000+04
PIPE VOLUME, CU.FT.	.9328932+03	.0000000	.5830583+03	.4664466+03
SODIUM WEIGHT, LB.	.5466754+05	.0000000	.3416721+05	.2733377+05
REYNOLDS NUMBER	.4859358+07	.0000000	.3612102+07	.3612102+07
SODIUM VELOCITY, FT./SEC.	.6096775+01	.0000000	.5828616+01	.5828616+01
FRICTION FACTOR	.1147431-01	.0000000	.1163227-01	.1163227-01
TOTAL VALVE COST, DOLLARS	.2150000+05	.0000000	.0000000	.2150000+05

COST DATA

SODIUM IN SECONDARY LOOP	-----	.2555708+05 DOLLARS.
SECONDARY PUMP	-----	.8275294+05 DOLLARS.
SECONDARY PIPE	-----	.6170053+06 DOLLARS.
SECONDARY LOOP VALVES	-----	.4300000+05 DOLLARS.
SECONDARY LOOP SURGE TANK	-----	.1102239+05 DOLLARS.
SECONDARY PUMP DRIVE	-----	.1900000+05 DOLLARS.
HIGH DESIGN PRESSURE PENALTY	-----	.0000000 DOLLARS.

TOTAL COST ----- .7983377+06 DOLLARS.

TOTAL INVESTMENT ----- .1317257+07 DOLLARS.

POWER COST PER YEAR ----- .4444051+04 DOLLARS PER YEAR.

TABLE B-48. SELECTION OF OPTIMUM PRIMARY AND SECONDARY LOOP DESIGNS.

PRIMARY LOOP DESIGN AND COST. PRIMARY PUMPS ARE IN HOT LEG.

CASE NO. 1 .1400000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 2 .1600000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 3 .1800000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 4 .2000000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 5 .2400000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 6 .3000000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

CASE NO. 7 .3600000+02 INCH PUMP DISCHARGE PIPE.
THE MINIMUM PROJECT COST OCCURS DURING TRIAL NO. 1

THE OPTIMUM CASE IS 2 THE MINIMUM PROJECT COST OCCURS DURING CASE 1

SECONDARY LOOP DESIGN AND COST. SECONDARY PUMPS ARE IN COLD LEG.

THE OPTIMUM CASE IS 2 THE MINIMUM PROJECT COST OCCURS DURING CASE 2

DISTRIBUTIONNo. Of Copies

25	<u>Atomic Energy Commission, Washington</u> Division Of Reactor Development Technology J. J. Morabito
280	<u>Division Of Technical Information Extension</u>
46	<u>Division Of Technical Information Extension</u>
(12)	UK/U.S. Fast Reactor Exchange
(34)	EURATOM/U.S. Fast Reactor Exchange
2	<u>General Dynamics Corporation, General Atomic Division</u> D. Coburn
6	<u>Douglas United Nuclear, Inc.</u> C. L. Abel J. T. Baker W. A. Crossman T. C. Hall M. M. McCartney (2)
1	<u>General Electric Company - Pleasanton</u> L. Wilkinson
4	<u>General Electric Company, Richland</u> D. W. Curtiss C. Gibbons J. C. Larrew GE File Copy
4	<u>General Electric Company - San Jose</u> AEC Site Representative (1) <u>Advanced Products Operation</u> J. H. Field (3)
1	<u>Isochem Incorporated</u> R. E. Olson
4	<u>Richland Operations Office - AEC</u> L. R. Lucas (2) R. K. Sharp Technical Information Library

DISTRIBUTIONNo. Of Copies

1	<u>San Francisco Operations Office - AEC</u> J. B. Radcliffe
1	<u>Stanford University</u> R. Sher
1	
1	<u>University Of California, Livermore</u> James Hadley
1	<u>Vitro Engineering Company, Richland</u> C. F. Gabel
28	<u>Battelle-Northwest</u> E. R. Astley C. L. Boyd D. L. Condotta D. R. Doman R. V. Dulin L. M. Finch C. D. Flowers C. L. Goss (2) V. W. Gustafson R. J. Hennig P. L. Hofmann M. T. Jakub H. G. Johnson (2) H. D. Lenkersdorfer W. B. McDonald R. E. Peterson W. E. Roake F. H. Shadel D. E. Simpson G. H. Strong C. D. Swanson Technical Information Files (3) Technical Publications (2)