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FFTF PRIMARY PUMP LOCATION

H. G. Johnson

A. L. Gunby

May 1968

AEC RESEARCH & DEVELOPMENT REPORT

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FFTF PRIMARY PUMP LOCATION

By

H. G. Johnson

A. L. Gunby

Reactor and Systems Analysis Section

FAST FLUX TEST FACILITY PROJECT

May 1968

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ABSTRACT

A study was completed of the effects of locating FFTF primary pumps in either the hot or cold leg. Main considerations in the study were (1) system costs, (2) system thermal transients, (3) pump reliability, and (4) plant safety. At the current stage of conceptual design, it was concluded that (1) hot leg and cold leg pump locations are both practical, (2) plant capital costs are about \$1 million less expensive for the cold leg location, assuming equal emergency cooling costs, (3) operating experience at other sodium-cooled reactor plants indicates a high probability of success for pump operation at FFTF cold leg temperatures, and (4) safety considerations and thermal transients do not lead to a preference of pump location at this time. This study tends to support the cold leg location at this time, but a firm decision must rest on whether the emergency cooling concept becomes a factor.

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INTRODUCTION

Primary loop pumps for sodium-cooled reactors have been placed in either the hot leg or cold leg, depending on requirements of each plant. Generally, a cold-leg location is favored because of materials problems at high temperatures, while a hot-leg location is favored because of pump suction head requirements. In order to reach a decision regarding placement of the FFTF primary loop pumps, information is required concerning the effects of pump location on (1) system costs, (2) system thermal transients, (3) pump reliability and plant availability, and (4) plant safety. This report considers these items within the limitations of the current FFTF conceptual design and presents cost optimizations of the heat transport system, coolant temperature transient studies for primary pumps, and qualitative discussions concerning reliability and safety.

The interfaces between the foregoing items are not clear-cut. For example, excessive thermal transients may affect system costs through additional design and development needed to cope with the transients. However, the study areas selected have proved, for the purpose of this analysis, to be sufficiently self-contained.

SUMMARY AND CONCLUSIONS

The effects of FFTF primary pump location (hot leg versus cold leg) on system costs, system thermal transients, system availability, and plant safety may be summarized as follows:

- Pump location is practical in either the hot leg or cold leg with IHX primary side pressure losses up to about seven psi.
- Plant capital investment for a cold-leg pump location is less expensive by \$1 million than that for a hot-leg location, provided emergency cooling costs are the same for each location.
- Pump location effects on operating costs are indeterminant at this time; however, operational costs appear to be of minor importance.
- The effect of pump location on the expected FFTF system thermal transients is negligible.
- Expected FFTF system thermal transients provide no clear-cut choice as to which pump location would receive greater thermal shocks.
- Insufficient failure rate data prevent a clearcut choice of pump location in regard to reliability of the pumps at elevated temperatures. However, operational experience with other sodium-cooled reactor plants promises a high probability for successful operation of primary pumps at FFTF cold-leg temperatures.
- Safety considerations do not lead to preference of a pump location at this time.

The cold-leg primary pump location appears to have an advantage due to cost differences and is also favored on the basis of operating experience at cold-leg temperatures. The preference may shift to the hot-leg location in the event emergency cooling at a cost great enough to offset the cold-leg advantage is found to be needed. On the basis of this latter possibility, a decision on the primary pump location must await further study and evaluation of emergency cooling costs. Both cost and and transient analysis of design change effects on pump location will also be continued during the FFTF design development phase.

DISCUSSION

BACKGROUND INFORMATION

Primary loop pumps have been placed in the cold legs of some sodium-cooled reactor plants while hot-leg locations have been used in other plants. The Fermi and EBR-II Plants are examples of plants using cold-leg pump locations, while the Hallam and SRE-PEP Plants are examples of plants using hot-leg locations. RAPSODIE utilizes a cold-leg location for the primary pump and a hot-leg location for the secondary. The process design sodium coolant temperatures and pump structural design temperatures for these examples and the FFTF are as follows:

TABLE I. Primary Pump Design Conditions for Various Sodium-Cooled Reactor Plants

<u>Plant</u>	<u>Coolant Temperature, °F</u>		<u>Pump Design Temperature, °F</u>
	<u>Hot Leg</u>	<u>Cold Leg</u>	
Fermi	900	600	1000
EBR-II	883	700	800
Hallam	945	610	1000
SRE-PEP	1200	650	1200*
RAPSODIE	1004	842	1200
FFTF	900-1200	550-900	

* *The SRE-PEP Plant was not operated at full temperature before it was deactivated.*

Feasibility of both pump locations was established by plant startup tests and operating experience in the Fermi, EBR-II, and Hallam Plants. However, choice of pump location in each case can be attributed to (1) better net positive suction head (NPSH), low reactor cover gas pressure, and high intermediate heat exchanger (IHX) primary pressure drop obtained in the hot leg, and (2) the relative lack of materials problems at elevated temperatures for the cold-leg location.

Since the rationale for the choice of pump location in other plants cannot be directly appropriated, the choice of primary pump location for the FFTF must be based on the following specific FFTF requirements: (1) four heat transport circuits, each designed for $1/3$ of the 400 MW_t total heat load; (2) centrifugal, single-stage, free-surface sodium pumps; (3) vertical, shell-tube counterflow IHX's; (4) secondary sodium pressure greater than primary pressure at the IHX; (5) compatibility of heat transport circuits with emergency heat removal system; and (6) designs utilizing existing technology adequate to assure steady-state and transient operation consistent with a 20-year plant life and 75% availability.⁽¹⁾

COST ANALYSIS

Approach to Cost Optimization

Many interacting variables must be considered in optimizing the heat transport system process design for each pump location. Those considered are:

- a. Primary pump speed.
- b. Primary pump shaft length and impeller submergence.
- c. Primary pump head
- d. Primary pump brake horsepower and drive requirements.
- e. Primary piping arrangement and size.
- f. Intermediate heat exchanger (IHX) primary side pressure loss.
- g. Location of primary coolant on shell or tube side of the IHX.
- h. Thermal baffling requirements of the IHX.
- i. Reactor vessel gas space pressure.
- j. Reactor vessel primary loop nozzle sizes.
- k. Primary and secondary system inert gas pressure requirements.
- l. Operating pressure in the secondary loops and surge tanks.

The interaction of these variables (with the exception of Items g and h) on process design is determined by a parametric study for a matrix of cases involving primary pump speed, primary pump shaft length, and IHX primary side pressure loss. The ADOPT Code⁽²⁾ provides the required heat transport process design information for each case, and enables an assessment of process feasibility for each case. The code also provides complete construction cost data for the heat transport system.

The incremental construction costs for all other systems, uninstalled spares, and design-development affected by the variables of this study are determined outside of the ADOPT Code. These costs are added to the heat transport system cost to give the incremental FFTF construction cost and equivalent capital investment for each case in the matrix.

Use of secondary loops between the primary loops and heat dump equipment, and an air-cooled dump heat exchanger (DHX) are assumed. The important process and design conditions held constant are listed in Table II. These values, although not firm, represent reasonable FFTF conditions. Changes in the values would not alter the conclusions reached in this study.

TABLE II. *Fixed Input Design Data*

<u>Input</u>	<u>Value</u>
<u>Process Data</u>	
System Power, MW	400
Number Installed Parallel Cooling Circuits	4
Number Redundant Circuits	1
Number of Operating Circuits for this Study	3
Primary Coolant Hot-Leg Temperature, °F	900
Primary Coolant Cold-Leg Temperature, °F	600*

* The reference primary cold-leg temperature for FFTF first core is 550 °F.

TABLE II. (contd)

<u>Input</u>	<u>Value</u>
<u>Process Data</u>	
Ratio of Temperature Rise of Secondary to Primary Coolant	1
Reactor Vessel Pressure Loss, psi	125
<u>IHX Data</u>	
Type	Vertical Shell and Tube with Removable Tube Bundle
Log-Mean Temperature Difference, °F	125
Number of Shell Side Passes	1
Number of Tube Side Passes	1
Weight of Tube Bundle Bypassing Coolant, %	
Shell Side	5
Tube Side	2.5
Tube OD, in.	1
Tube Wall, BWG	16
<u>Elevation Data</u>	
Operating Floor (reference elevation)	0'0"
Vessel Coolant Level	-8'4"
Secondary Surge Tank Coolant Level	20'0"
Secondary Pump Impeller	8'6"
<u>Primary Piping Arrangement</u>	
<u>Hot-Leg Pump Location</u>	
	Reactor Vessel to Pump
	Pump to IHX
	IHX to Vessel
Straight Pipe, ft	93
Number of Fittings and Valves:	43
90° Long Radius Elbows	2
	4

TABLE II. (contd)

<u>Hot-Leg Pump Location</u>			
	<u>Reactor Vessel to Pump</u>	<u>Pump to IHX</u>	<u>IHX to Vessel</u>
45° Elbows	2	0	0
Branch Flow Tees	0	0	1
Sudden Expansions	0	1	1
Sudden Contractions	1	0	1
Check Valves (open)	0	1	0
<u>Cold-Leg Pump Location</u>			
Straight Pipe, ft	93	43	123
Number of Fittings and Valves:			
90° Long Radius Elbows	4	2	4
45° Elbows	2	0	0
Branch Flow Tees	0	0	1
Sudden Expansions	1	0	1
Sudden Contractions	1	1	0
Check Valves (open)	0	0	1
<u>Secondary Piping Arrangement</u>			
	<u>IHX to DHX</u>	<u>DHX to Pump</u>	<u>Pump to IHX</u>
Straight Pipe, ft	422	172	247
Number of Fittings and Valves:			
90° Long Radius Elbows	9	3	8
Branch Flow Tees	0	1	0
Through Flow Tees	1	0	0
Sudden Expansions	0	0	1
Sudden Contractions	1	0	0

TABLE II. (contd)

<u>Liquid Metal Pumps</u>	
Type	Free Surface, Centrifugal, Single Stage
Location of Secondary Pump	Cold Leg
Speed Secondary Pump, rpm	1120
Drives	Squirrel Cage Induction Motors and Eddy Current Couplings for Speed Control
Motor Speed, rpm	1170
<u>Air Heat Dump Complex</u>	
Type Heat Exchanger	Forced Convection, Cross Flow, Extended Surface
Inlet Air Temperature, °F	100
<u>Miscellaneous</u>	
Minimum Pressure Difference Between Secondary and Primary Coolants in the IHX, psi (Secondary > Primary)	25
Maximum Allowable Payoff Period on any Incremental Capital Investment, yr	10
<u>Steady-State Process Design</u>	

General

The intermediate heat exchanger primary side pressure loss, primary pump shaft length, and primary pump speed are varied for each pump location. The ADOPT Code establishes (1) the optimum pipe sizes for the primary and secondary loops, and (2) the optimum air heat dump complex for the fixed input data given in Table II and for each combination of the foregoing input variables. The corresponding pump heads, pump and drive power requirements, reactor vessel and secondary surge tank gas space pressures, reactor vessel nozzle sizes, and system operating pressures are then established for each case. Two constraints are used as follows:

1. The maximum primary loop pipe size is 30 in. because this size appears to be the upper limit for reasonable FFTF piping arrangements. Larger pipe sizes could have the beneficial effects of lowering the reactor vessel gas space pressure, minimizing the primary pump shaft length, and/or maximizing the allowable IHX primary side pressure loss. However, the larger pipe sizes enable only marginal improvements and these improvements would be obtained at the expense of increased space requirements and increased project costs.
2. The maximum allowable reactor vessel gas space pressure is 10 in. of water whenever the combination of input values allows pressures equal to or less than the 10 in. In these cases, the ADOPT cost optimizations continue in the normal way. Cases in which the pressure limit is exceeded are not rejected but are reported using the maximum 30 in. pipe size between the reactor vessel and primary pump inlet.

IHX coolant location (primary coolant in tube or shell) and thermal baffling are not studied in a quantitative way. The IHX pressure loss parameter is used in such a way that the calculated data applies to primary coolant either in the shell or in the tubes. Low IHX pressure loss may lead to poor coolant flow distribution within the IHX, and heat transfer may be poor as a result. IHX arrangements with primary coolant on the tube side might be used if the maximum allowable IHX primary side pressure loss is shown to be inadequate (by heat exchanger design studies).

Protection of the upper tubesheet in the IHX by an inert gas space such as used in the Fermi heat exchangers is undesirable unless no other way can be found to provide adequate thermal baffling. The gas space introduces a third gas-liquid interface

into each primary loop. The interface in the IHX requires instrumentation and controls, wastes potential heat transfer surface, and introduces another place for gas entrainment. The gas space is especially undesirable for the hot-leg-located primary pumps because the space would have to be operated at pump discharge pressure which, in turn, introduces some unwanted coolant level and pressure balancing problems. Because the FFTF exchangers will probably be designed without the gas space below the upper tubesheet regardless of primary pump location, this thermal baffling variable is discounted as an important consideration in pump location.

Natural circulation requirements for the main heat removal system for emergency cooling could have a significant effect on the design of the main heat removal system. The effect is disregarded in these steady-state process design studies because natural circulation does not now appear to be a requirement for the main heat removal system; however, the effect of such a requirement on pump location is discussed in the section on Safety.

Process Design Results

The calculated process data are included in Tables III, IV, V, and VI for hot-leg and cold-leg primary pump locations. Conclusions concerning steady-state process design can be drawn as follows:

- Both primary pump hot-leg and cold-leg locations for forced circulation of primary coolant are feasible provided primary pump speed, primary shaft length, and primary pipe size are selected with care and with proper consideration for their interactions.
- Primary pumps located in the hot leg can be of either the Hallam or Fermi types (with the pump barrel in communication with the pump discharge or suction, respectively). The

TABLE III. Cost Optimization Results for Primary Pump Hot-Leg Location at 1140 rpm

	Case Number								
	1	2	3	4	5	6	7	8	9
Input Process Data:									
IHX Primary Side Pressure Loss, psi	4.39	7.05	10.3	4.39	7.05	10.3	4.39	7.05	10.3
Primary Pump Shaft Length, ft	20	20	20	23	23	23	26	26	26
Primary Pump Impeller Submergence, ft	11.2	11.2	11.2	14.2	14.2	14.2	17.2	17.2	17.2
Primary Pump Speed, rpm	1140	1140	1140	1140	1140	1140	1140	1140	1140
Calculated Process Data:									
Minimum Reactor Vesses Gas Space Pressure, psig	0.360	0.357	0.355	0.0433	0.0464	0.0500	0.000	0.000	0.000
Secondary Surge Tank Gas Space Pressure, psig	69	66	63	75	75	74	76	76	75
Minimum Required Primary Pump Suction Pressure, psig	3.79	3.79	3.78	3.53	3.53	3.54	3.53	3.53	3.53
Actual Primary Pump Suction Pressure, psig	3.79	3.79	3.78	3.53	3.53	3.54	4.58	4.58	4.58
Primary Pump Head, ft	394	388	384	422	429	438	422	429	438
Primary Pump Discharge Pressure, psig	147	145	144	157	160	163	158	161	164
Secondary Pump Discharge Pressure, psig	166	165	165	172	174	176	173	175	177
Primary Pump BHP	1450	1430	1410	1550	1580	1610	1550	1580	1610
Primary Pump Motor Rating, hp	1500	1500	1500	1750	1750	1750	1750	1750	1750
Secondary Pump BHP	786	802	824	786	802	824	786	802	824
Secondary Pump Motor Rating, hp	800	800	800	800	800	800	800	800	800
Primary Pipe Size, in.:									
On-Pump Suction	30	30	30	24	24	24	24	24	24
On-Pump Discharge	18	20	24	16	16	16	16	16	16
Construction Cost Data (in 1000 Dollars):									
IHX Complex/Circuit	724	688	673	724	688	673	724	688	673
DHX Complex/Circuit	1,172	1,172	1,172	1,172	1,172	1,172	1,172	1,172	1,172
Primary Loop/Circuit	788	814	872	757	760	763	782	785	788
Secondary Loop/Circuit	908	904	906	934	942	954	939	947	959
Sub-Total, Main Heat Removal System/Circuit	3,592	3,578	3,623	3,587	3,562	3,562	3,617	3,592	3,592
Electrical Supply System/Circuit (Incremental)	71	71	71	79	79	79	79	79	79
Sub-Total/Circuit	3,663	3,649	3,694	3,566	3,641	3,641	3,696	3,671	3,671
Total for Four Circuits	14,652	14,596	14,776	14,664	14,564	14,564	14,784	14,684	14,684
Reactor Vessel System (Incremental)	16	18	22	6	6	6	6	6	6
Uninstalled Spares (Incremental)	864	845	839	900	887	885	923	909	908
Design/Development (Incremental)	250	250	250	250	250	250	250	250	250
Direct Construction Costs	15,782	15,709	15,887	15,570	15,707	15,705	15,963	15,849	15,848
Capital Investment	26,040	25,920	26,210	25,690	25,920	25,920	26,340	26,150	26,150

TABLE IV. Cost Optimization Results for Primary Pump Hot-Leg Location at 870 rpm

	Case Number					
	10	11	12	13	14	15
Input Process Data:						
IHX Primary Side Pressure Loss, psi	4.39	7.05	10.3	4.39	7.05	10.3
Primary Pump Shaft Length, ft	15	15	15	20	20	20
Primary Pump Impeller Submergence, ft	6.2	6.2	6.2	11.2	11.2	11.2
Primary Pump Speed, rpm	870	870	870	870	870	870
Calculated Process Data:						
Minimum Reactor Vessel Gas Space Pressure, psig	0.000	0.000	0.000	0.000	0.000	0.000
Secondary Surge Tank Gas Space Pressure, psig	72	72	71	73	73	73
Minimum Required Primary Pump Suction Pressure, psig	-2.68	-2.68	-2.68	-3.21	-3.21	-3.21
Actual Primary Pump Suction Pressure, psig	-1.46	-1.46	-1.46	-1.83	-1.83	-1.83
Primary Pump Head, ft	426	433	442	431	438	447
Primary Pump Discharge Pressure, psig	154	156	160	155	157	161
Secondary Pump Discharge Pressure, psig	170	171	173	171	173	175
Primary Pump BHP	1570	1600	1630	1580	1610	1640
Primary Pump Motor Rating, hp	2000	2000	2000	2000	2000	2000
Secondary Pump BHP	786	802	824	786	802	824
Secondary Pump Motor Rating, hp	800	800	800	800	800	800
Primary Pipe Size, in.:						
On-Pump Suction	20	20	20	18	18	18
On-Pump Discharge	16	16	16	16	16	16
Construction Cost Data (in 1000 Dollars):						
IHX Complex/Circuit	724	688	673	724	688	673
DHX Complex/Circuit	1,172	1,172	1,172	1,172	1,172	1,172
Primary Loop/Circuit	753	756	759	759	762	758
Secondary Loop/Circuit	923	929	941	929	937	949
Sub-Total Main Heat Removal System/Circuit	3,572	3,545	3,545	3,584	3,559	3,552
Electrical Supply System/Circuit (Incremental)	87	87	87	87	87	87
Sub-Total/Circuit	3,659	3,632	3,632	3,671	3,646	3,639
Total for Four Circuits	14,636	14,528	14,528	14,684	14,584	14,556
Reactor Vessel System (Incremental)	3	3	3	2	2	2
Uninstalled Spares (Incremental)	926	911	905	905	931	922
Design/Development (Incremental)	250	250	250	250	250	250
Direct Construction	15,815	15,692	15,686	15,841	15,767	15,730
Capital Investment	26,090	25,890	25,880	26,140	26,020	25,950

TABLE V. Cost Optimization Results for Primary Pump Cold
Leg Location at 1140 rpm

	Case Number		
	16	17	18
Input Process Data:			
IHX Primary Side Pressure Loss, psi	4.39	4.39	4.39
Primary Pump Shaft Length, ft	20	23	26
Primary Pump Impeller Submergence, ft	11.2	14.2	17.2
Primary Pump Speed, rpm	1140	1140	1140
Calculated Process Data:			
Minimum Reactor Vessel Gas Space Pressure, psig	5.40	4.25	3.11
Secondary Surge Tank Gas Space Pressure, psig	0.00	0.00	0.00
Minimum Required Primary Pump Suction Pressure, psig	4.04	4.04	4.04
Actual Primary Pump Suction Pressure, psig	4.04	4.04	4.04
Primary Pump Head, ft	384	384	384
Primary Pump Discharge Pressure, psig	151	151	151
Secondary Pump Discharge Pressure, psig			
Primary Pump BHP	1410	1410	1410
Primary Pump Motor Rating, hp	2000	2000	2000
Secondary Pump BHP	786	786	786
Secondary Pump Motor Rating, hp	800	800	800
Primary Pipe Size, in.:			
On-Pump Suction	30	30	30
On-Pump Discharge	16	16	16
Construction Cost Data (in 1000 Dollars):			
IHX Complex/Circuit	584	584	584
DHX Complex/Circuit	1,172	1,172	1,172
Primary Loop/Circuit	826	841	857
Secondary Loop/Circuit	823	823	823
Sub-Total Main Heat Removal System/Circuit	3,405	3,420	3,436
Electrical Supply System/Circuit (Incremental)	87	87	87
Sub-Total/Circuit	3,492	3,507	3,523
Total for Four Circuits	13,968	14,028	14,092
Reactor Vessel System (Incremental)	69	59	45
Uninstalled Spares (Incremental)	827	827	832
Design Development (Incremental)	0	0	0
Direct Construction	14,864	14,914	14,969
Capital Investment	24,530	24,610	24,700

TABLE VI. Cost Optimisation Results for Primary Pump Cold-Leg Location at 870 rpm

	Case Number								
	19	20	21	22	23	24	25	26	27
Input Process Data:									
IHX Primary Side Pressure Loss, psi	4.39	7.05	10.3	4.39	7.05	10.5	4.39	7.05	10.5
Primary Pump Shaft Length, ft	20	20	20	23	23	25	26	26	26
Primary Pump Impeller Submergence, ft	11.2	11.2	11.2	14.2	14.2	14.2	17.2	17.2	17.2
Primary Pump Speed, rpm	870	870	870	870	870	870	870	870	870
Calculated Process Data:									
Minimum Reactor Vessel Gas Space Pressure, psig	0.00	2.23	5.50	0.00	1.08	4.35	0.00	0.00	5.20
Secondary Surge Tank Gas Space Pressure, psig	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minimum Required Primary Pump Suction Pressure, psig	-1.76	-1.76	-1.76	-2.01	-1.76	-1.76	-2.01	-1.76	-1.76
Actual Primary Pump Suction Pressure, psig	-1.32	-1.76	-1.76	-1.84	-1.76	-1.76	-0.69	-1.69	-1.76
Primary Pump Head, ft	383	391	382	387	391	382	387	391	382
Primary Pump Discharge Pressure, psig	146	148	144	147	148	144	147	148	144
Secondary Pump Discharge Pressure, psig	98	99	102	98	99	102	98	99	102
Primary Pump BHP	1410	1440	1410	1430	1440	1410	1430	1440	1410
Primary Pump Motor Rating, hp	2000	2000	2000	2000	2000	2000	2000	2000	2000
Secondary Pump BHP	786	802	824	786	802	824	786	802	824
Secondary Pump Motor Rating, hp	800	800	800	800	800	800	800	800	800
Primary Pipe Size, in.:									
On-Pump Suction	30	30	30	24	30	30	24	30	30
On-Pump Discharge	16	16	18	16	16	18	16	16	18
Construction Cost Data (in 1000 Dollars):									
IHX Complex/Circuit	584	555	541	584	555	541	584	555	541
DHX Complex/Circuit	1,172	1,172	1,172	1,172	1,172	1,172	1,172	1,172	1,172
Primary Loop/Circuit	850	852	870	799	868	855	817	884	901
Secondary Loop/Circuit	823	825	827	823	825	827	823	825	827
Sub-Total Main Heat Removal System/Circuit	3,429	3,404	3,410	3,378	3,420	3,425	3,396	3,456	3,441
Electrical Supply System/Circuit (Incremental)	87	87	87	87	87	87	87	87	87
Sub-Total/Circuit	3,516	3,491	3,497	3,465	3,507	3,512	3,483	3,523	3,528
Total for Four Circuits	14,064	13,964	13,988	13,860	14,028	14,048	13,932	14,092	14,112
Reactor Vessel System (Incremental)	14	36	70	6	25	60	6	14	48
Uninstalled Spares (Incremental)	887	878	868	903	891	881	919	905	896
Design Development (Incremental)	0	0	0	0	0	0	0	0	0
Direct Construction Cost	14,965	14,878	14,926	14,769	14,944	14,989	14,857	15,011	15,056
Capital Investment	24,690	24,550	24,630	24,370	24,660	24,730	24,510	24,770	24,840

pressure drop between the reactor vessel and pump suction can be made small enough with a hot-leg location to permit the selection of either type. The cold-leg-located primary pumps must be of the Hallam type because of the relatively large pressure drop through the IHX.

- Reactor vessel gas space pressures of essentially zero gage pressure are practical with either hot or cold-leg pump locations depending on the proper combination of primary pump speed, primary pump shaft length, primary pipe size, and IHX primary side pressure loss.
- Primary side IHX pressure losses of up to about 7 psi can be sustained for cold-leg primary pump locations. The hot-leg pump location does not place a restriction on the IHX pressure loss, but another item must be considered. For an assumed single stage, free surface centrifugal pump, greater IHX primary side pressure losses reduce allowable losses in the reactor pressure vessel. Hence, there is a real incentive to minimize out-of-core pressure losses to permit the use of available pump head in the core region, particularly since there appears to be an upper limit on available pump head.
- Primary pump design speed for a cold-leg located pump should not exceed about 870 rpm in order to avoid excessive reactor cover gas pressures. However, the design speed for a hot-leg pump could approach 1200 rpm, with operating speed depending on the pump drive provided.
- The secondary system operating pressure for the cold-leg primary pump runs about 63 to 76 psi less than that for a hot-leg located primary pump. The secondary surge tank pressure for the cold-leg primary pump cases is essentially zero gage pressure, whereas a pressure of 63 to 76 psig is needed for the hot-leg located primary pump cases. Secondary system pressures would be even greater if the

secondary pump were shifted to a hot-leg location instead of the cold-leg location assumed in this study.

Component Structural and Mechanical Design

The installed cost of some components is a function of pump location because of varying component structural and mechanical design requirements. The input cost data to the ADOPT Code allowed for the following significant areas of cost difference:

IHX

The shell thickness and shell nozzles are a function of pump location regardless of location of primary coolant in the IHX (shell side or tube side), assuming safety dictates the need for a secondary system pressure greater than primary system pressure. In this study, with the primary coolant on the shell side, the IHX sees primary pump discharge pressures for the hot-leg primary pump as contrasted to a low pressure for the cold-leg pump location. The shell side design pressure is taken as 200 psig for the hot-leg pump cases, while design pressure is 75 psig for the cold-leg pump cases. The tube bundle design is not affected by the pump location inasmuch as the tubes, tube-sheets, baffles, and shroud shell selected for the reference cold-leg pump location are adequate for the hot-leg pump location. However, design safety factors would be somewhat less for the hot-leg location than for the cold-leg pump location.

Primary Pump

The structural design temperature is taken as 1200 °F regardless of pump location, but it is expected that the design of some of the internal nonstructural parts would depend on the normal operating temperatures and hence, pump location. Hot-leg pump cost is expected to be greater than cold-leg for the same

speed, shaft length, flow, head, and horsepower, although accurate cost data are unavailable. For this work, a hot-leg pump is assumed to cost about 10% more than a corresponding cold-leg pump. In addition, the variations of speed and shaft length on cost are included.

Secondary System

The secondary system design pressure is influenced by the location of the primary pump. The surge tank, secondary pump casing and gas seals and valves are affected and thus input cost data are altered accordingly. The secondary piping and tube side of the dump heat exchanger are not affected because of inherent "over design" for the reference cold-leg primary pump location.

Cost Optimization Summary

Capital Investment

Construction cost and capital investment data are included in Tables III, IV, V, and VI. Costs are given for the main heat removal system, and incremental costs* are given for all other systems and special cost items affected by the primary pump location, pump design data, and/or IHX pressure loss.

The electrical power supply and reactor vessel systems are affected by pump location. However, costs are not significantly affected for the following systems:

- Instrumentation
- Inert Gas
- Sodium
- Equipment Maintenance
- Building and Structure.

* Those costs over and above some base cost uninfluenced by the variables of this study.

In addition, it is assumed that the cost of the emergency cooling system, currently undefined, is not affected by pump location.

Uninstalled spares and design/development are included as special costs. The costs of the removable IHX tube bundle and primary and secondary pumps are affected by the variables of this study. Therefore, uninstalled spare costs include these items.

The primary pump design/development is the only design/development item significantly affected by the variables of this study. The hot-leg-located pumps require more design/development than cold-leg pumps, especially because of the high 1200 °F operating temperature for the hot-leg pumps. The difference in the direct design/development costs between the hot-leg and cold-leg pumps is taken as the cost of a hot-leg primary pump without drive. This incremental cost amounts to about 250,000 dollars. The capital investment data in Tables III, IV, V, VI show the cold-leg pump location to be cheaper than the hot-leg location by over \$1 million.

Operational Costs

Inert gas, electrical power for primary pump motors, and primary pump maintenance parts are the only operational costs which vary with primary pump location and the other variables of this study. The inert gas and electrical power cost differences are minor and are not important factors in the selection of the primary pump location. No data are available to predict the difference in pump maintenance costs, but the hot-leg location probably would increase cost somewhat due to maintenance of pump seals and bearings. Because of the lack of meaningful data, it is impossible to evaluate quantitatively the importance of pump location on operational costs. However, operational costs appear to be of minor importance relative to FFTF expected overall operating cost.

SYSTEM TRANSIENT CONSIDERATIONS

Approach to Transient Analysis

The objective of this portion of the study is to determine the expected temperature transients at the pump location in either hot leg or cold leg and hence, the resultant pump vessel stress cycles. Several incidents could possibly produce large temperature transients during the life of the plant. In addition, normal operation will produce system temperature transients, generally, of a lower rate of change. For the purpose of comparing hot-leg and cold-leg pump location, incidents were studied with an analog-hybrid simulation of the FFTF under the following condition categories:

Scram Modes from Full Power

1. Reactor scram with full sodium flows
2. Reactor scram with pump scrams (to pony motor speed)
3. Reactor scram with full primary flow, secondary flow scram
4. Reactor scram with full secondary flow, primary flow scram
5. Reactor scram with pump scrams after one second delay.

Loss-of-Power Incidents

1. Loss of BPA power
2. Loss of BPA and emergency power
3. Loss of power to a secondary pump, scram reactor and primary flow
4. Loss of power to a secondary pump, scram reactor only.

The DHX fans were assumed to scram in all of the foregoing incidents.

Design differences between hot-leg pumps and cold-leg pumps are not apparent at the present stage of FFTF design. Thus, for the transient analyses, the same pump (with respect to torque-slip characteristics and inertia) is assumed to be used in either leg.

However, primary loop dimensions will change with pump location, as shown in Figure 1. Therefore, only the time delays for primary hot and cold legs are changed in the simulation.

The analytical results presented here must be regarded as preliminary because of the numerous changes in FFTF design. Two design areas of particular importance in regard to thermal transients are (1) sodium pump speed control, and (2) reactor vessel outlet plenum volume. For pump speed control, the current simulation uses a variable-speed, wound-rotor motor directly connected to the shaft and impeller. However, the reference system concept utilizes a magnetic clutch between a constant-speed induction motor and the impeller.⁽¹⁾ Flow transients will therefore be influenced by the torque-slip character of this clutch and the time constant of its excitation current. However, the current simulation is felt to be representative of the eventual design in regard to flow transients within 10 to 15% and is in close enough agreement for the comparison purposes of this report. Secondly, perfect mixing of the sodium is assumed for the outlet plenum volume. This assumption results in a first-order time lag which reduces the effect of reactor core temperature transients at the vessel outlet. A value for this mixing volume, based on a brief parameter survey over the design range, was selected. The experimental program for hydraulic mockup of the reactor will produce more accurate numbers.⁽³⁾

Finally, the simulation studies were performed for a reactor ΔT of 300 °F, corresponding to the minimum value for which the heat removal system is designed. Reference FTR operating conditions for the initial core include a 350 °F reactor ΔT but, for the purposes of comparing hot to cold-leg pump locations, the slightly smaller transients at a ΔT of 300 °F are sufficient.

(A) Pump in Hot Leg

(B) Pump in Cold Leg

FIGURE 1. Sodium Loop Dimensions for Pump Location
in Hot or Cold Leg

Model Description

The FFTF reactor and heat removal systems are simulated on an analog-digital ("hybrid") computer for the purpose of performing design parameter surveys, casualty studies, and control studies. A complete description may be found elsewhere.⁽⁴⁾ Emphasis is placed on detailed modeling of the heat removal system. Thus, the FTR core model is considerably less complex than models used for study of core internals, such as for fuel or clad melting studies. The following paragraphs briefly and adequately describe the simulation for the purposes of this report.

The FTR core simulation uses a three-group approximation for delayed neutron precursors, determined by the method of Albrecht and Metelmann.⁽⁵⁾ Scram reactivity is inserted as a negative ramp over a time interval of one second. Heat generation is divided between a fueled region and a radial reflector region. Sodium flow, except for some leakage around the reactor tubes, is divided between these two regions with coolant mixing in both inlet and outlet plenums. Heat transfer from fuel to coolant is modeled with a single axial node. This simplified model is adequate for studies of transients on the vessel and heat removal system.

Simulation of hydraulics in the coolant loop utilizes digitally-computed transport delays and standard Darcy-Weisbach expressions for friction losses in pipes and components. Coolant pumps are simulated with equations for dynamics of the impeller and motor. A variable-speed, wound-rotor motor is assumed. Thus, simulation of a flow scram to pony-motor speed requires a step change in the demand slip of the motor, while simulation of total power failure is accomplished by setting motor torque to zero.

The IHX heat transfer is simulated by a four-node model of the counterflow exchanger. Finite difference approximations are used to compute the temperature distribution along the flow axis. A similar three-node approach is used in modeling the DHX. DHX air flow is obtained by modeling a centrifugal fan and a control valve. The air hydraulics, assuming the ideal gas law, includes entrance, exit, and friction losses.

The FFTF will utilize multiple heat removal loops. However only one complete loop is modeled at present. For the purposes of this study, the present simulation is sufficient.

Analytical Results

Parameter Surveys

Design data used in the simulation reflects current concepts on core and heat removal system design. A listing of input data is inappropriate here except as such data affect the comparison of transients in the hot and cold legs. In this regard, scram reactivity and vessel outlet mixing volume are most important for hot-leg transients, and parameter surveys were performed for each.

The effect of scram reactivity on core sodium outlet temperature transients (not vessel outlet) due to scrambling the reactor with full coolant flow is shown in Figure 2. Little effect is seen for scram reactivities greater in magnitude than β_{15} . Since current designs call for scram reactivities between β_{15} and β_{20} , the lower figure was selected for ease of simulation. It must be noted that the transient magnitudes of Figure 2 represent transients at the outlet of average fuel channels for the initial FTR oxide core, and are presented only for the purpose of comparison.

Mixing of sodium coolant in the vessel outlet plenum will greatly decrease the magnitude of the above temperature transients. Figure 3 shows the effect on the vessel outlet

FIGURE 2. Effect of Scram Reactivity on Maximum Thermal Transient Rate at Core Outlet: Reactor Scram, Full Flow

FIGURE 3. Effect of Outlet Plenum Mixing Volume on Maximum Thermal Transient Rate at Vessel Outlet: Reactor Scram, Full Flow

transients of changes in the effective mixing volume. Current designs show mixing volumes in the range of 500 to 1800 ft³. The selected value of 1000 ft³ somewhat arbitrarily represents a design currently favored and an average of the design extremes. It is clear that should a smaller plenum be designed into the vessel, or should hydraulic testing reveal less than perfect mixing, the hot-leg transients will be greater than those presented here.

Scram Modes from Full Power

The most frequent transients the FFTF will encounter, apart from operational procedures such as startup and shutdown, are those produced by scrambling the reactor in response to incipient incidents or instrument malfunctions. While the FFTF mode of flow response to scram has not as yet been chosen, the following may be employed:

- No flow scram.
 - Flows scram to pony motor conditions with no delay.
 - No primary flow scram, secondary flow scrams to pony motor with no delay.
 - No secondary flow scram, primary flow scrams to pony motor with no delay.
 - Flows scram to pony motor with time delay after core scram.
- Each of these cases was simulated with the FFTF analog-hybrid model. For each case, the primary pump was "relocated" from hot to cold leg by changing the transport delays.

Results are presented in Figures 4 through 7. Each case assumed the shutdown of the DHX fan when the core is scrambled, with the resulting uncontrolled natural draft across the DHX stack. Runs were made with and without DHX air valve closure (therefore, with and without natural draft), with negligible effect on the transients within the first 5 min. No control

FIGURE 4. *Primary Loop Transients: Reactor Scram with Full Sodium Flows*

FIGURE 5. *Primary Loop Transients: Reactor Scram with Flow Scrams to Pony Motor Speed*

FIGURE 6. Primary Loop Transients: Reactor Scram with Full Primary Flow, Secondary Scram to Pony Motor Speed

FIGURE 7. Primary Loop Transients: Reactor Scram with Full Secondary Flow, Primary Scram to Pony Speed

functions are modeled in this simulation. The transient results are presented for the first 2 min following the scram. The transients would surely be smoothed out by control action by this time, if not before.

Figures 4 through 7 show the effect of moving the primary pump from the cold to the hot leg for the first four of the above scram modes. These transients occur at the vessel outlet and IHX outlet, but may be expected to be transported downstream. With few exceptions, the location of the primary pump has little effect on the temperature transients per se. The only real difference occurs in the case of maintaining full primary flow and scrambling secondary flow (Figure 6), in which the positive cold-leg transient reaches the core faster for the pump-in-hot-leg case and thereby limits the negative hot-leg transient. A difference of 30 °F in the overall temperature change is the result, whereas the rate of change remains unaffected. A word is necessary at this point concerning accuracy of the computations. Analog computers cannot be expected to perform more accurately than about $\pm 1\%$. Accuracies of $\pm 2\%$ are common, depending on maintenance of the machines. For the scaling of the FFTF simulation, errors of ± 10 °F can be expected. One may then conclude that with so little difference between the runs for the pump in the hot leg and cold leg, only a single transient needs to be simulated. Comparison of the temperature transients seen by the pump in either location may then be made by examining hot-leg and cold-leg transients for that particular simulation. Accordingly, even though the remaining studies were performed with transport delays for a cold-leg pump, the hot-leg transient data are valid for a pump in that location.

Figure 8 shows the transient result for the most probable scram mode as a scram of both flows and fans with a time delay after reactor scram. This case is compared to the similar case

FIGURE 8. *Primary Loop Transients: Reactor Scram with and Without Time Delay on Flow Scrams*

for no time delay. The time delay will probably be used for two reasons: (1) to assure that safety rods have dropped before flow is decreased; and (2) to remove stored heat in the oxide fuel, which otherwise would cause a coolant temperature rise if flow were to decay at the same time as power. The no-delay case is also shown as a comparison.

Loss-of-Power Incidents

In addition to reactor scrams, other incidents with a smaller expected frequency will produce temperature transients and must be analyzed. These may be grouped into the loss-of-power category, whether it be loss of all power to the entire system or merely to a single component. Four incidents were examined:

- Loss of BPA power (coolant flows to pony motor conditions), scram core.
- Loss of BPA and emergency power (flows to natural convection), scram core.

- Loss of power to a secondary pump (flow to pony motor conditions), scram core and primary flow after time delay.
- Loss of power to a secondary pump (flow to pony motor conditions), scram core after time delay, primary remains at full flow.

Each of these cases, simulated with the FFTF hybrid model, used the transport delays for a primary pump cold-leg location. As shown previously, hot-leg transients are still valid as primary pump transients. Only one loop of the multiloop system is modeled, however. Thus, the loss-of-secondary-pump cases are valid only for a cold-leg pump location and for one loop transport time, since the hot leg normally communicates with the other loops of the multiloop system through the reactor vessel.

Figures 9 through 12 show the transients resulting from the above incidents. Time delays for scrambling the core represent the extremes of the probable design range. The flow transients produced by the incidents are shown in Figure 13.

Comparison of Primary Pump Locations for the Thermal Transients

The maximum change rate of primary loop sodium temperature for each of the foregoing incidents is shown in Table VII. In general, only the initial transient is tabulated, as succeeding temperature changes are of lesser magnitude.

Transients in the hot leg have their source in the reactor itself and are highly influenced by two factors: (1) the outlet plenum sodium mixing volume; and (2) the type and design of the fuel. For the case of scrambling the reactor with full flow, Figures 2 and 3 show that the -44 °F/sec transient at the core outlet is reduced by half at the vessel outlet for a mixing volume of only 300 ft^3 . The analyses were performed for a relatively low power density oxide core. Should a more advanced core be employed (e.g., carbide fuel), the transient rate could increase greatly at the core outlet and vessel outlet.

Figure 9. Primary Loop Transients: Loss of BPA Power to Pumps and Fans, Reactor Scram After Time Delay

FIGURE 10. Primary Loop Transients: Loss of All Power to Pumps and Fans, Reactor Scram After Time Delay

FIGURE 11. Primary Loop Transients: Loss of Secondary Pump, Scram Reactor and Primary Flow After Time Delay

FIGURE 12. Primary Loop Transients: Loss of Secondary Pump, Scram Reactor After Time Delay, Primary Full Flow

FIGURE 13. Primary and Secondary Flow Transients: Scram to Pony Motor Speed and Loss of Power (Flow to Natural Convection)

TABLE VII. Primary Pump Temperature Transients for FFTF
Incidents from 400 MW, 300 °F ΔT

Type of Incident	Expected Occurrences In Plant Life	Temperature Transient, Maximum Rate of Change (°F/sec for --sec)	
		Pump in Hot Leg	Pump in Cold Leg
1. Scram Reactor, Full Flows	500*	-11 for 12	+2 for 40
2. Scram Reactor, Primary and Secondary Flow Scram		-1.5 for 120	-10 for 5
3. Scram Reactor, Primary Scram, Secondary Full Flow		-1.5 for 120	-13 for 5
4. Scram Reactor Secondary Scram, Primary Full Flow		-11 for 12	+9 for 10
5. Loss of Secondary Pump, Scram Reactor and Primary Flows (1 sec delay)	4**	-1.5 for 120	-10 for 3
6. Loss of Secondary Pump, Scram Reactor, Primary Full Flow (1 sec delay)		-11 for 12	+9 for 10
7. Loss of BPA Power	4	-1.5 for 120	-10 for 5
8. Loss of BPA and Emergency Power	1	-1/4 for 120	-10 for 5

* Total of types 1 through 4

** Total of types 5 and 6

Transients in the primary cold leg generally result from secondary or tertiary loop disturbances, and would be highly influenced by control action on secondary flow, primary flow, and/or DHX air flow. For example, the positive transients of Figures 4 and 7 (full flow in the secondary loop) are due to the excessive natural draft cooling at the DHX. No attempt was made to control the draft by dampers nor to perform a parameter survey on the DHX height for optimum draft inasmuch as such efforts were beyond the scope of this study. Proper control action, however, would minimize the transients seen by the primary cold leg.

Thus, the relative severity of transients in the hot and cold legs cannot be determined unless fuel design, outlet plenum mixing, and process control performance are known. Further, because the frequency of scram events is expected to exceed all other "incidents" by several orders of magnitude, and because of the widely differing effects of each possible mode, it is essential that the preferred mode of scram be known. Finally, the choice of the scram mode depends partially on the transient effects themselves. A definitive choice between hot and cold-leg pump location based on thermal transients is impossible at this time. However, a "most likely" situation may be outlined.

The most likely approach to reactor scram will consider the following factors:

1. Minimizing thermal transients on driver fuel and tests.
2. Assuring reactor scram before sodium flow is reduced.

These requirements are met by scrambling primary and secondary flow, with an appropriate delay after reactor scram. Such a transient is displayed in Figure 8, using a time delay of 1 sec (equivalent to safety rod drop time plus instrument delays). The results are nearly identical to those for flow scrams with no delay, in which the cold-leg transient rate is

six times greater than hot-leg rate (see Table VII). However, the total transient for the cold leg is limited to the 80 °F drop in IHX log-mean-temperature-difference (LMTD) while the hot-leg transient continues a temperature decline as long as it is allowed.

The less desirable pump location from the standpoint of transient behavior cannot be determined at this time. For example, the hot-leg transient can be more severe for (1) high power density fuel, and (2) poor outlet plenum mixing. Further, the cold-leg transient can be less severe for (1) mixing in an IHX outlet plenum, (2) lower IHX LMTD, and (3) a transport delay between the IHX outlet and the pump which would tend to "stretch" out thermal transients during flow decay. All of the above items are under study but complete results are not available.

Finally, assuming the results of Figure 8 to represent the scram transient for 20 years of plant life, the resulting cyclic stresses present little from which to choose. Table VIII shows the thermal stresses and the allowable number of scram cycles for each pump location, based on analysis of stresses in the pump casing itself. Nozzle stresses and pump internal stresses are of greater interest, but analysis must be deferred to a later design stage.

The hot-leg location has an apparent advantage in terms of stress magnitude. However, as hot-leg temperatures and core ΔT 's are increased for the facility objectives, the differences between locations in terms of thermal stresses decrease because of rapidly decreasing material strength at high temperatures. A small advantage then goes to the cold-leg location in terms of allowable number of cycles. However, since the allowable cycles at both pump locations are well above the expected number, there is little to choose between the two.

TABLE VIII. *Thermal Stress and Allowable Scram Cycles for Primary Pump Vessel*

	Primary Pump in Hot Leg	Primary Pump in Cold Leg
Operating Temperature, °F	900	600
Transient, $\Delta T/\Delta t^*$	-100 °F/60 sec	-80 °F/15 sec
Expected No. of Occurrences	500	500
Thermal Stress, kpsi**	12	19
Allowable Occurrences**	~250,000	>10 ⁶

* Overall transient over the first minute (see Figure 8) produced higher stresses than did the maximum rate noted in Table VII, Item 2.

** Based on thermal transient stresses in a 1 in. thick pump vessel, using the ASME Nuclear Vessel Code

In summary, either primary pump location may be used from the standpoint of allowable thermal transients known at this time. It should be clearly understood that other design considerations may produce a system facilitating a firm choice of pump location based on thermal transients. For example, should safety considerations dictate the continuous running of sodium pumps during a scram, a clear advantage for the cold-leg location becomes obvious. Analyses of system transients will continue as the FFTF system design is developed.

ADDITIONAL PRIMARY PUMP LOCATION CONSIDERATIONS

Pump Reliability and System Availability

To examine quantitatively the relative reliability of hot leg and cold-leg located FFTF primary pumps, failure rate data are needed as functions of such parameters as operating temperature and pump speed. Due to the limited number of large liquid metal pumps which have been operated at elevated temperatures, insufficient failure rate data are available. Hence, only a qualitative comparison between pump locations, based on operation experience at other sodium-cooled reactor plants (see Table I), can be made.

Operational experience with sodium pumps at other major facilities is summarized in Table IX. Each of the various pumps, although differing in design features, is a free-surface, centrifugal pump with at least one hydrostatic sodium-lubricated bearing. Some of the pumps encountered difficulties during initial testing, but then performed successfully after corrections were completed. Because details of each pump's operating history may be found in the literature,⁽⁶⁾ a survey will not be presented here.

Before a realistic reliability comparison of the two primary pump locations can be made, long-term testing of the pumps at FFTF hot-leg temperature is needed. However, the information of Table IX shows that the FFTF primary pumps may be designed with confidence for successful operation at FFTF cold-leg temperatures.

TABLE IX. Operating Experience with Sodium Pumps

<u>Facility</u>	<u>Pumps</u>	<u>Operating Time, hr</u>	<u>Temperature, °F</u>	<u>Flow, gpm</u>
Hallam	Primary (3)	20,000 each	to 1,000	to 7,200
	Secondary (3)	19,000 each	to 650	to 7,200
	Prototype	800	to 1,000	to 9,000
EBR-II	Primary (2)	12,000 each	to 900	to 4,670
	Prototype	16,000	to 900	to 6,500
Fermi	Primary (3)	>26,000 each	to 750	to 11,800
	Secondary (3)	>17,000 each	to 750	to 13,000
RAPSODIE	Test Loop	12,000	to 1,022	to 2,000
SRE-PEP ⁽⁷⁾	Primary	13,700	to 700	to 2,350
	Secondary	7,400	to 700	to 1,850

Pump Development Problems

Several areas of the FFTF primary pump design need special attention, with an emphasis on developmental testing. These are (1) shaft seals, (2) sodium-lubricated bearings, and (3) impeller-diffuser (from the standpoint of erosion and mass transfer). These items are strongly influenced by fluid temperature. In general, colder operating temperatures tend to reduce wear on seals, bearings, and impellers. In particular, hard surface materials now generally used for bearings sustain a reduction in hardness above 1000 °F.⁽⁸⁾ Thus, in view of the 1200 °F goal for primary hot-leg design, lower-temperature cold-leg operation of the primary pump promises the greater probability of success.

Safety

Pressurized Cover Gas Spaces

The design requirement of higher secondary sodium pressure at the IHX (relative to the primary side) results in a high secondary surge tank gas pressure (60 to 75 psig) for a primary pump hot-leg location. Reactor cover gas pressure for this situation would then be near zero gage. Conversely, because of NPSH requirements for the primary pump, pressurization of the reactor cover gas (on the order of 5 psig) may be required for a primary pump cold-leg location, dependent on the IHX primary head loss. The secondary surge tank need not be pressurized for this case. Thus, the cold-leg location has the apparent advantage of lower-pressure gas spaces to control.

In either case, the hazard of accidentally opening up pressurized gas spaces before pressure is relieved is relatively minor. Well-trained personnel and sound operating procedures should reduce such a hazard to a negligible consideration in the choice of a primary pump location.

Emergency Cooling Considerations

An emergency cooling system independent of the main heat removal system was assumed in the cost analysis. The conclusions based on this assumption may require revision if the main heat removal system is also to provide the emergency cooling function by means of natural circulation in the primary and secondary loops.

Piping and equipment for the primary and secondary loops must be specially arranged to assure sustained natural circulation following reactor shutdown for piping rupture or loss-of-pump accidents. The normal reactor core submergence (static sodium head above the core) is important in determining feasibility of arrangements for natural circulation. The hot-leg pump location lends itself well to feasible arrangements even for small amounts of core submergence. However, the same small submergence may be unfeasible for cold-leg-located primary pumps from the standpoint of requiring a separate emergency cooling system. The expense of a separate emergency cooling system may reverse the apparent cost advantage of the cold-leg location.

Another consideration besides normal core submergence may affect feasibility. The possible need for high reactor cover gas pressure to satisfy NPSH requirements on a cold-leg-located pump could (1) increase the rate of coolant loss in a piping rupture incident, or (2) produce a flow reversal in the core following pump coastdown, if the coolant piping break occurs between the checkvalve and the vessel inlet nozzle. It is concluded that a natural circulation requirement for the main heat removal system could, under certain circumstances, require location of the primary pumps in the hot legs regardless of cost, reliability, or transient considerations.

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