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EVALUATION OF ALTERNATE LOFT SECONDARY
HEAT REMOVAL SYSTEMS

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SUMMARY

This LTR documents the results of a trade-off study performed to determine which of the following alternate Secondary Coolant Systems was most desirable for LOFT.

(1) Dowtherm secondary system rejecting heat to:

- (a) an air-cooled secondary heat exchanger
- (b) a water-cooled secondary heat exchanger with cooling tower territory system.

(2) Steam secondary system rejecting heat to:

- (a) an air-cooled secondary heat exchanger
- (b) a water-cooled secondary heat exchanger with cooling tower territory system.

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SAFETY TEST ENGINEERING PROGRAM

EVALUATION OF ALTERNATE LOFT SECONDARY HEAT REMOVAL SYSTEMS

PREPARED FOR

ATOMIC ENERGY COMMISSION

IDAHO FALLS, IDAHO

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EVALUATION OF ALTERNATE LOFT SECONDARY HEAT REMOVAL SYSTEMS

I. INTRODUCTION

The first system proposed for test in the LOFT facility is a pressurized water reactor system, designed to operate continuously for up to 1600 effective full power hours at 50 mwt. Because of the experimental nature of the plant and its relatively short life, utilization of the reactor heat for power generation is not practical. Consequently, it is necessary to provide a secondary heat removal system capable of continuously removing up to 170×10^6 Btu/hr (50 mwt) from the primary coolant system and dissipating this heat to the atmosphere. In the LOFT Conceptual Design, IDO-16833 (Revision I), a heat removal system was proposed in which liquid "Dowtherm A" is circulated in a closed secondary loop between the primary heat exchanger and shell-and-tube secondary heat exchangers; in the latter the heat is in turn transferred to a tertiary system in which treated water is circulated between the secondary heat exchangers and an induced draft cooling tower.

In response to a KE recommendation that certain alternate heat removal systems might result in cost savings or improved operation, the Idaho Operations Office, USAEC, authorized an engineering and economic study comparing the Dowtherm system described above with a secondary system in which steam is generated from demineralized water in the shell side of the primary heat exchanger, the steam condensed and the condensate re-circulated back to the primary heat exchanger in a closed loop. This steam generation concept was to be evaluated both using a water-cooled condenser (the water circulating to a cooling tower as proposed in the Dowtherm system), and using an air-cooled condenser, eliminating the tertiary system. The results of this study are contained herein.

II. SUMMARY AND CONCLUSIONS

The results of the study indicate that both the Dowtherm secondary system (see Figure I) and the steam secondary system (see Figure 2) are feasible, using either air-cooled secondary heat exchangers or water-cooled secondary heat exchangers with cooling tower tertiary systems.

The use of a steam secondary system would result in direct construction cost savings of approximately \$42,000 when compared to the Dowtherm secondary system proposed in IDO-16833, Revision I, if both systems are compared using water-cooled secondary heat exchangers with a cooling tower tertiary system. The operating costs for either a Dowtherm or steam secondary system would be approximately the same, although the steam system can be expected to be easier to control.

If an air-cooled condenser were used with the steam secondary system, eliminating the cooling tower tertiary system, additional direct construction cost savings of approximately \$117,000 could be realized. The use of air-cooled condensers would result in reduced operating cost since the total motor horsepower will be less than that required with a tertiary cooling tower system. In addition, the use of air-cooled condensers would result in greater operating flexibility than the use of a water-cooled condenser system. 3

LOFT DOWTHERM SECONDARY SYSTEM

FIGURE NO 1

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OAKLAND, CALIFORNIA

LOFT STEAM SECONDARY SYSTEM

FIGURE NO 2

KAISER ENGINEERS
DIVISION OF HENRY J. KAISER COMPANY
OAKLAND, CALIFORNIA

LOFT COOLING TOWER TERTIARY SYSTEM

FIGURE NO 3

KAISER ENGINEERS
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OAKLAND, CALIFORNIA

KAISER ENGINEERS

The use of an air-cooled secondary heat exchanger would not reduce the cost of the Dowtherm system to the same extent as that estimated for the steam secondary system.

The use of a steam secondary system with an air-cooled condenser is recommended for the LOFT facility since it will result in substantial construction cost savings, lower operating costs, easier control and operating flexibility, elimination of certain fire and radiological hazards, and be more nearly typical of pressurized water reactor power plants than the heat removal system proposed in IDO-16833.

III. ASSUMPTIONS AND CONDITIONS

Range of Heat Removal Rates	0 to 170×10^6 Btu/hr
Primary Coolant	
Fluid	Demineralized water
Pressure	2500 psia (Design)
Average Temperature	540F (at all power levels)
Temperature Rise - Full Load	24F
Flow	5.6×10^6 lb/hr (14,000 gpm)
Heat Sink (Air)	
Design Wet Bulb	65F
Design Dry Bulb	90F
Dowtherm System (Per IDO-16833, Rev. 1)	
Fluid	Dowtherm A
Pressure	30 psia
Average Temperature	225F
Temperature Rise - Full Load	50F
Flow	8.0×10^6 lb/hr (16,000 gpm)
Cooling Tower System (Per IDO-16833, Rev. I)	
Fluid	Treated Water
On-Tower Temperature	140F
Off-Tower Temperature	85F
Flow	3.5×10^6 lb/hr (7,000 gpm)

IV. DISCUSSION

A. Systems Descriptions

The heat generated in the reactor is transferred to the pressurized water primary system. The primary coolant is cooled by transferring its heat to the secondary system. The secondary system in turn is cooled by the tertiary system which finally rejects the heat to atmosphere.

Two alternative secondary systems are shown on Figures 1 and 2. Both of these systems are designed to cool the primary system coolant from

552F to 528F at 100% load (50 MW) and to maintain a constant reactor coolant temperature of 540F at very low loads. The tertiary system used with water-cooled secondary heat exchangers is shown on Figure 3.

1. Dowtherm A Secondary

The Dowtherm secondary system is shown on Figure 1. The system is as described in IDO 16833, Rev. I. Eight million pounds per hour of Dowtherm A are circulated by two half capacity pumps, operating in parallel. In the primary heat exchanger, the Dowtherm is heated from 200F to 250F. The primary heat exchanger is shell-and-tube design with Dowtherm in the shell and pressurized water in the tubes. Two half capacity shell-and-tube secondary heat exchangers are provided to transfer the heat from the secondary system to the tertiary system. Dowtherm is circulated through the shell and cooling tower water through the tubes.

In addition to the heat transfer components, the Dowtherm System requires a surge tank with a nitrogen blanket, a storage tank with a steam coil and transfer pump and a dry chemical fire protection system. The fire protection system provides coverage on the dolly, in the process building, and along the secondary coolant pipe way.

All Dowtherm components are designed for 15 psig pressure. Carbon steel is the principal material of construction throughout the system, including heat exchanger tubes; piping between the primary and secondary heat exchangers is 18" O. D.

2. Steam Secondary

The steam secondary system is shown on Figure 2. At full load, 212,000 pounds per hour of saturated steam, at 340 psia, are generated in the primary heat exchanger and condensed in the condenser at 325 psia. The condensate flows from the condenser to a condensate receiver and is then pumped back to the primary heat exchanger. The primary heat exchanger is a typical FWR steam generator with a vertical U-tube bundle in a pressure shell. The heat flux in the primary exchanger is the same as used for the Dowtherm exchanger to have a common basis for comparison. To maintain a constant average primary coolant temperature of 540F at any load, the steam flow is throttled. This results in steaming at 963 psia at zero load. With the decreased steam flow at low loads, the condensing temperature approaches the cooling tower water temperature. Thus at low loads, the condensing temperature approaches the cooling tower water temperature. Thus at low loads, the condenser pressure will be subatmospheric. The condensate pump is sized to develop the required head and flow from 50% to 100% of full power. To operate between zero and 50% of full load, the booster pump will be operated in series with the condensate pump to develop the required head. The required capacity of the booster pumps is approximately 50% of full-load flow.

The shell of the primary heat exchanger is designed for 1000 psig and the shell of the condenser is designed for 400 psig. A pressure reducing valve is provided between the primary and secondary exchangers to limit the pressure in the condenser shell.

A 10" diameter steam header and 6" diameter feed water header are provided. Carbon steel is used throughout the secondary system, including heat exchanger tubes.

3. Tertiary System VS Air-Cooled Condenser

The systems outlined in items 1 and 2 above were compared assuming cooling tower water in a tertiary system as shown in figure 3. An additional evaluation was made utilizing an air-cooled condenser in conjunction with the steam secondary system. The use of the air-cooled condenser eliminates the need for the cooling tower and its associated systems including chemical treatment of the cooling tower water, circulating pumps and tower fire protection system.

Service water for equipment cooling and biological shield cooling will be raw water used on a once-thru basis.

The air-cooled condenser will be a multicell, forced draft unit with shutter and variable pitch fan control. The design pressure of the condenser is 500 psig.

B. Technical Evaluation of Alternate Systems

1. Dowtherm Secondary - Cooling Tower Tertiary System

The use of Dowtherm A in a secondary system has certain technical advantages. These include: low vapor pressure hence low system pressures, freedom from corrosion problems, and moderately good heat transfer properties. There are certain disadvantages of a liquid Dowtherm A system including its cost (approximately 40¢ lb), its flammability, and relatively low heat removal capacity per pound of fluid ($C_p \times \Delta T$). An additional problem in connection with the proposed application for the LOFT heat removal system is that should a Dowtherm leak develop within the containment building during blowdown, the presence of the Dowtherm vapors within the containment atmosphere might influence the behavior of the released fission products, hence invalidating the test results.

The use of a Dowtherm secondary system in conjunction with a cooling tower tertiary system introduces an additional problem in control and operation at less than full load. This results from the fact that the heat source, the primary coolant, is maintained at a constant average temperature and the heat sink, the cooling tower, is also at an approximately constant temperature, some 44°F lower. With fixed heat transfer surface in both the primary and secondary heat exchangers, at low load the maximum Dowtherm temperature must approach the primary water temperature while the minimum Dowtherm temperature approaches the cooling tower temperature, thus resulting in a very large

cooling or heating range for the Dowtherm in both exchangers. Assuming the heat removal system is to be operated only at full load and very low loads (less than 1%) this problem is not too serious. When the reactor is being brought up to full power, a combination of secondary system throttling, bypassing of the secondary heat exchanger, and throttling or recirculation of the cooling tower water, operated manually, will permit the transition from zero to full load operation. If operation at part loads is required, a more complex control system would be necessary. The cost of a control system required for part load operation is not included in the comparison discussed in Section C. below.

2. Steam Secondary-Cooling Tower Tertiary System

The technical advantages of a steam-generating secondary system include excellent heat transfer properties, high heat removal capacity per pound of fluid, and no flammability problems. An additional advantage of steam generation cooling for LOFT heat removal system is that it permits the use of the same fluid, demineralized water, in both the primary and secondary systems; thus steam leakage during or following a blowdown will not introduce extraneous vapors into the containment.

One other advantage of the steam system as proposed is that it is operable at all power levels from zero to full load. Moreover, the control is quite simple; the heat removal rate is established by the setting of the throttle or flow control valve.

Disadvantages include higher system pressures and higher corrosion rates than would result from the use of Dowtherm. On the other hand, the steam conditions proposed for use in the LOFT secondary system are typical of those used in many steam power plants with but little difficulty from corrosion and steam leakage.

Another disadvantage of the proposed steam system is that the steam pressure in the primary heat exchanger varies from approximately 340 psi at full load to 960 psi at zero load, while the condenser pressure varies from 325 psi at full load to 1 atmosphere or less at zero load. The high differential pressure between the condenser and steam generator at part load results in high pumping power requirements, but because of the much longer flow required for the steam secondary, the pumping costs are still comparable with the Dowtherm secondary.

3. Steam Secondary - Air-Cooled Condenser (No Tertiary) System

The use of a steam-generating secondary system with an air-cooled condenser retains all of the advantages of the steam-generating secondary with a cooling tower tertiary system previously discussed. Additional advantages include elimination of the cooling tower fire hazard and elimination of possible tertiary system contamination from fission product release after the blowdown test. The use of an air-cooled condenser will be easier and cheaper to operate since chemical treatment of cooling water is eliminated and motor horsepower is less. The proposed air-cooled condensers will more readily permit the control of condensing

temperatures at part loads and varying air temperatures than would a water cooled condenser system.

C. COST EVALUATION

1. Basis For Cost Comparison

Because of the small plant operating factor the various schemes have been evaluated on the basis of comparative direct construction costs only; indirect costs such as engineering, field overhead, etc., and items common to all schemes have not been included. In comparing the Dowtherm secondary and the steam secondary there is no significant difference in installed horsepower, and the operating costs are not anticipated to differ greatly. On the other hand, the operating costs for the air-cooled condenser scheme would be less than for the tertiary system with cooling tower because of significantly less installed horsepower, elimination of water treatment and reduced maintenance.

Using an air-cooled condenser instead of the tertiary system would require less space in the process building, but this additional saving has not been evaluated.

2. Cost Comparison - Dowtherm vs Steam Secondary With Water Cooled Condenser

Table I shows the cost comparison between Dowtherm and steam secondary systems. It can be seen that the use of a steam secondary system results in savings of approximately \$42,000 in direct construction cost. The principal items of cost savings for the steam system include the secondary heat exchanger, secondary piping, the initial fill (using Dowtherm cost of \$0.375 / lb) and fire protection. Lower cost items for Dowtherm include the primary heat exchanger and secondary pumps.

3. Cost Comparison - Air-Cooled vs Water-Cooled Condenser With Steam Secondary

Table II shows the cost comparison between air-cooled condensers and water-cooled condensers using a tertiary system. It can be seen that the use of an air-cooled condenser results in a saving of \$117,000 in direct construction cost (exclusive of additional savings by reduction in size of Process Water Building). The principal cost-saving item is the complete elimination of the cooling tower tertiary system which is only partially offset by the increased condenser cost.

TABLE 1COST COMPARISON - DOWTHERM VS STEAM SECONDARY SYSTEMS

(Cooling Tower Tertiary System Used in Both Cases)

	<u>Dowtherm</u>	<u>Steam</u>	<u>Savings Using Steam System</u>
Primary-Secondary Heat Exchanger	Base	4,000	\$(4,000)
Secondary-Tertiary Heat Exchanger	18,000	10,000	8,000
Secondary Piping	43,000	26,000	17,000
Secondary Pumps	16,000	27,000	(11,000)
Instrumentation and Control	-	-	
Dowtherm Storage Tank	5,000	-	5,000
" Surge Tank	1,000	-	1,000
" Initial Fill	15,000	-	15,000
" Pressurizing System	1,000	-	1,000
" Steam Coil Piping	1,000	-	1,000
" Fire Protection	10,000	-	10,000
Condensate Storage Tank	-	1,000	(1,000)
Net Direct Construction Cost Saving Using Steam Secondary System			<u>\$42,000</u>

TABLE IICOST COMPARISON - AIR-COOLED CONDENSER VS COOLING TOWER TERTIARY SYSTEM

(Steam Secondary System Used in Both Cases)

	<u>Tertiary System</u>	<u>Air-Cooled Condenser</u>	<u>Savings Using Air-Cooled Con- denser</u>
Tertiary System Cost (from estimate)	160,000	-	\$160,000
Condenser	10,000	75,000	(65,000)
Steam - Condensate Piping	26,000	30,000	(4,000)
Service Water Pumps	9,000	6,000	3,000
Fire Protection	Base	13,000	(13,000)
Electrical Equipment	Base	10,000	(10,000)
Net Direct Construction Cost Saving Using Air-Cooled Condenser			<u>\$117,000</u>
			<u>96,000</u>