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**A FEASIBILITY STUDY:
THE APPLICATION OF COOLING TOWERS FOR
REDUCTION OF HANFORD PLANT HEAT LOAD
TO THE COLUMBIA RIVER**

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A FEASIBILITY STUDY:
THE APPLICATION OF COOLING TOWERS FOR REDUCTION
OF HANFORD PLANT HEAT LOAD TO THE COLUMBIA RIVER

G. E. Peck
Reactor Modification Design
FACILITIES ENGINEERING SECTION

August 24, 1962

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A FEASIBILITY STUDY:
THE APPLICATION OF COOLING TOWERS FOR REDUCTION
OF HANFORD PLANT HEAT LOAD TO THE COLUMBIA RIVER

A. INTRODUCTION

Hanford production reactor operation requires the rejection of very large heat loads. At the present time the heat load is rejected to the Columbia River by the reactor effluent. At low river flows the hot effluent can have appreciable effects on river temperatures.

B. PURPOSE

The purpose of this study is to evaluate the feasibility and costs of Cooling Towers as a means of reducing the heat load rejected to the Columbia River.

C. CONCLUSIONS

After evaluation of published information, available data, and Hanford plant conditions, it is concluded that:

1. That an induced draft cooling tower, because of its longer cooling range, would be an effective cooling device for reduction of gross heat load rejected to the Columbia River. Additional study will be required to determine effective use on an area to area basis.
2. That a basically wood, counter-flow, induced draft cooling tower could be installed for approximately \$1600 to \$2000 per megawatt capacity. This cost is a probable minimum and might be increased by the cost of auxiliary features required for radiation control.
3. That additional study and developmental testing would be required to determine the extent of contamination problems which would result from the cooling tower installation. These problems would include the degree of contamination buildup both within the cooling tower and the surrounding area, the effect on operation and maintenance, and the economics and use of materials other than wood.
4. That certain areas of consideration which affect the installation of cooling towers at Hanford be studied. These areas (beyond the scope of this report) which require study are: cooling economics for reactors, total effluent facilities, and impact of atmospheric loading of contaminated moisture on the Hanford Plant area.

D. DISCUSSION

1.0 Water Cooling

1.1 Water Cooling Principles

The transfer of heat from water to the atmosphere can be effected by bringing the water and air together indirectly

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(non-contact) as is done with the automobile radiator, or directly as is done with evaporative-cooling equipment such as atmospheric spray ponds, cooling towers, etc. (2). Generally, the principle employed in water-cooling equipment is that of evaporative cooling (3).

Most of the heat taken from the water is removed as latent heat as a result of the evaporation which takes place when the water is brought into contact with the atmosphere. There is also a further small loss of sensible heat arising from the difference in temperature between the hot water and the air. Even if this temperature difference did not exist, evaporative cooling would continue as long as the air in contact with the water remained unsaturated. Other things being equal, the rate at which heat is removed from the water, both as latent and as sensible heat, depends upon the area of contact with the atmosphere. An important feature of all water-cooling equipment is thus the provision of a large area of contact, or interfacial area, between the air and water. (2)

When cooled by the evaporative effect, water transfers to the air approximately 1000 BTU for each pound of water evaporated. Air, absorbing heat from water in this manner, is capable of cooling the water below the atmospheric (dry bulb) temperature. This phenomenon is of basic importance to the subject of evaporative cooling. This method provides a great variety of temperature requirements, and it also enables a small volume of water to dispose of a much greater heat load than would otherwise be possible.

The rate of heat transfer by convection and evaporation, water-cooling effect, will be accelerated by:

- a. Increasing the velocity of air passing over the exposed water surface.
- b. Increasing the surface area of the water being exposed to the passing air.
- c. Lowering the atmospheric pressure (increasing elevation above sea level).
- d. Raising the entering water temperature.
- e. Reducing the water-vapor content (humidity) of the air.

The wet-bulb temperature of the air is a primary factor in designing, sizing, and selecting of evaporative water-cooling equipment. In practice water is cooled to a temperature approaching the wet-bulb. The closer this approach the larger the size of the cooling equipment required for a given duty. The exact wet-bulb

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temperature thus selected is determined largely by operating conditions, temperature limitations, and geographical location.

1.2 Definitions for Operating Terms

Development of a specialized type of equipment usually results in a concurrent specialized glossary of words and phrases that describe particular related functions, parts, or characteristics of such equipment. Definitions common to such terms applied to atmospheric water-cooling equipment are as follows:

Cooling Range (Figure 1) is the degree F that the water is cooled with the evaporative equipment. It is the difference in temperature between the inlet hot water and of the cold water leaving the tower.

Approach (Figure 1) is the difference in degrees F between the temperature of the cold water leaving the cooling tower and the wet-bulb temperature of the surrounding air.

Heat Load is the amount of heat dissipated by the water-cooling tower in BTU per hour (or per minute). It is equal to the pounds of water circulated times the cooling range.

FIG. No. 1

Pumping Head is the pressure required to lift the water from the top of the water in the basin to the top of the tower and force it through the water distribution system. It is equal to the static head plus the velocity head and friction loss in the distribution system.

Drift is the small amount of water that escapes from atmospheric water-cooling equipment in the form of fine droplets and is that water which is entrained by the circulating air. Drift is a water loss independent from that water lost by evaporation; it can be reduced by good design.

Recirculation is that condition existing when hot, humid exhaust air is blown back to the air intake of the cooling tower.

1.3 Methods of Cooling Water

The methods of cooling water can be roughly divided according to the types of equipment or features utilized as follows:

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Cooling pond or lake
Spray ponds
Atmospheric towers (natural draft)
Chimney towers (natural draft)
Mechanical draft towers
 Forced draft
 Induced draft
 Counter flow
 Cross flow
Dry cooling

Hanford studies have been made of a canal-lake system (1) and cooling-tower usage (4) with reference (9) summarizing the above and other previous studies. Past consideration of cooling towers has been primarily for a closed-loop arrangement whereby the water is recirculated. This report will consider a different application, that of an open system or once-through cooling utilizing the longer cooling range of the induced draft cooling tower. The longer cooling range available for this application allows consideration of only a portion of the effluent stream passing through the cooling tower. This is attractive since the size of piping and equipment is reduced. While this study is primarily concerned with the feasibility of the induced draft cooling tower all types of cooling devices are discussed briefly in Appendix A to provide desirable background to the selection of water cooling devices.

2.0 Cooling Tower Application

2.1 Selection Criteria

Application of cooling towers for the Hanford plant require development of basic criteria from which the feasibility could be considered. Since all cooling devices depend upon atmospheric air for evaporation or direct absorption of heat, appropriate design temperatures for the area must be selected. The design temperature for ambient air were set at 65 F wet-bulb and 95 F dry-bulb for this study. Assuming that effluent would leave the retention basins at 190 F and that a 15 F approach to wet-bulb would be practical, cooled water would leave the tower at 80 F which gives a cooling range of 110 F. After considering the heat loads rejected by the reactors, a cooling capacity of 900 megawatts was selected as most suitable to incremental application of cooling tower units. For the selected cooling load and range, the tower would cool approximately 56,000 gpm of effluent and require about 50 ft. of pumping head to cover lifting effluent to the top of the tower and resistance of the distribution system.

A counter flow induced draft cooling tower was selected as the type of cooling device which met the above service requirements, for advantages described under Appendix Section A, and for the ease

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of maintenance in replacing tower fill material. This basic tower unit, composed of eight cells, each with two 100 HP fans, is one of standard design and commercially available materials, and is the basis for determining estimated costs for a Hanford installation.

For the above cooling tower, the materials of construction were selected on the basis of common commercial practice which is basically wood construction, usually California redwood. This construction material is the most reasonable and therefore a desirable base for developing cost comparisons. Asbestos-cement board is commonly used at the present time for cooling towers and is the preferred material for sides and intake louvers and costs no more than the double-sheathed wood sides of standard construction. Asbestos-cement board (CAB) can be used for fill material and for mist eliminators but increases the tower costs by about 25%. Plastic materials for fill materials would be most satisfactory if the inlet temperature of the effluent to the tower were not so high. Steel structural members, which are placed outside the sheathing of the sides and which support the fill from above, would eliminate wood structural members which are subject to deterioration and contamination; however, steel is subject to rust which would be contaminated by exposure to radioactive ions contained in mist escaping from tower and be a further source of contamination spread unless adequate means of preventing rust could be found. Discussion of the effect of contamination upon the materials of construction is to be found under Section 2.4.

2.2 Effect of Temperature

The wet-bulb temperature is the single most important factor affecting the performance of the cooling tower. The selected design wet bulb of 65 F is only exceeded 3.8% of the average hourly readings during the warm months which is conservative compared to ordinary commercial practice. Reference to the psychrometric data below, which was extracted from (13), reveals, for example, that the average wet-bulb for September is 52.7 F which is considerably lower than the design temperature, therefore increased efficiency of the cooling tower could be expected most of the time.

The efficiency of the cooling effect for induced draft towers is only slightly affected by changes in dry-bulb temperature and relative humidity. This is especially true for the longer cooling range applicable to this study.

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PSYCHROMETRIC DATA (1950-1957)									
	Dry Bulb			Wet Bulb			Relative Humidity		
	Ave.	High	Low	Ave.	High	Low	Ave.	High	Low
Jan.	28	62	22	25.8	53	22	76	100	29
Feb.	35	65	21	31.3	53	21	70	100	20
March	42.7	69	8	36.3	53	7	57	100	12
April	53	84	27	42.7	62	24	45	100	9
May	62.1	98	29	49.4	67	24	43	99	7
June	67.8	100	40	53.6	70	36	41	100	10
July	76.4	106	45	57.4	70	41	33	95	6
Aug.*	74.9	105	46	57.0	69	43	35	100	7
Sept.*	67.9	102	38	52.7	70	31	40	100	10
Oct. *	53.2	84	28	45.6	62	26	59	100	10
Nov.	39.2	66	0	35.7	54	1	74	100	27
Dec.	34.5	59	4	32.0	52	2	79	100	28

From HW-57722, P. 73.

* Months of normal cooling tower operation, see Section 3 for discussion of operating period.

2.3 Effect of Wind and Recirculation

Wind data has been recorded and reported in various reports. Reference (13) was used to collect data on wind direction and speed to assist with analysis of effect on cooling tower performance. The extracted data is shown in Chart Nos. 2, 3, 4, and 5. Analysis of wind data for prevailing wind direction was based on (14) and wind roses shown in Appendix B. A prevailing wind direction is important to the directional orientation of the cooling tower for minimizing the effects of wind on air recirculation.

From (12) it is reported that winds of 6-12 mph. produce the maximum recirculation of warm humid exhaust air through the cooling tower which has the effect of raising the wet bulb temperature as much as 7 F. From Chart No. 3 Appendix B, it is found that approximately 60% of the time the wind velocity at the Hanford weather tower falls in the 4-12 mph. range; therefore, it can be expected that recirculation will be a factor which must be considered.

The Cooling Tower Institute has an empirical method of taking design consideration of recirculation by introducing a correction to the design wet bulb temperature. Charts and graphs which provide solution for this correction factor are to be found in "Cooling Tower Institute Bulletin PFM-116 dated April 1959.

2.4 Radioactive Contamination

There is no known installation of a cooling tower operating under direct-cycle service conditions involving water contaminated with radioactive material such as the effluent from Hanford Reactors. The following discussion can only point to possible or probable problem areas arising from contaminated water service. A pilot testing program is the only way in which accurate data can be obtained which can be used for correlation to full scale cooling tower installations.

Under ordinary operating conditions the effluent from the reactors contains radioactive material both as dissolved and particulate matter which will escape with the vaporized water and mist (the latter is entrained droplets or spray). The mist would be the principle escape source of contamination to the area round the cooling tower. Although well designed mist extractors limit this spray or mist escape to less than 0.2% of the total flow, there is still an appreciable amount which will escape with a cooling tower handling 56,000 gpm. Adoption of the direct-cooling method would involve acceptance of continuous injection into the atmosphere of about 3 curies per day of effluent radioactivity from each unit with an equilibrium level of 30 to 40 curies in the immediately surrounding area. After a continuous operating period, it is estimated (16) that wind-borne mist will contaminate an area within 200-400 yards of the tower with a maximum level of 50 to 100 mrad/hr. However, the distance of contaminated area could be much greater for fine mist and contaminated dust, and could create a difficult radiation control problem. The contamination of the surrounding area would as a minimum require a sprinkling system which would prevent spread of contamination with wind-blown dust and leach out or otherwise reduce radiation levels in the area round the cooling tower.

Within the cooling tower the contact of effluent with the wood fill and structural members would result in absorption of dissolved radioactive contaminants by soaking action. The penetration and the type of isotopes and degree of absorption by the materials of construction would determine the decay period and the radiation levels which would develop and can be determined with accuracy only under a testing program. It has been estimated (16) that tower radiation build-up could be expected to reach 1-3 rads per hour during continuous service. Since the cooling tower would be operated only a few months of the year, drying of the interior fill could be expected to leave particulate radioactive material deposited on the surface of the fill. Action of the wind through the tower would spread this contaminated material outside the tower unless provisions were included in the tower installation to prevent such spread either by covering openings or a water wash down or scrubbing action.

CAB material for fill and drift eliminators would be preferable to wood from a deterioration standpoint but the surface would absorb some water due to rough porous surface and allow radiation level build-up but probably have considerably lower level, at least in the zones continuously worked by the effluent. The smooth surface of plastics in specially formed shapes for fill material would seem ideal from the standpoint of radioactive contamination, however, as

pointed out previously, plastics of the type generally used for cooling towers cannot be recommended where service temperature is over 130 F. Specific information could not be found but it is possible that high density molded styrene plastic would withstand 190 F effluent temperature without warping.

An alternate to the contamination problem involved with evaporative cooling is to contain the effluent in a coil shed and use uncontaminated recirculating water from the cooling tower to fall on the coil shed and cool the effluent by heat exchange.

2.5 Operation and Maintenance

Conventional cooling tower operation and maintenance practices were adequately presented in reference (4). This study deals with more unconventional application which requires special consideration. With an operating period of only a few months in the year, special care must be taken to prevent damage to tower internals due to drying out exposure to solar heat during inactive period. Since the effluent is contaminated with radioactive material SWP work conditions and radiation monitoring alter the conventional operation and maintenance practices to a marked degree particularly with respect to costs. Remote instrumentation can handle many of the routine operational checks made on the performance of the cooling tower so as to limit exposure of personnel. Maintenance for this application would be necessary primarily after the active operation period was ended and for the first few years be more or less limited to minor replacement of fill and louver (in the case of wood construction) and the infrequent repair of the fan, gear box, and electric motor drive.

Perhaps the most unusual consideration for this application of cooling towers is the necessity of taking operation and maintenance precautions necessary to prevent wind borne spread of contaminated material. Other than the above, the problems concerned with operation and maintenance are considered no more severe than those met with any equipment when placed in nuclear service.

2.6 Location and Space Requirements

The cooling tower should be located for downstream connection to the effluent line from the retention basin to avoid as much as is possible gross contamination from fission products in the event of process tube rupture in the reactor by permitting valving off of the cooling tower immediately following rupture. A typical installation of a cooling tower to the effluent line is shown in Figure 2 on the next page.

While the induced draft tower is not affected by physical conditions to the same extent as other evaporative type coolers, its location is important to its efficiency and its effect on other portions of the plant site. Placing the

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FIG. NO. 2
ISOMETRIC OF
TYPICAL COOLING TOWER
INSTALLATION FOR
REACTOR EFFLUENT

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tower too close to the retention basins would result in loss of efficiency with moist warm air from the basins being drawn in the tower intake; this would have the same effect as recirculation in raising the effective wet bulb temperature.

Where multiple tower units are necessary there are certain spacing requirements which are necessary to minimize the problem of air recirculation. These requirements for spacing are to be found in the "Cooling Tower Institute Bulletin PFM-110" and the recommendations found therein were used in making tentative location of towers for the reactor areas.

The 48" connecting piping for the cooling tower makes the closest feasible location to the effluent line of prime economic importance.

The typical layout of primary cooling tower facilities in Figure No. 2 should be self explanatory; tentative location discussion for each area and sketches take up the remainder of this section.

100-B-C - The location selected will require approximately 1900 feet of 48" pipe and two 48" valves. Alignment with prevailing wind direction (WNW) at the selected location allows most of the contamination from escaping mist to fall in an area where there are no buildings.

100-KE-KW - The amount of piping and other equipment required for this location are found in Appendix Section D, since this area was selected as the base case upon which to make an estimated cost of installation. This is the only location where a dike around the cooling tower would be required to prevent flooding during high river flows. The cost of such a dike would be offset by the savings in the amount of piping required if the towers were placed at more distant (but higher elevation) location from the effluent piping system.

100-D-DR - Unless some manifolding arrangement were installed between the 60" effluent lines at this area as they leave the detention basin the minimum installation to service a cooling tower would be installation of a butterfly valve in one line. Additional material requirements for a tower connection would be approximately 1050 feet of 48" pipe and two valves.

100-F Area - Location of one tower can be made inside the area fence with installation of approximately 950 feet of 48" pipe with two valves and installation of butterfly valve in the effluent line. Additional units would have to be located outside the area fence due to the location of the existing crib and other facilities in a southerly direction from the retention basin.

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SKETCH OF
PROPOSED
100-B, C AREA
COOLING TOWER
LOCATIONS

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NOTE:

DRAWN FROM HALF SIZE PRINT.
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REF. DWG { OUTSIDE SEWER LINES-100K AREA
M-1904-K SHEET 2

SKETCH OF
PROPOSED
100 KE-KW AREA
COOLING TOWER
LOCATIONS

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SKETCH OF
PROPOSED
100-D AREA
COOLING TOWER
LOCATIONS

REF DWG { OUTSIDE SEWER LINES-1000 AREA
M-1904-D SHEET 8

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NOTE
DRAWN FROM AIR FORCE 100-D
100-D AREA SCALE

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GRID NORTH
MANFOLD
GRID NORTH

27354

SKETCH OF
PROPOSED
100-F AREA
COOLING TOWER
LOCATIONS

W40000

W39600

W39200

W38800

W38400

W38000

W37600

60" STL PIPE
UNDERGROUND

107

UNDERGROUND AT LINE

COLUMBIA RIVER

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N96400

N96000

N95600

N95200

NOTE:
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900 MW COOLING
TOWER

UNDERGROUND
50'x50' ROCKFILL
CRIB

REF. DWG { OUTSIDE SEWER LINES
100-H AREA H-1904-H SHEET #4

ALTERNATE
LOC OF TOWER

SKETCH OF
PROPOSED
100-H AREA
COOLING TOWER
LOCATIONS

PREVAILING
WIND AREA

EMERG CRIB

100-H Area - Initial location of one cooling tower would require installation of approximately 2200 feet of 48" pipe and two valves. The tentative location of the tower is with the same orientation as the other areas for a prevailing WNW wind direction, however, investigation by field testing may reveal a better orientation from the standpoint of recirculation and possible savings of installed pipe. The wind data for this location indicates that the wind is less severe in strength and of no greatly predominating direction. Almost any orientation probably would be satisfactory for installation of a single tower but if more than one tower were required more specific data and location of tower would probably result in savings for the total installation.

3.0 Operation Period

Operation of the cooling tower for cooling reactor effluent on the basis of once-through cooling depends on the temperature of the Columbia River and its concurrent flow rate. The Columbia River has a broad range of flows and temperatures and the recorded information on seasonal variations is sufficient to make prediction of operating period for conditions affecting river temperature. A graph to assist in making an estimated operating period was prepared from data given in reference (15) to form 10 year average of flows and temperatures. The Trinidad flows noted on the graph (on the next page) should be representative of flows past the Hanford plant but the temperatures were used for Rock Island which is a considerable distance upstream and won't necessarily be representative of temperatures found on the Hanford reservation.

The conditions selected for cooling tower operation would depend on a number of factors which are not available or beyond the scope of this study. These conditions will be found under the sections on economic factors and areas for additional study. However, for example, if we select a period for flows below 150,000 cfs. and above 58 F the operating period would be 80 days by using Figure No. 3 on the next page.

4.0 Economic Factors

This study is limited to economic factors concerned with the size and type of cooling unit, materials of construction, operation, maintenance and installation. Items such as radioactive contamination and reactor operation are areas requiring additional study and therefore are not discussed. There are several ways in which basic installation costs can be compared; this document will use the cost per megawatt cooling capacity in making economic comparisons.

As indicated earlier in this report, a cooling tower of 900 megawatt cooling capacity was selected for making an analysis of costs and feasibility.

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The cost of cooling towers vary widely depending upon the type of unit and the materials of construction. The counterflow type was selected as more appropriate to Hanford application than the cross flow type. The basic material of construction for cooling towers is wood and the estimated cost starts with this material. A counterflow tower is estimated to cost \$416,000 which is \$6,000 more than the cross flow type. If the same tower were to have steel structural members, wood fill and eliminators and CAB siding the cost would be approximately \$820,000. Replacement of wood portions with CAB material would add an additional \$100,000 to the cost. No estimates were obtained for other materials of construction.

Operation costs are mainly for the electrical power to operate the fans on the cooling tower and the pumps which provide head to lift effluent to the top of the tower and through the distribution system. Power costs were based on purchase of Bonneville power at \$22.50 per kilowatt-year. Pumping would cost \$15,097 per year for 900 horsepower installation and 1600 fan horsepower would cost \$26,842 per year. Operation of cooling towers require only a very small portion of the operating personnel's time therefore no costs are included.

Ordinary application of cooling towers would justify using 3% of the unit cost for the cost of maintenance to wood cooling towers, but with contaminated service the cost would be at least double due to SWP work conditions. Again this is an item which requires additional study before a reasonable basis can be determined for making an estimate.

An installed cost estimate was made and is itemized in Appendix Section C. Based on this estimate, a cooling tower installation could be made for \$1,644 per megawatt cooling capacity. Air coolers would cost $1\frac{1}{2}$ to 2 times as much as the towers and therefore are not considered an economic source for cooling.

5.0 Areas Requiring Additional Study

As this study progressed it became evident that certain areas were beyond the scope of this report and should require further investigation.

Cooling economics for reactor operation should be determined. The effluent from upstream reactors is known to have an effect on the inlet cooling water temperatures of downstream reactors. Since reactor operation depends on the inlet cooling water temperature the economics of increased production should be analyzed with reference to cooling effect obtainable by the devices reported in this document.

Total effluent facilities planning should be coordinated. For example extraction facilities to limit toxic and radiological material introduction to the river could influence the location of cooling towers or other devices. An overall plan that would provide for future contingencies would be useful to the design of cross-connections between effluent lines and to allow operating flexibility of the various installations.

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The use of a direct-cooling tower for radioactive service is not known to have been attempted previously. A testing program would seem to be the most practical method of investigating the spread of contamination and the level of build-up both in the cooling tower and the surrounding area. Such data as could be collected would be invaluable in making economic selection of materials of construction and location of a full scale cooling tower installation. The testing program would also serve to provide analysis of the effect of contamination on the operation and maintenance of cooling towers.

6.0 Effluent Heat Load Effect on River Temperatures

Hanford plant reactor effluent is introduced to the Columbia River at various points along 14.3 river miles. The gross effect of the heat load dumped into the river is considered here; the effect of lesser amounts at the several locations with cooling between, the lack of thorough mixing or channeling, and the effect of surface evaporation from the river will require further study to determine the effect at each reactor and the overall effect.

In considering bulk or gross heat load effect on the Columbia River temperature, basic assumptions were made that all heat rejected to the river would effect river temperature and that density of water would remain relatively constant. While these assumptions are not strictly true, the results obtained by using them are of sufficient accuracy for the purposes of this study.

Tabulated below is the calculated maximum bulk heat load rejected to the river during the late summer months of the year for present reactor operational capabilities.

<u>Reactor</u>	<u>Process Flow Capability</u>	<u>Maximum Coolant Temp. Increase °F</u>	<u>Maximum Reactor Heat Load - Megawatts</u>
B	88,000	132.3	1,707
C	101,000	135	1,999
KE	205,000	135	4,057
KW	205,000	135	4,057
D	88,000	132.3	1,707
DR	87,000	135	1,722
H	88,000	132.3	1,707
F	89,000	132.3	1,726
TOTAL BULK LOAD MEGAWATTS			18,682

The above does not include the N Reactor now under construction. On the assumed basis that cooling towers would be an effective cooling device if approximately half of effluent passed through tower, one 900 megawatt tower would be required at each of the reactors except the K Reactors which would require two each for a total cooling capacity of 9,000 megawatts. A graphical relationship of bulk heat load to selected river flows which will effect temperature rise of the river is shown on the next page. For the above gross heat load, the graph shows a rise of approximately 7.8 F for a river flow of 36,000 cfs and a cooling effect of 3.8 F for 9,000 megawatts of tower capacity, thus, limiting the river temperature rise to 4 F.

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BULK HEATING LOAD EFFECT
ON RIVER TEMPERATURES
AT SELECTED FLOW RATES

BULK HEATING LOAD, MW

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APPENDIX A

METHODS OF COOLING WATER

A.1 Summary

This will summarize the cooling devices, which are discussed in detail by following sections of Appendix A, with particular application to the Hanford manufacturing plant areas.

Cooling ponds and lakes have been discussed for Hanford (1) but for application to individual areas, in summary, it can be said that this method of cooling is inefficient when compared to all other methods of evaporative cooling and the cooling range is limited by practical considerations below that necessary for application at Hanford without increasing several times the required area. For normal use the cooling pond requires 500 to 1000 times the area of an induced draft tower.

Spray ponds are more efficient requiring approximately 50 times the area of a cooling tower but still objectionable for the same reasons which include limited cooling range, limited approach to wet bulb temperature, and dependence on wind velocity.

Natural draft towers are more efficient than the previous types but are dependent on wind velocity or the temperature difference of the air and the incoming water to generate the draft which is directly responsible for efficiency of evaporation, i.e., cooling. The dependence upon physical conditions which have considerable variance at Hanford would make this a poor choice for this particular application. The installed cost would be approximately the same as an induced draft tower and yet would not have the efficient control of outlet water temperature possible with the latter type.

Mechanical draft towers with long cooling range, close approach to wet-bulb temperature, independence from dry-bulb temperature, relative low space requirement, and close possible control of cooled water temperature are considered the most favorable application of the various devices for cooling Hanford effluent. The forced draft type is limited by the fan size which can be used and the greater recirculation rate of this type compared with cross flow and counterflow types. The use of crossflow and counterflow types overlap but for longer cooling ranges, such as at Hanford, the counterflow type with the more efficient evaporation action is considered to be the most effective type. This type also uses heavier fill which means less maintenance, and replacement of fill is accomplished easier than with the crossflow type.

The dry cooler, or sometimes called air cooler or fin-fan, is limited to about a 40 F approach to the design dry-bulb temperature. For Hanford this would mean a cooling range of exactly half that possible with the induced draft towers which make it an uneconomic choice on the basis of cooling efficiency. This type has an important advantage in that effluent

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water would not be exposed to the atmosphere and therefore present no problem of spreading contamination to the surrounding area.

For some applications such as at Hanford, a combination of cooling devices will prove to be an economic choice. For example, an air cooler might be used with cooling tower in series or a coil shed might be used under a cooling tower. The latter would limit the spread of contamination but also cost appreciably more for first-cost installation and for operation and maintenance.

A.2 Cooling Ponds and Lakes (5, 6, 10)

The first and simplest method of cooling industrial water was that obtained by allowing it to flow into an open place which would expose a maximum surface to the air, but it is also the most inefficient. A cooling pond has the following advantages:

- a. It may be constructed at relatively low cost by pushing up an earth dike six to eight feet high or by using a natural depression as a lake.
- b. In cases where contamination of the water may occur, the pond serves as a retention basin.

Its disadvantages:

- a. Low heat transfer rate; approximately $3\frac{1}{2}$ BTU per hour per square foot of surface per degree temperature difference, or for example, a cooling range of 30 degrees F, one square foot of surface cools four to six pounds of water per hour.
- b. Large size needed; the surface area of a cooling pond will be twenty times the size of a spray pond of equivalent heat duty and 500 to 1000 times the size of an induced cross-draft cooling tower.
- c. Heat rejection to the atmosphere is very dependent on the velocity of wind over the surface of the pond and the relationship of water to air temperature and relative humidity.
- d. There are practical limitations on the cooling range and the approach between cooled water and wet-bulb temperature of the air.

A.3 Spray Pond (7, 10)

It is a pond with a spray system located about six to eight feet above a large natural or artificial reservoir. The water is sprayed into the air to break it up into smaller particles, by discharging it through spray nozzles. The water issuing from the nozzles creates a draft which aided by the natural breeze, effects the evaporation necessary to cooling. Obviously the spray pond was an improvement over the cooling pond. The spray pond requires 50 times as much area as a cooling tower. One square

foot of surface is required for each 150-250 pounds of water cooled per hour. The cooling range is more restrictive than for a tower.

Objections to this method are low cooling capacity or limited performance, high water loss (including spray on neighboring buildings, walks, and streets) and the required area. Additional objections to either ponds or spray ponds are those particular to the Hanford site. Frequent high gusts of wind deposit tumble weeds, trash, and silt which clog canals and ponds and restrict flow of water. This presents an operational problem of some magnitude. The nature of the soil and the fact that the effluent is contaminated with radioactive material would require lining canals and ponds unless contamination build-up of the ground water were allowed. A pond or lake of sufficient size such as the one proposed in reference (1) would raise the water table with possible detrimental effect on building foundation stability at certain areas of the Hanford site.

A.4 Atmospheric Tower (Natural Draft) (10)

Is one in which the air movement through it is dependent only upon atmospheric conditions. Winds generally blow in a near horizontal direction and the water falls vertically, thus a cross flow pattern in the tower. Advantages of this type are:

- a. No mechanical parts.
- b. Low maintenance costs.
- c. Not subject to recirculation.
- d. Long trouble-free life.

Disadvantages are:

- a. Great length of tower required because of narrow width.
- b. High initial cost (about the same as mechanical draft tower).
- c. High pumping head.
- d. Must be located in an unobstructed area.
- e. Cold water fluctuates in temperature with wind changes in direction and velocity.
- f. The air flow must be throttled in order to reduce spray loss (increase in size necessary to compensate for restricted air flow).
- g. Towers must be securely anchored to prevent uplift or over-turning during high winds.

A.5 Chimney Tower (Natural Draft) (10)

Is a tower with a large, high stack above the packing which induces a draft. At the present time there are no known towers of this type in the United States, but it is a favored type in Europe. The chimney stack tower has been built in a hyperbolic shape and the largest built to date is 340 feet high and 270 feet in diameter at the base. In general, the hyperbolic tower is at its best when the difference between the desired

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cold water temperature and the wet bulb temperature is equal to, or greater than, the difference between the hot water temperature and the cold water temperature. In cooling tower language, this would be an approach equal to, or greater than the range. (11) The draft through the tower results from a number of very complicated inter-related effects:

- a. Atmospheric air pressure difference due to stack height.
- b. Induced draft due to wind velocity differentials.
- c. The temperature difference of the air heated by the water.
- d. An increase in volatility due to vaporization.

Owing to the variability of some of these factors chimney towers are difficult to design. In certain circumstances they have distinct advantages over mechanical draft towers. The main advantages are as follows:

- a. They produce cooling effects similar to those provided by mechanical draft towers without the mechanical parts and the power required to run them.
- b. Maintenance costs are negligible.
- c. They can practically never break down.
- d. Compared with atmospheric towers they are independent of wind velocity.
- e. They can cope with tremendous water loads.
- f. The stream of air is in the opposite direction to that of the falling water with the coldest air meeting the colder water first which ensures no loss in efficiency.

The principle disadvantages are:

- a. Resistance to air flow must be kept at a minimum, hence grid sections must be shallow unless some form of film flow is used.
- b. The great height necessary to produce the draft.
- c. Inlet hot water temperature must be kept hotter than the air dry bulb temperature (not a problem at Hanford).
- d. Exact control of outlet water temperature is difficult to achieve.
- e. High capital cost compared to mechanical draft towers.
- f. Additions to capacity cannot be made as with mechanical draft towers which can increase capacity by adding another cell.

A.6 Mechanical Draft Tower (10)

Is one characterized by the use of fans to produce the draft of air. The fans are an integral part of the structure and furnish absolute control over the air supply. Other than certain economic considerations, there are no limiting factors of air resistance in the tower, wind direction or velocity. The advantages of the mechanical draft tower are:

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- a. Close control of cold water temperature.
- b. The small ground area in which it can be maintained.
- c. The generally low pumping head.
- d. The location of the tower is not restricted.
- e. More packing per unit volume of tower.
- f. A closer approach and longer cooling range are possible.
- g. Capital cost is less than for a natural draft chimney.

The principle disadvantages are:

- a. A considerable expenditure of horsepower is required to operate the fans.
- b. It is subject to mechanical failure.
- c. It is subject to recirculation of hot humid exhaust air vapors into the air intakes.
- d. Maintenance costs are high.
- e. Operating costs are high.
- f. Performance will vary with wind intensity, unlike the atmospheric tower, the performance decreases with increase in wind strength, until a certain critical velocity (approximately 25 mph. (12) is reached, after which the performance improves, due to a fall-off in recirculation.
- g. Exhaust heat loading and climatic conditions can be prejudicial to the economic use of a mechanical draft tower.

Forced Draft Tower (10)

Is one which has one or more fans located in the air intake as illustrated in the schematic arrangement below. This was the

Forced Draft Tower

first mechanical draft tower produced but is seldom built today since the relatively more efficient and flexible induced draft towers have replaced it. It keeps vibration down since its mechanical equipment is located near ground on a solid foundation. The location of the mechanical equipment in dry air stream reduces moisture condensing in the gear box. It is more prone to recirculation of hot, humid air and is limited to a 12 foot fan size or less which means more fans, motors, starter and wiring are needed than by the induced draft tower.

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Counterflow Induced Draft Tower (10)

Is one which provides vertical air movement across the filling, as illustrated at the right. It has the advantage that the coldest water contacts the driest air and warmest water contacts the most humid air. Maximum performance is thus obtained. The restricted louvre area at the base and resistance to upward air travel against the falling water both result in greater horsepower requirements than in the cross draft tower. Air velocities are uneven across the filling - very little movement in the center and near the walls of the tower. Other disadvantages of the counterflow tower are limited water load capacity, inaccessible hot water distribution system for maintenance, high inlet velocities suck airborne trash and dirt into the tower, limited eliminator area restricts air flow, and higher pumping head required due to packing being placed higher in the tower to give unobstructed air intake at the base.

Counterflow Tower

Cross Draft Tower (10)

Is an induced draft cooling tower which provides horizontal air flow as the water falls across the air stream. It is illustrated

Crossflow Tower

in schematic form at the left. This cooling device has the following advantages: low pumping head, low static pressure drop, convenient distribution system arrangement, distribution system can be cleaned while tower is in operation, the fill height is approximately equal to the tower height, more air moved per fan horsepower, more fill surface per cubic foot of tower volume, higher water loadings and a larger diameter fan can be used for a given capacity. The disadvantages of the crossflow tower consist mainly in: distri-

bution pans and orifices becoming clogged by algae and debris that ordinarily collect in the system, the entire water distribution system is exposed to the air which accelerates the tendency for algae to grow under

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normal conditions, and under certain operating conditions such as long range and close approach pumping heads, fan horsepower, and ground area may be greater than that required for a counterflow cooling tower. Disadvantages listed for algae are not expected to be present at Hanford because of the short residence time and the temperature of the incoming water.

A.7 Dry Cooler

Is sometimes known as air cooler or fin-fan and is a unit for cooling fluids in finned or other shaped tubes by forcing or inducing atmospheric air across the coil section. These are not evaporative coolers and are mentioned because they can sometimes be used with advantage in conjunction with cooling towers. In hot services, they can take up to 75% of the heat load off a cooling tower. Its advantages are: use where fluids to be cooled are at high temperature, elimination of spray nuisance, freezing hazard and fouling, and there is no upper limit to which air can be heated. The main disadvantages of this type of device are: it is generally less economical than the ordinary evaporative type, the specific heat of air is approximately one-fourth that of water, and for some services the prevention of corrosion can be more costly.

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APPENDIX B
HANFORD WIND DATA

CHART NO. 2
WIND SPEED MPH

<u>MONTH</u>	<u>DIRECTION</u>	<u>AVERAGE SPEED</u>	<u>HIGH AVE.</u>	<u>LOW AVE.</u>	<u>PEAK GUST SPEED</u>	<u>DIRECTION</u>
June	WNW	9.0	10.7	7.7	72	SW
July	WNW	8.5	9.4	6.8	50	WSW
August	WNW	7.9	9.1	6.0	50	SE
September	WNW	7.2	8.5	5.4	65	SSW
October	WNW	6.6	9.1	4.4	63	SSW

CHART NO. 3
RANGE OF WIND SPEEDS, PERCENT OF TIME

<u>SPEEDS</u>	<u>JUNE</u>	<u>JULY</u>	<u>AUGUST</u>	<u>SEPTEMBER</u>	<u>OCTOBER</u>
0-3	18	21	25	32	40
4-7	32	37	37	34	31
8-12	26	24	22	20	19
13-18	17	13	11	10	8
19 and over	7	5	5	4	2

CHART NO. 4
WIND DIRECTION VERSUS PERCENT OF TIME

<u>DIRECTION</u>	<u>JUNE</u>	<u>JULY</u>	<u>AUGUST</u>	<u>SEPTEMBER</u>	<u>OCTOBER</u>
SW	6	7	7	6	7
WSW	10	9	8	8	9
W	10	9	8	8	9
WNW	22	21	21	15	15
NW	18	18	16	15	14

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CHART NO. 5
WIND DIRECTION VERSUS PERCENT OF TIME AT
VARIOUS SPEEDS

<u>DIRECTION</u>	<u>0-3</u>	<u>4-7</u>	<u>8-12</u>	<u>13-18</u>	<u>19+</u>	<u>TOTAL</u>
SW	1.4	1.7	1.5	1.2	1.0	6.8
WSW	1.6	2.8	2.4	1.3	.7	8.8
W	1.9	3.6	2.2	.7	.2	8.6
WNW	2.5	5.5	6.2	2.8	.9	17.9
NW	3.1	5.0	4.4	2.4	1.3	16.2

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APPENDIX C

ESTIMATED INSTALLED COST
900 MEGAWATT CAPACITY
COUNTERFLOW COOLING TOWER

<u>Item</u>	<u>Quantity</u>	<u>Unit</u>	<u>Cost</u>
a. Cooling Tower	1	Ea.	\$416,000
b. Basin	20,000	SF	60,000
c. 48" OD Steel Pipe	1,000	LF	70,000
d. 42" Motor Operated Valve with valve box	1	Ea.	10,000
e. 48" Motor Operated Valve with valve box	2	Ea.	22,000
f. 18" OD Steel Pipe	500	LF	20,000
g. 18" Manual Operated Valve	1	Ea.	5,000
h. Crib	25,000	CT	20,000
i. Dike, 10' high	800	LF	20,000
j. Electrical Power	1	Lot	220,000
k. SWP Tie-in	3	Ea.	27,000
l. Pump, 28,000 gpm @ 50' head	2	Ea.	50,000
m. 48" OD Pipe (difficult const.)	500	LF	80,000
Total Construction Cost			<u>\$1,020,000</u>
Title III			35,000
Contingency			315,000
General Overhead			35,000
Design			<u>75,000</u>
TOTAL PROJECT COST			\$1,480,000
COST PER MEGAWATT CAPACITY			\$ 1,544

COOLING DEVICE ESTIMATED COSTS

1. Crossflow Induced Draft Tower
Fan Horsepower - 1,000
Wood Construction

Estimated Cost - \$410,000
2. Counterflow Induced Draft Tower
Fan Horsepower - 1,600
Wood Construction

Estimated Cost - \$416,000
3. CAB Material for sides of (1) and (2)
at no extra cost.

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4. (2) with Structural Steel Wood fill
and Eliminators

Estimated Cost - \$820,000

5. CAB Fill and Eliminators for (4)

Estimated Cost - \$100,000

6. Air Cooler
1,100 Fan Horsepower
450 Megawatt Capacity
Aluminum Construction

Estimated Cost - \$307,500

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