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Environmental Protection Technology Series

Reviewing Environmental Impact Statements - Power Plant Cooling Systems, Engineering Aspects

National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Corvallis, Oregon 97330

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EPA-660/2-73-016
October 1973

REVIEWING ENVIRONMENTAL IMPACT STATEMENTS - POWER PLANT COOLING SYSTEMS, ENGINEERING ASPECTS

by
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CORVALLIS, OREGON 97330

ABSTRACT

This report describes the approach and technical base that have been used by EPA's National Thermal Pollution Research Program for reviewing those portions of Environmental Impact Statements (EIS's) relative to the engineering aspects (including economics) of cooling water systems for thermal power plants. The report provides techniques and data to enable the EIS reviewer to make sound judgments concerning the adequacy of both the cooling water system selected for the power plant and the EIS comments on that system. Literature citations are provided to direct the reviewer to additional and more detailed information.

The report provides information and discussions on cooling system configurations, operation, environmental effects, and costs. Consideration is given to the intake as well as the discharge.

Various closed-cycle cooling systems employing cooling towers, cooling ponds, spray systems, and other devices are covered. Methods of assessing alternative selections and benefit-cost analyses are presented. Non-thermal aspects of cooling water systems are discussed.

The report lays the groundwork for a technically sound EIS review; however, the reviewer must supplement the material presented herein with references and perhaps technical consultation to prepare comprehensive and detailed review comments.

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ACKNOWLEDGEMENTS

The principal individuals contributing individually and collectively to the substance of this report are, in alphabetical order: Alden G. Christianson, Frank H. Rainwater, Mostafa A. Shirazi, and Bruce A. Tichenor.

SECTION I
SUMMARY

This report provides the Environmental Impact Statement (EIS) reviewer with background information to assist in the development of technically sound review comments. The techniques and data presented herein must be supplemented by the references cited to give the review process a substantial technical base. This report is limited to discussions of the engineering aspects of power plant cooling system, and does not deal with the biological portions of EIS's.

In most cases, the material presented will enable the reviewer to make an initial and reasoned judgment as to the adequacy of the EIS. For example, "Are the data presented on cooling tower water loss accurate?", "Is the cooling pond size reasonable?", or "Are the costs excessive?" It must be recognized, however, that a complete technical analysis of a specific problem, such as for an adversary proceeding, will require the use of techniques beyond the scope of this report. These techniques are presented in the references. In addition, some problems preclude an easy solution (e.g., thermal plume analysis). Here again, the reviewer will have to rely heavily on the reference material. Consultation with specialists may also be required.

While this report provides substantial information relative to the review of thermal power plant cooling systems, in the end the responsibility for the technical adequacy of the review rests with the reviewer. He must use all of the technical and intellectual resources available to him. Individual initiative coupled with common sense must be applied to the review process, and no report or reference can supply these requirements. Thus, the review process requires substantial effort; it is hoped that this report will provide a solid basis for that effort.

SECTION II
INTRODUCTION

PURPOSE

Section 102 of the National Environmental Policy Act of 1969 (NEPA) requires Federal Agencies to evaluate the environmental impact of their actions, including licensing. The Calvert Cliffs decision (U. S. Court of Appeals, District of Columbia, Nos. 24839 and 24871) highlights the applicability of NEPA to the licensing of nuclear power plants and leaves no doubt as to the need for technically sound and comprehensive environmental impact statements (EIS's) as a basis for licensing.

The Atomic Energy Commission[1] has issued guidelines for applicant's reports used in preparation of environmental impact statements, which have proliferated in response to current requirements. Through May 31, 1973, the National Thermal Pollution Research Program has provided technical input to EPA's review comments on about 80 draft environmental impact statements for nuclear power plants, covering a wide range of siting, engineering, and ecological combinations. Review of nuclear power plant EIS's will be a continuing function of regulatory agencies; fossil fueled plants will also require EIS's in some cases and detailed review in others. From the standpoint of technical analysis of cooling systems, fossil fired plants do not differ from nuclear plants, and most of the technical material in this report are applicable to both types of thermal power plants.

The purpose of this report is to (1) identify the environmentally critical facets of cooling water systems, (2) point out some of the problems that frequently surface in impact statement reviews, and

(3) summarize and reference the many research products applicable to the engineering-economic-environmental analysis required of EPA. Water quality criteria are not included.

Figure 1 provides a "flow chart" of the review process for thermal power plant cooling systems. More specifically, Figure 1 highlights particular points of concern which will require technical consideration by the reviewer.

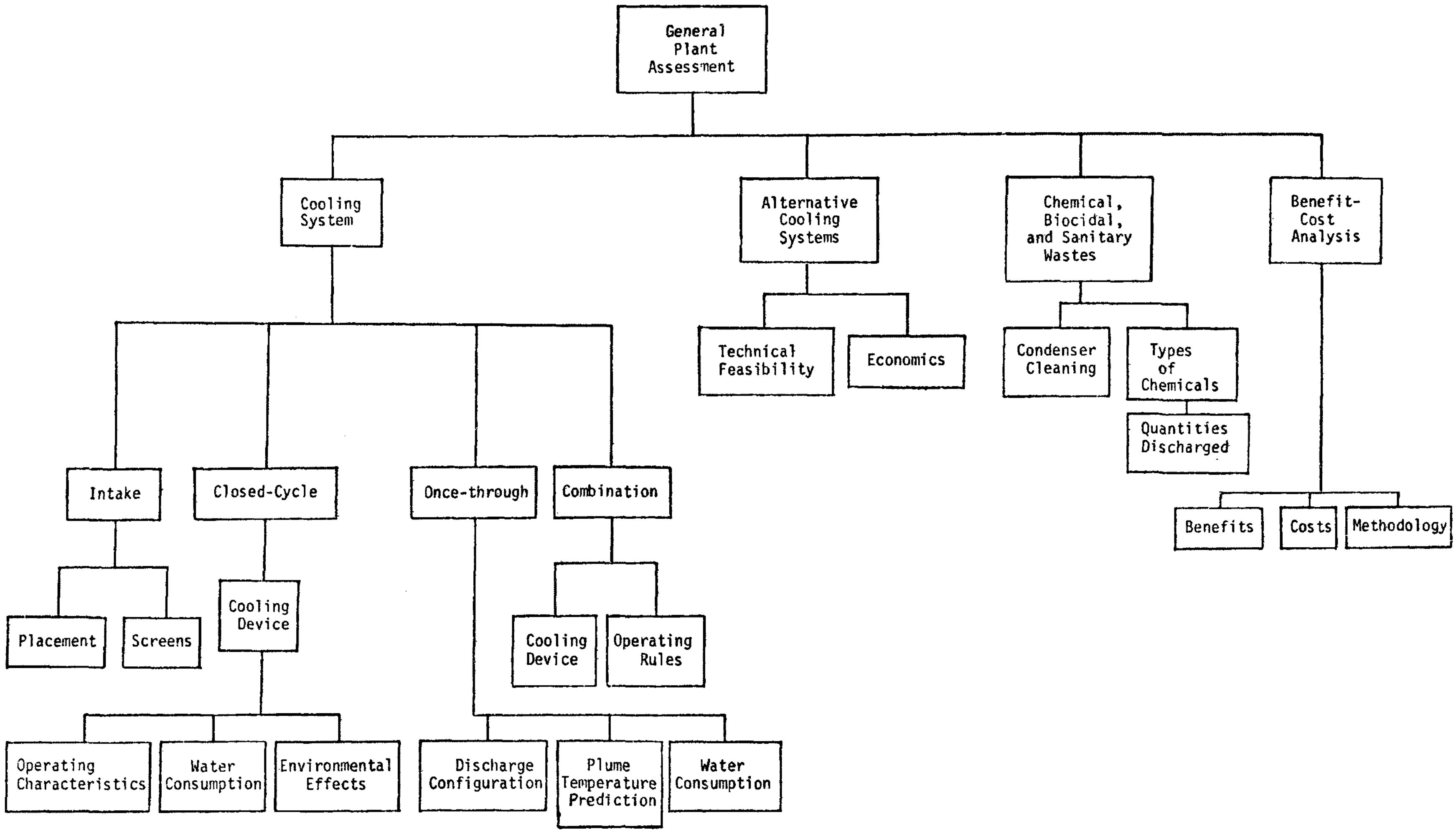


Figure 1. Flow Chart for Evaluating Thermal Power Plant Cooling Systems

CRITICAL ENVIRONMENTAL ASPECTS OF COOLING WATER SYSTEMS

Cooling systems can impact the environment several ways. The word "system" is chosen advisedly. Most components are interrelated and hence can and should be considered together for environmental optimization. It is significant to note that of the many plants reviewed to date, only one is so poorly sited that design of an environmentally acceptable cooling systems is virtually impossible.

The EIS review should consider as a minimum the following:

1. Rate of cooling water withdrawal, with respect to:
   a. Local and regional water supply and uses and the effect of proposed withdrawals thereon.
   b. Entrainment and subsequent kill of planktonic organisms in passing through the condenser.
2. Intake design and hydraulics with respect to entrapment and damage to fish.
3. Temperature rise across the condenser.
4. Effluent mixing zone.
   a. A maximum temperature of discharge increase in temperature above natural.
   b. Size and geometry.
5. Land requirements for cooling systems, particularly ponds.
6. Water loss.
7. Local meteorological effects such as fog or ice.
8. Drift characteristics and terrestrial impact.
9. Chemical or physical cooling water treatment program.
10. Blowdown.
    a. Cycles (multiples) of concentration and flowrate
    b. Treatment and/or disposal
11. Overall minimization of waste discharges to water, air, and land.
12. Cost implications of environmentally desirable refinements or alternatives.

GENERIC DEFICIENCIES OF ENVIRONMENTAL IMPACT STATEMENTS

Although the technical quality of draft statements differs widely, the major, or more frequently occurring, deficiencies are in five areas:

1. The staff preparing the statement ignores or does not describe proximal and cumulative waste sources, and presents the plant as discharging into virgin waters. An "area of influence" approach to environmental assessment is required.

2. Inadequate data or description of methodology are presented in the draft or supplemental Environmental Reports for EPA's independent review and evaluation. EPA cannot accept unsupported statements such as "applicable water quality standards will be met" or "the 3°F isotherm will encompass only 35 acres."

3. Alternative cooling systems are treated in a cursory manner. Such treatment is justified only if the proposed system is obviously the best choice to protect the environment. Otherwise a thorough and accurate analysis of secondary environmental impacts and costs is required.

4. Data or conclusions presented on cooling system performance and secondary environmental impacts are obsolete or grossly inaccurate.

5. Economic (benefit-cost) analysis of alternative systems is inadequate or inapplicable to system selection.

SECTION III
GENERAL PLANT ASSESSMENT

No two sites or plants are identical. Seldom, if ever, is a power plant located or designed with environmental protection as the primary objective function. This is not to say that some progressive utilities do not do everything reasonable to negate or minimize adverse impacts. It follows that such differences between plants affect the feasibility of various cooling alternatives, the choice among alternatives for maximum environmental protection, and the monetary costs.

As a first step in the review process, it is advisable for the reviewer to become familiar with the plant as a whole as described in the EIS and in backup material such as the utility's environmental report. Information pertinent to the cooling system evaluation is often found scattered throughout various EIS sections. All applicable information should be located.

The initial perusal should also be used to catalog general information affecting the acceptability of the cooling system choice. This includes such factors as hydrologic and meteorologic conditions, general water and land availability and use, recreation, etc.

In the general assessment, the reviewer considers the size of the generating unit or units covered in the statement and any additional units existing or planned at the site. He must also consider the plant's thermal output, the cooling water requirements, and the temperature rise across the condenser. The interfaces of the plant characteristics with cooling systems are described in two EPA contract reports prepared by Dynatech R/D Company[2] and Hittman Associates, Inc.[3]

Location characteristics such as hydrology, meteorology, topography, land area, and rural versus urban setting should also be considered because they can influence the cooling system choice. A few generalizations (which may not hold for any particular site) exemplify such relations:

1. If intake water is scarce or water appropriation is an issue, the cooling system should be designed to minimize water intake and consumption. Normally, once-through cooling is out and cooling towers or spray systems would be preferable over cooling pond construction because of the differential in water loss.

2. Meteorology controls the efficiency and limits of all cooling systems and influences their potential adverse environmental effects.

3. There are several regional generalizations related to geography or topography. Along much of the West Coast and some of New England, deep, cold ocean receiving water can be reached by a discharge pipe in a short distance and at reasonable cost. In such cases, the rapid mixing attributes of submerged diffusers on a once-through system might be exploited. Conversely, most of the coastal waters of the Gulf of Mexico and the southeastern United States are too shallow for submerged diffusers to be either effective or economical. In the Applachian Highlands natural draft towers are usually selected over mechanical draft towers to get the exhaust plume up over the ridges and minimize contribution to characteristic valley fog. Conversely, in the hurricane or tornado prone Atlantic Seaboard or Midwestern Plains, the comparative structural stability of mechanical and natural draft towers can favor the former. In the Colorado River Basin and other parts of the arid west, the probability of fogging problems is remote, but water availability and salinity are prime water quality problems; in this case, cooling system selection and operation should be developed to minimize consumptive use of water and salinity contribution. In fact, dry or wet/dry towers on mine mouth plants are not beyond the pale of economic feasibility in the region.

4. The significance of land availability and urban versus rural setting are rather obvious. Usually the exclusion zone and other site limitations for nuclear power plants provide ample space for closed-cycle

cooling systems, but attention must be given to items such as tower height, proximity to airports, and the probability for fogging of major highways.

5. Added benefits may accrue to cooling ponds from recreational use. On the other hand, such large areas are required for nuclear power plants that close attention must be given to other land use penalities and to the efficiency of the pond design (see Section IV); the least -cost design--measured in terms of construction--can be wasteful both in terms of land and water resources. Ponds are somewhat unique among cooling systems in that electric utilities may in some locations acquire under condemnation proceedings land that will actually appreciate in value over the life of the plant.

In addition to plant and site characteristics, the stage of design or construction is an important factor. A plant ready to go on line or for which most components are installed cannot be sent back to the drawing board. The draft review must be directed to the question, "What is reasonable for <u>this</u> plant at <u>this</u> time?"

The reviewer will usually find that much more information is given relative to the cooling system selected by the utility than to alternative possibilities. This is more acceptable in some cases than others. For example, when commitments and funding for design, equipment, or construction have already been made, the cost-benefit ratio has been biased in favor of the chosen system; it is then very difficult to justify a complete system change unless environmental effects are totally unacceptable. In this case, it is most important to place primary review emphasis on the design and operation of the chosen system to ensure that the utmost environmental compatibility is achieved under the circumstances.

In cases where significant commitments and funding have not been made toward a specific design, a more unbiased situation exists and the reviewer should evaluate all possible alternatives in a thorough and like manner. This will require more back-up information on all systems so that a truly optimum system may be obtained.

After initial familiarization with all available information and general assessment of broad considerations described in this Section, the reviewer can proceed with the more detailed evaluation of the proposed cooling system and its alternatives.

SECTION IV
COOLING SYSTEMS

A. INTRODUCTION

Thermal power plant cooling systems contain three basic elements:

1. An intake for supplying cooling water to the power plant.
2. A condenser where the turbine exhaust steam is condensed at low temperature and pressure while transferring the waste heat to the cooling water.
3. A device or mechanism for transferring this waste heat to the atmosphere (and finally to the ultimate sink--outer space).

These three elements should be designed to "match" the steam turbine in an optimum manner to minimize the cost of producing electric power and, at the same time, prevent adverse environmental effects[4]. In evaluating the environmental effects of a power plant cooling system, most of the attention is focussed on the third element--the mechanism used to transfer the waste heat from the cooling water to the atmosphere.

In practice, there are three basic methods of dissipating the waste heat to the atmosphere:

1. Closed-cycle cooling--this method requires an off-stream cooling device (i.e., pond, tower, spray system) to transfer the waste heat to the atmosphere. The cooling water is recycled through the cooling device after each pass through the condenser, and only a small portion of the cooling water (blowdown) is discharged to an adjacent water body or to an additional treatment facility.

2. Once-through cooling--in this method the cooling water is pumped from an adjacent water body (i.e., river, lake, reservoir,

ocean, etc.) through the condenser and discharged back to the water body. The waste heat is transferred to the atmosphere from the heated receiving water.

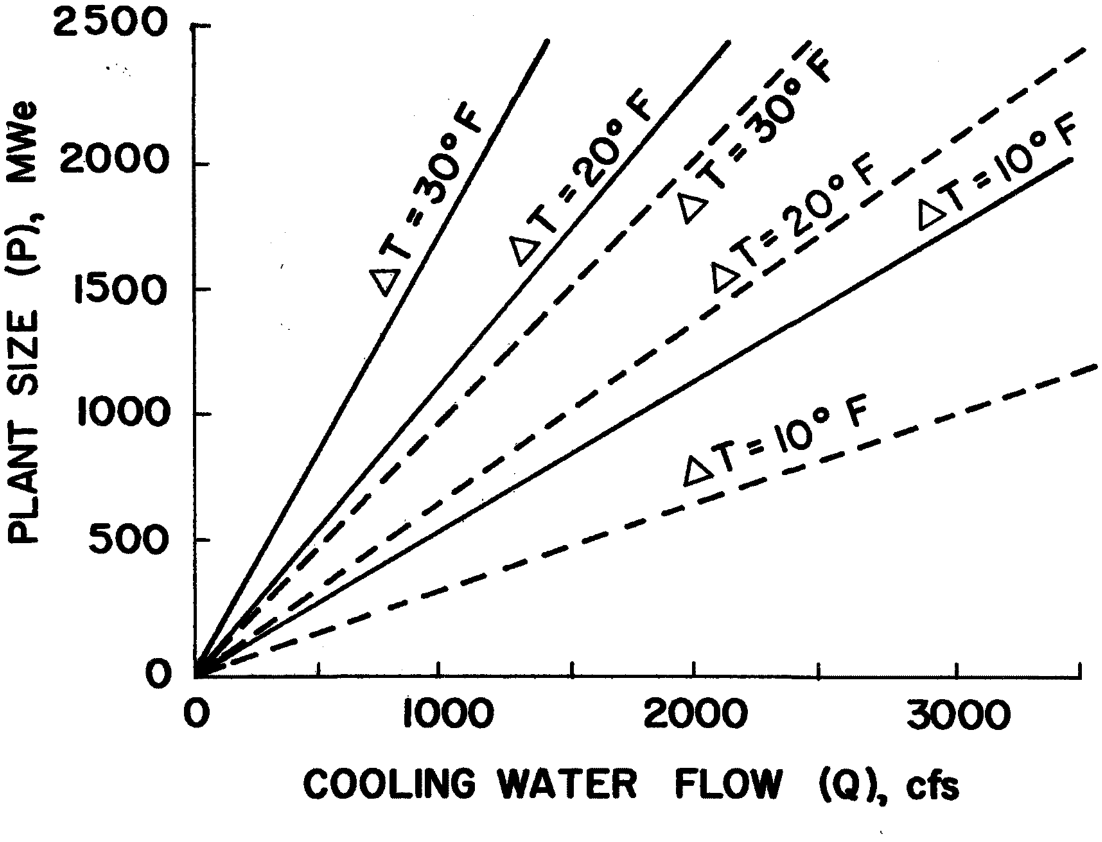
3. Combination cooling--this mode utilizes an off-stream cooling device to dissipate a portion of the waste heat load. The cooling water flow from this device may be sent directly to the receiving water or it may be recycled back to the condenser.

For any given power plant, the method of dissipating the waste heat dictates the amount of water flow through the intake. For once-through systems, a continuous flow of a thousand or more cfs is required for large nuclear power plants (see Figure 2)[5]. For closed-cycle systems, intake requirements are substantially less. Other water requirements (e.g. - service water, boiler make-up, etc.) are low in volume and can generally be disregarded in an evaluation of the waste heat disposal problem.

FIGURE 2
COOLING WATER REQUIREMENTS FOR
FOSSIL AND NUCLEAR POWER PLANTS

--- NUCLEAR, η_t = 33%, IN-PLANT LOSSES = 5%

—— FOSSIL, η_t = 40% IN-PLANT AND STACK LOSSES = 15%



ΔT = CONDENSER TEMP. RISE

η_t = PLANT THERMAL EFFICIENCY

B. INTAKES

Cooling water intake structures for thermal power plants encompass a wide variety of designs. In general, however, intakes usually consist of:

1. A log boom to prevent large floating material from entering the intake area.

2. A trash rack to hold back medium size (approximately 4") debris.

3. A wire mesh screen to prevent the passage of small debris and fish through the condenser.

Variations of these standard components include the lack of log booms on submerged offshore intakes and the use of skimmer walls on canal type intakes.

The problems associated with the intake of large volumes of cooling water include:

1. The entrainment of organisms and subsequent passage through the power plant cooling system where, depending on design, time and temperature of exposure, and species of organisms, a variable fraction are killed.

2. The impingement of fish on intake screens.

3. The entrapment of fish in the intake structure (i.e., screenwell).

Intakes can and should be designed to reduce these effects.

The major environmental design problem is the prevention of fish kills at the intake. Naturally, the best technique is to minimize the number of fish which enter the intake area. This can be accomplished by locating the intake in an area of low fish population, reducing the velocity of the intake water, and eliminating areas where fish can be trapped (e.g., screenwells with no fish by-pass). If fish do go as far as the screens, provisions for fish by-pass or collection and harmless removal should be provided.

It should be noted that wire screens are used to "protect" the power plant, not the fish. Vertical travelling screens (the most common type) are usually moved only after a specified pressure drop across the screen face is reached. Thus, a fish may be impinged on the screen for several hours before removal, and thus suffer damage and possible death. In many cases, whether the fish is alive or not does not matter, since the material on the screen is often disposed of in a manner which causes mortality. Therefore, fish should be by-passed or collected prior to impingement on such screens. If continuously moving screens are employed, a suitable fish removal technique might be developed.

Several general criteria can be suggested for proper intake design and placement:

1. Place the intake to avoid recirculation of the discharged cooling water. Recirculation will cause increased thermal stress to entrained organisms as well as reduce the plant's thermal efficiency. If intake and discharge points must be separated by considerable distance to prevent recirculation, overall biological damage is reduced if the intake is the long leg and the discharge is the short leg of the cooling water system.

2. Avoid placing the intake in an area of high biological value (e.g., spawning, rearing, migration areas).

3. Reduce intake velocities to below 0.5 ft/sec at the trash rack to enable fish to escape the screenwell. Note that the use of fish avoidance techniques such as electrical fish "screens," air bubble "curtains," light, and sound have proven generally ineffective under field conditions (e.g., air bubbles and electric screens at Indian Point[6]). Thus, low velocity is the only effective method, at present, to prevent fish from entering the intake.

4. For off-shore, submerged intakes, velocity caps should be used to reduce fish entrainment. Note, however, that the effectiveness of such devices is not universally accepted[6].

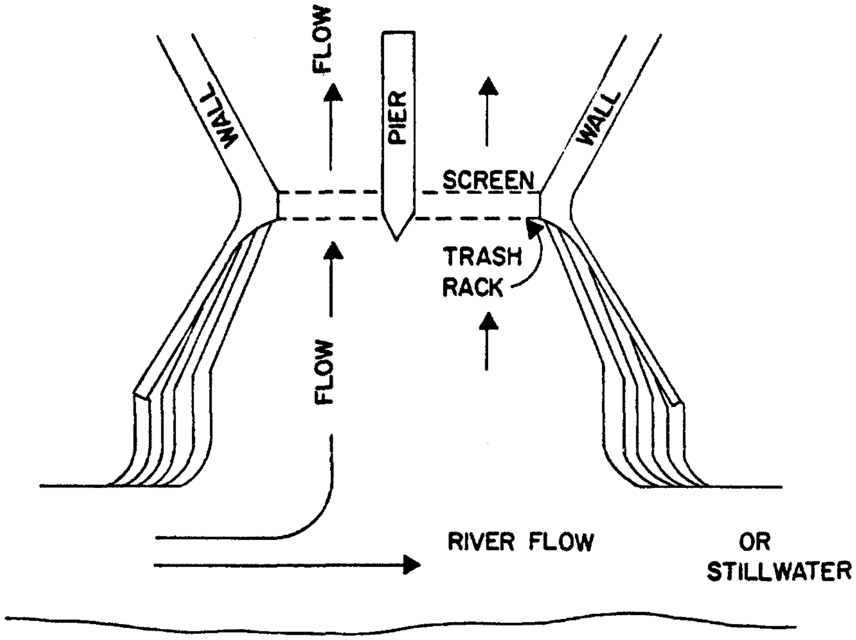
5. For shoreline intakes, avoid breaks in the natural shoreline and avoid the use of intake canals, since both may act as "fish traps."

6. Fish by-pass or collection and removal facilities should be provided in the screenwell. Stationary louvers have proved effective in guiding fish and could be employed as a fish by-pass system.

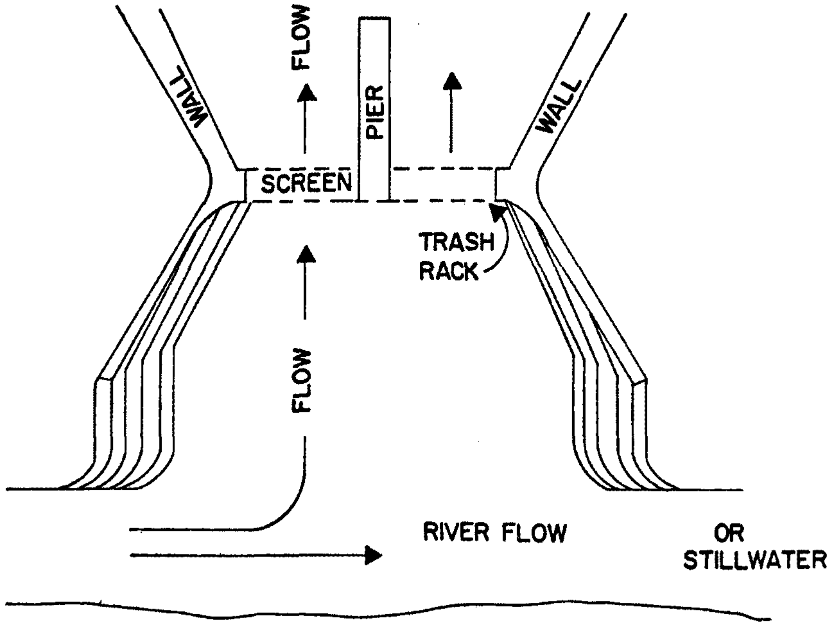
7. Travelling screens (mesh size of 3/8" or less) should be employed. Continuous movement with suitable fish removal procedures is preferred over intermittent movement. Note that horizontal traveling screens, now under experimental investigation, may prove effective as fish by-pass devices.

As an aid in assessing the adequacy of a given intake design, the reader is referred to Figures 3 through 5 taken from a report prepared by the State of Washington Water Research Center under an EPA grant[7]. These figures indicate both good and bad intake design configurations.

All other factors being equal, biological damage due to condenser passage is directly proportional to the volume of make-up water withdrawn. Thus, closed-cycle systems will cause less damage of this type than once-through systems. The following portion of this Section includes discussion of intake flow rates for closed-cycle cooling systems.

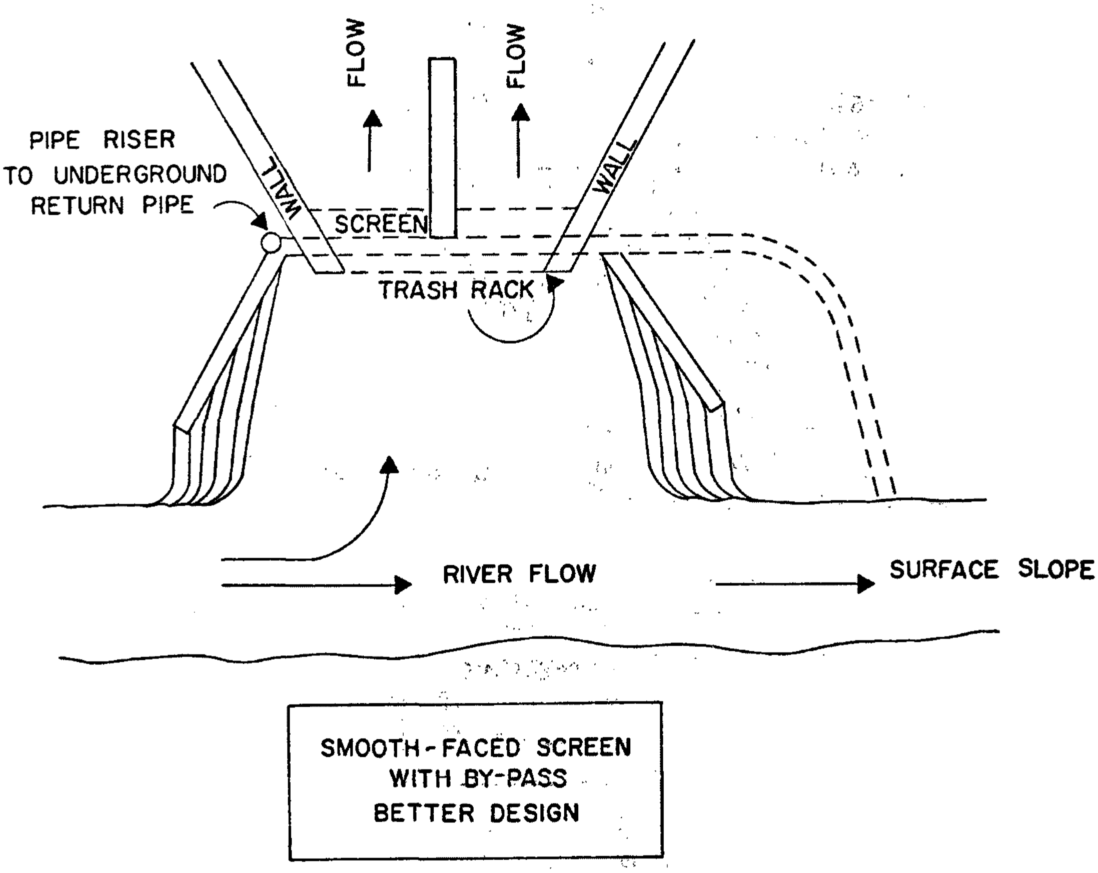


RECESSED SCREEN
NO BY-PASS
POOR DESIGN



SMOOTH FACED SCREEN
NO BY-PASS
SOMEWHAT BETTER DESIGN

FIGURE 3
INTAKE DESIGNS[7]



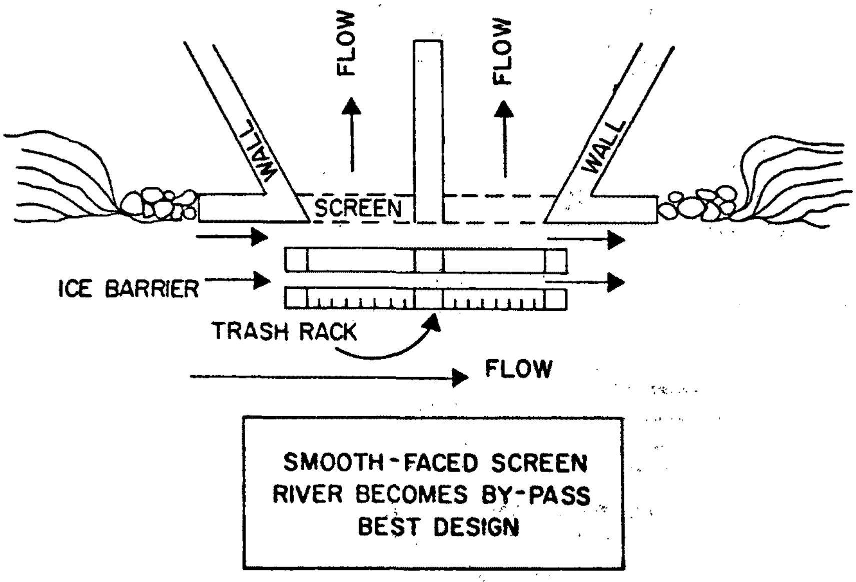


FIGURE 4
INTAKE DESIGNS [7]

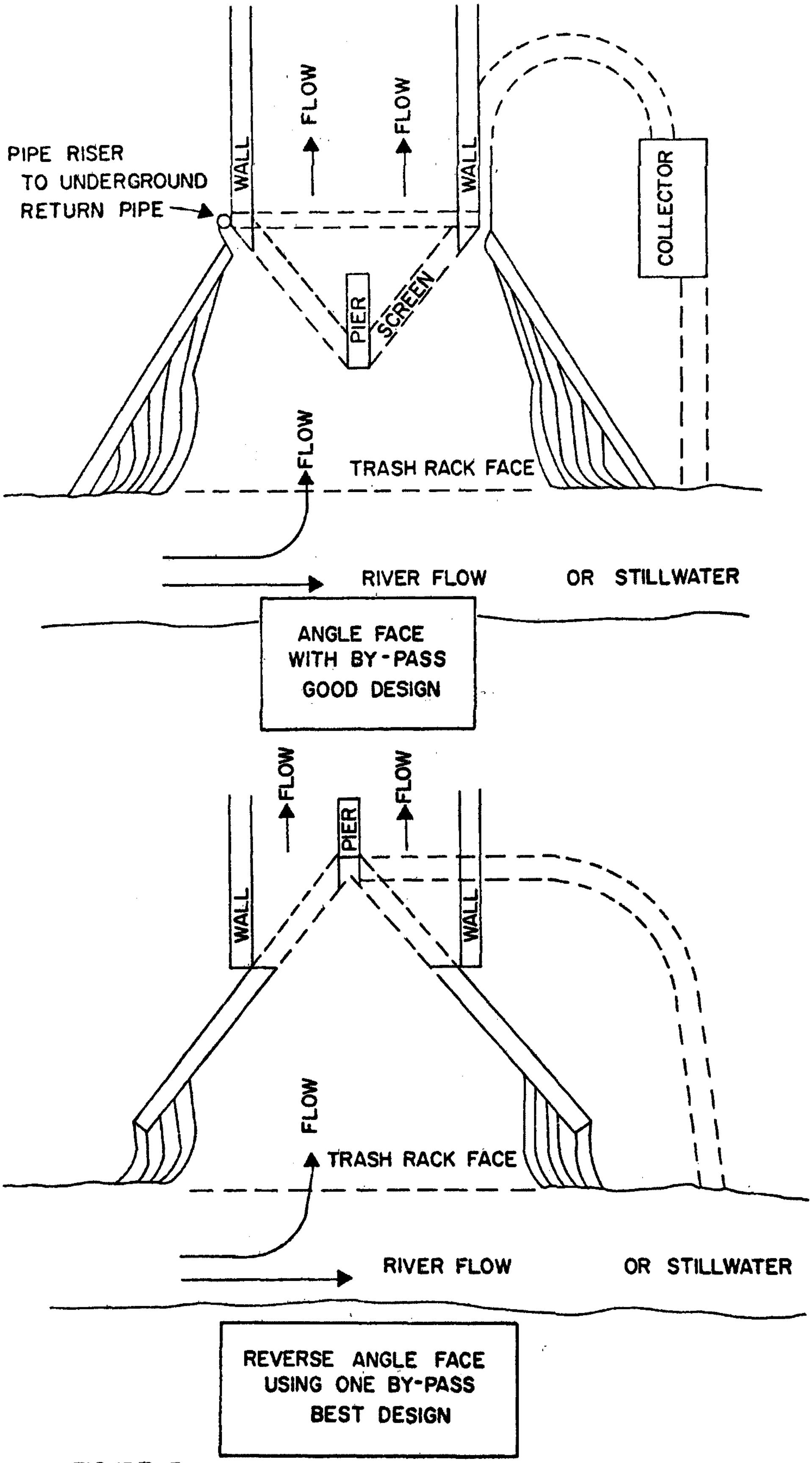


FIGURE 5
INTAKE DESIGNS [7]

Intake icing should also be considered. Severe icing could cause flow restrictions and/or structural damage, so de-icing procedures are sometimes employed. Such procedures generally include the discharge of warm condenser effluent in the vicinity of the intake (i.e., purposeful recirculation). If such warm discharges act as fish attractants, increased entrainment problems could occur. In addition, rapid "shut off" of this heated discharge at the conclusion of the de-icing program could cause cold shock to nearby organisms. Thus, the EIS reviewer should carefully evaluate proposed de-icing plans.

For further information on intake design considerations, the reviewer should consult the reports by Hanford Engineering Development Laboratory[6], State of Washington Water Research Center[7], and Johns Hopkins[8].

C. CLOSED-CYCLE COOLING

Several types of cooling devices are available for use in a closed-cycle cooling system, including:

1. Wet cooling towers (mechanical or natural draft).

2. Cooling ponds (flow-through or completely mixed).

3. Spray cooling systems (canal or pond type).

4. Dry cooling systems (direct or indirect; mechanical or natural draft).

5. Wet/dry cooling towers (mechanical or natural draft).

In reviewing an EIS for a plant using closed-cycle cooling, three basic factors should be considered:

1. Operating characteristics

2. Water consumption

3. Environmental effects.

Following is a discussion of these factors relating to the above cooling devices.

Wet Cooling Towers

Operating Characteristics -

Wet cooling towers, both mechanical and natural draft, dissipate the majority (approximately 75 percent) of the waste heat in the cooling water by latent heat transfer (evaporation) with the remainder lost by sensible heat transfer (conduction-convection). The wet-bulb temperature of the ambient air is the minimum temperature to which the water can be cooled. The tower is designed to cool the water to some specified temperature above the wet-bulb temperature.

The approach of the tower is defined as the difference between the cool outlet water and the wet-bulb temperature. Approaches of 15-20°F are generally used. The cooling range is the difference between the hot inlet water temperature and the cool outlet water temperature. In a closed-cycle system the range equals the condenser temperature rise and is generally between 25 and 40°F. Thus, given information on the approach, range, and wet-bulb temperature, one can determine the inlet (hot leg) and outlet (cold leg) tower temperatures.

In evaluating these temperatures, one must differentiate between design conditions and average conditions. Design wet-bulb temperature is often designated as not to be exceeded more than a fixed percentage (say 5%) of the time during the summer months. It represents a severe condition. Average conditions will be much more moderate. For example, a particular tower may be designed for a 15°F approach, a 30°F range, and 75°F wet-bulb temperature. This would provide a 120°F tower inlet temperature with a 90°F outlet temperature. Under more moderate off-design conditions, much cooler temperatures will be realized.

In reviewing an EIS, substantial operating and design data with respect to heat dissipation are not required. It is generally sufficient to assume that the particular tower design selected will be adequate to dissipate the waste heat load. However, information on the water balance of the tower is critical to the review process.

For more details on cooling tower operation and design, the reviewer is referred to Marley[9], McKelvey & Brooke[10], and Dynatech[11].

Water Consumption -

Since wet cooling towers operate primarily by latent heat transfer, significant quantities of water are consumed by evaporation. Two rough methods estimating the water loss by evaporation are available.

1. Assume that 75 percent of the waste heat is dissipated by latent heat transfer. Thus, using a value of 1,000 Btu/lb for the latent heat of vaporization for water, one can easily calculate the approximate evaporative loss on the basis of total waste heat to the cooling water. For example, a 1,000 MWe nuclear power plant with a thermal efficiency of 33 percent and 5 percent in-plant losses discharges 6.4×10^9 Btu/hr to the cooling water. Thus, one can compute the tower evaporation loss as:

$(6.4\times10^9$ Btu/hr) (75%)/(1000 Btu/lb) = 4.8×10^6 lb/hr or 21.4 cfs.
(Conversion factor: 1 cfs = 0.225×10^6 lb/hr)

2. One can also compute the evaporation loss given data on cooling water flow rate and condenser temperature rise. Using the same assumptions as above, the evaporation loss is equal to 0.75 percent of the flow rate per 10°F drop (or rise) in cooling water temperature. Thus, for the example shown above (temperature rise equals 30°F, flow rate equals 950 cfs, see Figure 2) the evaporation loss equals:

(0.75%) (950 cfs) (30/10) = 21.4 cfs.

Both of these calculations were conducted assuming the plant was operating under full load. To compute the average annual evaporation loss, one should multiply this value by the annual plant load factor. For example, given the same data as above with an annual load factor of 82 percent, the average annual evaporation loss would be:

(21.4 cfs) (82%) = 17.5 cfs

Finally, to compute the maximum (or design) evaporation rate under high dry-bulb temperature conditions which will minimize convective heat loss, one should assume that 95 percent of the waste heat in the cooling water is lost by evaporation. Thus, the maximum evaporation rate for the above example would be:

(21.4 cfs) (95/75) = 27.1 cfs

Note that the methodology presented above is only approximate, but it should enable the reviewer to evaluate the EIS data on evaporation in a reasonable manner. A more detailed technique is presented by Hittman Associates, Inc.[3]

Another mechanism by which water is lost from a wet cooling tower is drift. As the water falls down through the tower packing and below, it is possible for small droplets to become entrained in the air stream moving out through the tower top. These droplets have the same chemical characteristics as the cooling water in the system. The use of drift eliminators above the packing can reduce the drift loss substantially. State-of-the-art design can be used to obtain drift losses of 0.005% of the circulating flow rate for mechanical draft units and 0.002% for natural draft towers[12]. In no case should the drift loss exceed 0.01% for modern, well-designed towers. The only exception would be for a tower designed to maximize the drift loss in order to reduce the blowdown volume (see below).

The process of evaporation in a wet cooling tower causes an increase in the concentration of dissolved and suspended material in the circulating water. In order to prevent a build-up of undesirably high concentrations in the system, a small portion is continually or intermittently bled from the system. This stream is called blowdown. The blowdown (B) is a function of the available make-up (B+D+Ev) water quality and is related to evaporation (Ev) and drift (D) in the following manner:

$$C = (B + Ev + D)/(B + D) \qquad (1)$$

In this equation, C equals cycles of concentration, a dimensionless number which expresses the number of times the concentration of any constituent is multiplied from its original value in the make-up water. (It does not represent the number of passes through the system). B, Ev, and D are expressed in consistent units (e.g. percent of circulating water flow rate or actual flow rate).

For average make-up water quality, conventional practice sets the value of C between 4 and 6. For extremely high makeup quality water (or treated water) C values of 15 and above are possible. For salt or saline water, C values as low as 1.2 to 1.5 may be required. This is usually not a materials or operating limit, but rather a means of preventing biological damage from blowdown salinity.

The chemical characteristics of the recirculating water (treated or untreated) determine the maximum C value. Table 1 provides some "rules of thumb" to be used in establishing the maximum C value. Note that the $C_{subscript}$ designations used in the table represent individual constituent concentrations and should not be confused with C, cycles of concentration used above.

Table 1

RECIRCULATING WATER QUALITY LIMITATIONS

Characteristic	Limitation	Comment
pH and Hardness	Langelier Saturation Index = 1.0	Langelier Saturation Index = pH-pHs where
pH and Hardness with addition of proprietory chemicals for deposit control.	Langelier Saturation Index = 2.5	pH = measured pH pHs = pH at saturation with $CaCO_3$ See Sisson[13] for nomograph solution.
Sulfate and Calcium	$(C_{SO_4}) \times (C_{Ca}) = 500,000$	C_{SO_4} = concentration of SO_4 in mg/l C_{Ca} = concentration of Ca in mg/l as $CaCO_3$
Silica	$C_{SiO_2} = 150$	C_{SiO_2} = concentration of SiO_2 in mg/l
Magnesium and Silica	$(C_{Mg}) \times (C_{SiO_2}) = 35,000$	C_{Mg} = concentration of Mg in mg/l as $CaCO_3$

The "Limitation" column in Table 1 indicates the maximum value allowed in the recirculating water for each chemical characteristic given. The maximum C value would be established when any one of the "Limitations" is exceeded. Note that this table provides "rule of thumb" estimates, which may not be applicable to unique water quality problems.

The equation for C can be rewritten for blowdown (B):

$$B = \frac{Ev-D(C-1)}{C - 1} \tag{2}$$

In order to minimize the total amount of make-up water by the cooling tower, one should operate at as high a C value as possible. The following data were computed using the above equation and illustrate the effect of C on the blowdown and make-up flow rates:

C (cycles of concentration)	Blowdown (cfs)	Make-up (cfs)
1.2	107	128
1.5	42.8	64.2
2.	21.4	42.8
5.	5.3	26.7
10.	2.3	23.7
20.	1.1	22.5

This table was developed assuming an evaporation rate (Ev) of 21.4 cfs and a drift rate (D) of 0.05 cfs (0.005% of 950 cfs).

There are several advantages to maintaining a high C value:

a. Minimizing the make-up water requirement, thus reducing the number of organisms entrained in the cooling water.

b. Minimizing the volume of blowdown water to be discharged.

c. Reducing the size and cost of make-up and blowdown handling facilities (i.e., pumps, pipes, screens, etc.).

Environmental Effects -

In addition to the consumption of water, wet cooling towers can cause potential adverse side effects due to the vapor plume, drift, and blowdown.

Cooling tower plumes have the potential for causing or increasing local fogging or icing conditions. The key word here is potential, since in most cases, no such problems will occur. Fog is defined here as a condition where vision is obstructed.

Cooling towers do produce visible plumes; however, plumes are normally not a problem unless they reach the ground. Under normal conditions, cooling tower plumes rise due to their initial velocity and buoyancy and rarely intersect the ground before they are mixed with the ambient air and dissipated. However, under adverse climatic conditions (i.e., high humidity and low temperature), the moisture could produce a fog condition if it were trapped in the lower levels of the atmosphere, such as during a period of high atmospheric stability (i.e., an inversion). In almost all cases, natural draft towers are less likely to cause fogging problems than mechanical draft towers. Mechanical draft towers may cause problems, but in most cases fogging and icing would be on-site (i.e., within 1000-2000 ft of the tower). Also the limited vertical mixing occurring during neutral stability conditions could limit plume dispersion.

Several analytical techniques have been used to evaluate the fog potential of cooling tower plumes:

1. One method is to estimate the concentration of liquid water added by the cooling tower plume to the ambient atmosphere in the vicinity of the cooling tower. EG&G[14] indicates that the amount of liquid water added by cooling towers is normally between 0.1 and 0.5 grams per cubic

meter, one or more kilometers downwind from cooling towers. Thus, any time the difference between the liquid water content of saturated air and the liquid water content of the ambient air is less than 0.1 to 0.5 grams per cubic meter, there is a potential for fog conditions within the specified distance from the cooling tower. Thus, a method which can be used to determine whether or not fog may occur for a particular tower is to evaluate the percent of time that the ambient air contains a liquid water concentration sufficiently close to the saturation liquid water content (i.e., within 0.1 to 0.5 grams per cubic meter). This method was used in analysis of potential fog from cooling towers in the vicinity of Lake Michigan and is described in detail in a 1970 FWQA report[4].

2. Another method involves approximating the dilution of a cooling tower plume by the ambient atmosphere using standard methods of evaluating smoke plumes from a point source. In this method one computes the total amount of liquid water added by the cooling tower and determines the downwind mixing with the ambient atmosphere by using the classical Gaussian dispersion models available in standard textbooks on air pollution[15]. This method was also used in evaluating potential fog from cooling towers in the vicinity of Lake Michigan[4].

3. Also available are mathematical models of cooling tower plumes which take into account the rise of the plume using information on cloud physics, such as liquid-vapor phase change reactions, liquid water content, and precipitation. To date, such models lack complete verification with field data and are thus subject to engineering judgment in their use. References on such models include EG&G[14], Hanna[16, 17] and Sierra Research[18].

4. Finally, empirical methods are also used in the prediction of potential fog from wet cooling towers. These methods utilize field observations from existing towers and correlation with meteor-olgical information. TVA has developed such models using data from their Paradise plant[19].

In reviewing that portion of the EIS describing the fogging potential of a cooling tower, one should assess the duration (e.g., hours per year or percent of time), frequency (number of occurances per year), and location (e.g., highway, airport, residential or industrial area) of the predicted episodes. A careful check of the methodology coupled with a critical evaluation of the meteorological data is required. In addition, the description of the methodology used for prediction should be sufficiently detailed to allow the reviewer to prepare independent calculations. In many cases, only a cursory analysis is provided, which may be sufficient if the site is not subjected to prolonged periods of high humidity and low temperature. A final point to consider is a possible interaction between the cooling tower plume and nearby point sources of air pollution from industrial plants. Potential problems such as acid mist may occur due to such interactions and would require further analysis.

As a rough check on the fog potential of power plant cooling towers, Figure 6 may be used. According to EG&G[14], this map provides a "qualitative classification for the potential for adverse cooling tower effects." The following criteria were used by EG&G[14] in developing this map.

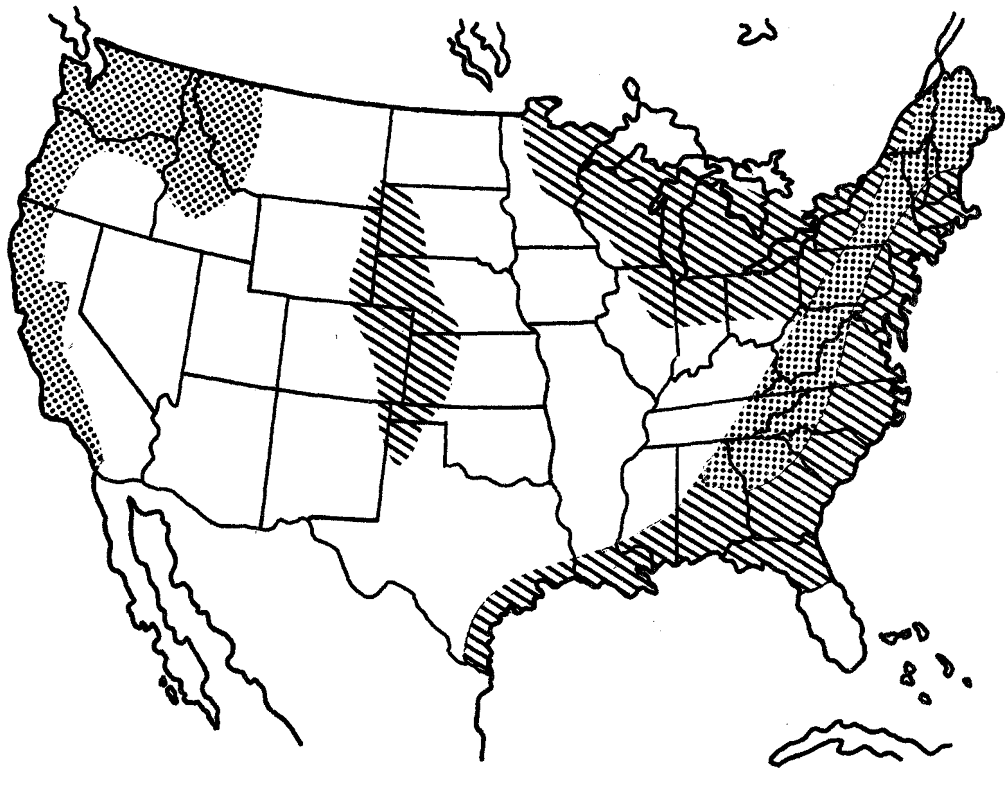
a. <u>High Potential</u>.

Regions where naturally occuring heavy fog is observed over 45 days per year, where October through March the maximum mixing depths are low (400-600 meters), and the frequency of low-level inversions is at least 20-30 percent.

b. <u>Moderate Potential</u>.

Regions where naturally occuring heavy fog is observed over 20 days per year, where October through March the maximum mixing depths are less than 600 meters, and the frequency of low-level inversions is at least 20-30 percent.

FIGURE 6
GEOGRAPHICAL DISTRIBUTION OF POTENTIAL ADVERSE EFFECTS FROM COOLING TOWERS



HIGH POTENTIAL
MODERATE POTENTIAL
SLIGHT POTENTIAL

c. Low Potential.

Regions where naturally occuring heavy fog is observed less than 20 days per year, and where October through March the maximum mixing depths are moderate to high (generally greater than 600 meters).

It must be emphasized that the classifications of "high," "moderate," "low" potential are relative rather than absolute descriptors. Thus, a cooling tower located in an area of "high potential" would be more likely to cause a fogging problem than one located in an area of "moderate" or "low potential," but whether or not the tower ever produced a fog problem would depend upon specific site and climatic conditions.

During sub-freezing weather, fogging and drift conditions may result in icing. As with fog, experience with large power plant cooling towers has not resulted in major icing problems. Methods of predicting the accumulation of ice due to cooling tower plumes are not widely reported. In general, icing caused by plumes will be a low-density accumulation of granular ice tufts and is unlikely to cause damage due to its weight. A problem to be considered would be associated with the danger of icy roads. It should be noted that icing caused by the plume will be generally limited to vertical surfaces, and icing of horizontal roadways will be less severe. When such conditions may occur, the EIS should contain data on icing frequency, duration, and location. Also, suggestions for preventing safety problems should be made (i.e., plans for caution signs and/or lights).

As discussed above, drift is entrained water that is carried out of the top of a wet cooling tower in liquid droplets rather than as vapor. While some objection has been raised concerning the environmental effects from freshwater cooling towers, more vocal opposition has been expressed to large salt water towers because of the potential damage to the surrounding area from fallout of salt discharged to the atmosphere in drift particles.

In addition to data on the amount of drift given previously, some information is also available on the size of drift particles. Environmental Systems Corporation[12] conducted measurements on a mechanical draft tower (drift rate 0.005%) which showed that the size of particles contributing the majority of the total mass ranged from about 100 to more than 300 microns in diameter. Particles less than 100 microns in diameter contributed only about 5 percent of the total drift mass. On the other hand, measurements taken a few feet above the eliminators in a natural draft tower showed few particles greater than 100 microns.

In order to evaluate the environmental effect of drift, one must be able to predict the amount of deposition on the surrounding landscape. Unfortunately, the state-of-the-art is inadequate to precisely quantify the fallout characteristics of cooling tower drift; however, qualitative deductions are possible. Papers by Stewart[20] and Hosler, et. al.[21] can be used to provide such qualitative deductions. In general, these papers indicate that the majority of the drift particles will fall out within 2,000 feet of a cooling tower under normal conditions.

Two basic problems prevent one from making a firm judgment on the severity of environmental problems associated with cooling tower drift from salt water towers. First of all, only limited and qualitative information is available on the effect of various levels of salt concentration on various species of vegetation. Second, in order to effectively evaluate the cooling tower drift effect, information on the salt concentration in the ambient atmosphere and its deposition must be obtained. Such data are generally unavailable.

While limited experience has been gained in the operation of salt water cooling towers, no adverse environmental effects have been experienced at a tower which has been operating in Fleetwood, England, for several years. In addition, cooling towers associated with oil refineries in Texas and New Jersey have been operated on salt water for some time without objectionable effects. However, these examples should not be cited as proof, at the present time, that salt water towers can be used at any given site without drift damage to any type of surrounding. Finally, large natural draft cooling towers have been planned for operation on salt water at the Chalk Point power plant in Maryland and the Forked River nuclear power plant in New Jersey.

Two excellent references which discuss the problem of drift from salt water cooling towers are a report by Westinghouse[22] and the Forked River EIS[23].

The environmental effects of blowdown and its treatment and disposal are discussed later in Section V of this report.

Cooling Ponds

Operating Characteristics -

Cooling ponds are simply open bodies of water which use the natural heat exchange processes of evaporation, radiation, and conduction-convection to dissipate a power plant's waste heat load. The design of a cooling pond depends upon the plant size, the local meteorology, and the pond type--mixed or flow-through. Mixed ponds have uniform surface temperatures; flow-through (or slug flow) ponds are designed to exhibit a temperature decay from the warm inlet to the cool outlet. Flow-through ponds require smaller surface areas than mixed ponds.

The determination of cooling pond area requires an analysis of the pond's energy budget. An approximate analysis of the energy budget can be used by the EIS reviewer to calculate pond size. This method is referred to as the equilibrium temperature technique and involves a one-dimensional exponential temperature decay equation. Assuming a flow-through pond, the pond performance is described by:

$$T_{out} = (T_{in} - E) \exp(-0.505KA/\rho C_p Q) + E \qquad (3)$$

where T_{out} = pond outlet temperature, °F

T_{in} = pond inlet temperature, °F

E = equilibrium temperature, °F

K = energy exchange coefficient, Btu/day ft^2 °F

Q = cooling water flow, cfs

ρ = water density, lb/ft^3

C_p = specific heat, Btu/lb°F

A = pond surface area, acres

K and E values are basically functions of meteorological conditions. Methods of computing these parameters are found in Edinger and Geyer[24] and in the Industrial Waste Guide on Thermal Pollution[25]. Brady, et. al.[26] provide approximate techniques for computing K and E values. Also, values of K and E for average and extreme meteorological conditions are contained in a report by Vanderbilt[27] for various locations throughout the United States. K and E values should be averaged over the time of passage through the pond, which is usually at least a week.

The above equation can be simplified in order to provide direct computation of pond area. Given a water density (ρ) of 62.4 lb/ft^3 and specific heat (C_p) of 1 Btu/lb°F and solving for A gives:

$$A = (123Q/K)\ln [(T_{in}-E)/(T_{out}-E)] \qquad (4)$$

Defining:

T_{out} - E = cooling pond "approach" and

$T_{in} - T_{out}$ = condenser ΔT for a closed cycle pond, equation 4 can be rewritten as:

$$A = \frac{123Q}{K} \ln \left(\frac{\Delta T + \text{Approach}}{\text{Approach}}\right) \qquad (5)$$

A graphical representation of this equation is presented in Figure 7 for a 1,000 MWe nuclear power plant (η_t = 33%, in-plant losses = 5%). Q and ΔT values were obtained from Figure 2. Three values of K and two "approach" levels are provided. Note that pond size decreases with increasing values of K, ΔT, and approach (with all other factors being constant). The effect of higher waste heat loads at a higher "approach" due to an increase in plant heat rate is not represented. Figure 8 and Table 2 provide information on the relationship between pond size and pond inlet water temperature for various regions of the U.S. under design summertime conditions for a 1,000 MWe nuclear power plant (η_t = 33%, In-plant losses = 5%). Note that as the inlet temperature increases, the required pond area decreases.

Table 2. K AND E VALUES[29]

Location	Location in U. S.	K (Btu/ft^2-day °F)	E (°F)
Portland, OR	Northwest (NW)	128	87
Dallas, TX	South Central (SC)	202	92
Bakersfield, CA	Southwest (SW)	166	88
Atlanta, GA	Southeast (SE)	132	98
Boston, MA	Northeast (NE)	184	87
Chicago, IL	Great Lakes (GL)	203	89

FIGURE 7
COOLING POND SIZE VS. ΔT

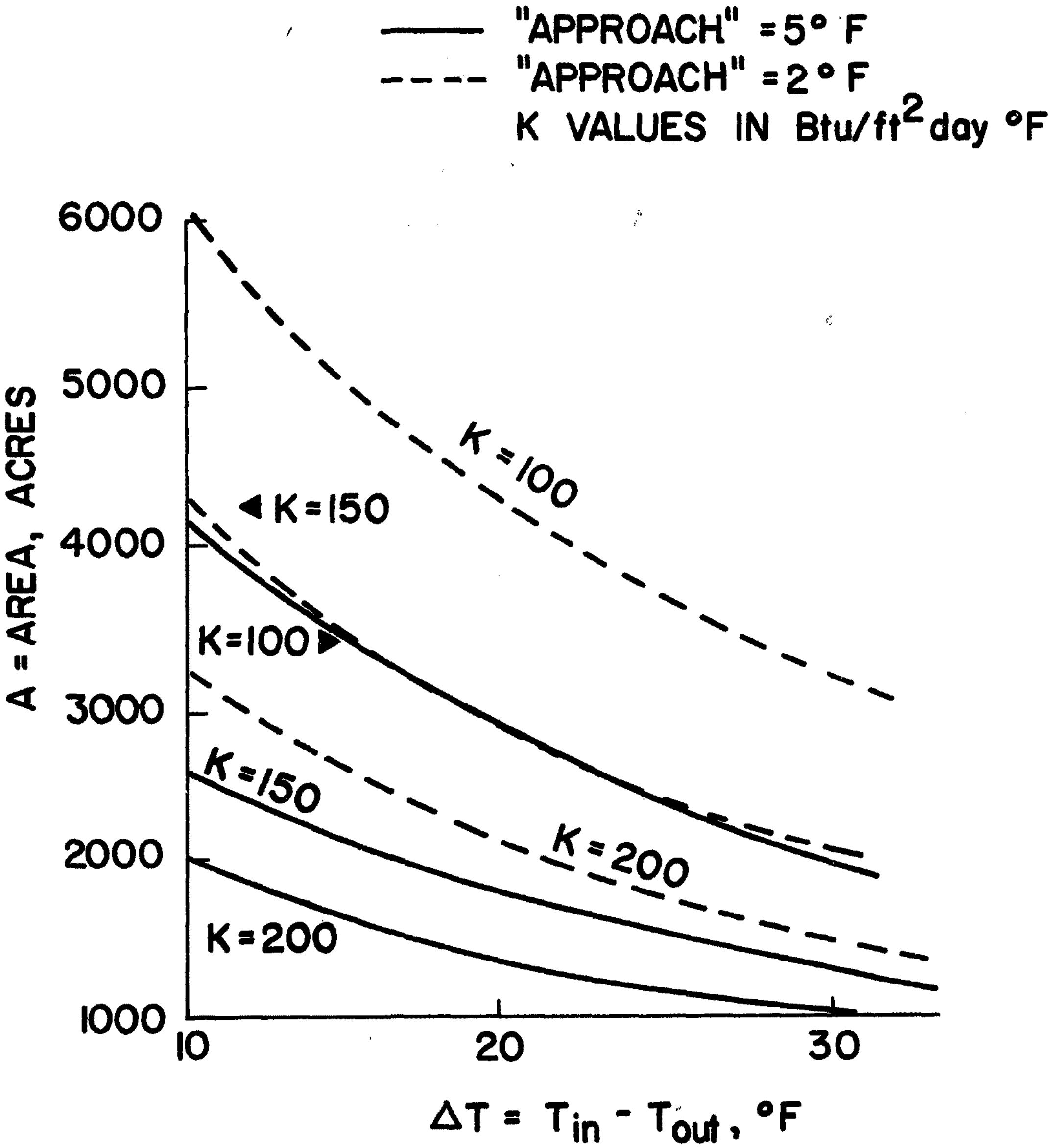
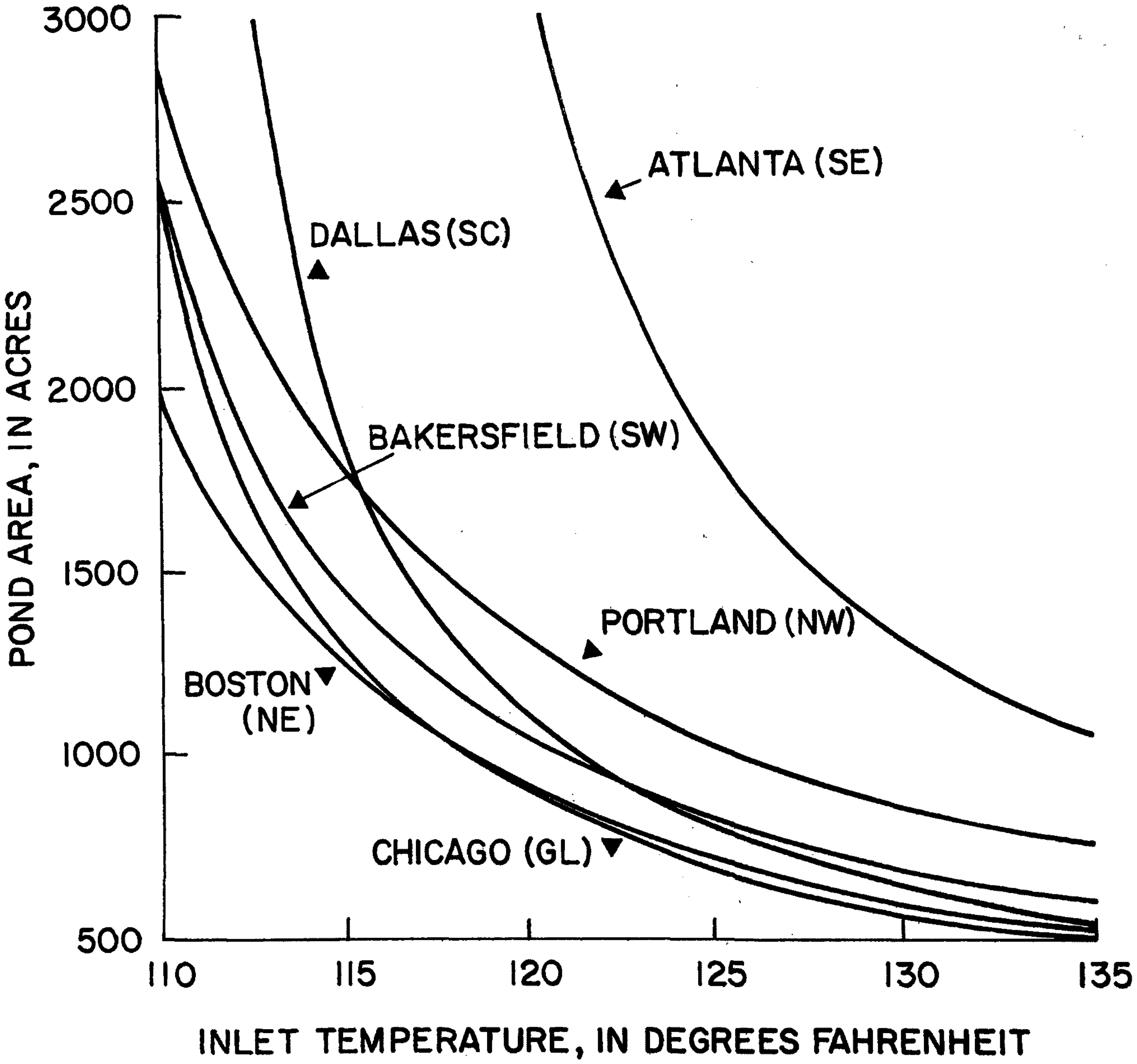


FIGURE 8
POND AREA VERSUS
INLET TEMPERATURE



The equilibrium temperature method is normally used to determine pond size under design meteorological conditions. It can also be used to evaluate pond performance under off-design conditions.

The equations presented above are for flow-through ponds. In order to obtain a truly flow-through configuration, the water must be directed through the pond by baffles or dikes, since the natural topography is often not adequate to provide the proper flow configuration. In many cases, a cooling pond will contain "dead spots" such as bays or inlets which do not participate in the heat exchange processes. In such cases, one should reduce the effective pond area to account for this reduced cooling capability. Also, ponds may be configured such that a portion is operating as a completely mixed pond rather than as a flow-through pond. In such cases, one should evaluate the lower effectiveness of the completely mixed portion.

Edinger and Geyer[24] present a table relating the temperature excess ratio, $(T_{out}-E)/(T_{in}-E)$ to the ratio of areas for the two pond types (mixed pond area/flow-through pond area). Figure 9 provides a plot of these data. This figure illustrates the fact that for a given value of E and condenser ΔT, the cooler the desired pond outlet temperature, the greater the area of a mixed pond with respect to that of a flow-through pond.

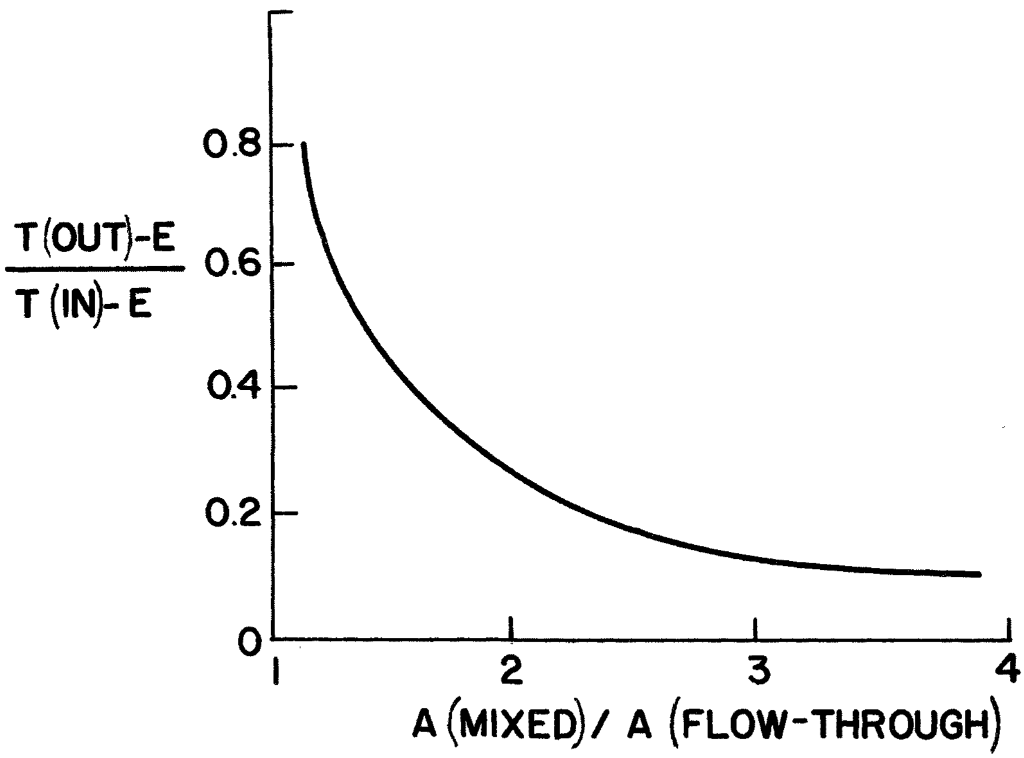
One can evaluate the temperature of the completely mixed portion of a cooling pond by using the following relationship:

$$T_m = \frac{(123\ QT_{in} + KAE)}{(123\ Q + KA)} \qquad (6)$$

where T_m = surface temperature of mixed pond, °F

In using the the relationship, note that T_{in} is the inlet temperature to the completely mixed portion of the pond, which may not equal the overall pond inlet temperature. Also, A is the area of the completely mixed portion.

FIGURE 9
MIXED VS FLOW-THROUGH PONDS



In evaluating pond designs presented in an EIS, the use of the above relationships is preferred over the application of "rules of thumb" for pond sizes. Meteorology plays such a dominant role in pond design that wide variations in pond sizes can be expected for similar power plants in different locations.

The material presented above merely highlights one method for calculating pond size. More complete information on cooling pond size and performance can be found in reports by FWPCA[25] Hittman[3], Littleton[28], Brady et. al.[26], Vanderbilt[27], Tichenor and Christianson[29], and Hanford Engineering Development Laboratory[30].

Water Consumption -

The computation of water consumption from cooling ponds cannot be accomplished with simplified "rules of thumb" as is possible for wet cooling towers. As discussed above, cooling pond operation is dictated by all components of the energy budget and thus a simple percentage estimate of latent heat transfer is not possible. Two methods are available for computing cooling pond evaporative water loss:

1. Energy budget - this method requires a complete evaluation of all components of the energy budget (e.g., long and short wave incident and reflected radiation, conduction-convection, and back radiation) to compute evaporative water loss, knowing the pond temperature. The reader is referred to Edinger and Geyer[24] for details of such computations. It must be noted that small variations in pond temperature can cause large changes in evaporation, thus one should use the energy budget method of evaporation prediction only when high confidence is placed in the pond temperature data.

2. Mass transfer equations - this method employs empirical equations of the form*:

$$Q_E = f(w)\ (e_s - e_a)A \qquad (7)$$

*This is the most common form used in such calculations, however, many other forms are available in the technical literature.

where Q_E = evaporative water loss, cfs

$f(w)$ = wind speed function, w(wind speed) in mph

e_s = vapor pressure of saturated air at the pond water temperature, inches Hg

e_a = vapor pressure in the ambient air, inches Hg

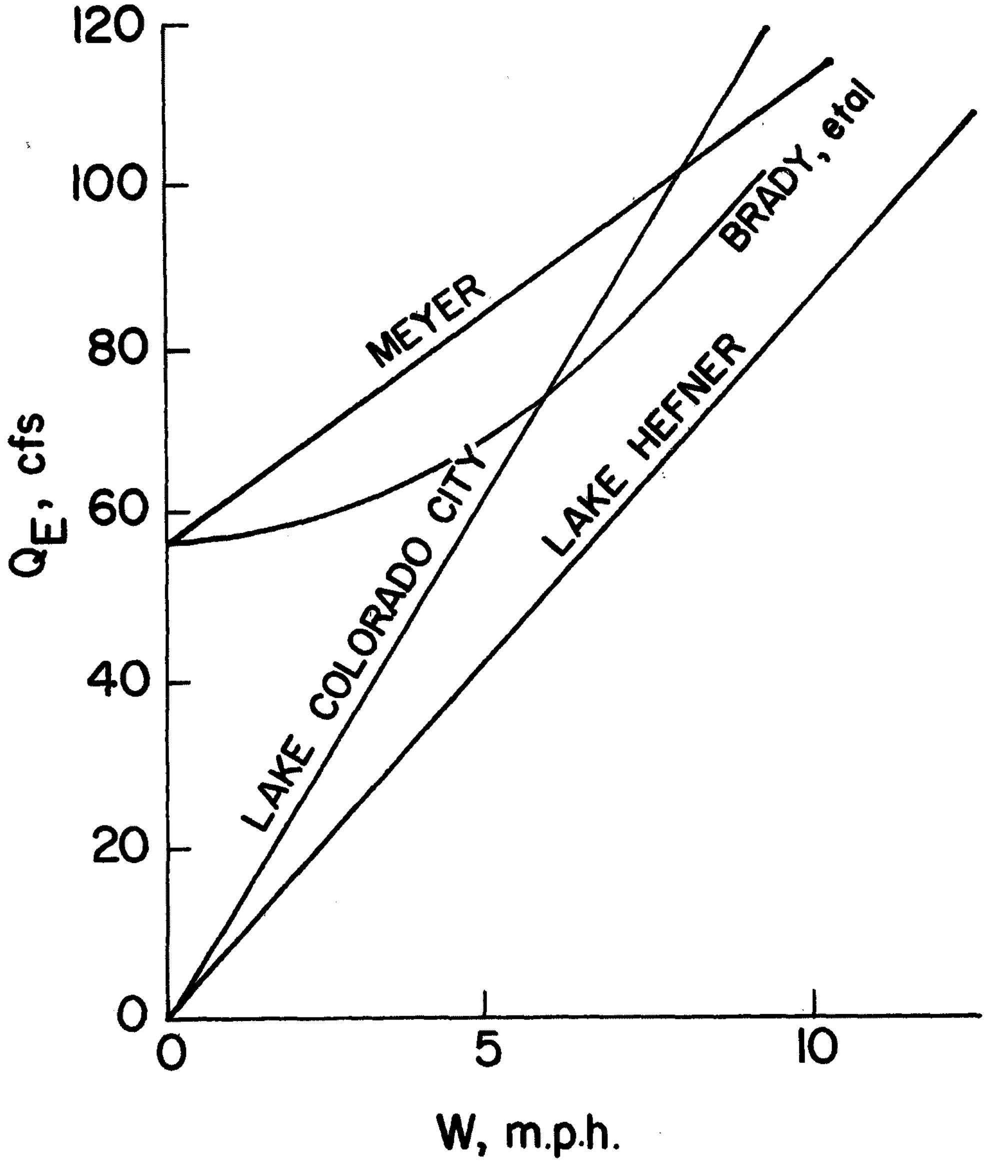
A = pond size, acres

The value selected for the f(w) coefficient is critical to the computation, and several values can be found in the literature[24, 26]. The following values of f(w) are presented in units consistent with this report:

Equation	f(w)
Lake Hefner[24]	$(2.25 \times 10^{-3})w$
Lake Colorado City[24]	$(3.31 \times 10^{-3})w$
Meyer[24]	$1.44 \times 10^{-2} + (1.44 \times 10^{-3})w$
Brady, et. al.[26]	$1.38 \times 10^{-2} + (1.38 \times 10^{-4})w^2$

Figure 10 shows the relationship between Q_E and w for $(e_s - e_a)$ = 2 inches Hg for these four values of f(w), for a 2,000 acre pond. Unfortunately, no blanket statement can be made regarding the applicability of these or other estimates of f(w) to a particular situation. All formulations of f(w) given above are based on specific empirical data and none may be strictly applicable to a given cooling pond. Historically, the Lake Hefner function is the "most popular;" the Brady, *et. al.*[26], function was derived

FIGURE 10
POND EVAPORATION VS WIND SPEED
Q_E VS. W, $e_s - e_a = 2$ in Hg
A = 2000 acres



from cooling ponds located in the Southeast and South Central United States and is probably the "best" one to use in those locations.

When using Equation 7 to compute evaporative water loss for a flow-through cooling pond, one should not simply use the average pond temperature, (i.e., $(T_{in} - T_{out})/2$) to obtain e_s, because e_s is a nonlinear function of water temperature. A preferable method is to segment the pond into several areas of similar temperature and perform calculations on each segment.

Figure 11 illustrates the effect on evaporative water loss of varying the inlet temperature for a closed-cycle cooling pond serving a 1,000 MWe nuclear power plant. The curves in this figure were constructed using $f(w) = (2.96 \times 10^{-3})w$ for design summertime conditions at the indicated locations. The data on pond areas contained in Figure 8 were also used.

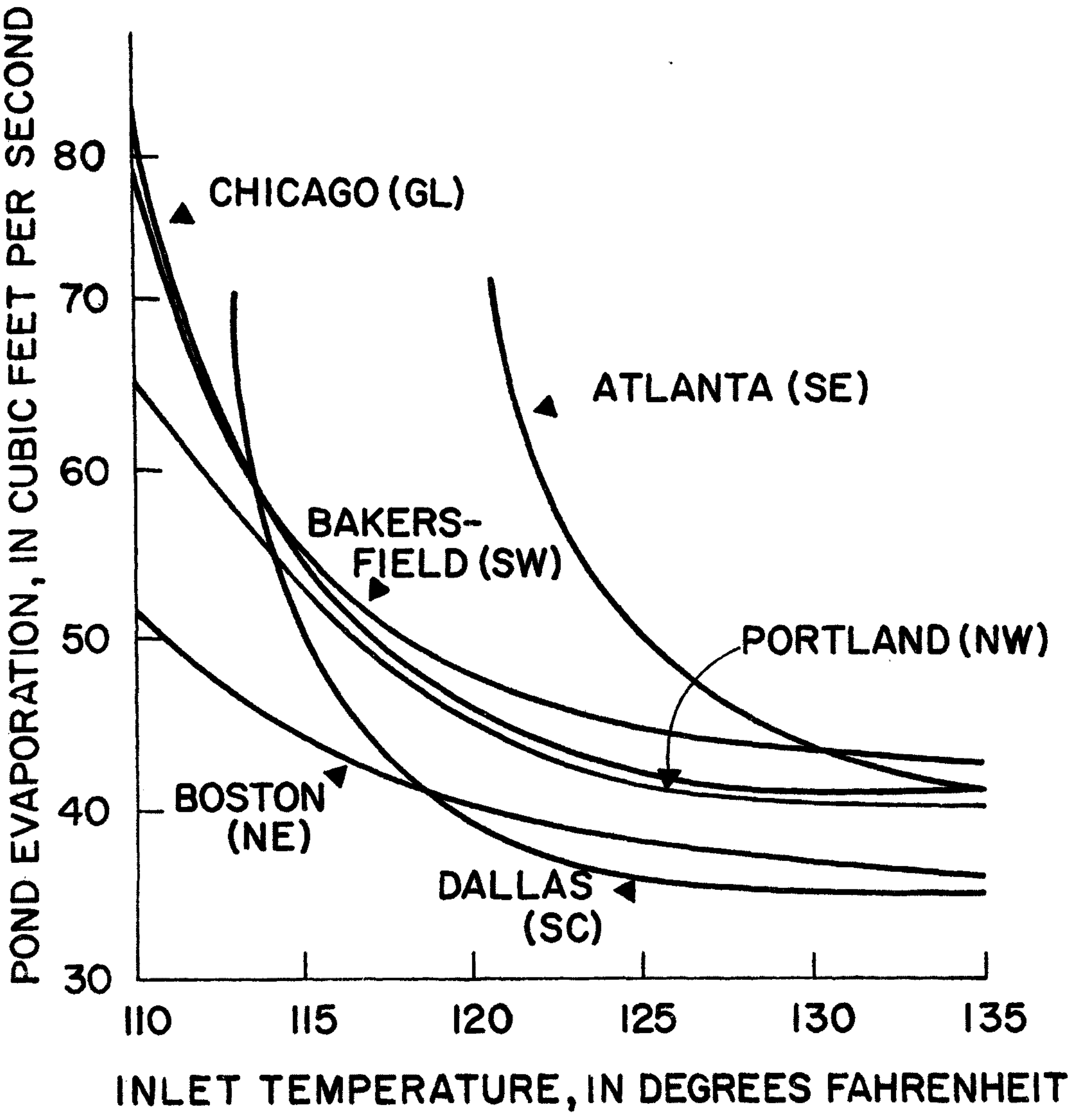
The above information can be used to estimate pond evaporation. In the case of cooling ponds, however, <u>evaporation</u> is <u>not</u> equivalent to <u>consumptive water loss</u>. The following considerations apply to the evaluation of consumptive water loss.

1. Cooling ponds will gain water by direct precipitation and runoff and possibly by infiltration. This water is subtracted from the evaporative loss in computing consumptive water loss.

2. If the pond existed prior to its use as a cooling facility, the natural evaporation from the pond must be subtracted in evaluating consumptive water loss.

3. For new ponds, the previous natural evapo-transpiration of the area covered by the pond should be subtracted in estimating consumptive water loss.

FIGURE 11
POND EVAPORATION VERSUS
INLET TEMPERATURE



4. Seepage from the pond should be added to the consumptive water loss.

As with cooling towers, the average annual consumptive water loss from cooling ponds is substantially lower than the loss under design meteorological and full load conditions. No simple "rules of thumb" can be provided to estimate this difference due to the complex nature of cooling pond consumptive loss mechanisms and regional differences in meteorological conditions. It would not be unusual, however, for average annual water losses to be less than half the losses under design conditions.

Cooling ponds may require a blowdown discharge. Since no drift will occur, Equation 2, can be rewritten as:

$$B = \frac{Ev}{(C-1)} \qquad (8)$$

This equation assumes no precipitation, runoff, infiltration, or seepage. Precipitation, runoff, and infiltration would reduce the "effective evaporation" and lower the blowdown rate. Seepage would act as blowdown, and thus reduce the blowdown required.

If the pond requires blowdown, the make-up requirements would equal pond evaporation plus blowdown and seepage minus precipitation, runoff, and infiltration.

The methodology presented above provides the EIS reviewer with one technique for estimating cooling pond water consumption. Nomographs for computing pond evaporation are also available[3].

Environmental Effects -

Cooling ponds dissipate a large portion of the waste heat load by evaporation. Thus, large amounts of water vapor are discharged to the atmosphere. As with cooling towers, this phenomenon has the potential for increasing local fogging and icing. Unlike cooling towers, however, the water vapor is discharged over an extensive area and thus elevated plumes are unlikely.

There is limited information concerning the fogging potential of cooling ponds. Ponds do exhibit a "steam fog" directly over the surface during cold weather periods[30]. Experience with such ponds indicates, however, that this fog will not extend over the land surrounding the pond for more than a few (i.e., 10-100) yards. However, under extreme conditions, the fog may extend over land a mile or more. Also, steam fogs have been observed to cause icing on the vegetation near the pond. The icing is of a low-density, granular nature and is unlikely to cause weight damage.

The potential for cooling pond fogging and icing increases as the air temperature decreases, the humidity increases, and atmospheric stability increases. The downwind distribution of water vapor can be estimated using the dispersion calculations discussed previously with regard to cooling towers.

In reviewing an EIS, one should consider the factors given previously for cooling tower fogging.

Spray Cooling Systems

Operating Characteristics -

Spray cooling systems, using fixed or floating spray nozzles or spinning discs, are available from several manufacturers. They provide cooling by evaporative and convective heat exchange between the spray droplets and the ambient air.

A great deal of flexibility is available in the design of a spray cooling system. They can be used in a canal (e.g., as designed for the Quad Cities plant) or a pond in a closed-cycle configuration. Also, they can be used in a canal in combination with a standard cooling pond (e.g., the Dresden Station). they may also be used in a combination cooling system in a discharge canal (e.g., the Chesterfield plant).

As with wet cooling towers, spray systems are designed for a specified range and approach. The EIS reviewer may generally assume that the system configuration provided by the manufacturer is adequate for the given design conditions.

Water Consumption -

Evaporation from spray systems is comparable to that from wet cooling towers except for ranges less than 10°F, and the estimates presented previously can be used. For closed-cycle spray systems, blowdown rates will also be comparable to wet cooling towers. Drift rates from spray systems have not been adequately studied, however, the contribution of drift to consumptive water loss is negligible. In summary, the make-up water requirements and consumptive water loss for closed-spray systems can be evaluated using the procedures given previously for wet cooling towers.

Environmental Effects -

As with wet cooling towers and cooling ponds, spray systems have the potential for fogging. Due to limited operating experience and minimal research on the problem, one can only provide a qualitative judgment on this potential. In general, under cold or humid weather conditions, the immediate area of the spray system will probably be foggy. Normally, this fog would not be extended over adjacent land. Extreme meteorological conditions could cause a greater area to be covered, and the EIS reviewer should use the techniques presented previously for cooling tower fogging to assess such a situation.

Icing due to spray systems is also a potential problem. Vegetation near the system can be expected to receive a coating of low density ice during cold weather periods; no structural damage to trees should occur. More widespread icing is not probable; however, the considerations presented for wet cooling towers would be applicable in evaluating extreme conditions.

Spray systems drift rates are not generally available. In terms of drift deposition on adjacent land and structures, two inherent characteristics of spray systems contribute to lessening the effect:

1. Low profile - the top of the spray pattern is only about 20 feet above the water surface.

2. No vertical air movement is involved, so the drift particles will not be carried aloft.

Also, spray systems that produce large droplets will cause fewer drift problems than those which operate with small droplet size.

Dry Cooling Systems

Operating Characteristics -

Dry cooling systems use only sensible heat transfer and are appropriate in areas of little or no water. There are two types of dry systems:

1. The direct air condenser where the turbine exhaust steam is condensed by the air and no cooling water is employed.

2. Indirect type dry systems where direct spray condensers (Heller type) are used and the cooling water and steam are mixed, with the resultant hot water going through an air heat exchanger. Thus,

there is no separate cooling water system. Recent studies indicate that a standard surface condenser could be used in place of a direct spray condenser.

Several dry cooling systems are operating and under construction in Europe; however, the only United States experience with dry cooling for power plants is at the Simpson station in Wyodak, Wyoming. This 20 MWe unit employs a direct air condenser. An additional unit several times this size is being planned for the Simpsom station using a dry cooling system.

The economic and technical feasibility of dry cooling systems has been widely reported[31, 4]. The major obstacle to their use on large power plants in the United States appears to be the lack of suitable high back pressure steam turbines. A wider use of dry towers in the United States awaits the successful demonstration of a large prototype. The most obvious use of dry systems is at fuel rich and water poor locations. Since nuclear power plants are not generally located with respect to fuel source, the major use of dry towers will probably be at mine-mouth fossil fueled plants. The exception would be the use of a dry system to alleviate environmental effects.

For information on technical and economic aspects of design and operation of dry cooling systems, the EIS reviewer should consult an EPA report by R. W. Beck and Associates "Research on Dry-Type Cooling Towers for Thermal Electric Generation"[31].

Water Consumption -

Dry cooling systems have essentially zero water loss. Heat exchanger leaks are possible, but would cause only minute water loss in comparison to wet cooling devices.

Environmental Effects -

By the nature of their operation, dry cooling systems will not cause fogging, icing, drift, or blowdown problems. There is some controversy over what the overall environmental effects of the warm air discharge from a dry cooling tower might be. A beneficial effect may be to increase ventilation in inversion prone areas. The potential modification of local meteorology, such as triggering the formation of cumulus clouds, requires further study. Also the overall meteorological consequences of large heat releases should be assessed; however this problem should be considered in the broad context of all large heat sources. In general, dry towers can be expected to be good environmental "neighbors," with the possible exception of noise problems.

A comprehensive analysis of the potential environmental effects of dry cooling towers is contained in a recent report by Boyack and Kearney[32] of Gulf General Atomic Company.

Wet/Dry Towers

Operating Characteristics -

Wet/dry cooling towers have received intensive study in recent years by several manufacturers. These systems, as the name implies, are constructed with both dry and evaporative heat exchangers. The normal design provides initial cooling water passage through a dry heat exchanger with the water then falling through conventional wet cooling tower packing. Other configurations are also possible, such as separate closed-loop cooling circuits for the wet and dry sections as proposed by Heller[33]. To date, only mechanical draft units have been tested on a full-scale. Single cells are operational, but no power plant operates completely on wet/dry towers.

The purposes of utilizing wet/dry towers are two-fold:

1. To reduce or eliminate the visible plume emission by a) decreasing the moisture content of the vapor discharge and b) heating the plume to allow it to hold more water vapor before becoming saturated.

2. To reduce water consumption. The tower designer can specify what proportion of the waste heat load must be rejected by the dry section and design the tower accordingly (i.e., 50% dry, 50% wet; 30% dry, 70% wet; etc.). In general, the dry section will have a larger heat rejection capacity than the wet section when water conservation is the goal.

The operation of the wet/dry tower will depend on meteorological, hydrological, and plant-load factors. For example, during meteorological conditions conducive to fog problems, maximal use of the dry section will reduce or eliminate the visible plume. During other weather conditions, the tower may operate primarily as an evaporative cooler. Low availability of make-up water will also require maximal use of the dry section, with due consideration to the effect of high turbine back pressure on the plant's capacity and efficiency (see Section VII).

As with both wet and dry towers, the EIS reviewer can assume that a design providing a wet/dry tower for a given closed-cycle cooling system is suitable to dissipate the waste heat. The reviewer can refer to the previous sections on wet and dry towers for operating and design information concerning the appropriate segment of the wet/dry tower. Reference should also be made to information contained in the technical literature[34, 35, 36, 33].

Water Consumption -

The water consumption from a wet/dry tower will vary considerably depending on the design (i.e., % dry vs. % wet), operation, and meteorology. Given this information, the EIS reviewer can use the procedures described previously for wet and dry towers to estimate water consumption.

Environmental Effects -

As discussed above, fogging (and thus icing) can be controlled by the design and operation of wet/dry towers. The EIS reviewer can use the information presented previously on fogging and icing for wet towers to assess a similar problem for wet/dry towers. Care must be taken, however, to include the effect of the dry heat exchange in evaluating the plume moisture.

<u>Drift</u> is caused by "mechanical" forces and is not affected by the heat exchange in a tower. Therefore, if all of the water is circulated through the wet section of a wet/dry tower, one would not expect the drift rate and subsequent deposition to be much different than for a conventional wet tower. Thus, the EIS reviewer can use the information presented on drift from wet towers to evaluate drift from wet/dry towers.

Conclusion

The material provided above on various closed-cycle cooling systems should provide the EIS reviewer with sufficient information to assess the great majority of power plant closed-cycle cooling systems. Unique systems, such as fan assisted natural draft towers[37], and oversized towers for fog control as proposed for the Sherburne County plant in Minnesota[38], were not discussed. However, enough general information is presented to enable the reviewer to address such unique systems in an informed manner.

D. ONCE-THROUGH COOLING

Introduction

The increasing scarcity of water supplies adequate to accomodate large multiple generating units, water temperature standards and mixing zone specifications, power plant effluent limitations, and the national goal of eliminating industrial waste discharges will tend to preclude once-through cooling for most new plants that use fresh water. In the remaining fresh and salt water cases, evaluation of the applicant's methods, findings and conclusions are required.

Data to support proposed once-through cooling may be in the form of physical model results, mathematical model results, transposition of data from an existing plant to an undeveloped site, or combinations of these. Although data transposition can complement model data, it will seldom stand alone in marginal cases because of physical, hydraulic, and plant dissimilarities between sites. So we turn here to physical and mathematical models.

The first question in evaluation is the suitability of the applicant's model to the case at hand.

Applicability of Models

Unfortunately, models are not always made to behave identically to their natural counterparts (that is, to their prototypes). The reasons are these: (a) Even if it were possible to formulate most general mathematical models so that they closely resemble nature, they would (1) become too difficult to solve mathematically, and (2) would depend on certain inputs that are not easily available; (b) Physical models can be made to closely reproduce the behavior of a prototype only if they are made as large and as complicated as the prototype itself.

For the reasons mentioned above, all practical models, whether mathematical or physical, are simplified so that (a) they become amenable to analysis, and (b) they are economically feasible to build and operate. Nevertheless, if simplification is made at the expense of those very processes in nature that the models are assumed to imitate, then the benefit derived from such models is limited proportionately to the sacrifice made to arrive at simplification. This should not imply that good models must be necessarily complicated, but it does mean that (a) a simple model can be developed to represent and predict reasonably well few (but not all) particular processes in nature, and (b) a complicated model may fail to predict a simple process if not properly applied.

In short, it is always important to examine all assumptions used in developing a model and to guard against applying the model to situations they are not intended to represent.

A report by Silberman and Stefan[38a] discusses the attributes and limitations of physical modeling. Where boundary conditions are complex or mathematical models are otherwise unreliable, an applicant seriously proposing once-through cooling should provide physical model data along with sufficient description of the model and studies for EPA evaluation.

In general, mathematical analytical techniques can be classified with respect to submergence of the discharge.

Deep submergence implies the absence of extraneous effects, such as proximity of the water surface and the ocean or river floor or any wall or barrier that might affect the plume trajectory. The jet must be submerged at least 40 or more diameters deep. Reference 39 provides a useful compilation of numerous practical analyses of this discharge category.

In a shallow discharge the effects of such disturbances as the bottom, water surface, and downstream flow conditions are accounted for either analytically or experimentally. Examples of vertical discharge in shallow water without current are given in Reference 39. Reference 40 is a comprehensive review of shallow discharges and provides analysis and experimental results of multiport diffusers. Reference 41 deals with single jet discharges. It contains limited but useful data.

State-of-the-art information on surface discharges is presented in Reference 42. Reference 43 is a User's Manual for surface discharges and Reference 44 is a compilation of recent data.

<u>Generalizations on Plume Behavior</u>

Thermal plume behavior depends on characteristics of both the receiving water and the discharge. Plume analysis is primary a matter of hydraulics (mixing); heat exchange between water surface and atmosphere usually, but not always, plays a relatively minor role in the location of isotherms less than about Δ2°F.

Inasmuch as receiving water charactersitics at a site are generally fixed whereas discharge characteristics are variable, the former imposes the first set of limitations on designing an acceptable once-through discharge.

The following is a listing of some possible receiving water characteristics that affect mixing:

a) The ambient water could be i) nearly motionless, such as in a lake, ii) flowing, such as in a river, or iii) intermittent, such as tidal waters.
b) The water body may be without temperature or salinity stratification or partially or totally stratified.

c) The water basin near the discharge may be deep and vast or there may be effects of boundaries, such as shoreline and bottom slope.

d) The ambient water may be influenced by the action of wind. This effect may be very strong or negligibly small at times.

Pertinent discharge characteristics include:

a) Submerged or surface discharge.

b) Discharges from single or multiple round ports or from a rectangular port.

c) Discharges from an open channel or a closed conduit.

d) Discharges in the general direction of the current, cross current, counter current, or other angles.

e) Discharges in a vertical, horizontal, or inclined direction.

f) Generally uniform and constant discharges or intermittent and time varying discharges.

Other factors being equal, the greatest degree of mixing can be accomplished with multiple port discharges in deep water. This is usually preferred from a biological standpoint because the smallest volumes of water are subjected to excess temperatures for the minimum length of time. Stratification with little or no mixing can result from a surface discharge from a channel. In rivers, such heated surface layers are usually not acceptable if they cover a major portion of the river width. A high velocity discharge into a cross current may in some cases cause too much penetration and blockage of the waterway, thus preventing the natural migration and other activities of fish. For this reason, discharges at an angle may be more desirable.

In the majority of situations, it is desirable to locate the discharges **at some** distance downstream of the intake; also when there is no predominant ambient current, to locate the discharges at a higher elevation than the intake, in order to avoid or eliminate the possibility of recirculation.

Once-through discharges using ocean water often require large diameter pipes extending hundreds or even several thousand feet into the ocean to reach deeper waters so that shallow coastal waters are protected from excess heated water. Such pipes are often made of concrete and they can be more than ten feet in diameter. Typical jet diameters for single port discharges may be on the order of ten feet and for a multiple port discharge, on the order of one foot. Typical dimensions of a surface jet channel may be up to one hundred feet wide and up to 30 feet deep. Typical discharge velocities from a submerged jet are 6 to 17 ft/sec and for surface discharges, 1 to 6 ft/sec. Excess temperature is on the order of 15 to 30°F depending on the waste heat load and the flow rate used.

The interaction of the plume with the ambient water results in the following:

a) dilution is enhanced by the turbulence in the ambient current, by wind, and by a high velocity discharge into a current,
b) plume rise from a submerged discharge is delayed by ambient current, and by jet inclination,
c) plume rise can be totally terminated in a stratified environment,
d) the discharge from the shore into a river can result in deep penetration if the jet velocity is much greater than the river current--otherwise the plume hugs the shoreline,
e) the plume width is generally greater in stagnant water than in moderate currents.

Water Consumption

The amount of water consumed by wet cooling devices (see information presented in Section IV-C) is often noted as an adverse effect. This may or may not be true, depending upon the local availability of water. A point often overlooked, however, is the fact that once-through cooling systems also cause water consumption (i.e. evaporation) to occur. A significant portion of the waste heat in the discharge is ultimately transferred to the atmosphere by latent heat exchange at the water surface, which incidentally, may cause a "steam fog" to occur. For example, a once-through cooling system for a 1000 MWe fossil plant on Lake Michigan could cause an annual average evaporation loss in excess of 8 cfs[4]. The EIS reviewer should make sure that a value for this evaporative loss is provided, to assist in both his assessment of the system and his comparison of alternatives.

Suggestions for Review

Although certain deviations may be necessary, the following checklist and approach have been useful.

1. The reviewer should familiarize himself with the general topography of the site, particularly with respect to the water body that is being used as the source of cooling water and as a recipient of the heated effluent. Important items to be reviewed are:

   a) ambient flow conditions, such as the velocity, flow rate, tidal exchange and tidal prism, etc.,

   b) water depth at the discharge and intake as well as the general depth contours,

   c) seasonal variation in flow, particularly the extreme (such as the 7-day, once in 10-year occurrance) and average conditions as obtained from past records, and

   d) the ambient weather conditions, particularly the presence of prevailing wind and severe or extreme climates.

2. The reviewer should then briefly check the applicant's calculation for the flow rate at a given ΔT against the quantity of heat that the plant is expected to release. The following equation can be used:

$$Q = 0.00445 \, (WH) \, (P)/\Delta T \qquad (9)$$

where Q = Flow rate, cfs

WH = Waste heat to cooling water, Btu/KWH

P = Plant size, MWe

ΔT = Cooling water temperature rise, °F

Figure 2 is a graphical representation of this equation.

3. Some of the preliminary environmental considerations can be sized up at this point, as follows:

a) compare the relative flow rate of the ambient water against the discharge. If the river flow or tidal exchange is, say ten times the discharge rate or less, then the assessment of the physical impact, if not already obvious, should be reserved for further detailed examination,

b) check if the discharge is reasonably well extended into the deeper waters,

c) check if there is obvious scouring of the bottom or obvious plume hugging of the shoreline,

d) check for minimum length of piping ahead of the diffuser to see if the exposure time to heat could be minimized--note also the competing results from c) and d),

e) examine some of the results, such as centerline temperature, plume dimensions and plume areas enclosed by specified isotherms.

If in the above considerations, the following are observed, closer examination is needed:

a) if the plume area is relatively large compared with the gross water surface area near the discharge,

b) if the topography is very complex, such as shorelines, bends, etc.,

c) if there is tidal fluctuation, and

d) if there is the possibility of a sinking plume. The latter possibility could present itself if the discharge water is more saline than receiving water, or if there is temperature stratification under winter operating conditions, such that the discharge could be locally more dense than the receiving water anywhere along the trajectory of the plume.

4. There are situations where the reviewer may form a definite idea at this point as to whether or not the once-through system is an acceptable alternative. This happens only when there are clear indications of environmental acceptability of the plan or a clear indication of lack of such acceptability. In the other cases, however, a more detailed study may be required.

It should be pointed out that a complete analysis of once-through systems requires expertise in several disciplines including engineering, economics, and biology. Important factors in all these disciplines dictate the method of discharging heated water from a once-through system. Among the factors to be considered in selection of one method of discharge over another are:

a) environmental impact,

b) temperature criteria,

c) cost,

d) cooling performance, and

e) cooling water recirculation.

E. COMBINATION COOLING SYSTEMS

Operating Characteristics

Combination cooling systems have characteristics of both closed-cycle and once-through systems. Although terminology often differs, the "helper" category includes any of the cooling devices discussed previously in this section to recirculate any portion (0-100%) of the cooling water requirement. The operating mode is determined by the temporal characteristics of water supply availability, water temperature, meteorology, and by applicable water quality standards. Another combination system uses a "terminal difference" or auxiliary cooling device which removes a portion of the waste heat from a once-through system.

Cooling systems involving helpers should be reviewed carefully, inasmuch as the tempting by-pass option is always present. In terms of economics, any advantage of helper over closed-cycle for optimized new plants is marginal due to the interrelationship of the turbine condenser and cooling device[2, 3, 4]. For retrofitting an economic advantage may exist. In any event, the economic analysis must be approached on a case-by-case basis.

One problem with helpers is the inadequacy of the management (decision making) system in comparison to the versatility of the hardware. While theoretically a helper system can be tuned and operated so that the discharge quality will "just meet" water quality standards or effluent limitations, a rather sophisticated in-stream and in-plant sensing network coupled with a conditional probability program is required to turn the right valve at the right time. We have not seen such a system described in any environmental impact statements reviewed.

An EIS on a helper system should contain the following information:

1. The percent of time the cooling device will be operated.

2. The operation schedule throughout the annual cycle.

3. The amount of waste heat removed with respect to 1 and 2, above.

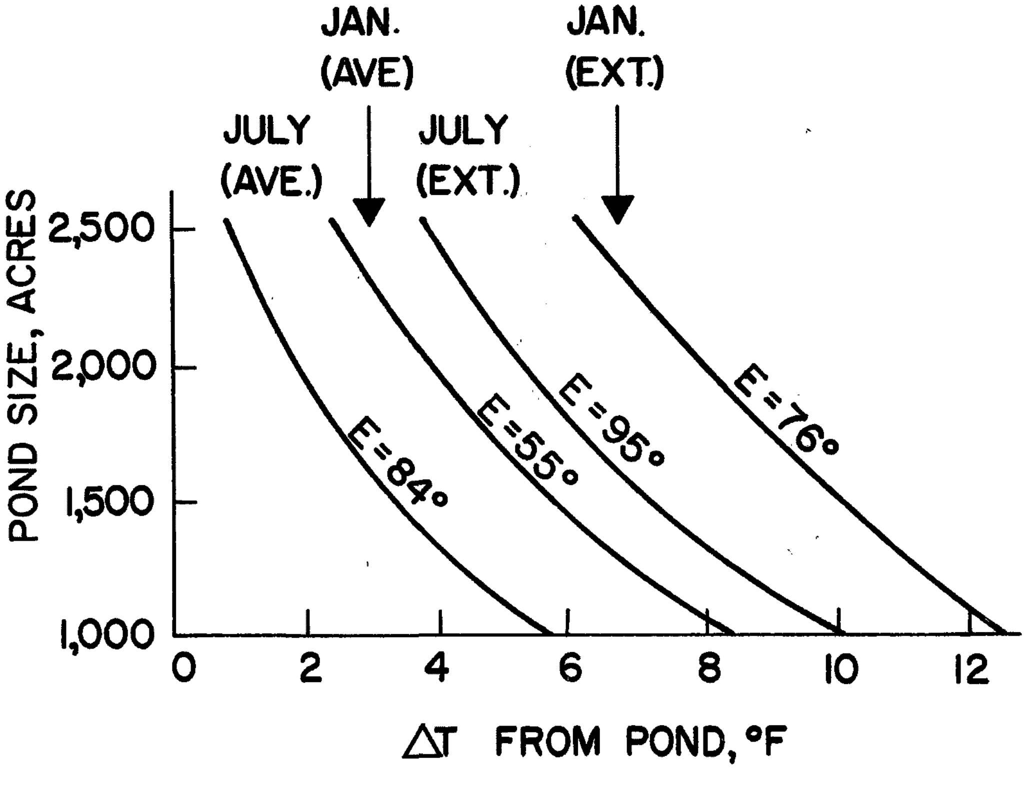
4. How the operation according to 1 and 2 above will affect the water consumption, fogging and icing potential, drift, and blowdown (if any).

The consent decree in the case of Houston Lighting and Power versus Ruckelshaus, et. al. allows an auxiliary system. In this instance, a cooling pond on a once-through cooling system dissipates a seasonally variable fraction of the waste heat from the condenser effluent for discharge into Trinity Bay.

Practical cooling limits of evaporative auxiliary systems, as related to equilibrium temperature and evaporation rate or wet bulb temperature, should be examined throughout the annual cycle. A system that can meet water quality standards in the summer, under design conditions, frequently will not in the winter if such standards limit the temperature rise above ambient temperature. Figure 12 exemplifies seasonal variations in cooling pond efficiency near Galveston Bay, Texas for an auxiliary pond on a 1,500 MWe fossil fueled station.

For cooling towers, an approach to wet bulb temperature of less than 10°F is rarely achieved under design conditions and certainly the approach is never less than 5°F. Therefore, to determine the effectiveness of auxiliary cooling towers on a once-through system, one can compare the practical cooling limit, (wet bulb plus approach) to the receiving water temperature. Table 3 provides such a comparison for the same geographical area. Note that through much of the year a tower effluent would be appreciably warmer than the receiving water.

FIGURE 12
SEASONAL PERFORMANCE OF AN AUXILARY COOLING POND FOR A 1500 MWe FOSSIL FUELED POWER PLANT



NOTES:
T IN = E + 20 °F
T OUT = E + ΔT FROM POND
AVE. = AVERAGE METEOROLOGICAL CONDITIONS
EXT. = EXTREME METEOROLOGICAL CONDITIONS

Table 3. COMPARISON OF MECHANICAL DRAFT TOWER COOLING LIMITS TO RECEIVING WATER TEMPERATURE

Month	Cooling Limit (°F) 5°F Approach	Cooling Limit (°F) 10°F Approach	Receiving Water Temp (°F) Average	Receiving Water Temp (°F) Maximum
Jan	73	78	56	63
Feb	73	78	53	60
Mar	75	80	62	67
Apr	79	84	72	80
May	83	88	80	86
Jun	86	91	84	86
Jul	85	90	86	90
Aug	85	90	86	90
Sep	85	90	85	90
Oct	85	90	72	79
Nov	83	88	72	76
Dec	78	83	55	64

When air and water temperatures drop, prudence imposes another lower practical limit on tower effluent. Regardless of meteorologic limits on cooling capability, no plant superintendent is going to run a tower with a cold leg anywhere close to freezing temperatures because of the hazard of tower icing, which can be very costly.

Any wet cooling device can be used in a combination system for either an original design or a backfitted situation. For backfitted systems, the design and construction flexibility of spray systems is often overlooked in the EIS.

Water Consumption

The amount of water consumed by a combination cooling system will be governed by the same factors discussed previously for closed-cycle and once-through cooling systems. The EIS reviewer can compute the total water consumed on a design and annual basis using the procedures given previously coupled with information on the percent of waste heat dissipated and the seasonal operating schedule.

Environmental Effects

The environmental effects of combination systems can be assessed using the techniques described previously for closed-cycle systems. The operational characteristics of the combination system may ameliorate some environmental problems (e.g., reduced use of cooling towers in cold weather will lower probability of fogging and icing problems). On the other hand, an auxiliary cooling tower will increase the time-temperature exposure for entrained organisms and probably cause more damage to such organisms. Thus, the fact that an auxiliary cooling device will permit water quality standards to be met does not insure an improvement in the environmental acceptability of the cooling system.

In summary, any proposed combination cooling system should be viewed, initially at least, with judicious scepticism.

SECTION V
CHEMICAL, BIOCIDAL, AND SANITARY WASTES

Numerous chemical wastes and other effluents are generated during startup and normal operation of a nuclear power plant. Many of these effluents are totally independent of the type of cooling system utilized; however, it is common practice in most cases to combine these effluents with the cooling water or blowdown discharges at some point before final release. Therefore, although the quantity of many constituents is unrelated to the cooling system choice, the concentration of the constituent in the discharge stream may well be determined or influenced by cooling system choice and operating characteristics.

Although the combining of effluent streams before discharge is a common and acceptable practice, the dilution effect should not be pursued as a substitute for treatment of wastes prior to discharge. Since the quantity of blowdown is governed by the cycles of concentration in a closed-loop system (i.e. low C, greater blowdown volume), the reviewer is encouraged to assess carefully the reasons for running at the proposed number of cycles, especially if the C value appears excessively low. Cycles of concentration should be governed by water quality limitations as described in Section IV-C and should be as high as possible. Treatment of wastes may be required before dilution with other effluent streams.

Radioactive wastes and most toxic wastes are processed through the radwaste system. The following discussion is primarily oriented toward other wastes, from the plant or from cooling water treatment, which the reviewer should survey in connection with cooling system alternatives. Sanitary waste treatment is usually dictated by State requirements, to which conformance is normally verified quite easily.

Only a few of the most common chemical pollutants are cited herein because of the great variability of treatment requirements (and resulting effluent characteristics) occurring from site to site. The best approach for the reviewer is to carefully assess: (1) The quantity of each constituent added for plant operations, and (2) the before/after comparison of the concentrations of any constituent causing potential pollution concern. Resulting constituent levels in discharge effluents should then be compared with Water Quality Standards or applicable effluent requirements or pertinent information which may indicate the reasonableness or environmental acceptability of proposed discharges.

Liquid wastes with pollution potential emanate primarily from condenser cleaning, water treatment, and blowdown operations.

An important area to review is the method of control of biological growth in the condensers. Periodic addition of chlorine is an effective method of control which has been widely used in the power industry. However, the toxic effects of chlorine or chlorine derivatives to aquatic organisms require minimization and close control of these constituents in effluent discharges. When chlorination is proposed, the length of time and the concentration of residual chlorine (free and combined) in discharges should be reviewed for compliance with recommendations by Brungs[45], which follow in Table 4. It should be noted that these recommendations apply only to freshwater aquatic life and that the criteria vary according to time factors and type of organisms.

Table 4

RESIDUAL CHLORINE RECOMMENDATIONS, from Brungs[45]

TYPE OF CHLORINE USE	CONCENTRATION OF TOTAL RESIDUAL CHLORINE	DEGREE OF PROTECTION
Continuous	A. Not to exceed 0.01 mg/l	This concentration would not protect trout and salmon and some important fish-food organisms, it could be partially lethal to sensitive life stages of sensitive fish species.
	B. Not to exceed 0.002 mg/l	This concentration should protect most aquatic organisms.
Intermittent	A. For a period of 2 hr a day, up to, but not to exceed, 0.2 mg/l	This concentration would not protect trout and salmon.
	B. For a period of 2 hr a day, up to, but not to exceed, 0.04 mg/l	This concentration should protect most species of fish.

If proposed chlorination practices are deemed unacceptable, various approaches may be applicable, depending on the situation, for further control, including:

(1) Practicing split stream chlorination, i.e. treating one condenser at a time.

(2) Reducing the chlorine feed period.

(3) Combining a discharge stream with another in-plant stream which has a high chlorine demand.

(4) Discontinuing blowdown during periods when residual chlorine is present in the cooling tower sump.

(5) Decreasing the rate of chlorine addition during feed, in proportion to the reduction of chlorine demand of recirculating water in closed-cycle systems. This method maintains a constant residual chlorine level at the condenser discharge.

(6) Adding sodium sulfite, sodium bisulfite, or sulfur dioxide to blowdown to reduce residual chlorine.

A recent report by Nelson[46] provides specific information on evaluating many of these control techniques.

A different type of control from those cited above is that of mechanical cleaning of condenser tubes which, from an environmental standpoint, is the preferred method because no chemicals are employed. Balls (Amertap System) or brushes (MAN System) are passed through the condenser tubes periodically to cleanse them of biological growth. Mechanical cleaning is being used in numerous instances, particularly in new plants where it can be incorporated into the initial design. Mechanical cleaning may promote better heat transfer efficiency; disadvantages include installation and maintenance problems and potentially higher costs than chemical cleaning. Also, the condenser alone is treated whereas chemical cleaning affects the entire cooling system.

Boiler water treatment wastes include demineralizer regenerant wastes, filter backwash and coagulant sludge blowdown. In this category total dissolved solids (mostly sodium sulfate) are most notably increased.

Steam generator blowdown may contain phosphate loads which could affect receiving water nuisance growth potential. Morpholine, a pH control agent, might also be present in this blowdown and has potential adverse aquatic effects.

Cooling tower blowdown will contain constituents in the makeup water and materials in the recirculating water which are scrubbed from the air and concentrated due to continual water evaporation by the cooling tower.

Other chemicals may be added infrequently or in small amounts for various purposes during plant operation. These can include deposit control agents (which may contain nitrogen or phosphorous), cleaning agents, or proprietary biocides, as required.

Corrosion control may be required in a very small number of cases, primarily those with high chloride concentrations in the circulating water. Generally, however, corrosion is not a significant factor because potential problems can be averted through proper choice of corrosion resistant materials or coatings. Where protection is required, chromate, zinc, or phosphate based inhibitors may be proposed. Their presence in blowdown waters requires careful assessment with regard to permissible concentration levels and potential reduction and/or removal.

The assessment of the above general or unpredictable plant wastes must be approached on an individual constituent basis, as mentioned previously. Waste characteristics and potential impact will vary from site to site, depending on source and receiving water quality, system type and operating procedures, required treatment, discharge procedures, etc. Common waste sources and constituents are covered here to orient the reviewer toward potentially significant areas, but individual parameters must be viewed in the context of applicable regulations and/or practical alternatives or treatment for the given situation.

SECTION VI
ALTERNATIVE COOLING SYSTEMS

The reviewer's objective in this area is basically three-fold: (1) to assure that all feasible cooling system alternatives are included in the EIS presentation, (2) to assure that alternatives are described accurately and thoroughly, and (3) to judge the validity of the applicant's proposed choice when compared to the alternatives described.

The AEC's Regulatory Guide 4.2, "Preparation of Environmental Reports for Nuclear Power Plants"[1] provides guidance to applicants for presenting information which forms the basis of the EIS. The following excerpts from this guide are cited below to indicate the intent and scope of the coverage of alternatives:

> "The applicant should ... show how the proposed plant design was arrived at through consideration of alternative designs of identifiable systems and through their comparative assessment."

> "The applicant should limit the discussion to those alternatives which the current state-of-the-art indicates are technically practicable."

> "The discussion should describe each alternative, present estimates of its environmental impact and compare the estimated impact with that of the proposed system."

> "Environmental effects of alternatives should be fully documented."

"The acquisition and operating costs of individual systems and their alternatives (as well as costs of the total plant and transmission facility and alternatives) are to be expressed as power generating costs."

If cooling system alternatives are described in full accordance with the context of the above instructions, the reviewer will have little problem in meeting his objectives. He should, however, follow a general stepwise procedure in his overall assessment.

The reviewer is referred to Section V - C for the description of devices, in addition to once-through, which are technically feasible under the current state-of-the-art. However, this does not imply that all of the systems described must be considered as viable alternatives for every situation.

Technical infeasibility may be established in instances where physical or operational design flexibility does not exist. For example, dry cooling towers are usually not applicable to backfitting situations, i.e. existing plants or those in design/construction stages where a turbine is on order. Space availability may also preclude consideration of certain control devices, most notably cooling ponds which require large land areas. Meteorological hazards may be a governing condition, e.g. natural draft towers may likely be excluded in areas of high hurricane potential. These examples indicate that there are a multitude of valid reasons why some devices are not feasible in some cases. The reviewer is encouraged to use the devices described in Section V - C as a check-list; if these devices are not presented as alternatives, he should look for valid reasons for their exclusion.

The description of each of the alternatives must be accurate and complete enough to permit an unbiased comparison of potentially applicable systems. Again, the reviewer is referred to the detailed technical and economic considerations for each system as presented in respective sections of this guide. Considerable judgment must be exercised in determining exactly what information must be included. Although the system characteristics discussed elsewhere should be used as a check-list, it is not possible to set absolute coverage requirements. There is a tendency in some EIS presentations to provide extensive coverage of the proposed system and lesser coverage of alternatives. It is the responsibility of the reviewer to see that each valid alternative is addressed in a manner which satisfies his evaluation needs. If he feels that inadequate information is provided, it should be expressed in review comments.

The ultimate purpose of reviewing cooling system alternatives is to support or challenge the applicant's choice. This decision must consider the overall relative implications of each system. Individual systems all have their own merits and disadvantages, so that a clear-cut choice is not always apparent. In the end, the reviewer's recommendations, comments, or conclusions should be based on a reasonable balance between technical/economic feasibility and environmental impact, as revealed through his review process.

SECTION VII
BENEFIT-COST ANALYSIS

The objective in this area of review is to assess, verify, and compare the economic implications of various cooling system alternatives. The emphasis is, therefore, placed upon incremental values associated directly with specific cooling systems rather than the absolute magnitude of basic factors which are not affected by the cooling system choice, such as the value of power to be sold or the cost of the basic plant excluding cooling system choice. In general, the EPA technical review is not concerned with other alternatives, such as alternative methods of providing power.

BENEFITS

The single direct benefit from a proposed power plant is represented by the total revenues to be obtained from sale of electrical energy, steam, or other products produced by the plant. In most cases the product will be electrical power and the amount to be generated will be specified, regardless of the choice of cooling system. Although the present value of this benefit can be checked rather easily, it is not necessary to do so for review purposes. It is important to recognize, however, that this is the single direct benefit from the proposed plant. Any other benefits that might be cited, e.g. taxes, employment, research, regional products, etc., are already covered by the single direct benefit. If these types of indirect or secondary benefits are attributed to the plant, they should be labeled as such.

COSTS

The review of the cost analysis related to cooling system alternatives is not a clear-cut approach, since judgment must be applied throughout. The basic reasons for this are as follows:

(1) Various environmental effects (costs) associated with different cooling systems cannot easily be monitized. Therefore, one can not adhere to a strict to ratio for comparisons and the review may approach more of a net cost ranking of alternatives than an absolute quantification.

(2) Equipment and operating costs attributable to specific cooling systems are not easily identified for comparative purposes.

(3) The degree of committment to a proposed plant design can alter the benefit-cost analysis. For example, if sizeable expenditures for design and construction have occurred, a cost analysis of alternatives is strongly biased toward the chosen system since others would incur the cost penalty of "scrapping" the system under construction.

The proposed plant and cooling system design serves as the reference design case in an EIS cost analysis. Monitary costs of alternative systems are presented in terms of incremental generating costs, on a total present worth or annualized basis, as compared to the reference design. Incremental generating costs reflect the combined effect of all fixed and variable cost differences from the reference design. An EIS will usually not provide the extensive background information which would be needed to individually reconstruct the two components of the incremental generating cost. However, in the majority of reviews it will not be necessary to attempt cost verification through such a complex procedure. The approach here will be to first provide the reviewer with general guidelines by which the reasonableness of incremental costs may be judged for the majority of cases. Secondly, a brief discussion of the scope of a detailed verification is presented along with numerous referenced sources of additional information pertinent to such a review.

Generalized Cost Verification Procedure

The information presented in this section will usually suffice for reviewing the following cases:

(1) When the base design and alternative cooling systems being considered are closed-cycle.

(2) When the proposed cooling system for a new plant is undoubtedly desirable in terms of minimized environmental effects. In this case, the outcome of the monitized cost comparison is of secondary importance.

(3) When plant construction has progressed to the point where "sunk" costs bias or control the benefit-cost ratio. In this case, it is obvious that monitary considerations alone will not indicate that a complete change in cooling system design is desirable. Environmental acceptability with minimum added cost must be sought.

In the EIS, the total capital cost of the reference plant may or may not be broken down into costs for the basic plant and costs for the cooling system. The basic plant cost, excluding the cooling system, varies greatly with site, design, and economic conditions and need not be challenged. Where capital costs of cooling systems alone are identifiable, one can compare the reasonableness of the costs with the typical values for new plants cited in Table 5.

Table 5. CAPITAL COSTS FOR NUCLEAR PLANT COOLING SYSTEMS[47]

Once-through system:	3	to	5	$/KW
Natural draft cooling towers:	9	to	13	$/KW
Mechanical draft cooling towers:	8	to	11	$/KW
Cooling pond:	6	to	9	$/KW
Spray system*:	7	to	10	$/KW

The values cited above do not reflect operating penalties of the systems and therefore, cannot be used as a primary judgment factor. However, the capital cost comparison should be used as a first-cut evaluation which may identify systems requiring more detailed scrutiny.

The once-through system costs cited herein, later used as the basic or reference case, reflect a more-or-less typical or uncomplicated once-through situation. Long outfalls with diffusers can be quite costly, depending on site-specific factors. Economic data on long outfalls and diffusers are limited, but the following design-cost studies on existing installations are mentioned here to provide a feeling for the magnitude of costs which might be quoted.

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* Independent estimates, not in reference.

In 1967, Parkhurst, Haug, and Whitt[48] of the Sanitation Districts of Los Angeles reported on five major outfalls on the Pacific Coast. Their tabulation includes trunk diameters up to 12 ft, overall lengths up to 22,000 ft, and depths of discharge in excess of 200 ft. Costs range from slightly over $100/ft to almost $500/ft. The cost data are probably low by today's scale.

A 10 ft diameter steel sewer outfall running 18,000 ft out into Lake Ontario from Rochester, New York, is described in the September 17, 1970, issue of Engineering News Record[49]. The cost reported is 18.7 million dollars, or about $1,000 per ft.

Kempf and Fletcher[50] report on the effects of site selection on the capital costs of nuclear electric plants. They cite design data typical of construction costs for discharges on the West Coast. Overall unit costs range from $233 to $872 per ft, depending partially on trunk diameters, which range from 7.5 to 14 ft.

A more sensitive approach for judging cost reasonableness is to look at the magnitudes of incremental generating costs presented for the alternatives. As noted earlier, incremental generating costs reflect all capital and operating cost increases attributable to a cooling system; the percent increase is, therefore, also comparable to calculated increases in busbar costs for a given plant output.

In the EPA analysis of cooling system alternatives for new nuclear power plants near Lake Michigan[4], the maximum busbar cost increases were determined, as cited in Table 6:

Table 6

BUSBAR COST INCREASES--COOLING SYSTEMS FOR POWER PLANTS NEAR LAKE MICHIGAN

Type of Cooling System	Percent Busbar Increase Over Reference
Once-through (Reference)	----
Cooling Pond	< 1%
Wet Mechanical Draft Tower	2%
Wet Natural Draft Tower	3%

Since incremental generating costs may be expressed in either total present worth or annualized figures, the reviewer should be careful to use consistent bases when calculating the percent increase over total generating cost. Regardless of the choice, the percentage increase in generation cost due to respective cooling systems should generally correspond to the percentages cited above for new plants of optimized design.

Another way of looking at the magnitude of costs attributed to cooling systems is to express the cost difference from the reference design in terms of mills/KWH of electricity produced and them compare these figures with recent study results reflecting busbar cost variations. One should use annualized incremental generating costs between each pair of cooling systems being compared, thus:

$$\Delta \text{Mills/KWH} = \frac{[\Delta \text{ Annualized Cost, \$}] \times [1000 \text{ Mills/\$}]}{[\text{Plant capacity, KWe}] \times [\text{Annual Plant Factor,\%/100}] \times [8760 \text{ hr/yr}]}$$

Table 7 contains referenced results of busbar cost increases for new plants, compared to once-through, which can be used in comparing the relative magnitudes of busbar cost differences in mills/KWH:

Table 7

RELATIVE BUSBAR COSTS (Mills/KWH)
FOR NUCLEAR POWER PLANT COOLING SYSTEMS

Sources	Once-through Fresh Water	Once-through Salt Water	Cooling Pond	Mechanical Draft Tower	Natural Draft Tower
Woodson[51]	--	--	+0.08	+0.11	+0.22
EPA[4]	--	--	+0.06	+0.14	+0.22
Hauser[52]	--	+0.3	+0.09	+0.21	+0.20

The variation in the values cited above is worth noting. It points out the fact that one cannot go too far in evaluating cooling system costs of a specific plant by comparing them to general norms. However, the above costs do establish a relative level for reasonable incremental cooling system costs. Deviations from these levels may well be justified, but the reviewer is encouraged to investigate the reasons behind gross deviations.

One reason for differences in values given above is that penalties for various cooling systems are based on varying assumptions. Two cost penalties often identified specifically in EIS cost analyses are:

1) Capability loss (or capacity loss), which occurs when higher condensing temperatures, determined by the type of cooling system and meteorological conditions, cause higher back pressure on a turbine at full-load and reduce its output. Capability loss occurs only when the turbine's rated capacity can not be attained due to high back pressure.

(2) Added fuel cost (or effeciency loss), which is also a result of high turbine back pressure because it increases the heat rate (Btu/KWH) of the turbine for any level of output, thus more fuel is required to generate a KWH of electricity.

Costs for capability loss and added fuel cited in an EIS Benefit-Cost Analysis can have a sizeable impact on the economic feasibility of the systems involved, and it is important to have a gauge of their reasonableness. The work of Hauser[52] also includes an incremental cost breakdown (in mills/KWH) for capability loss and for added fuel cost for new plants. Table 8 presents this information along with an additional column showing the magnitude of annual costs represented by these two penalties. The annual costs were calculated by using the formula for Δ mills/KWH given above and from Hauser's assumptions of a 1000 MWe nuclear plant operating with an 80% plant factor.

Table 8

COSTS OF CAPABILITY LOSS AND ADDED FUEL
ATTRIBUTED TO VARIOUS COOLING SYSTEMS

Type of Cooling System	Capability Loss (Mills/KWH)	Fuel Cost (Mills/KWH)	Combined Annual Cost (1000 MWe Plant)
1. Fresh Water (Once-through)	Base	Base	Base
2. Cooling Ponds	0.0300	0.0240	380,000
3. Sea Coast (Once-through)	Base	Base	Base
4. Wet Cooling Towers Mechanical Draft	0.0300	0.0240	380,000
5. Wet Cooling Towers Natural Draft	0.0300	0.0300	380,000
6. Dry Cooling Towers	0.1590	0.1272	2,000,000

As with other cost values presented herein for comparisons, it is important to realize that these figures are given to indicate reasonable cost levels; values for specific plants can vary considerably from site to site. Also, these figures were calculated in 1970 for new plants; hence, normal cost escalation should be taken into account. These factors do not detract from the intended use of the figures for guideline purposes, however.

Scope and References for Detailed Cost Verification Procedure

In a relatively small number of cases the validity of costs projected for various cooling system alternatives becomes paramount. This situation is usually encountered when a proposed once-through cooling system is questioned or challenged on environmental grounds while the applicant is attempting to justify his proposed choice, partly on the basis of economics. If the reviewer is faced with such a situation the benefit-cost analysis requires a thorough verification not only of the final figures presented but also of the values, assumptions, and procedures used in determining the costs cited for considered systems.

It is beyond the scope of this presentation to cover the multitude of assumptions, inputs, and calculations required for verifying a cost analysis in detail. Table 9 provides sources of more detailed information on procedures and economic factors. The EIS reviewer is urged specifically to obtain reference 3, which provides nomograph solutions for many of the cost estimates required.

Table 9

REFERENCES FOR DETAILED ECONOMIC REVIEW

Subject	References
1. AEC recommended approach for benefit-cost analysis.	1
2. Plant and/or cooling system economic analysis procedures.	3, 4, 52, 53
3. Plant and/or cooling system costs.	3, 4, 53, 55, 60
4. Fuel Costs.	3, 4, 53, 55, 59, 60
5. Production Costs.	3, 4, 53, 55, 60
6. Backfitting Costs.	3, 4, 56, 57, 58

Backfitting Costs

The reviewer will need to familiarize himself completely with power plant economics to do an acceptable job of reviewing an EIS benefit-cost analysis in detail. Many site specific factors arise with respect to individual plants which necessitate such familiarity for valid judgments to be made. A good example is for backfitted situations.

Estimates on the cost of backfitted cooling facilities are available for a large number of specific plants. These data are, for the most part, contained in utility environmental reports and AEC draft environmental impact statements. The most striking aspect concerning these data is the lack of consistency in the methods of reporting. This results in widely different cost estimates. For example, total capital cost data for backfitting power plants on Lake Michigan reported by Argonne National Laboratory[57] ranged from $19.4/KW to $95.7/KW for wet towers. Assuming a fixed charge rate of 14 percent and a plant load factor of 82 percent, the increase in busbar cost would be 0.38 and 1.86 mills/KWH, respectively. Thus, these backfitting costs differ by a factor of five.

In computing the increased busbar cost due to backfitting, care must be taken to use realistic values for plant capacity factor and fixed charge rate, since a short amortization period will increase the fixed charge rate. Reducing the capacity factor and/or increasing the fixed charge rate will increase the busbar cost differential for the same total capital cost differential.

While no single value for backfitting costs can be given with assurance, in general increased cost for retrofitted cooling systems will be from two to three times the increase in costs for optimized cooling systems given previously for new plants. On the basis of literature information, Tichenor[56] estimates that:

"Increased cost due to backfitting with a conventional wet tower system is about 0.6 mills/KWH; however, site specific problems can cause wide variations, both up and down, from this general value."

Finally, it is recognized that this report can not provide the expertise required to evaluate crucial or particularly difficult cases, and in such cases it is advisable for the reviewer to solicit outside help from sources experienced in power plant economic evaluations.

SECTION VIII

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16. Abstract

This report describes the approach and technical base that have been used by EPA's National Thermal Pollution Research Program for reviewing those portions of Environmental Impact Statements (EIS's) relative to the engineering aspects (including economics) of cooling water systems for thermal power plants. The report provides techniques and data to enable the EIS reviewer to make sound judgements concerning the adequacy of both the cooling water system selected for the power plant and the EIS comments on that system. Literature citations are provided to direct the reviewer to additional and more detailed information.

The report provides information and discussions on cooling system configurations, operation, environmental effects, and costs. Consideration is given to the intake as well as the discharge.

Various closed-cycle cooling systems employing cooling towers, cooling ponds, spray systems, and other devices are covered. Methods of assessing alternative selections and benefit-cost analyses are presented. Non-thermal aspects of cooling water systems are discussed.

The report lays the groundwork for a technically sound EIS review; however, the reviewer must supplement the material presented herein with references and perhaps technical consultation to prepare comprehensive and detailed review comments.

17a. Descriptors

Thermal power plants*, Nuclear power plants*, Environmental effects*, Electric power, cost-benefit analysis, cooling towers, thermal pollution

17b. Identifiers

Environmental Impact statements*, Cooling water systems*

17c. COWRR Field & Group: 06G, 05B, 06B

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