United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-79-251a
November 1979

EPA

Effects of Pathogenic and Toxic Materials Transported Via Cooling Device Drift - Volume 1. Technical Report

Interagency Energy/Environment R&D Program Report

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Effects of Pathogenic and Toxic Materials Transported Via Cooling Device Drift - Volume 1. Technical Report

by

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Contract No. 68-02-2625
Program Element No. INE624A

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Prepared for

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Washington, DC 20460

ABSTRACT

The report describes a mathematical model that predicts the percent of the population affected by a pathogen or toxic substance emitted in a cooling tower plume, and gives specific applications of the model. Eighty-five pathogens (or diseases) are cataloged as potentially occurring in U.S. waters, but there is insufficient data to predict the probability of occurrence or relate their occurrence to public health, population, or pollution. Sixty-five toxic substances are cataloged as potentially occurring in U.S. waters, but the actual number is probably many times the EPA-supplied list. Toxic concentrations to persons, animals, and plants are known for only a few of the chemicals: most toxic levels can be only inferred from animal studies. In the population as a whole, the epidemiological impact of a pathogen is a function of age, sex distribution, racial (genetic) distribution, general health and well-being, prior exposure, and immunological deficiency states. While cooling device drift may not be directly responsible for epidemics, it may potentiate the burden in an already weakened population, raising a segment of the population into the clinical state. The effect of toxic substances is difficult to evaluate because of inadequate data on humans. The effect is a function of concentration in susceptible tissue, and is much less dependent than pathogens on host resistance.

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LIST OF ABBREVIATIONS AND SYMBOLS

BTU	British Thermal Unit
BW	Biological Warfare
Ca	Calcium
Cl	Chlorine
cm	centimeter
DAT	Dynamic Aerosol Toroid
EMV	Encephalomyocarditis Virus
EST	Eastern Standard Time
FD	Forced Draft Cooling Device
Fe	Iron
g	grams
gpm	gallons per minute
HCO_3^-	bicarbonate ion
ID	Induced Draft Cooling Device
K	Kelvin
Km	Kilometer
l	liter
L/G	Water rate/air rate (lbs/time)
m	meter
m^3	cubic meter
mb	millibar
mm	millimeter
mg	milligrams
mw	megawatt
Na	Sodium
O	Oxygen
$(OH)^-$	Hydroxide ion
ppm	parts per million
r	radius
RH	Relative Humidity
SO_4^{2-}	Sulfate
SV_{40}	Simian Virus 40
Teo	ambient temperature near exit from tower
Tpo	plume temperature
μ	micron
VSV	Vesicular Stomatitis virus
WB	Wet Bulb

SECTION 1

INTRODUCTION

The recent trend in the electric power generating industry and major industries has been the use of closed circuit cooling devices. The use of these devices supercedes the use of once-through cooling systems which had the disadvantage of harmful thermal discharges into surface waters and fish impingement or entrainment. However, the closed circuit systems, or cooling towers, have potential problems, too.

Previous studies have shown that a potential health hazard could exist if pathogens were to be dispersed in cooling tower drift (Lewis, 1974; Cummings, 1964; Dvorn and Wilcox, 1972). This could occur as a result of drawing make-up water from highly polluted surface waters or from the use of processed wastewater (reclaimed water) with inadequate microbial control. In addition to the direct effects on plants such aerosols might potentially cause severe environmental damage, and present legal difficulties to the source operator, especially if the aerosol source impacted dense population centers.

Two prior studies were conducted by H2M for the Consolidated Edison Company of New York (Con Ed) and for a midwest utility that prefers to remain anonymous. Under the provisions of the work statement for the Con Ed study, H2M was to:

a. Inventory the sources of possible pathogen pollution in the Hudson, from the Bronx to Albany.

b. Prepare a catalogue of all possible organisms which could reasonably occur in the area and be transported by the cooling tower drift route.

c. Estimate the magnitude of the severity of the problem.

d. Describe the water treatment methods which would be needed to provide positive control over pathogens and totally eliminate the problem.

The one month study, based entirely upon published data and no field observations, drew the following conclusions:

a. Based upon coliform bacterial levels, used as indicators of fecal pollution, the contamination of the Hudson is sufficiently high to present the possibility of the occurrence of pathogens.

b. The physical conditions of temperature, pressure and flow in the cooling tower circuit will not attenuate pathogens, and during some months, may even prolong survival. The biocides which are added for algae control are ineffective against many pathogens (viruses, spores, etc.).

c. Many pathogens will survive aerosolization and can be transported in a virulent condition over thousands of square miles.

On the basis of the findings of this early study, it was concluded that the possibility of disease transmission through cooling tower drift exists. It was also concluded that the probability of this happening is very low. However, it is remotely possible that the proper combination of a badly contaminated slug of water, inadequate biocidal treatment, plus unfavorable atmospheric conditions could disperse millions of virulent organisms. Even if not particularly virulent, the constant loading of the atmosphere with biological and chemical respiratory offenders presented a potential of a general increase in "colds" and allergies, contributing to the overall discomfort and loss of productivity of populated areas.

That study did not produce firm recommendations due to the inadequacy of factual information. It did however conclude that the problem is sufficiently critical to warrant further study.

A study performed by NUS in 1974 for Public Service Gas and Electric Company of New Jersey, on the potential virus hazard from their Bergen, Burlington and Mercer plants concluded that there would be no hazard. But the authors neither sampled virus from the rivers of the respective plants, nor did they discuss any literature addressing specific organisms. Meanwhile, a very comprehensive review of the "health significance of airborne microorganisms from wastewater treatment processes," by Hickey and Reist (1975) stated:

> "The body of evidence is persuasive that some as yet undetermined health effects occur from viable wastewater aerosols."

This premise was confirmed by Walka (1976) in a thesis on the distribution of bacterial aerosols from a sewage treatment plant. He concluded that a survey is needed, especially examining the epidemiological effect of aerosols on populations surrounding wastewater treatment facilities. It was not felt that additional microbial monitoring around aeration tanks would be productive.

Work currently in progress by Lewis and Adams (1978) includes development of a sampling program seeking opportunistic bacteria, indicated by coliforms, in cooling device drift. Sampling was performed at five sites, drawing make up water from a variety of polluted sources. One completed study examines asbestos in cooling waters and a subsequent study is planned to sample for asbestos in the ambient environment.

Work has proceeded in examining the chemistry and effects of biocides in cooling towers (Jolley, 1977), and on the health of humans and aquatic organisms. The Electric Power Research Institute (EPRI) has acknowledged the need for further research and has been looking into the state of the art.

SECTION 2

CONCLUSIONS

In summary, the following conclusions may be drawn from this study.

I. OCCURRENCE

1. Pathogens Potentially Present

Eighty-five (85) pathogens (or diseases) have been catalogued as potentially occurring in United States waters. There is insufficient data to predict the probability of occurrence or relate their occurrence to public health, population, or pollution. The coliform test has no proven relationship between the occurrence of coliforms and specific pathogens, except for the one case of Salmonellae in which the frequency of occurrence varied directly with coliform values, (Geldreich and Van Donsel, 1970). It must be assumed that polluted water or sanitary effluent may carry pathogenic viruses, bacteria, fungi, protozoa, or helminths, either as indigenous organisms or introduced through any of several natural or anthropogenci routes.

2. Toxic Substances Potentially Present

Sixty-five (65) toxic substances have been catalogued as potentially occurring in United States waters, although the actual number is probably many times this EPA-supplied list. The occurrence of specific substances has been definitely related to land usage. Toxic concentrations to man, other animals and plants are known for only a few of the chemicals, for most toxic levels can be only inferred from animal studies. Concentrations in natural waters or wastewater effluent are not well documented, but toxic levels have been reported in many parts of the country. Although it is a natural goal to remove these materials from the environment, it must be assumed that they may be present. It must also be assumed that these substances are capable of producing clinical or sub-clinical toxic reactions in humans and other living organisms, even though the relationship has not always been demonstrated.

3. Use of Polluted Natural and Waste Waters as Make-Up Water

If cooling devices draw make-up water from polluted natural waters or wastewater with less than total purification, it must therefore be assumed that microorganisms and toxic substances capable of producing disease may be incorporated into the circulating water of the device. As major cooling devices withdraw large quantities of water to replace that lost by evaporation (e.g. 16 mgd for a 1,000 megawatt fossil fuel power plant), the probability of taking up pathogens or chemical substances is great if these occur in the source of make-up water.

II. SURVIVAL IN THE COOLING DEVICE

1. Pathogens

Most cooling devices have a mean circulating water temperature close to human body temperature and the temperature which favors the growth of mammalian pathogens. Therefore, in the absence of biocides, the microorganism will survive and may multiply if suitable nutrients are present. Biocides, of the type usually used to control algal growth, may have limited efficiency in destroying, or attenuating pathogens, and even the strongest of commercial disinfectants may have little effect on viruses. The removal of some of the circulating water through "blow-down" may establish a steady state population of viable organisms in the circulating water.

2. Toxic Substances

Dissolved or suspended toxic substances will not normally be attenuated in circulating water within the cooling device. Pretreatment of make-up water, or the use of water "conditioners" may precipitate-out or otherwise attenuate the concentration of these substances. Removal of the substances in the "blow-down" may establish a steady state concentration.

3. Survival and Persistence

It must be assumed that pathogens and toxic substances will survive and persist within the cooling device environment.

III. CONVERSION INTO DRIFT

1. Droplet Size and Composition

As drift is produced as droplets of water, the size of the droplets is adequate to contain almost all pathogenic microorganisms and dissolved or suspended toxic materials. The drift will have essentially the same chemical and biological composition as the circulating water.

2. Quantity of Loss through Drift

Although the loss of water as drift is a small percentage of the circulating water, the quantities are still large in major cooling devices. (e.g. a 1,000 megawatt fossil fuel power plant may release 13 mgd of water as drift, equivalent to the water consumption of a city of 250,000 people.)

3. Passage of Pathogens and Toxic Substances into Aerosol State

The potential is therefore great for the passage of substantial quantities of pathogens and toxins into drift, if these are present in the circulating water.

IV. TRANSPORT IN AEROSOL DRIFT

1. Deposition of Drift

A substantial portion of the drift will be deposited in the vicinity of the cooling device, as demonstrated in drift models and studies with drift generating devices. However, meteorological phenomena could incorporate the drift into strong surface winds, clouds, or the upper atmosphere, resulting in transport over hundreds of miles.

2. Pathogen Transport in Aerosol Drift

Pathogens are of such size that they are capable of being transported in the drift or atmosphere for substantial distances. This transport has been documented.

3. Toxin Transport in Aerosol Drift

Toxic substances will behave as the water droplets in the drift.

V. SURVIVAL IN AEROSOL DRIFT

1. Pathogen Survival in Aerosol Drift

Microorganisms in drift are normally attenuated by dessication, temperature and ultraviolet radiation. A drift produced in an arid climate during the day would show a great reduction of some pathogens, principally bacteria and protozoa. A drift produced in a humid atmosphere, at cold temperatures, and at night would have little attenuation. Drift droplets that freeze would insure survival of almost all pathogens. Dense cloud cover, or the density of the plume itself, would restrict UV penetration, and would reduce attenuation.

2. Toxic Substance Integrity in Aerosol Drift

Few of the toxic substances considered were sensitive to light or moisture. Attenuation in the drift would be negligible. Even if the water of the drift evaporates, most substances would be suspended as gas, aerosols or particles, without modification. In some cases, toxic materials could undergo photochemical reactions, increasing their toxicity.

3. Effect of Ambient Environment on Survival and Integrity

It must be assumed that drift can transport pathogens and toxins without significant attenuation. Ambient site characteristics influence the viability of some microorganisms, but have little effect on toxic molecules as a whole.

VI. PRODUCTION OF DISEASE OR CLINICAL MANIFESTATIONS

1. Human Susceptibility

Pathogens

The pathogens' ability to produce disease or clinical manifestations is a function of arrival of a sufficient number of infective particles at a suitable portal of entry and the susceptibility of the host. Bacterial infectivity is a function of a stoichiometric relationship between the number of organisms and hosts' antibodies, and the number required may vary from a few to several hundred thousand. For viruses, protozoa, fungi, and worms, the number of infective particles may be as few as one. As the half life of pathogens in the environment may be long, accumulation or continuous exposure could bring the number of particles to critical levels.

In the population as a whole, the epidemiological impact is a function of age, sex distribution, racial (genetic) distribution, general health and well-being, prior exposure and immunological deficiency states. While cooling device drift itself may not be directly responsible for epidemics, it may potentiate the burden in an already weakened population, raising a segment of the population into the clinical state.

Toxic Substances

The effect of toxic substances is difficult to evaluate because of inadequate data on humans. The effect is a function of concentration in susceptible tissue, and is much less dependent on host resistance than for pathogens. Immunity can not be acquired either.

Death directly due to most drift borne toxic substances is unlikely, based upon the concentrations implied by the limited data. Cancers are most likely, but the data is also insufficient to draw any conclusions. A highly probable but speculative impact is the weakening of individuals, making them susceptible to infection, or allergic reactions.

2. Animal Susceptibility

Pathogens

The general pathogen considerations for animals are the same as for humans, except that herbivores graze directly on vegetation and therefore have a greater potential for accumulating infectious particles from plants exposed to drift.

Toxic Substances

The accumulation of toxic substances on vegetation presents a greater probability of accumulation to toxic levels within grazing herbivores.

3. Vegetation Susceptibility

Pathogens

Only the fungi and viruses are significant as pathogens, and the usual route of transfer is by vectors or dry wind. Cooling device drift is not a significant factor.

Toxic Substances

The effect of the toxic substances considered is not well documented, but drift transport does not appear to be a significant factor. The water droplets themselves, humidity, or ordinary salts in the drift are documented as causes of plant disease.

VII. PROBABILITY OF OCCURRENCE

In determining the relative probability of host contamination, a number of assumptions and parameters had to be worked into the mathematical model. These specifically include:

a.	Cooling tower height:	400 ft.
b.	Top diameter:	300 ft.
c.	Exit air volume:	23×10^6 cubic feet per min.
d.	Evaporative loss:	13 cubic feet per second
e.	Aerosol loss:	0.01 cubic feet per second
f.	Wind Speed:	30 feet per second
g.	Air temperature:	300 K.
h.	Relative humidity:	70%
i.	Circulating water volume:	5×10^6 cubic feet

j. Blow-down: Complete blow-down @ 1.5:1 concentration ratio

Other parameters which were selected for inclusion in the model were based on typical power plant load profiles and weather conditions for 24 hour periods. Each 24 hour period was divided into four hour segments and it was assumed that conditions remained constant over this period. The numerical values which were chosen and integrated into the model were considered typical for a natural draft cooling tower for a plant of approximately 1000 MW capacity. These parameters include drift fraction e.g. 5x10 $^{-5}$ glg, salt concentration ratios of 30%, weather conditions for typical seasonal, day and evening instances, plant operating capacity and atmospheric stability. The specific values assigned to the parameters are detailed on the printout of each case.

A calculation was then performed to determine the probability of contamination using those assumptions and parameters. The following is a sample of the results achieved for a summer's day case.

-------------- 24 HOUR TOTALS --------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .34

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	0.0	0.0
0.15	1107339.0	454345.4
0.20	311119.8	129253.4
0.30	98662.0	41190.6
0.50	105227.0	232410.3
0.75	215556.6	369901.7
1.00	280964.0	379159.9
1.50	155911.4	141004.1
2.00	94571.7	58955.1
2.50	66768.6	33844.5
3.00	50172.2	21953.7
4.00	17523.1	5660.8
5.00	12931.0	3511.6
7.00	8573.2	1983.8
9.00	6487.0	1202.0
10.00	5151.9	756.5
12.00	4226.6	604.1
15.00	1685.0	230.4
20.00	986.8	107.6
25.00	664.9	54.7

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	0.0	0.000
0.15	1561684.4	18.135
0.20	440373.2	0.486
0.30	139852.6	1.223
0.50	337637.3	20.000
0.75	585458.3	9.244
1.00	660123.9	13.324
1.50	296915.5	18.221
2.00	153526.8	11.626
2.50	100613.1	10.064
3.00	72125.9	5.507
4.00	23183.9	0.486
5.00	16442.5	1.914
7.00	10557.1	0.318
9.00	7689.0	0.006
10.00	5908.4	0.000
12.00	4830.7	0.000
15.00	1915.4	0.000
20.00	1094.5	0.409
25.00	719.6	0.215

SECTION 3
RECOMMENDATIONS

I. General Epidemiology and Microbiology

As in all public health and water supply work, the confidence in health hazard projections is low because of inadequate data. To compensate for the inability to make accurate projections, the United States had adopted a technology of extra caution in water treatment. While this has brought this nation an absence of infectious disease heretofore unknown in the history of mankind, it has imparted cost, energy and environmental penalties, as well as possible health hazards of the non-infectious type.

A. Society must establish the level of public health that it is willing to accept, together with the economic and social cost. This is a political decision beyond the scope of cooling devices alone, but it is incumbent upon science and engineering to develop the costs and benefits of alternative technologies. Studies to develop these, and measure public attitudes, should be performed.

B. The use of the coliform test as an indicator of health hazard is a poor substitute for actual pathogen monitoring, justifiable only when no alternative methods were feasible. Today, equipment and procedures exist for rapidly identifying specific pathogens. The advances of space technology and diagnostic medical microbiology should be applied to water monitoring, for cooling devices and all other water use sciences.

C. Aerobiological and aerochemical studies should be performed in the United States and Europe to determine if the microbiological and chemical load imposed upon the atmosphere by cooling device drift is so significantly above background as to constitute a possible health hazard. Studies using "tagged" organisms and chemicals should be considered in addition to environmental monitoring.

D. Epidemiological studies should be conducted in areas in which major cooling devices have been in use, especially those which use polluted water for make-up. The selection of sites is very critical. They must have adequate health data prior to the use of the cooling device, and the general level of health should be good. Such study sites may be found in Europe.

E. Laboratory models should be constructed, using polluted water, cooling device drift simulation, and animals, to experimentally derive data on health impact.

F. Special attention should be given to subclinical and allergic manifestations of infection and toxicity produced by cooling device drift and other sources of air pollution. Current health data suggest an increase of health problems directly related to environmental pollution. Those which result in clinical symptoms are easiest to document, however, there appears to be an increase in those conditions which cause discomfort, decrease resistance to infectious disease, initiate autoimmune "cancerous" conditions, and generally shorten life or decrease productivity. These are typified by allergies, "colds," etc., i.e. those conditions which do not call for a medical practitioner, but are nevertheless debilitating or unrecognizable.

II. Cooling Device Technology

A. In as much as cooling devices may be used in close proximity to sources of gaseous or particle emissions, such as smoke stacks, studies should be conducted on the relationship between drift and capture and transport of atmospheric pollutants. These studies should be field monitoring as well as laboratory simulation.

B. The need and means of controlling the emission of pathogens and toxic substances should be investigated, irrespective of any findings under epidemiology. The epidemiological, microbiological, and chemical studies on drift may be inconclusive, and will certainly be of long duration. If public policy is to avoid potential risks, as it does in public water supply, then safety precautions should be imposed on cooling device design and operation. Such precautions should represent a Best Available Control Technology (BACT).

C. The viability of pathogens in drift should be studied to develop biological half-life projections as a function of atmospheric conditions. This is necessary because it does not appear that the historical concepts of aerobiology and attenuation of organisms apply to dense aerosols.

III. Modeling

Procedures should be further refined for mathematical modeling of the health impact of cooling device drift. This requires more precise input on variables which have been only assumed in this study, and better integration of drift and infectivity models.

SECTION 4

OBJECTIVES

The objective of this study was to complete a comprehensive review and analysis of potential hazards to humans, plants and animals that might be caused by pathogens and toxins transported via cooling device drift.

For the purpose of program organization and control, the project was divided into six tasks, which are shown on the following Information Flow Diagram (Figure 1) and detailed in the following sections. Two pathways were postulated. The "normal pathway" represents situations which might occur in the everyday ambient environment under normal conditions. The worst case pathway represents the highest possible concentrations of pathogens or toxic substances in cooling water, failure of water treatment or biocide systems in the cooling device, atmospheric conditions insuring pathogen viability, toxin integrity, and entry into a susceptible host in sufficient concentration to produce disease.

TASK I

The primary function within this task was to inventory the types of pathogens and toxic substances which may be present in cooling device drift. The inventoried pathogens and toxins originate in recycled industrial, municipal and/or agricultural wastewaters, and polluted river waters, which would be used as cooling tower makeup. It was deemed necessary to include polluted river waters because power plants using treated effluent will generally require a back-up source of surface water in case of wastewater treatment failure or supply inadequacy.

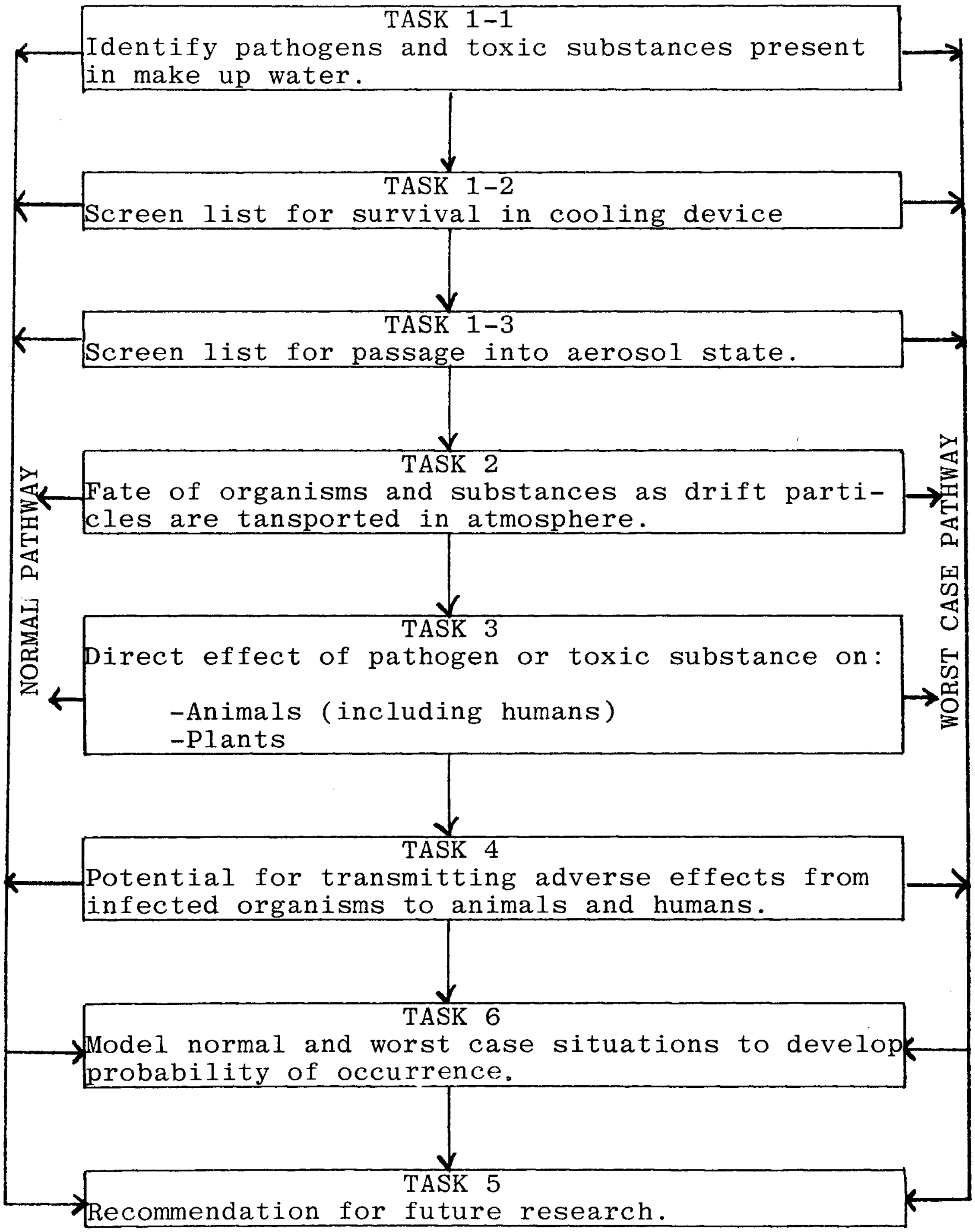
The process of preparing the inventory was to:

1. List most commonly known pathogens and toxic substances found in wastewater and polluted water, with typical concentrations when known. The microorganisms which were surveyed included the following groups:

Viruses	Pleuropneumonia-like Organisms (PPLO)
Richettsia	Protozoa
Bacteria	Invertebrate Parasites
Fungi	

FIGURE 1
INFORMATION FLOW DIAGRAM

Effect of Pathogenic and Toxic Materials
Transported via Cooling Device Drift



Only those organisms which could reasonably be found in America were catalogued. This list also included certain foreign species which are being imported by world travelers, and which are recognized as potential health hazards.

Chemical substances which were surveyed included:

1. Metals
   a. Heavy metals
   b. Transitional metals
2. Macronutrients
3. Micronutrients (Organic and Inorganic)
4. Chlorinated Hydrocarbons
5. Chlorinated and Ozonated Amines
6. Petrochemicals
7. Other toxic organics (e.g. pharmaceuticals)
8. Industrial Chemicals
   a. Plasticizers and other organics
   b. Process wastes
   c. Radioactive wastes.

2. The list was screened and categorized as to the susceptibility of organisms and substances to control by wastewater treatment or natural water purification processes.

3. The list from Step 2 was further screened to characterize only those organisms and substances which could be aerosolized. This step required input and coordination with the aerosol physics aspects of the program.

The end product of this task is a CATALOGUE which lists separately for each organism and toxic substance the following data:

Organism name or chemical substance
Disease name
Medical significance
Location of occurrence
Frequency of occurrence
Survivability in surface water
Survivability in treated effluent
Survivability in air and/or aerosol fomites
Control methods in water or effluents

The catalogue treats microorganisms as both infectious agents and allergens. Chemical irritants were considered in a slightly different manner including concentration as a parameter, when available.

There is also an estimated probability of occurrence in water. Except for a few cases where data was available, this was a qualitative judgment.

TASK II

Under this task the transport of pathogens and toxic substances in aerosol drift is assessed. Utilizing the inventory of substances and organisms produced under Task I, Task II investigates three areas:

1. A review and evaluation of the production of drift by cooling devices and the atmospheric physics of drift particles.
2. The transport of toxic substance in drift.
3. The aerobiology of organisms in drift.

Drift Physics

The primary objective here is to define drift as a function of selected cooling device designs. The data provided includes the following:

Drift size distribution
Drift mass distribution
Drift composition
Drift emission rate based on liquid flow to air flow ratio
Parameters as functions of wet-bulb/day, bulb temperature, relative humidity
Heat capacity
Exit velocity.

The matrix on the following page depicts the types of devices that were considered (Table 1).

The analysis concentrated on the cooling devices of larger sizes, from 10^9 to 10^{10} BTU/hr., since these have the greatest impact. Consideration was given to units which are capable of producing drift and of using polluted water. Although spray pond cooling devices do produce drift they were not considered because their impact is extremely localized. Therefore, the emphasis of this task is the examination of large capacity evaporative cooling devices.

Special attention was given to physical size. There is a significant difference between the mechanical type towers and the natural draft towers in the following aspects.

1. The bulk of the towers is conducive to wake entrainment at elevated wind-speeds.

TABLE 1

TYPES OF COOLING TOWERS

	Mechanical Draft Forced	Mechanical Draft Induced	Natural Draft	Mixed
Wet				
Crossflow	no	yes	yes	yes
Counterflow	yes	yes	yes	yes
Wet-Dry				
Parallel flow	no	yes (note a)	no	no

Note a: This type is to be considered only when in the wet mode.

2. The height of the towers contributes to the drift particle growth and dispersion patterns.

3. The height of the towers and their emissions will determine the potential for scrubbing action of chemicals and microorganisms from the local ambient atmosphere.

Drift emission rate was considered. The amount of drift is a tower design function. Previous design practice has been to use as an upper limit, a guaranteed drift rate not to exceed 0.2% of the water circulation rate. Recent designs of drift eliminators have resulted in drift guarantees of from 0.05% to 0.002% of the circulating water flow. These values may be interpreted in terms of parts per million by using a design ratio, L/G, which is the ratio of the water rate to the air rate, both in pounds per unit of time.

Data was evaluated on the initial drop size distribution. This is an area of great uncertainty. The drop size distribution in the cooling tower drift was related to tower design parameters. Estimates were made of the limiting size, which must be such that the gravitational fall velocity of a droplet is less than the air speed at the exit of the tower. Estimates were also made of the water mass distribution, and finally, the initial composition of the drift particles was described in relation to the make up water.

Transport of Toxic Substances

The transport of toxic substances in the changing structure and composition of the plume, relative to the ambient air, and the distribution of drift over the terrain was evaluated.

The following device parameters were taken into account with respect to the incorporation of toxic substance into drift:

Downwash
Supersaturation
Effect of effluent latent heat on plume rise
Effect of saturated ambient air on plume rise
Prediction of condensation

Existing models were critically screened and typical results were evaluated with respect to the general task objective. Evaluations for transport and fate were made on the basis of the following functions:

Selected cooling device types - considering the range of operational characteristics.
Ambient seasonal climatology.
Terrain characteristics (shoreline, valley, plains, urban, rural, etc.).

Conditions conducive to survival of organisms (humidity, UV screening, temperature).

Deposition rates were evaluated in order to determine the loss of compounds from the plume and concentrations of compounds in the receiving environment.

The effects of oxidation or photochemistry upon toxic materials were assessed. Taken into consideration were atmospheric conditions, plume density, and particles resident time in the atmosphere. This evaluation essentially relates toxic substance concentration to time and distance.

Aerobiology

The ability of each pathogen group to be effectively transmitted by aerosols was reviewed and documented. This process took into account the following factors for the different particle size ranges:

1. Attenuation due to desiccation
2. Attenuation due to solar radiation
3. Protective mechanisms due to dissolved chemicals in the aerosols.

This information was gathered from published scientific and medical literature, and from personal liaison with former participants in biological warfare (BW) study programs which have now become declassified.

TASK III

The potential effects upon inhalation by, or contact with, animals or plants.

The arrival of a pathogen or toxic substance at a plant or animal does not, per se, mean the manifestation of disease. The offender must interact with the body and overcome the body's defense mechanisms.

For each pathogen or toxic substance which was identified in Task I, and which survived aerosol transport, an assessment was made of the probability of initiation or aggravation of disease. This assessment included:

a. A description of the normal means of entry of the offending agent into the body.
b. A description of the normal body susceptibility.

This information was abstracted from epidemiological literature for plants, animals and humans.

The result of this task is an estimate of the probability of a pathogen or toxin producing disease, after arriving within capture range of the host. This probability is expressed in general terms based on an analysis of factors including:

a. Induced or natural immunity
b. Strain resistance
c. Synergistic or antagonistic factors
d. Age
e. Sex
f. Route of entry

These factors were evaluated in relation to occurrence and transmission, and faction. Where possible chronic and acute severity is also discussed for both individuals and population groups.

TASK IV

Potential for transporting adverse effects from affected plants and animals to other animals and humans.

This task is very closely related to the objectives of Task III. For pathogens, literature review and assessment covered zoonoses. Within this epidemiological evaluation, transmission of pathogens from plants to humans considered their role as fomites and vectors.

An effort was made to identify those toxic substances which would be assimilated in edible plant parts and phytoplankton. Consideration was given to detoxification mechanisms in plants and where possible estimates were given for residual concentrations which could be consumed by herbivores.

The data from this task was, as in Task III, incorporated into the catalogue format for a comprehensive review of each pathogen and toxin.

TASK V

Conclusions and recommendations for future research.

Regardless of the specific conclusions which were drawn from the study, it was obvious that there is little data available. Data gaps exist, identifying areas to be researched. Further comments were made in the areas of:

1. Theoretical and analogue simulation, and modeling.
2. Field measurements on the actual occurrence of pathogens in the drift in the vicinity of cooling devices.
3. Technological methods of control.
4. Epidemiology in the vicinity of polluted water cooling towers.

TASK VI

Predicative model development.

One very useful way to evaluate the possible impact of cooling tower drift on public health is by the establishment of suitable predicative mathematical models. It is clear for this case, as in many other systems modeled, that all the desired parameters, constants and variables may not be clearly identifiable or definable. However, this does not at all preclude the development of utilitarian models that can be modified as more data become available and as it becomes apparent that some "tuning" of the model is necessary as a result of experience.

The question approached in the predicative model development was the liklihood of a pathogenic organism or toxic substance reaching and affecting the public. Because answers to this type of inquiry are probabilistic, they should be answered by the development of a stochastic (probabilistic) rather than deterministic model. Less work has been done with stochastic models because they are more difficult to deal with. Even so, their use has become increasingly common as the shortcomings of completely deterministic models became more apparent.

There is a logical sequence involved in evaluating the possible erosion of public health as a result of cooling tower drift. Some of the major events in this sequence, which were discussed are:

1. Probability of occurrence of pathogens or toxic substances in makeup or other input waters.
2. Probability of survival of pathogens or toxic substances in cooling towers.
3. Probability of hazardous materials being carried into the atmosphere.
4. Probability and time duration of survival of hazardous materials in the atmosphere.
5. Probability of interception by an appropriate host or vector.
6. Probability of development of harmful effects.

Each of these events were developed from other events which are probabilistic in and of themselves (e.g. presence of sunlight, air and water temperatures, residence times, wind direction and velocity, etc.). Knowing something about the parameters that affect each event postulated, the predicative model was developed for each event that establishes the possiblity of that event occurring. A serial model, as outlined above has a condition that the possibility of the preceeding event occurring must exist. In the modeling of this system as outlined, it is apparent that there are many similarities to the extensive simulations for reliability and availability predictions for electronic systems. There is extensive literature on such simulations and predicative models and as applicable serves as a base for the establishment of the proposed predicative model.

The problem of random events was solved by substituting for the actual event or function, a simpler one where the desired probability laws are obtained by drawing random numbers. These methods, based on game theory are called Monte Carlo methods. These techniques have been well developed for the investigation of predicative stochastic models such as are suited to this study and form the basis for aspects of the model development.

In this task, a predicative mathematical model is developed. To the extent possible that known (or suspected) variables can be included, either on the basis of known or hypothetical grounds, the model incorporates them. Areas of question are identified and provisions are made for incorporation of new or speculative items as required. Model testing is accomplished using routine establishment of probabilities using available statistical data, and by using Monte Carlo methods for prediction of probabilities. The models developed are carefully documented in flow chart design and development of algorithms. Also the programming was written in one of the higher level languages (FORTRAN). This allows for future building on the developed model as more data becomes available from future work.

SECTION 5

METHODOLOGY

This study attempts to further define and assess the potential health hazards resulting from cooling tower drift. Although it has already been shown that data is lacking, this study attempts to answer questions and make a valid assessment utilizing existing sources and references. It is certainly hoped that this investigation will provide some answers, but it will also be considered a significant effort to direct the need for future study.

To complete the study a staff of outstanding subcontractors and consultants were assembled. The specialists and their fields are as follows:

1. Aerosol Physics and Cooling Tower Emissions.
   (Subcontract to York Research Corp., Stamford, Conn.)
   Edward J. Kaplin, M.S.: Principal Scientist.
   Alan D. Goldman: Environmental Meterologist.
   Experience in theoretical and applied design of cooling devices, and monitoring emissions.

2. Microbiology.
   Henry David Isenberg, Ph.D.: Chairman, American Board Medical Microbiology; Editor, Journal of Clinical Microbiology; Chief of Microbiology, Long Island Jewish Medical Center.

3. Epidemiology.
   Cyrus C. Hopkins, M.D.: Hospital Epidemiologist, Massachusetts General Hospital; Assistant Physician, Massachusetts General Hospital; Assistant Professor Medicine, Harvard Medical School.

   Robert Harold Rubin, M.D.: Infectious Disease Unit, Massachusetts General Hospital; Assistant Professor of Medicine, Harvard Medical School.

4. Zoology and Animal Pathology.
   Basil P. Tangredi, D.V.M.: Practicing veterinarian.

   Sydney Anderson, Ph.D.: Curator of Mammals, American Museum of Natural History, New York.

5. Botany and Plant Pathology.
   Leonard Weinstein, Ph.D.: Director, Environmental Laboratory, Boyce Thompson Institute.

   Delbert C. McCune, Ph.D.: Plant physiologist, Boyce Thompson Institute.

6. Aerobiology.
   Philip Cooper, M.S.: Formerly a research scientist at the United States Air Force Air Medical Research Laboratory.

These specialists were assigned their scope of work under the task structure described in the Objectives (see Figure 2). All research was secondary, to be taken from known and accepted sources. Data was submitted according to a task schedule and compiled in house.

FIGURE 2
TASK ASSIGNMENT DIAGRAM

Effect of Pathogenic and Toxic Materials
Transported via Cooling Device Drift

TASK 1-1
Identify pathogens and toxic substances present in make up water.
H2M, Drs. Hopkins, Rubin & Isenberg

TASK 1-2
Screen list for survival in cooling device.
H2M, Dr. Isenberg

TASK 1-3
Screen list for passage into aerosol state.
H2M, York Research

TASK 2
Fate of organisms and substances as drift particles are transported in atmosphere.
York, H2M, Dr. Isenberg, Mr. Cooper

TASK 3
Direct effect of pathogen or toxic substance on:
- Animals (including humans)
  Drs. Hopkins & Rubin (humans)
  Drs. Andersen & Tangredi (animals)
- Plants
  Drs. McCune & Weinstein

TASK 4
Potential for transmitting adverse effects from infected organisms to animals and humans.
Animals - Drs. Andersen & Tangredi
Humans - Drs. Hopkins & Rubin

TASK 6
Model normal and worst case situations to develop probability of occurrence.
Dr. Uzzo

TASK 5
Recommendation for future research.
H2M

SECTION 6

RESULTS

RESULTS OF TASK I - INVENTORY

Disease means any pathological manifestation, caused either by micro-organisms or by nonliving substances. There are several major routes for the transmission of disease:

1. Water
2. Air
3. Vectors (e.g. insects)
4. Fomites (contaminated food, dust, aerosols, etc.)
5. Direct contact with diseased organisms

Of these, water is probably the most serious. Water becomes contaminated easily, it can transport germs or dissolved substances greater distances, and it is universally required in large quantities by all living things.

The principal source of contamination with human pathogens is through fecal discharge, and to a lesser extent, with other products of human metabolism (mucus, pus, etc.). As a solvent and flushing agent, water picks up and carries contaminated road and field sediments, food and industrial wastes, animal feces, etc.

Contamination of surface waters must be accepted as an accomplished fact due to the combination of storm runoff and the lack of adequate sewage treatment. Natural surface and ground waters are also subject to purification mechanisms, such as settling, aeration solar radiation and phagocytosis. The extent to which contaminated waters can purify themselves is a function of the pollution concentration, the time available for action, and the biological properties of the organisms. Whether or not contaminated waters are capable of producing disease in humans is a function of the etiology of either of two types of pathogens which may be present.

1. Certain organisms, such as many of the enteric viruses, are normal inhabitants of the human intestine and continue to exist in a circulating stock so long as humans are present. Illness does not occur, because populations acquire immunity, either naturally or artificially.

The poliomyelitis virus is an example of such an organism. Immunization prevents the appearance of clinical symptoms of the disease, but the threat can never be removed and the unprotected human will continue to develop the disease.

A particular danger with these indigenous organisms is that they change to produce new strains, and there is no assurance that the immunity against one strain will protect against another strain. While many avenues of research are promising, there is still no effective drug or body substance that will confer broad resistance against all present and new pathogens.

2. Other organisms are not indigenous, and can be introduced only from a diseased person. For example, if no cholera is present in the population, there can be no source of the bacterium. Obviously the key to the control of these diseases lies in maintaining a healthy population.

The United States has been very effective in achieving a marked reduction or elimination of diseases which were dreaded less than a century ago. Recently, however, there has been an increase in the incidence of those diseases that were considered things of the past, because of the proliferation of world-wide travel. Tuberculosis, for example, has risen to such an extent that New York hospitals are reopening T. B. clinics that had been closed.

In addition to the importation of foreign diseases, another source of pathogenic organisms is the "carrier," or one who harbors the disease organisms but does not manifest clinical symptoms. Such an individual can continue to contaminate waters and escape detection and cure.

The inventory of diseases which can be transmitted through the water route is substantial. Here in the United States, water borne diseases have been kept under control by meticulous attention to the purification of public water supplies, and health standards for private water supplies, recreational waters and shellfish. Although there is a national effort to purify sewage, the fact remains that most of the country has no sewage treatment or only primary treatment.

Table 2 lists those pathogens which are most likely to be found in polluted waters. Also included in this list are pathogens which are indigenous abroad but may be introduced into the U.S. by travelers. Pathogens that may not naturally occur in surface or ground waters, but may be introduced into waters from external sources, are also included.

Toxic materials are introduced into surface water as a result of raw or inadequately treated wastewater, storm water runoff, solid waste leachate from landfills, rainfall, dredge spoiling, and a variety of other activities. As a result of the recent national effort to reduce point source pollution, the quantity of toxic materials introduced into surface water is being attenuated. However, because of the magnitude of the non-point pollution control problem, it is doubtful that surface water pollution will ever be reduced to zero in the vicinity of human habitation. Cooling devices that draw water from such areas will intake chemical substances which will eventually incorporate into the aerosol drift.

TABLE 2

PATHOGENS MOST LIKELY TO OCCUR IN COOLING TOWER MAKEUP WATER SOURCES

Absidia corymbifera	Basidiobolus haptosporus
Absidia ramosa	Blastomyces dermatitidis
Acanthamoeba (Naeglenia)	Bordetella spp.
Actinomyces israeli	Bordetella parapertussis
Actinomyces keratolytica	Brucella abortus
Actinomyces spp.	Brucella canis
Adenovirus and Para influenza virus	Brucella melitensis
Aspergillus spp.	Brucella suis
Aspergillus flavus	Candida albicans
Aspergillus fumigatus	Candida spp.
Aspergillus nidulans	Cladosporium spp.
Aspergillus niger	Clostridium botolinum
Aspergillus niveus	Clostridium perfingens
Aspergillus restrictus	Coccidioides immitis
Aspergillus terreus	Conidiobolus coronatus
Bacillus anthracis	Corynebacterium spp.
Bacillus cereus	Corynebacterium diphtheriae
Bacillus subtilis	Corynebacterium ulcerans
Bacteriodes spp.	Cryptococcus neoformans

TABLE 2 cont.

Dermatophilus congolensis

Echo virus, coxsackie A & B, Polio

Enterobacteriaceae

Escherichia coli

Fuscobacterium spp.

Geotricium candidium

Haemophilus aegyptius

Haemophilus influenzae

Klebsiella pneumonia

Listeria monocytogenes

Mucor pusillus

Mucor ramosissimus

Mucor spp.

Mycobacterium spp.

Mycobacterium tuberculosis

Nocardia asteroides

Nocardia brasiliensis

Nocardia caviae

Peptococcus spp.

Peptostreptococcus spp.

Phialophora spp.

Proteus mirabilis

Prototheca spp.

Pseudomonas aeruginosa

Pseudomonas mallei

Pseudomonas pseudomallei

Rhinocladiella spp.

Rhizopus arrhizos

Rhizopus oryzae

Salmonella spp.

Salmonella typhi

Shigella spp.

Shigella boydii

Shigella dysenteriae

Shigella flexneri

Shigella sonnei

Sporothrix schenckii

Staphylococcus agalactiae

Staphylococcus aureus

Staphylococcus spp.

Streptococcus faealis

Streptococcus pneumoniae

Streptococcus pyogenes

Streptococcus pyogenes (Group A)

Streptococus spp.

Torulopsis glabrata

Vibrio parahemolyticus

Yersinia enterocolitica

Yersinia pestis (Pasteurella)

Yersinia pseudotuberculosis

Zygomycetes (Phycomycetes)

Various viruses, nematodes and protozoans

Salt, although it is naturally occurring substance in estuarine waters, might be considered a toxic material for terrestrial plants. Salt drift has been identified as a potentially serious cause of injury to sensitive species of natural foliage and crops in the vicinity of cooling devices.

The effect of airborn toxic material on human health has been intensively studied, but the impact is highly controversial. Toxic substances, including acid sulfates and nitrates, and certain metallic compounds may produce acute or chronic respiratory symptoms, including increased airway resistance, asthma, bronchitis, cardio-pulmonary disease, increased sputum, and even death.

Allergens, although not necessarily toxic, may cause asthma and hay fever, two of man's most annoying diseases. Airborne pollutants may potentiate or mimic allergens on sensitive individuals. "Red tide" aerosols from dinoflagellate blooms have been documented.

Environmental pollutants may also be the principal cause of cancer or may serve as co-carcinogens. This has been documented for the particulates such as asbestos and beryllium, and for self-inflicted gaseous chemicals from smoking tobacco. The extent to which industrial and transportation emissions are related to cancer of the lungs, stomach, intestine, and of the immune system may be related to environmental pollutants.

The origin of most gaseous (or small particle) pollutants is combustion. Since cooling tower aerosols may be generated adjacent to combustion exhausts, or may pass over industrial emissions, they may contribute to the transport of pollutants by solubilizing gases or trapping particles in the aerosol droplets. This is outside the scope of the present study, but it should be recognized that under those conditions, cooling tower drift may potentiate health problems, if not be directly responsible for them.

Toxic chemicals in cooling tower water can also originate directly from the biological and chemical reactions that occur in the system. These reactions are dependent upon the characteristics of the device and the make-up water. All cooling devices can be subject to the following:

1. Scaling on heat exchange surfaces.
   Scaling is a land adherent type of deposit caused by the precipitation of hardness elements from the water in the form of salts or oxides.

Principal scales are calcium carbonate and magnesium silicate. A characteristic of these salts they have inverse water solubilities with respect to temperature. Increased scaling can occur as the water temperature increases in a cooling system or as the concentration of salts increases through evaporation. Factors that determine or control scaling include such analytical values associated with water quality as pH, calcium content, total alkalinity, dissolved solids and temperature.

Scaling is generally controlled by chemical adjustment of the alkalinity and/or recycle times. The alkalinity is controlled by the addition of acid - usually sulfuric acid - to maintain a pH range between 6.0 - 7.0 and/or by using surface active phosphates and organic agents. It is noted that pH also affects corrosion inhibition so that a balance is necessary.

2. Sludge formation on heat exchange surfaces. Sludge formations are caused by combinations of dirt, oil, calcium and magnesium salts, organics, and other chemical products, particularly phosphates. These fouling masses can mechanically filter dust from circulating water and serve as focal points for difficulties in the form of reduced heat transfer and corrosions. Additive control agents function through a physical phenomenon which results in an extremely thin layer of contaminant being deposited on surfaces in the cooling tower system while the rest is maintained in suspension.

3. Corrosion of piping, pumps and heat exchanges. Corrosion is caused primarily by the dissolved oxygen content of the water although a high chloride content in the water will also lead to corrosion. By the very nature of wet cooling towers, the contact of the water with air assures that the circulating water will be continuously saturated with dissolved oxygen and is thus the major single source of corrosion difficulties.

    Corrosive inhibitors are generally combinations of chromates, zinc and phosphates. The chromates and phosphates act as anodic inhibitors. They form a surface film which restrains the anodic corrosive reaction:

$$Fe \rightleftharpoons Fe^{++} + 2e$$

When used alone, anodic inhibitors must be present in a large quantity. This can be substantially reduced with the addition of zinc, a cathodic inhibitor. the cathodic reaction is:

$$O_2 + 2H_2O + 4e \rightleftarrows 4(OH)^-$$

This reaction is the rate controller and it is limited by the rate at which oxygen can diffuse to the metal surface. The cathodic reaction generates hydroxide ions which increase the pH at the cathodic area. The zinc precipitates with the increased pH and forms a barrier to oxygen diffusion:

4. Biological fouling.
The tremendous potential for biological fouling through slime, algae formation and all forms of microbiological growth exists in a wet tower system because of the high average water temperature, oxygen - saturated environment that is provided. The seed organisms are always in fresh supply by the process of scrubbing from the tower air as well as from any make-up water.

In so far as the cooling tower operation is concerned, biological fouling can greatly decrease heat transfer. This can be attributable not only to the organisms themselves but also to their metabolic products. The bulk, once deposited, serves as a further trap for debris, chemical and otherwise.

The principal microbiological organisms involved are bacteria, fungi and algae. The bacteria are the most troublesome type of organism. Aerobic slime-forming bacteria thrive in tower environs both in the bulkwater and on exposed surfaces.

The control of biological growths in circulating water requires its periodic treatment with biocides. Chlorine, chlorinated phenols and non-oxydizing biocides are effective as growth controls.

Chlorine may in some instances be depleted by its reactions with other treatment chemicals in a system. Non-oxidizing biocides may be used to supplement chlorine treatment or as a replacement. It is noted, however, that for non-oxidizing biocides to be effective they must be present in toxic dosages.

The addition of copper citrate, cholophenates, tribictyl tin, quaternary amines, methylene bis-thiocyante and chlorination are only a few of the biological control compounds and methods used.

5. Delignification of wood parts.
   Delignification of wood surfaces in a cooling tower proceeds by two basic mechanisms: chemical attack and biological attack.

   The chemical attack is a function of high alkalinity content of the circulating water which is generally a function of high alkalinity of make-up water. This condition is alleviated by pH control, usually with sulfuric acid.

   A more important delignification mechanism is the attack on the wood or fill cellulose by fungi. Their control is by preservative coatings on wood surfaces, and chlorination and/ or non-oxidizing biocides.

   It should be noted that wood preservative methods have included the impregnation of the wood, prior to usage, with a copper salt followed by an arsenic salt to precipitate copper arsenic within the wood or the impregnation of the wood with creosote.

   Without specific consideration to the type of make-up water to be used in any given drift-generating cooling device, it is seen that chemical additives are in routine use for reasons which include:

   a. The assurance of continued effective heat removal.
   b. The reduction of metal and wood deterioration.
   c. The minimization of investment and utility costs.
   d. The influencing and development of design practices.
   e. The making practical of less costly designs

The consideration of make-up water in the form of recycled industrial, municipal and/or agricultural wastewater must now be evaluated in respect to treatment requirements necessary for proper operation of an appropriate cooling device as well as for the presence of pathogens and/or toxic chemicals that will pass through the device. This becomes necessary based on the premise that each drift particle droplet will be a microcosm of the water mixture within the cooling device itself.

In any given operational environs, the make-up water will be a function of local and prior usage by industrial, municipal and agricultural sources. It will be affected by the degree of reclamation treatment by each user prior to their recycle efforts. This treatment effort may range anywhere from 0-100%. On this basis, specific categorization of any given water source, in general, will be difficult without prior knowledge of its past and present history, and knowledge of constituent residence times. In these considerations radiological waste discharges are also important. Of equal importance is the water source itself, its size (volume), flushing rate and/or drainage, or percolation rate separate from the constituent residence time.

In terms of industrial wastes and to some extent agricultural wastes, broad categories can be defined immediately with some brief delineations:

1. Wastes Containing Mineral Impurities.
   Examples of wastewater containing large and/or detrimental amounts of mineral impurities are steel-pickling liquors, copper-bearing wastes, electroplating wastes, oil-field brines, petroleum refinery wastes and mining wastes.

2. Wastes Containing Organic Impurities.
   The most important organic waste producers are milk-processing plants, meat packing establishments, breweries, distilleries, canneries, and medical institutions (e.g. hospitals, nursing homes).

   It is noted that stock-yards associated with meat-packing are also a source of organics and pathogenic organisms.

3. Wastes Containing Both Organic and Mineral Impurities.
   Some examples include the textile industry, laundries, tanneries and paper mills, as well as the fertilizer industry.

4. Radioactive Wastes.
   The wastes may originate in hospitals and research laboratories and in the laundries serving them; in water-cooled nuclear reactors and chemical plants that process reactor fuels; and from mining operations.

The types of substances potentially present in cooling device drift due to agricultural and industrial wastes, internal reactions, leachate, runoff and other surface waters were considered and incorporated into the inventory of toxic substances. Many of the substances examined are known or suspected carcinogens. A list of such substances was supplied by EPA Corvallis and then expanded to include others of interest. Table 3 is a listing of the toxic substances included in the inventory.

TABLE 3

TOXIC SUBSTANCES POTENTIALLY PRESENT IN

COOLING MAKE-UP WATER

Acenaphthene

Acetone

Acreolein

Acrylonitrile

Aldrin

Antimony and compounds

Arsenic and compounds

Asbestos

Benzene

Beryllium and compounds

Biphenyl

1, 2 Bis-chloroethyoxy ethane (haloether)

Bromochlorobenzene (chlorinated benzene)

Cadmium and compounds

Carbon tetrachloride

Chlordane

Chlorinated benzenes

Chlorinated ethanes

Chlorinated napthalene

Chlorine

Chloroform

2-Chlorophenol

Chromium and compounds

Copper and compounds

Cyanides (barium, calcium, hydrogen, potassium, sodium, zinc)

DDT and metabolites

Diabyl ethers

Dichlorobenzenes

Dichlorobenzidine

Dichloroethylene

2, 4 Dichlorophenol

Dichloropropane and Dichloropropene

Dieldrin

2, 4 Dimethylphenol

2, 6 Dinitrotoluene

Diphenylhydrazine

Endosulfan and metabolites

Endrin and metabolites

Ethylbenze

Haloether

Halomethane

Heptachlor and metabolites

Hexachloro 1,3 Butadiene

Isophorone

Lead and inorganic compounds

Lindane

Mercury and compounds

Methyl ethyl ketone (Butanone)

Naphthalene

Nickel and compounds

Nitrites

Nitrobenzene

Nitrophenols (m,o,p)

Nitrosamines

Pentachlorophenol

Phenols

Polychlorinated biphenyl's (pcb's)

Phthalate esters

Secondary amines

Selenium and compounds

Silver and compounds

Sodium chloride

Styrene

Thallium and compound

Toluene

Toxaphene

Vinyl chloride

Zinc and compounds

RESULTS OF TASK I - ATTENUATION OF ORGANISMS AND SUBSTANCES

Naturally, not every toxin or pathogen found in sources of make-up water will enter the cooling device. As stated earlier, the quantity of toxic materials in surface waters is being attenuated in a effort to reduce point source pollution. "Common" pathogens, generally bacteria, are attenuated through the processes of chlorination, and occasionally sedimentation, filtering or addition of biocides.

The initial inventory of pathogens and toxins was screened for attenuation through water treatment. For the purposes of our study, there are three general classifications of treatment; physical, chemical and biological.

Physical treatment normally includes settling, centrifugation, filtration and UV or nuclear radiation. Conceivably heat or sonic energy could also be used. Chemical treatment is by chlorination, or other biocides (e.g. silver, organic alogens) and control of pH. More specific processes such as addition of corrosion inhibitors, or measures required by specific industries are also included. Biological treatment encompasses any of the methods presently employed in treatment of sludge and sewage.

The following matrices (Tables 4 and 5), screen the inventory of pathogens and toxins indicating those which would not be attenuated by any means of wastewater treatment or natural purification processes. This study is primarily concerned with these substances and organisms. It is expected that due to the inability to control these, cooling device operators should be concerned with their possible dissemination.

Within the tables, the attenuating treatment(s) is identified for each pathogen and toxic substance in our inventory. Because some of these substances may only be treated by one type of treatment process, and others by two or three, there is a distinction made between those retained for a worst case situation.

Under the status column are the letters P,S,T, or W. These indicate the following:

- P - Is not attenuated by any treatment process. This pathogen is of primary importance.
- S - Attenuated by one process, therefore, the organism or substance is of secondary importance. It would be a significant concern should the appropriate treatment

process fail for any of these.

T - These pathogens or toxins can be controlled by two processes. It is less likely that both treatments should fail, or not be applied. Therefore, these are of tertiary concern.

W - It is least likely that pathogens and toxins which may be treated by all three types of treatment processes will be present in make-up water. These are reserved for a worst case situation.

TABLE 4

ATTENUATION OF PATHOGENS

AND STATUS IN MAKE-UP WATER

PATHOGEN	TREATMENT PROCESS Biological	Chemical	Physical	STATUS
Absidia corymbifera	x	x	x	W
Absidia ramosa	x	x	x	W
Acanthamoeba (Naegleria)				
Actinomyces israeli		x	x	T
Actinomyces keratolytica	x	x	x	W
Actinomyces spp.		x	x	T
Adenovirus and Parainfluenza				P
Aspergillus spp.	x	x	x	W
Aspergillus flavus	x	x	x	W
Aspergillus fumigatus	x	x	x	W
Aspergillus nidulans	x	x	x	W
Aspergillus niger	x	x	x	W
Aspergillus niveus	x	x	x	W
Aspergillus restrictus	x	x	x	W
Aspergillus terreus	x	x	x	W
Bacillus anthracis			x	S
Bacillus cereus	x	x	x	W
Bacillus subtilis		x	x	T
Bacteroides spp.	x	x	x	W
Basidiobolus haptosporus	x	x	x	W
Blastomyces dermatitidis	x	x	x	W
Bordettela spp.	x	x	x	W
Bordettela parapertussis	x	x	x	W
Brucella abortus		x		S
Brucella canis		x		S
Brucella melitensis		x		S
Brucella suis		x		S
Candida albicans		x	x	T

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 4

ATTENUATION OF PATHOGENS

AND STATUS IN MAKE-UP WATER

PATHOGEN	TREATMENT PROCESS Biological	Chemical	Physical	STATUS
Candida spp.		x	x	T
Cladosporium spp.		x	x	T
Clostridium botulinum			x	S
Clostridium perfingens	x	x	x	W
Clostridium tetani			x	S
Coccidioides immitis		x	x	T
Conidiobolus coronatus		x	x	T
Corynebacterium diptheriae		x	x	T
Corynebacterium spp.		x	x	T
Corynebacterium ulcerans		x	x	T
Cryptococcus neoformans		x	x	T
Dermatophilus congolensis	x	x	x	W
Echovirus, Coxsackie A & B, Polio				P
Enterobacteriaceae	x	x	x	W
Escherichia coli	x	x	x	W
Fuscobacterium spp.	x	x	x	W
Geotricium candidium	x	x	x	W
Haemophilus aegyptius	x	x	x	W
Haemophilus influenzae	x	x	x	W
Histoplasma capsulatum		x	x	T
Klebsiella pneumonia				
Listeria monocytogenes	x	x	x	W
Mucor pusillus		x	x	T
Mucor ramosissimus		x	x	T
Mucor spp.		x	x	T
Mycobacterium spp.		x	x	T
Mycobacterium tuberculosis	x	x	x	W
Nocardia asteroides		x	x	T

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 4

ATTENUATION OF PATHOGENS

AND STATUS IN MAKE-UP WATER

PATHOGEN	TREATMENT PROCESS Biological	Chemical	Physical	STATUS
Nocardia basiliensis		x	x	T
Nocardia caviae		x	x	T
Peptococcus spp.	x	x	x	W
Peptostreptococcus spp.	x	x	x	W
Phialophora spp.		x	x	T
Proteus mirabilis	x	x	x	W
Prototheca spp.	x	x	x	W
Pseudomonas aeruginosa	x	x	x	W
Pseudomonas mallei		x	x	T
Pseudomonas pseudomallei	x	x	x	W
Rhinocladiella spp.		x	x	T
Rhizopus arrhizus		x	x	T
Rhizopus oryzae		x	x	T
Salmonella spp.	x	x	x	W
Salmonella typhi	x	x	x	W
Shigella boydii	x	x	x	W
Shigella dysenteriae	x	x	x	W
Shigella flexneri	x	x	x	W
Shigella sonnei	x	x	x	W
Shigella spp.	x	x	x	W
Sporothrix schenckii	x	x	x	W
Staphylococcus agalactiae	x	x	x	W
Staphylococcus aureus	x	x	x	W
Staphylococcus spp.	x	x	x	W
Streptococcus faealis	x	x	x	W
Streptococcus pneumoniae		x	x	T
Streptococcus pyogenes		x	x	T
Streptococcus pyogenes (Group A)	x	x	x	W

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 4

ATTENUATION OF PATHOGENS

AND STATUS IN MAKE-UP WATER

PATHOGEN	TREATMENT PROCESS			STATUS
	Biological	Chemical	Physical	
Streptococcus spp.	x	x	x	W
Torulopsis glabrata	x	x	x	W
Vibrio parahemolyticus	x	x	x	W
Yersinia enterocolitica	x	x	x	W
Yersinia pestis (Pasteurella)	x	x	x	W
Yersinia pseudotuberculosis	x	x	x	W
Zygomycetes (Phycomycetes)	x	x	x	W
Var. Nematodes, Protozoans, and viruses				P

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 5

ATTENUATION OF TOXIC SUBSTANCES

AND STATUS IN MAKE-UP WATER

TOXIC SUBSTANCE	TREATMENT PROCESS			STATUS
	Biological	Chemical	Physical	
Acenaphthene			x	S
Acetone	x		x	T
Acrolein			x	S
Acrylonitrile			x	S
Aldrin			x	S
Antimony and compounds		x	x	T
Arsenic and compounds		x		S
Asbestos				S
Benzene	x		x	T
Benzidine			x	S
Beryllium and compounds		x		S
Biphenyl		x	x	T
Cadmium and compounds		x		S
Carbon Tetrachloride			x	S
Chlordane			x	S
Chlorinated Benzene			x	S
Chlorinated Ethanes			x	S
Chlorinated Ethylenes			x	S
Chlorinated Napthalene			x	S
Chlorine			x	S
Chloroform			x	S
2-Chlorophenol			x	S
Chromium and compounds		x		S
Copper and compounds		x		S
Cyanides		x		S
DDT and metabolites			x	S
Diabyl Ethers			x	S
Dichlorobenezenes			x	S

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 5

ATTENUATION OF TOXIC SUBSTANCES

AND STATUS IN MAKE-UP WATER

TOXIC SUBSTANCE	TREATMENT PROCESS			STATUS
	Biological	Chemical	Physical	
Dichlorobenzidine			x	S
Dichloroethylene			x	S
2,4 Dichlorophenol			x	S
Dichloropropane and Dichloropropene			x	S
Dieldrin			x	S
2,4 Dimethyl Phenol	x		x	T
2,6 Dinitrotoluene	x		x	T
Diphenylhydrazine			x	S
Endosulfan and metabolites			x	S
Endrin and metabolites			x	S
Ethylbenzene	x		x	T
Halo Ether			x	S
Halo Methane			x	S
Heptachlor and metabolites			x	S
Hexachloro-1,3-Butadiene			x	S
Isophorone			x	S
Lead & inorganic compounds		x		S
Lindane			x	S
Mercury and compounds		x		S
Methyl Ethyl Ketone (Butanone)	x		x	T
Naphthalene	x		x	T
Nickel and compounds		x		S
Nitrites			x	S
Nitrobenzene	x		x	T

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

TABLE 5

ATTENUATION OF TOXIC SUBSTANCES

AND STATUS IN MAKE-UP WATER

TOXIC SUBSTANCE	TREATMENT PROCESS			STATUS
	Biological	Chemical	Physical	
Nitrophenols (m,o,p)			x	S
Nitrosamines			x	S
Pentachlorophenol			x	S
Phenols			x	S
Phthalate Esters	x	x	x	W
Polychlorinated Biphenyl's (PCB's)			x	S
Secondary Amines			x	S
Selenium and compounds		x	x	T
Silver and compounds		x		S
Sodium Chloride			x	S
Styrene			x	S
Thallium and compounds		x	x	T
Toluene	x		x	T
Toxaphene			x	S
Vinyl Chloride			x	S
Zinc and compounds		x		S

P - of primary concern
S - of secondary concern
T - of tertiary concern
W - retain for worst case

After screening the lists of pathogens and toxins and their methods of attenuation, a "FAILURE" list was derived. The pathogens included in this list, Table 6, are retained to be used in generating "WORST CASE" probabilities, should all methods of attenuation fail.

The same screening was applied to the list of toxins. It was determined that none may be retained in a "FAILURE" list. The toxic substances which are being examined in this study may only be attenuated by one or two of the possible three types of treatment. Because they have fewer means of control, toxic substances are more subject to treatment system failure.

TABLE 6

PATHOGENS POTENTIALLY PRESENT ONLY IN A WORST CASE SITUATION

Absidia corymbifera
Absidia ramosa
Actinomyces keratolytica
Aspergillus flavus

Aspergillus fumigatus
Aspergillus nidulans
Aspergillus niger
Aspergillus restrictus

Aspergillus terreus
Bacillus cereus
Bacteroides spp.
Basidiobolus haptosporus

Blastomyces dermati+idis
Brodetella spp.
Bordetella parapertussis
Clostridium perfingens

Dermatophilus congolensis
Enterobacteriaceae
Escherichia coli
Fuscobacterium

Geotrichium candidium
Haemophilus aegyptius
Haemophilus influenza
Listeria monocytogenes

Mycobacterium tuberculosis
Peptococcus spp.
Peptostriptococcus spp.
Proteus mirabilis

Prototheca spp.
Pseudomonas aeruginosa
Pseudomonas pseudomallei
Salmonella spp.

Salmonella typhi
Shigella boydii
Shigella dysenteriae
Shigella flexnei

Shigella sonnei
Shigella spp.
Sporothrix schenckii
Staphylococcus agalactiae

Staphylococcus aureus
Staphylococcus spp.
Streptococcus faealis
Streptococcus pyogenes (Group A)

Streptococcus spp.
Torulopsis glabrata
Vibrio parahemolyticus
Yersinia enterocolitica

Yersinia pestis (Pasteurella)
Yersinia pseudotuberculosis
Zygomycetes (Phycomycetes)

Aerosolization of Organisms and Substances.

The next step was to screen the remaining pathogens and all of the toxic substances to determine which could become aerosolized. The results are shown in Tables 7 and 8.

Essentially the pathogens and toxins which are listed in these tables are those with which cooling device operators should be most concerned. These may be controlled by only one or two means of treatment, if any. Should the appropriate means fail, these organisms and substances may become aerosolized. Further evaluation in the study discusses the aerosol transport of, and potential health effects on plant, animal and human life from these pathogens and toxins.

Complete discussion of the treatment methods and aerosolization of each pathogen and toxin is found in the Catalogue of Aerosol Drift Health Hazard Assessment, Appendix A. (Volume II)

TABLE 7

SCREENED PATHOGENS CAPABLE OF BECOMING AEROSOLIZED

Actinomyces israeli
Actinomyces spp.
Bacillus anthracis
Bacillus subtilis

Brucella abortus
Brucella canis
Brucella melitensis
Brucella suis

Candida albincans
Candida spp.
Cladosporium spp.
Clostridium botulinum

Clostridium tetani
Coccicioices immitis
Conidiobolus coronatus
Corynebacterium spp.

Corynebacterium ulcerans
Cryptococcus neoformans
Histoplasma capsulatun
Mucor pusillus

Mucor ramossissimus
Mucor spp.
Mycobacterium spp.
Nocardis asteroides

Nocardia brasiliensis
Nocardia caviae
Phialophora spp.
Pseudomonas aeruginosa

Pseudomonas mallei
Rhinocladiella spp.
Rhizopur arrhizus
Rhizopus oryzae

Streptococcus pneumoniae
Streptococcus pyogenes
Var. nematodes, protozoans and Viruses

TABLE 8

TOXINS CAPABLE OF BECOMING AEROSOLIZED

Acetone	Endrin and metabolites
Acrolein	Halomethane
Acrylonitrile	Heptachlor and metabolites
Arsenic and compounds	Mercury and compounds
Asbestos	Methyl Ethyl Ketone (Butanone)
Benzene	Napthalene
Cadmium and compounds	Nitrites
Carbon Tetrachloride	Nitrobenzenes
Chlordane	Nitrophenols (m,o.p)
Chlorinated Ethanes	Nitrosamines
Chlorinated Ethylenes	Pentachlorophenol
Chlorine	Phenols
Chloroform	Secondary Amines
2-Chlorophenol	Selenium and compounds
Cyanides	Styrene
2, 4 - Dichlorophenol	Toluene
Dieldrin	Vinyl Chloride
2, 4 - Dimethylphenol	

RESULTS OF TASK II - TRANSPORT

The function of this task is to provide the necessary information for determining the potential for the transport of pathogenic organisms and toxic substances via atmospheric dispersion of drift produced by cooling systems. The function of a cooling system is to move waste heat from a primary system to a heat sink, usually air or water, where the heat is dissipated. Of the many types of cooling systems, the ones that produce drift utilize evaporative cooling where heat is dissipated to the atmosphere by evaporation of a portion of the water used for cooling. The vast majority of evaporative cooling systems utilize cooling towers.

In the process of circulating water through a cooling tower, a small percentage of the water splashing over the fill becomes entrained in the exiting air flow. The entrained water is in the form of liquid droplets. These droplets constitute the cooling tower drift and have essentially the same chemical composition as the circulating water. The drift droplets are dispersed into the atmosphere and deposited downwind of the tower. Therefore, if there are pathogenic and/or toxic substances present in the circulating cooling water, these same substances can be transported from the cooling tower into the atmosphere as part of a liquid droplet. A number of droplets reach the ground before they have completely evaporated. Any pathogens or toxins found in the remaining droplets evaporate reaching the ground as dry particles.

In order to evaluate the potential for the transport and survival of pathogenic and toxic substances released in drift it is necessary to know the cooling device and power plant design conditions and the concentrations of pathogenic microorganisms and toxic substances in the make-up water.

Cooling Tower Internal Conditions.

As stated, any one common set of specified internal cooling tower air and water parameters can be duplicated in all types of evaporative cooling towers. Therefore, the air and water conditions that do exist in a cooling tower are primarily dependent on performance criteria specified by the power plant designer, not on the type of cooling tower.

Typical water and air conditions in an evaporative cooling tower used in a large power plant application are as follows:

1. Incoming Air Temperature.

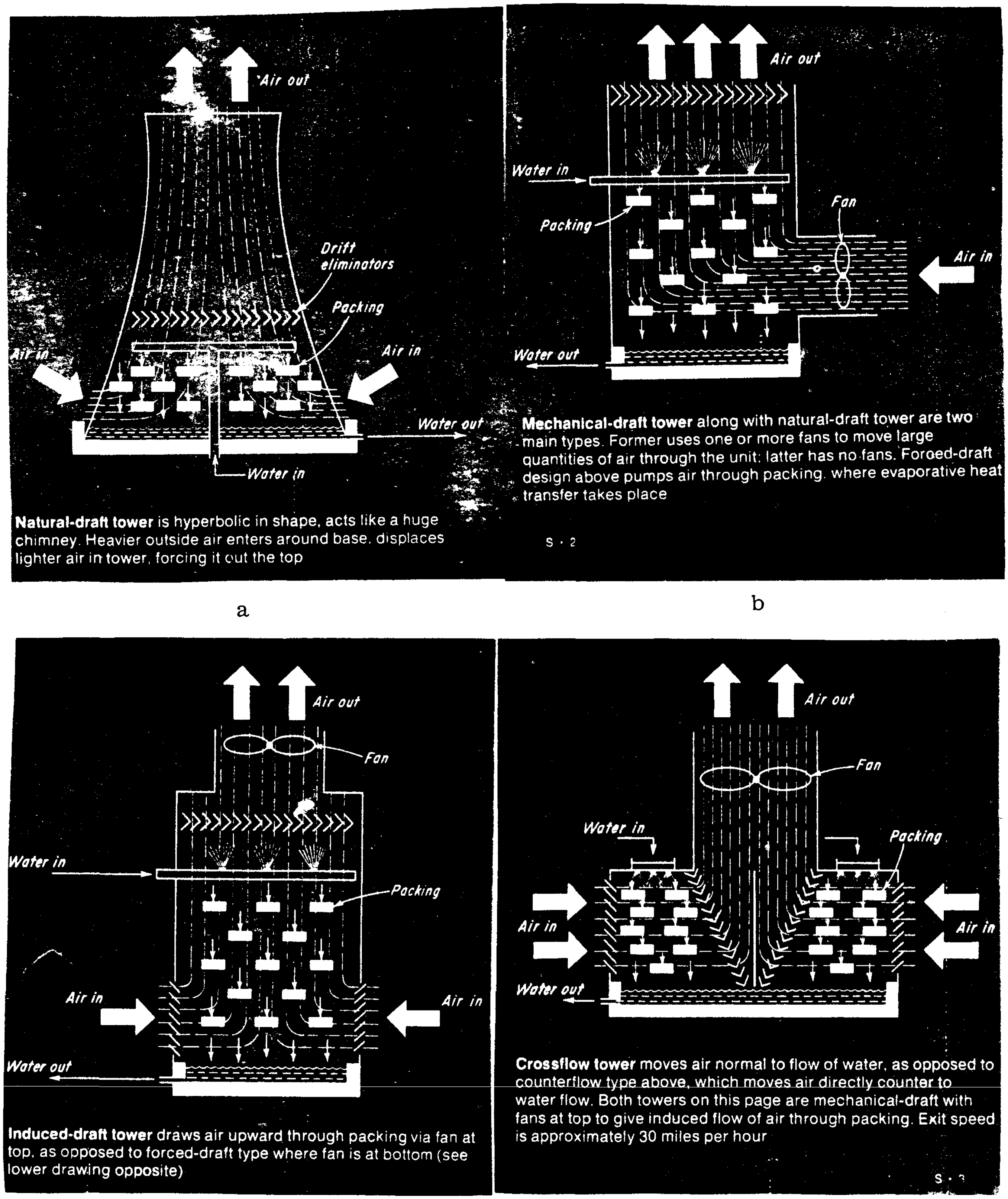
   The incoming air temperature is dependent on geographic location and time of year. Design conditions can range between 19° - 28°C WB (WB = wet bulb). The design condition is the wet bulb temperature which will not be exceeded more than 5-10 percent of the time.

   Toxins and pathogens will survive in these incoming temperatures. The most common temperatures used to incubate bacteria range from 20°C - 37°C.

2. Cooling Tower Plume Exit Temperature and Relative Humidity.

   The temperature of the plume exiting the cooling tower depends on the incoming air temperature and the temperature of the water entering the cooling tower. Values between 28° and 38°C are common, but higher exit temperatures do occur (43°C would not be abnormal). Under most conditions the plume exiting the tower is very near saturation (or 100 percent relative humidity). Therefore, the temperatures given are dry bulb and wet bulb.

FIGURE 3
TYPICAL NATURAL AND MECHANICAL DRAFT COOLING TOWERS



a

Natural-draft tower is hyperbolic in shape, acts like a huge chimney. Heavier outside air enters around base, displaces lighter air in tower, forcing it out the top

b

Mechanical-draft tower along with natural-draft tower are two main types. Former uses one or more fans to move large quantities of air through the unit; latter has no fans. Forced-draft design above pumps air through packing, where evaporative heat transfer takes place

S · 2

c

Induced-draft tower draws air upward through packing via fan at top, as opposed to forced-draft type where fan is at bottom (see lower drawing opposite)

d

Crossflow tower moves air normal to flow of water, as opposed to counterflow type above, which moves air directly counter to water flow. Both towers on this page are mechanical-draft with fans at top to give induced flow of air through packing. Exit speed is approximately 30 miles per hour

S · 3

SOURCE: (ELLIOT, 1973)

Again these temperatures are within the optimal range of incubation temperatures. The most common temperature used to incubate total coliform bacteria is 35°C; and 45°C for fecal coliforms. The toxins with which we are concerned should remain stable.

3. Plume Exit Velocity.

   Mechanical draft towers emit drift at the rate of 35 ft/sec. Natural draft towers give off plumes at the approximate rate of 5 ft/sec. It is at these speeds that pathogens or toxins entrained in the drift will be emitted.

4. Cooling Tower Exit Water Temperature (cold water temperature).

   This temperature is in practice the same as the temperature of the water in the cooling tower basin. Since the design cooling range of most large towers is 11°C - 17°C, the cold water temperature is usually between 32°C - 38°C, a favorable range for most bacteria. This is not expected to affect chemical substances.

Relevant Power Plant Design Information.

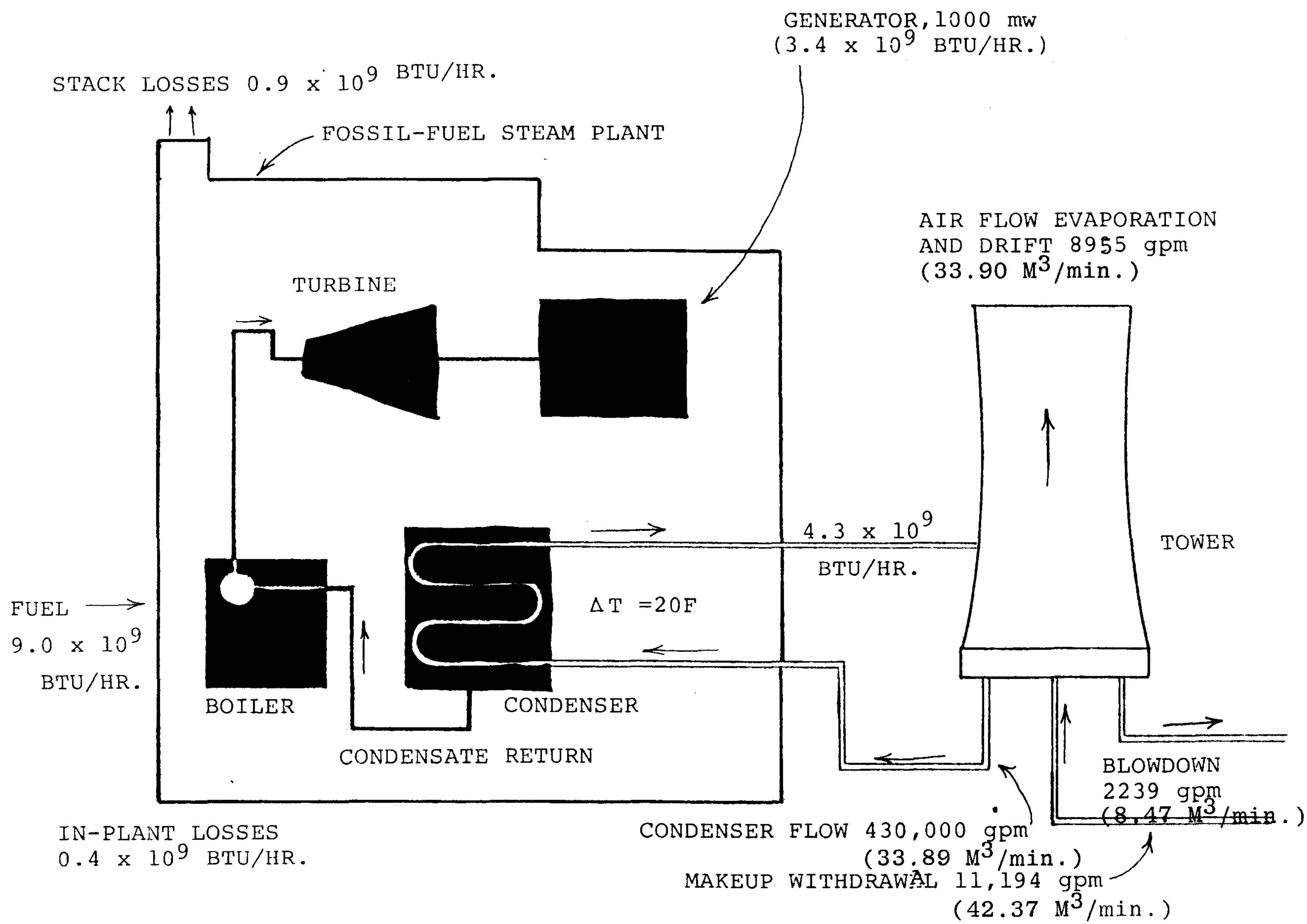
Simplified flow diagrams for typical 1000/MW fossil-fuel and nuclear power plants are given in Figures 4 and 5. The following concepts are pertinent to our discussion of tower design parameters.

1. The circulating water (i.e. the water flowing from the cooling tower to the condenser and back to the cooling tower) never comes in physical contact with the main steam from the turbine or the condensate return.

   Although temperatures do exist in a typical power plant which would thermally destroy pathogens, since the circulating water is not exposed to these conditions, any pathogens present, will not be destroyed by exposure to extreme heat.

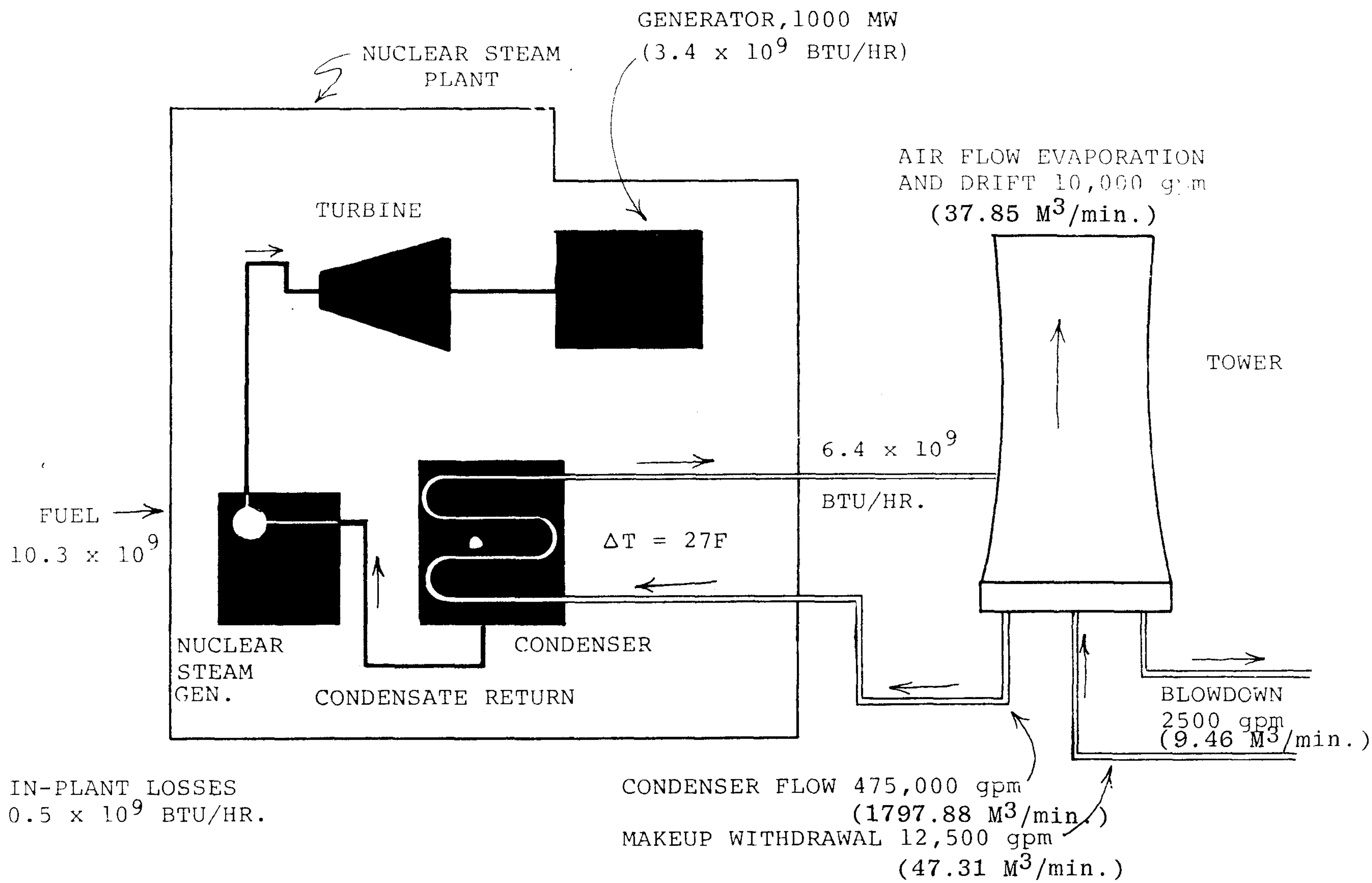
2. The time it takes for the circulating water to make one "round trip" (i.e., from the cooling tower basin to the condenser, back to and through the cooling tower) can vary between 2.5 minutes and approximately 2 hours. This is dependent on the size of the tower basin.

   If pathogens are capable of surviving, and toxins remain stable in water, whether they are exposed for two minutes or two hours should have no effect.



FOSSIL-FUEL STEAM ELECTRIC PLANT USING HYPERBOLIC TOWER HAS A HEAT BALANCE AS SHOWN FOR 1000-MW CAPACITY

FIGURE 4



NUCLEAR STEAM-ELECTRIC PLANT USING HYPERBOLIC TOWER HAS A HEAT BALANCE AS SHOWN FOR 1000-MW CAPACITY.

FIGURE 5

3. The amount of water released as drift is approximately 0.005 percent of the circulating water flow. In a modern cooling tower the drift rate can be as low as 0.001 percent. The amount of water released through evaporation is approximately 2.0 percent of the circulating water flow. The amount of water released as blowdown is approximately 0.5 percent of the circulating water flow. The amount of make-up water (i.e., water usually taken from a river, lake or ocean to replace the water losses given above is approximately 2.5 percent of the circulating water flow.

   These factors may be used in calculating the water loss through drift emission. If the concentrations of pathogens and toxins in the water are known then one can roughly calculate the quantity of these agents emitted in drift.

4. The time that the circulating water is actually circulating through the condenser is on the order of 10-20 seconds. The temperature of the saturated steam entering the condenser is typically about 103^{o}C. The temperature of the condensate return is approximately 88^{o}C - 93^{o}C.

Chemical Treatment of Circulating Water.

A large range of treatment chemicals are available today to meet the four major categories of cooling water problems - corrosion, scale and deposits, fouling, and microbiological growth. Some of the major chemicals used in cooling tower circulating water treatment are identified in Table 9. These are among the candidates for consideration in this study.

The most commonly used chemical corrosion inhibitors are chromates, polyphosphates, zinc, molybdenum, ferro-cyanides, and organics. Chromic acid and its salts provide the base for the most popular and cost/effective corrosion inhibitors in use today. The chromates, considered anodic inhibitors, are often formulated with other inhibitors such as zinc, molybdenum and phosphates. The discharge of chromate, in its hexavalent state, is likely to be severely restricted as we proceed into an era of greater regulatory control and enforcement. The most commonly accepted effluent guideline limits plant chromate discharges to 0.05 mg/l as hexavalent chromium and total chromium to 1.0 mg/l and less in many individual situations.

At the present, chlorine is the most popular oxidizing agent used to control microbiological growth. Chlorine is usually batch fed; an average application might be 0.5 mg/l chlorine for one-half hour every four hours.

TABLE 9

COMMON WATER TREATMENT CHEMICALS

Chemical	Purpose	Concentration
Chlorine (usually batch fed)	microbiocide	1-2 ppm free chlorine for 2-4 hours
chromates	corrosion inhibitor	20-40 ppm
zinc	used in conjunction with chromate	2-3 ppm
Phosphates	corrosion inhibitor (substituted for chromates)	4-6 ppm as total phosphate
Polymers (e.g. poly acrylic acids)	silt dispersion	5-10 ppm
Phosphonates	scale control	5-10 ppm

The phosphonates represent a relatively new and extremely useful class of scale control agents. Several types of these compounds may be found in general cooling water scale control use. Among the most popular versions is an aminomethylene-phosphonate compound that employs the highly stable carbon to phosphorus bond.

Some of the commonly used scale inhibitors are polyphosphates, phosphonates, phosphate esters, polyacrylates, and sulfonated polystyrenes. In addition to being classified as corrosion inhibitors, the polyphosphates may also function as scale inhibitors at "threshold" levels. It is thought that polyphosphate is adsorbed on the growing face of calcite crystals, aborting normal growth patterns and reducing the hard scale normally associated with precipitating calcium carbonate.

Transport of Toxic Substances as a Function of Drift Characterization.

Cooling tower drift is defined as mechanically entrained water droplets which are generated inside the cooling tower and carried along with the air flowing through the tower and exhausted to the environment. (Chen *et al*. 1977) As defined, these water droplets have essentially the same chemical composition as the circulating water in the cooling tower. Therefore, toxic substances would retain the same concentrations in drift as in the circulating water.

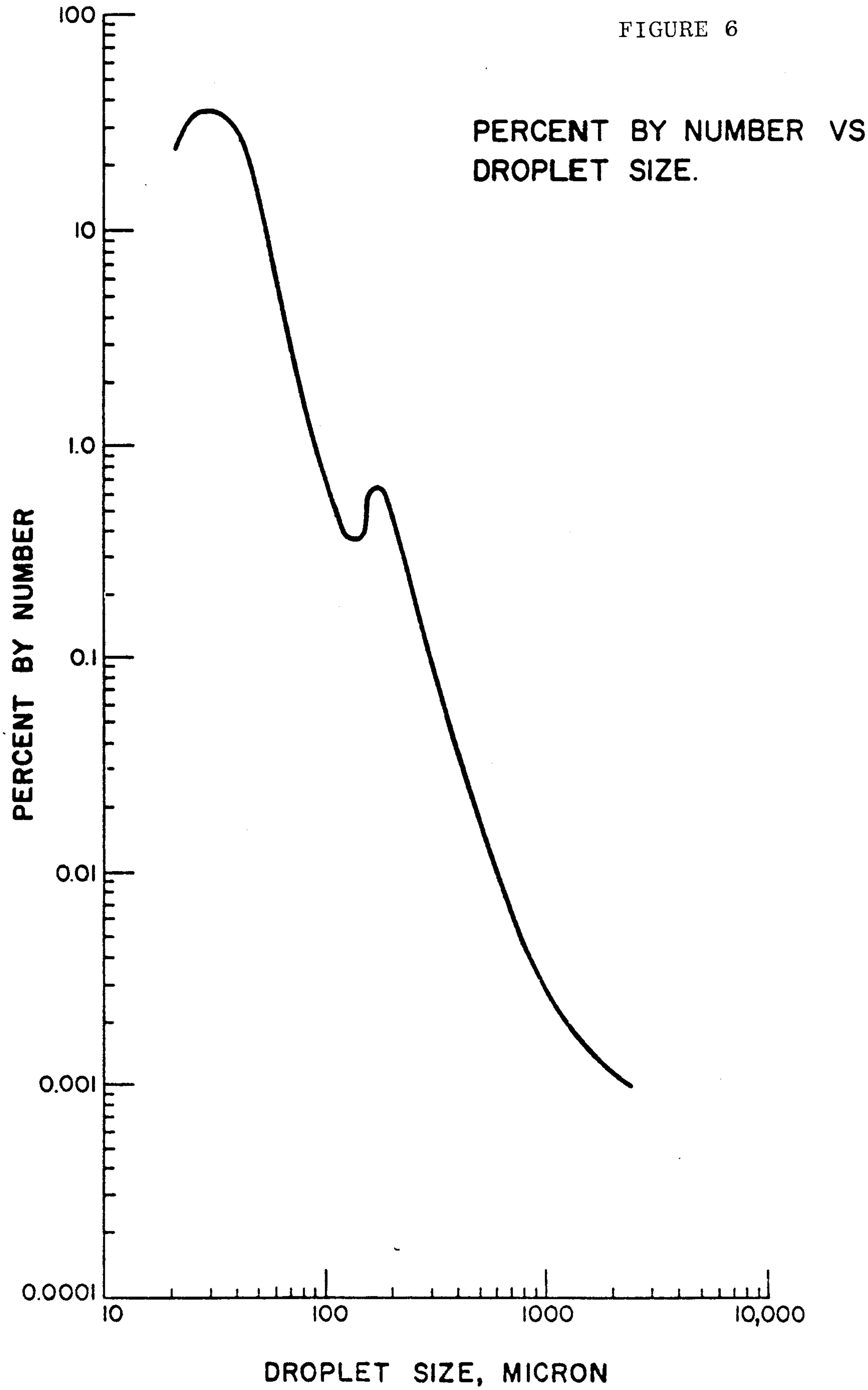
Most drift loss guarantees are quoted as a percent of the circulating water rate with a tacit implication that the drift impurity level is the same as that of the water circulated. We differentiate between drift and the liquid water added to the air due to condensation during the cooling of the tower plume since condensed water is "pure" water. Evaporated water is not objectionable from the standpoint of adding an impurity to the environment. However, the addition of moisture, contributing to a change in relative humidity, may be undesireable. In the evaluation of drift and its potential environmental hazard, we are ultimately interested in the total quantity of drift droplets discharged to the environment, their chemical impurities, and the subsequent behavior of this drift as it interacts with the environment.

To assess the environmental significance of drift it is necessary to establish the actual total drift emission rate from towers of the type found in industry today. The drift particle size and mass distributions must be determined before the dynamic and thermodynamic behavior of the drift as it interacts with the environment can be evaluated.

Particle Size and Mass Distribution.

Figure 6 presents the drift droplet size and mass distribution respectively at the stack discharge based on field tests. (Wistrom and Ovard, 1973). Note that these tests were run on towers where the total drift loss was measured at 0.001 percent of the circulating water rate and therefore, are representative of the current state of the art of drift eliminator designs.

FIGURE 6


PERCENT BY NUMBER VS
DROPLET SIZE.
100
10
1.0
0.1
0.01
0.001
0.0001
PERCENT BY NUMBER
10
100
1000
10,000
DROPLET SIZE, MICRON

KEY TO FIGURE 6

SIZE AND MASS DISTRIBUTION OF DRIFT PARTICLES

DROPLET DIAMETER (MICRON)	% OF SAMPLE BY NUMBER	% MASS BY DROPLET SIZE
22	24.0	0.43
29	36.0	1.49
44	26.0	3.76
58	6.3	2.09
65	4.0	1.86
87	1.4	1.56
108	0.67	1.43
120	0.43	1.26
132	0.28	1.09
144	0.26	1.32
174	0.65	5.81
300	0.11	5.04
450	0.027	4.17
600	0.011	4.01
750	0.0055	4.00
900	0.0033	4.03
1050	0,0024	4.57
1200	0.0019	5.46
1350	0.0016	6.80
2250	0.00095	17.99
2400	0.0010	21.83

Examination of these results reveals several important aspects of drift. First, it is noted that the exhaust drop size distribution is bimodal with peaks in the 35 micrometer and 200 micrometer size ranges respectively. In contrast, natural atmospheric aerosols exhibit a unimodal size distribution. This difference is not surprising when one considers that the air entrained drops in a cooling tower are both generated and removed by mechanical means within a few seconds. Secondly, whether bi-or uni-modally distributed the droplet sizes are capable of carrying two to thousands of particles or bacterium in each droplet.

Fall Velocity of Entrained Droplets

The terminal fall velocity of a drop is established when the aerodynamic drag force is equal to the weight of the drop. It has been shown that larger drops are not spherical, and in fact experience a marked flattening on their lower surface which materially affects fall velocity. The fall velocity drop size relationship is shown in Figures 7 & 8. Droplets smaller than 100 micrometers have fall velocities which are extremely low, indicating that weight of these small drops has a minor influence on their dynamic behavior. Thus, their path and position and that of entrained toxins and pathogens will be primarily governed by aerodynamic forces; most important of which are wind, buoyancy of the exhaust plume, and vertical eddies or turbulence in the atmosphere. Plume buoyancy and vertical atmospheric turbulence will tend to keep these small droplets in suspension for an extended period. The small droplets will essentially follow the plume path and their concentration at any point downwind will be governed by atmospheric dispersion. If the atmosphere is cold, the exhaust air is rapidly cooled and becomes super-saturated. The small drift droplets and entrained particles that remain entrained in the exhaust vapor act as condensation nuclei and tend to grow in size as long as this supersaturated condition remains.

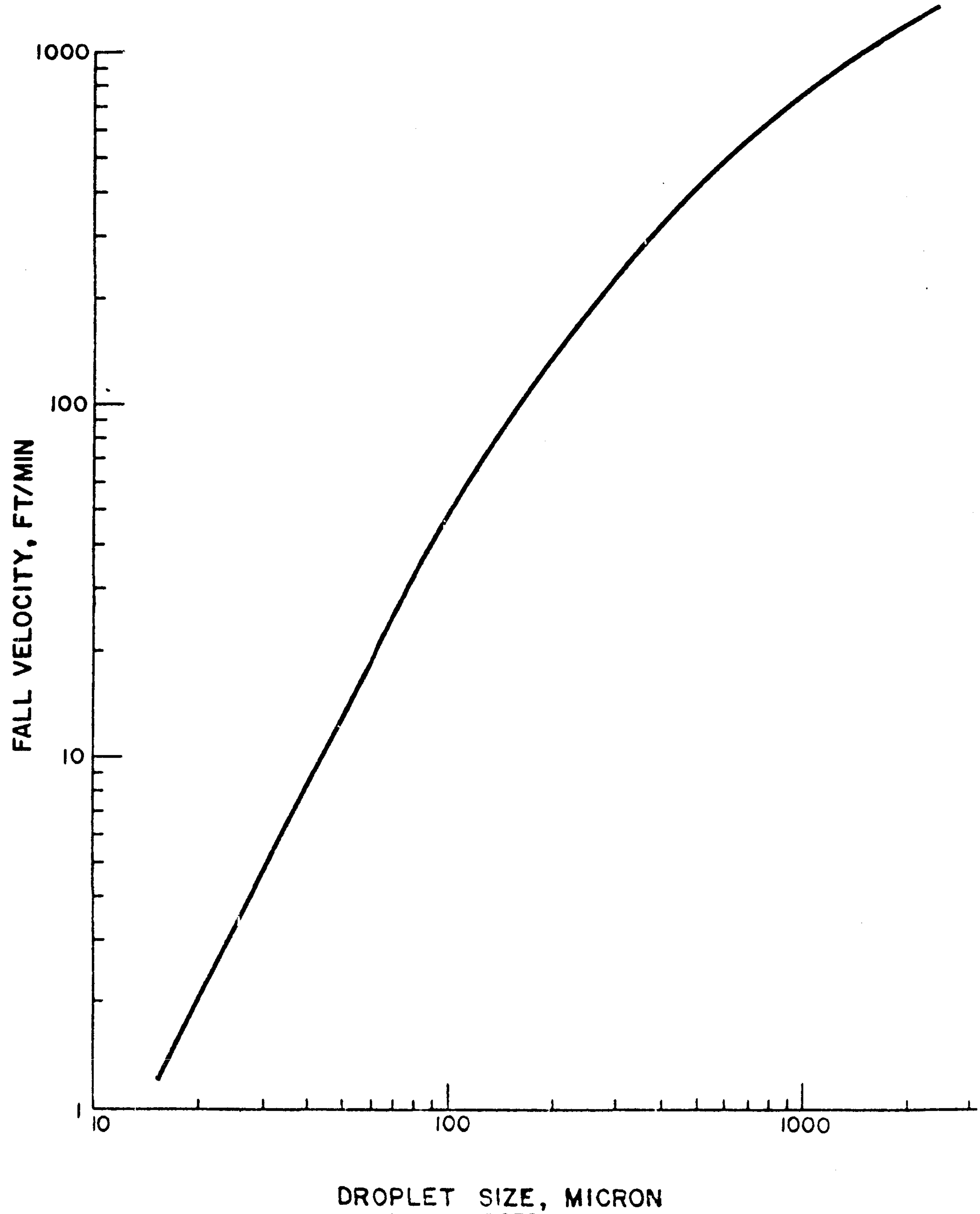
Figure 6 also shows that a few drops in the 1000-2400 micrometer range are present in the exhaust air. Even a casual field observation shows that water droplets in this size range are emitted from a cooling tower since they are clearly visible and easily detected. Field observations and drift size tests conducted directly behind the drift eliminators showed that most of these large droplets are generated in the tower plenum area where impinging drift and vapor condensation accumulates on structural members. Some of this collected moisture is eventually reentrained as larger droplets.

Drift Physics as a Function of Cooling Tower and Power Plant Design Conditions.

In an evaporative cooling tower, the water containing the

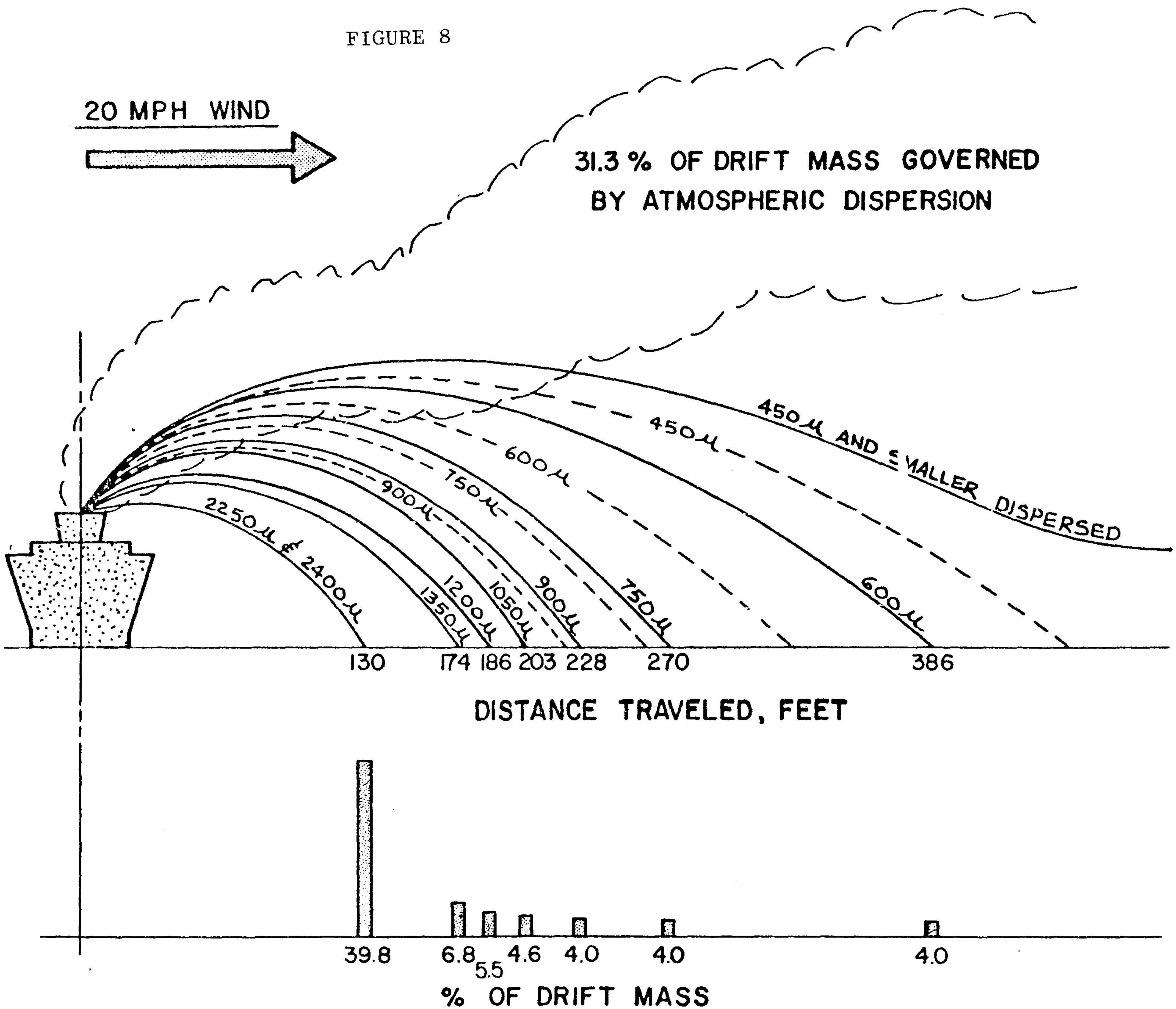
FIGURE 7

FALL VELOCITY OF WATER DROPS
AS FUNCTION OF SIZE



SOURCE: Wistrom and Ovard, 1973

FIGURE 8



SOURCE: Wistrom and Ovard, 1973

waste heat comes in direct contact with the ambient air flowing through the tower. The various types of cooling towers are classified by the method used to create the air movement through them. In natural draft towers, air movement is induced by a large chimney utilizing the density difference between the air inside and outside the chimney. In a mechanical draft tower air is moved by fans; either the induced draft type (ID) that pulls air through the tower or the forced draft type (FD) that pushes air through the tower. Figure 3 (a-c) shows a typical natural draft tower and an induced draft and forced draft mechanical draft cooling tower.

Towers are further classified by the relative flow directions of the air and water in the tower. In a crossflow tower, the air flows perpendicular to the falling water (see Figure 3 (a)). In a counterflow tower the air flows vertically upward, counter to the falling water (see Figure 3 (b, c)).

However, the water and air conditions that exist in a cooling tower are dependent on the performance criteria specified by the design engineer, not on the type of tower or its air flow direction. Any one set of specified internal cooling tower water and air conditions can be duplicated in any of the types of cooling tower described above. The choice of cooling tower is usually made on the basis of economic and environmental considerations rather than on the basis of achieving certain design conditions.

The results presented here are considered typical for most drift eliminator designs. However, variations in the plenum environment and drift eliminator design will have a significant effect on the discharge drop size distribution. The older drift eliminator designs are characterized by the presence of more of the larger drops which appreciably increase the total drift loss and dispersion of a greater quantum of toxins and pathogens.

Figure 9 is a drift droplet size distribution after Chen, (1977) averaging 5 different sets of drift dots each for natural draft towers and mechanical draft towers. The only major difference between them is the maximum drop capable of being supported by the plume exit velocity.

Condensation Nuclei

Under ambient atmospheric conditions, natural cloud droplets are formed by the condensation of water vapor onto microscopic particles or condensation nuclei.

In the past, the actual size of these nuclei had only been determined by indirect methods. Recently electron microscopic measurements have been utilized. Presently, condensation nuclei are classified into three size groupings; Aitken, Large and

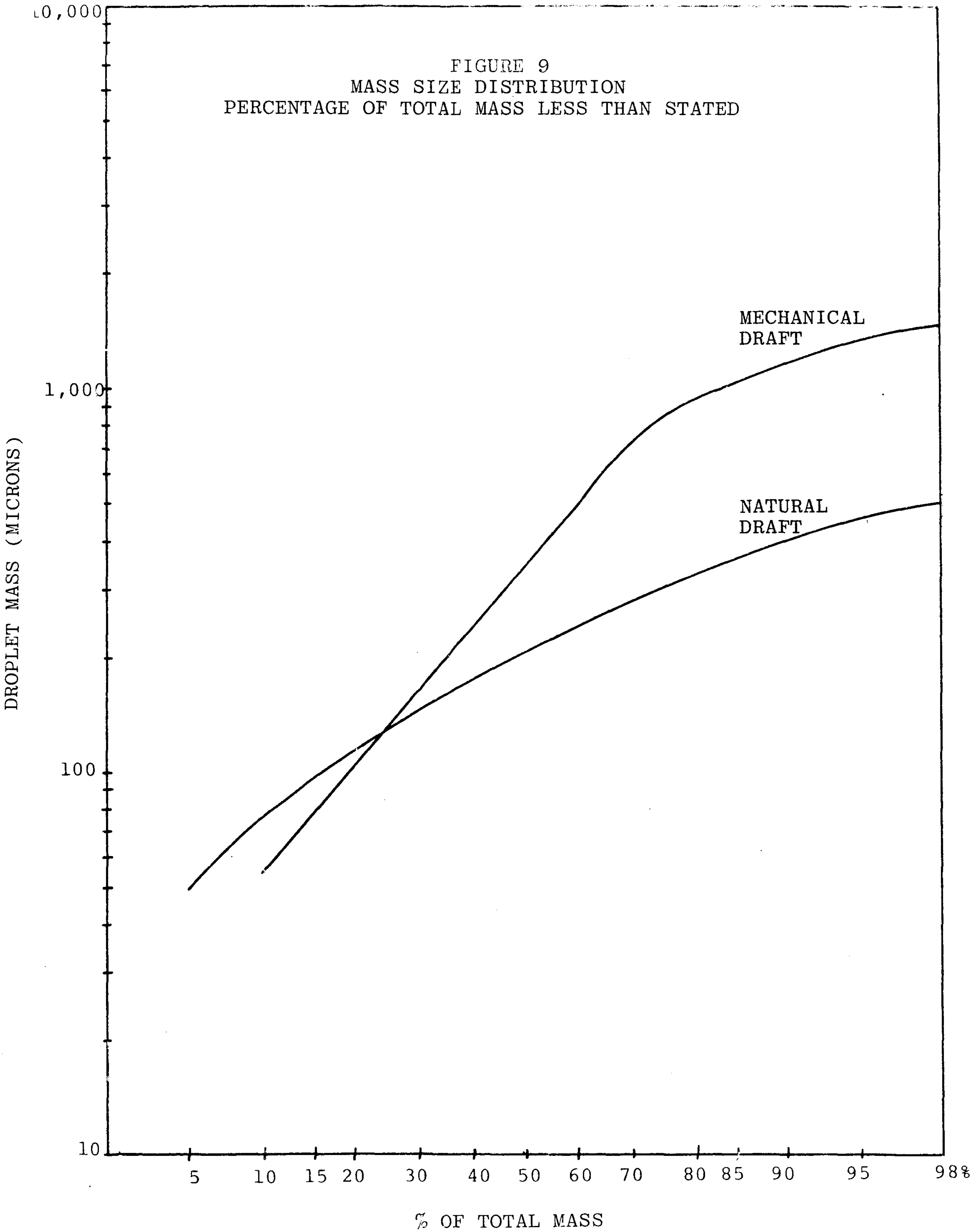


FIGURE 9
MASS SIZE DISTRIBUTION
PERCENTAGE OF TOTAL MASS LESS THAN STATED
MECHANICAL DRAFT
NATURAL DRAFT
10,000
1,000
100
10
DROPLET MASS (MICRONS)
5
10
15
20
30
40
50
60
70
80
85
90
95
98%
% OF TOTAL MASS

Giant. The size range for each of these classifications is found in Table 10.

Aitken nuclei are the most numerous type in aerosols. Their concentration exceeds that of large nuclei by 2.0 or 2.5 orders. The concentration of giant nuclei is insignificant, on the order of several nuclei per liter of air. The mass of individual nuclei varies between 10^{-15} and 10^{-11} g. Giant nuclei may have a mass as great as 10^{-8}g (see Table 10). Pathogenic and toxic particles, should they form condensation nuclei would constitute aitken nuclei.

Given an initial distribution of particles of every size, particles whose radius is $> 10^{-2}\mu$ become attached to larger particles due to Brownian motion. Those particles with radii greater than 20μ are sufficiently heavy to precipitate out. Both processes result in a distribution of particle size with fixed upper and lower limits. Between these upper and lower limits, the mass is distributed fairly evenly.

Condensation Nuclei Composition

The nature (chemical composition) of condensation nuclei is usually studied via the chemical and spectral analysis of samples of raindrops and cloud droplets. Analysis of rainwater shows the following average composition:

1 mg/l	CI^-
2 mg/l	NA+
3-5 mg/l	CA+
5-10 mg/l	$SO_4 2-$
5-15 mg/l	HCO_3

Maximum values in the analysis reached 10-15 times greater than these averages, and minimum values 10-20 times smaller. Other substances were also found in smaller amounts.

Impurities may be captured by raindrops during their fall. Analysis of water obtained from cloud droplets indicates the chemical composition of these nuclei. Analyses of aerosol particles collected in various atmospheric layers was carried out by Junge et. al. Chlorides were present in all samples varying between tenths of, and several mg/l.

The most common nuclei were found to contain compounds of chlorine, sulfur, nitrogen, carbon, magnesium, sodium and calcium. Sodium chloride is very frequently encountered in nuclei.

Various types of bacteria and viruses may act as condensation nuclei. A number of species have been determined to be active ice nuclei. They have been observed to initiate ice in supercooled water at -1.3°C in concentrations of up to 10^8 nuclei active at-5°C per cubic centimeter of culture. Species

TABLE 10

CHARACTERIZATION OF CONDENSATION NUCLEI

SIZE CLASSIFICATION	RADIUS (cm)	CONCENTRATION (cm^{-3})	MASS (g/M^3)
Aitken	$5X10^{-7}$ - $2X10^{-5}$	42500	17.
Large	$2X10^{-5}$ - $1X10^{-4}$	132	25.
Giant	$1X10^{-4}$ - $10X10^{-4}$	2.195	41.4
Giant distribution	$1X10^{-4}$ - $2X10^{-4}$	2.08	23
	$2X10^{-4}$ - $3X10^{-4}$	0.09	4.2
	$3X10^{-4}$ - $5X10^{-4}$	0.02	5.1
	$5X10^{-4}$ - $10X10^{-4}$	0.005	9.1

that have been specifically identified are *Pseudomonas syringae*, *Pseudomonas fluorescens* and *Erwinia herbicola*. Two other species have not been specifically identified although they have been shown to be active nuclei. Many other species have been tested for their ice nucleating ability, producing negative results.

Condensation and Drop Formation

The essential physics of condensation of water vapor onto acceptable nuclei includes surface tension characteristics, hygroscopic effects, the rate of diffusion of water vapor to the droplet and the rate of conduction of latent heat away from the droplet.

The most important factor involved in the formation of clouds is chilling of humid air, which can happen due to the following causes:

1. adiabatic expansion of air on vertical ascent,
2. turbulent transfer,
3. radiation (radiative chilling).

Cooling of air during adiabatic expansion involves a reduction in pressure. The main factor here is the movement of air into higher atmospheric layers. Average daily drops in atmospheric pressure (5-6 mb/day) chill each layer of air by 1-2° each day. Vertically ascending air, containing unsaturated water vapor, is cooled adiabatically by 1° for each 100 m of ascent.

When convection is well developed the air may rise by a height on the order of kilometers. This would result in a very strong cooling trend. Chilling of the air by turbulent transfer and mixing depends on the vertical distribution of temperature. In a stable stratification the upper portions of the layer in which turbulent transfer takes place will be cooled. If this cooling is accompanied by the transport of nearly saturated water vapor, its condensation may lead to the formation of stratus clouds.

Finally, the third cause of chilling is radiation. This process is manifested by the cooling of air layers containing a large amount of water vapor together with dust particles, condensation nuclei and smoke particles. It is also evident in nighttime chilling of the upper cloud boundary. Radiation often results in the appearance, and sometimes intensification, of the comparatively thin nighttime sub-inversion clouds.

In nature these processes act in combination. However, the prime factor in cloud formation remains the vertical movement of air.

The act of condensation begins, air is cooled and increases the relative humidity. Before the relative humidity reaches 100% (in terms of a plane surface of pure water), condensation begins on larger, more active nuclei. When the humidity approaches 100%, these have become full sized cloud droplets. Generally, the available water vapor is used by the larger nuclei and the smaller, less active nuclei remain unused. Therefore, the number of cloud droplets is greatly exceeded by the number of available nuclei.

An average active salt nucleus is 1 μ in diameter. When condensation occurs on such a particle, 1 second suffices for it to grow to the size of a small cloud droplet (10 μ). It will take about 500 seconds for the droplet to grow to a large cloud droplet (100 μ) and about 10,000 seconds (or 3 hours) for it to grow to the size of a small raindrop (1,000 μ, or 1mm). It would take several days for a large raindrop to form through condensation only. Thus it is seen that although the condensation process is capable of producing cloud droplets, it is far too slow to produce raindrops of the size actually observed. Therefore, there must be present some mechanism or combination of mechanisms that will cause cloud particles to join and form raindrops. Again, large magnitudes are involved. It will take about one million average cloud droplets to account for the water contained in a large raindrop. The mechanism for increasing the size of cloud droplets to raindrops is called accretion. Accretion occurs when a larger falling drop collides with other smaller droplets. These collisions critically depend on the position and radii of the two drops. Not all droplets that collide with the large drop adhere to it, however this coalescence increases rapidly in effectiveness as the drop size increases in size. This process is more significant than condensation in the ultimate formation of clouds.

Through all of these processes, condensation nuclei of pathogenic organisms and toxic substance particles, and aerosol droplets containing these may be incorporated into larger droplets and clouds. Under these conditions these particles and infectious agents may travel further, potentially governed by the weather patterns as well as local wind currents.

External Conditions Relevant to Drift Behavior

If atmospheric air is cold, the exhausted drift is rapidly cooled and becomes supersaturated. The small drift droplets remain entrained and act as condensation nuclei. As long as the supersaturated condition remains, they become enlarged due to condensation. Drift droplets affected by this phenomenon typically represent less than 12% of the total drift mass. Significant condensation occurs only during brief periods when a prolonged supersaturated plume conditon exists.

The relative humidity of the atmosphere, peripheral to the site of drift emission, may affect aerosol drift transport. In relatively dry areas, any substance or pathogen which is carried by aerosol drift, or constitutes the condensation nucleus of a droplet, will travel over further distances.

In dry areas the moisture in the aerosol or drift will evaporate rapidly. The particle or substance remaining will have a lower fall velocity than the initial droplet. Its transport will not be governed by air currents rather than by the drift itself. The ultimate deposition of these particles will resemble a Gaussian distribution.

In relatively damp areas organisms or substances carried by the aerosol or comprising the condensation nuclei will be transported shorter distances. The droplets will accrete moisture and due to the additional mass, the fall velocity increases. These droplets will fall out of the drift more rapidly, depositing the particles in a more immediate area.

The location and type of cooling device itself will affect local relative humidity. In dry areas, emitted drift will evaporate rapidly creating little if any change in the relative humidity. However, in damp areas, the air is less capable of absorbing this additional moisture. There may be an appreciable difference in the local relative humidity.

Natural draft towers are less likely to affect relative humidity at or near ground level than mechanical towers. Mechanical towers due to their lower height emit drift closer to ground level, and may produce an appreciable difference in the moisture content of the air.

This discussion on relative humidity will be particularly important in our subsequent analysis of direct effects on plants.

Ice-Crystal Process

In damp areas or when the atmosphere is near saturation, there may be problems from precipitation modification resulting from aerosol drift. One manifestation of this problem is the formation of ice crystals. Pathogenic or toxic particles may aid in this process, acting as nuclei.

Observation has shown that cloud droplets do not freeze until the temperature is far below the freezing point. Even as low as -30°C, perhaps one in a thousand droplets freeze. As the temperature approaches -40°C they freeze rapidly and at lower temperatures, clouds consist of crystals.

Liquid water that exists at temperatures below 0°C is said to be "supercooled". Observation has shown that freezing is initiated by a variety of impurities such as organisms or particles of chemical substances. The cloud droplets are exceptionally pure as compared with water on or in the ground.

Layers of cloud that contain a mixture of water droplets and ice crystals are unique because the saturation vapor pressure over ice is lower than over water. Although the difference is small, it is highly significant. In a cloud that consists of both droplets and crystals, the actual vapor pressure will be a compromise between the two saturation pressures. While the air is not quite saturated in respect to water, it is slightly super-saturated in respect ot ice. This, then, will cause water to evaporate from the droplets and vapor to condense on the ice particles. We have here a process which will cause a few cloud elements (those that consist of ice) to grow at the expense of the other elements.

As condensation is initiated on certain nuclei, freezing in undercooled clouds (between 0 and -40°C) is initiated by freezing nuclei, (a particle that will initiate the growth of an ice crystal out of a liquid water under these conditions). Minute ice particles are excellent freezing nuclei, and a number of other particles (natural or man-made) will also cause such growth.

Approximate estimates and observations show that for supersaturations of the order of 10-12% (assuming a concentration of about 100 per cubic meter) the ice crystals may grow within 4-5 minutes the mass of a crystal will equal that of a water droplet with a radius of about 100-200 μ. This rapid growth by sublimation is the reason why even thin (about 1 km thick) ice-crystal clouds with small velocities of rising air currents can produce precipitation bands. These sometimes reach the earth's surface in the form of fine, light snow or rain.

Substantially different conditions prevail when the ice particle occurs in the vicinity of water droplets, as is the case in mixed clouds. Conditions here are very favorable for sublimation growth, especially if there are many more supercooled droplets than crystals in the cloud. When relative humidity in the cloud decreases as a result of the sublimation of water vapor on ice particles, conditions of phase equilibrium over the droplets are disrupted. The latter start evaporating, thereby adding to the supply of moisture for crystal growth. Thus a special process of "transfer" (distillation) of water from supercooled droplets to crystals begins to operate.

In a supercooled droplet cloud rapid growth by distillation of vapor from droplets will set in as soon as ice particles with a radius of the order of 10^{-6} cm appear. As a result the crystals will be able to grow to large sizes until all the droplets evaporate. The initial excess of water vapor condenses upon the crystals and the cloud has been completely transformed into an ice-crystal cloud. Calculations show that the role of this process in the initial growth of ice particles occurring in a medium containing supercooled droplets is very great.

The initial stage of ice-crystal growth by sublimation takes place far more rapidly (10-20 times) than the condensational growth of water droplets. The point at which the process of accretion becomes dominant in the further growth of the ice crystals (r=50-60μ) is reached within a few minutes.

When considering the accretion of ice crystals it should be borne in mind that falling crystals have a greater capture surface than droplets for the same mass. At the same time, their fall velocity is lower than that of spherical particles. This accounts for the faster growth of non-spherical ice crystals by accretion and for the diversity of their shapes. It may roughly be estimated that ice particles grow 5-6 times more rapidly than droplets with the same mass.

Precipitation (Snow) From Cooling Tower Plumes.

During the winter of 1975-1976 significant environmental effects were observed from large natural-draft towers. They produced plumes persisting as far as 70 km in which the supercooled water droplets changed to ice crystals and produced light snowfall. Measurable accumulations of snow were observed on the ground. The falling snow restricted visibility to less than 1600 m close to the ground. From December 1975 through March 1976, this conversion of liquid droplets to ice crystals was observed ten times at several power plants. One of these incidents is described below.

During a period of clear weather on 18 January 1976, from 0755 to 1111 E.S.T., a flight test was conducted in the vicinity of a plant, located 25 km northwest of Charleston, West Virginia. This coal-fired plant has three hyperbolic cooling towers serving three generators totaling 2900 Mw. The weather was cold and clear with temperatures of -12°C near the surface, decreasing to -20°C at 1600 m above ground. The plumes from the three cooling towers merged and rose to form a typical liquid droplet cloud between 900 and 1600 m. The plumes mixed with the smokestack effluent at 400 m. The rise of the cooling tower plume stopped at the base of an elevated temperature inversion, also at 1600 m. The change from supercooled droplets to ice crystals began at 5 km and was complete 11 km downwind of the towers. This ice crystal cloud persisted aloft to a distance downwind of 43 km. Snow began descending from the base of the plume when the conversion from droplets to ice crystals started, and it first reached the ground at 13 km. Snowfall on the ground also continued to at least 43 km. The maximum accumulation of snow (very light fluffy snow) was 2.5 cm.

The ground measurements outside of the plume shadow indicated that the plume trajectory had changed from the initial conditions. The visibility in the clear air was greater than 15 km, but it was restricted to approximately 1600 m in the snow near the ground level, as it would be in a natural snowfall.

Snow from cooling tower plumes reached the ground only at considerable distances from the cooling tower (a minimum distance of 8 km was measured in one case).

In some of the tests, natural clouds were present and snow or snow showers came from them. This natural snow occurred before, during, or after the observations of snow from the cooling tower plumes. Snow was observed from the tower plumes, however, when it was not falling from natural clouds. Moreover, the conversion of the tower plumes from liquid drops to ice crystals sometimes induced a similar change in the natural clouds, creating an obvious "hole" in an otherwise unbroken cloud deck.

We cannot specify precisely the conditions required for induced snow. Observations to date have indicated that induced snow has been associated with low temperatures and with plumes diffusing in relatively stable conditions. The key parameters are air temperatures of -12°C or less and relatively stable diffusion conditions at plume height. The rate of water vapor emission from the towers must be critical also, since this is the source of the additional water vapor.

The artificial snowfall occurs when the atmosphere is cloudy and snow would be expected. In tests, natural snow often coincided with tower-induced snow or occurred soon afterward.

However, the observations made during the winter of 1975-1976 are not unique. A similar snowfall was observed at Oak Ridge, Tennessee, in 1960. The water vapor released from clusters of mechanical draft towers at the gaseous diffusion plant at Oak Ridge approximated that from a large power plant, and the weather conditions were similar to those which induced snow in the Charlestown observations. Agee has also described the artificial inducement of snowfall, but the incident he described appears to have been caused by a seeding effect of particles in supercooled fog.

The details of the Oak Ridge case are also presented here. The snow was intermittent and fairly light. Downwind from the cooling towers, snow began falling about 3 miles distant and continued to be deposited noticeably on the ground up to 5 miles. Some very light snow was reported as far as 10 miles from the towers late in the morning, but by noon all activity seemed to have ceased. The srow that was deposited 3 to 5 miles from the cooling towers was normal in appearance with some flakes up to 1/4-inch in size. The snow falling farther downwind was finer in structure and, in the sun, appeared almost crystalline in nature. Since there were no roads perpendicular to the direction of travel of the plume estimates of the lateral distance of snow deposit were not possible. The valley contour, however, suggested a possible width of approximately one mile.

The snow had been falling during the night, or at least prior to sunrise. Between 0800 and 0900 EST there were no clouds outside the affected area. In the area, the clouds ranged from scattered cumulus at 1,000 to 1,500 feet to low stratus (base less than 300 feet) as it snowed. Moisture from the cooling towers rose to an initial height of about 1,500 feet, then, as it progressed downwind, the resulting cloud decended, intermittently reducing visibility on the ground to less than 500 feet. A freezing nuclei detector operating at the time of the snowfall showed no increase of detectable nuclei.

Ground Level Drift Deposition

The drift deposition problem is a complicated one involving several interrelated processes: the dynamics and thermodynamics of drops in a rising plume, the point of which the drops break free from the plume, dispersal by atmospheric turbulence, and possible evaporation in the ambient atmosphere. To make deposition estimates, the source characteristics of the tower such as tower geometry, amount of water circulated, effluent speed, droplet emission spectra, drift rate, and salt concentration, must be known. Calculations must be made of the plume rise, which in part depends on the initial momentum and buoyancy flux and on the ambient atmospheric conditions. Droplet transport, which depends on meteorological conditions such as the atmospheric relative humidity, turbulence, temperature and its gradient, and wind velocity, must be estimated.

Thus, we see then an already difficult problem of modeling plume dispersion becomes considerably more complicated when we attempt to predict deposition of drift emitted with the plume. In addition, at the present time there is no reliable field data on drift deposition so that existing models cannot be evaluated as to their predictive capabilities. Chen and Hanna (1977) compared the results of ten different drift composition models. Typical natural cooling tower input conditions are given in Table 11. The individual results are given in Chen and Hanna (1977). The results of the ten models were averaged, producing the concentration factors in Table 12. By multiplying the concentration factor in Table 12 by the total mass emission rate of the substance of interest (Kg/month), the ground level concentration of the substance is determined. The concentration is that which would be determined by averaging the ten different model predictions using the input data of Table 11.

TABLE 11

MODEL INPUT PARAMETERS FOR CALCULATION OF TABLE 12

Plume initially saturated

Plume temperature at exit from tower, T_{po} = 305°K

Ambient temperature near exit from tower, T_{eo} = 275°K

Tower height = 100m

Tower exit diameter = 60m

Efflux velocity = 4.3 m/sec

Amount of circulating water = 499,338 gpm (1890 m^3/min.)

Drift rate = 2 X 10^{-5}

Water salinity = 3.45%

Wind speed = 4.3 m/sec.

Calculate salt deposition rate for a sector of 22.5°

Frequency of wind direction which blows toward the sector = 1

Ambient relative humidity = 70% (constant with height)

Isothermal ambient atmosphere (slightly stable atmosphere)

Drop size distribution:

Diameter interval	Mass mean diameter for interval (um)	Mass fraction
0-100	50	0.05
100-200	150	0.3
200-300	250	0.4
300-400	350	0.15
400-500	450	0.075
500-600	550	0.025

TABLE 12 TYPICAL* GROUND LEVEL DISTRIBUTION OF DRIFT PARTICLES FROM NATURAL DRAFT COOLING TOWERS

Downwind Distance (Km)	Area of 22½° Sector (Km²)	Deposited** within Sector (Kg/month)	% of Total Deposition (%)	Concentration** within Sector (Kg/Km²-month	Concentration*** Factor
.25 - .6	0.058	1246.	2.1	21483.	.3718
.6 - .8	0.055	810.	1.4	14727.	.2549
.8 -1.0	0.071	732.	1.2	10310.	.1784
1.0 - 1.5	0.254	2585.	4.3	10177.	.1761
1.5 - 2.0	0.344	2324.	3.9	6756.	.1169
2.0 - 4.0	2.356	6933.	11.7	2943.	.0509
4.0 - 10.0	16.493	17566.	29.6	1065.	.0184
10.0 - 30.0	157.081	21291.	35.8	135.	.0023
30.0 - 60.0	530.144	5023.	8.5	9.5	.0016
60.0-100.0	1256.638	870.	1.5	0.7	.0001
Total	1963.494	59380.	100.		

* Average of predicted deposition values of ten models, each using the input parameters of Table 1 (see ref. 1).

** Frequency of wind direction which blows toward sector = 1

*** Multiply the total mass emission (Kg/month) from the tower by the concentration factor to immediately determine the ground level concentration (Kg/Km²) - month) within the distance interval.

A similar analysis was performed for the drift dispersion from a mechanical draft cooling tower. The input data is given in Table 13. The results, given in Table 14 are those predicted by one proprietary model. Therefore, the results are probably not as representative as those given for natural draft towers. A comparison of the results for natural and mechanical draft towers is given in Figure 10.

Aerobiology

The air as a route for the spread of infectious disease has been well documented in microbial and epidemiological literature. It is established, beyond any question, that droplet infection can spread epidemics although the transmission range is relatively short for respiratory diseases.

In recent years, much of the attention on the long range transmission of infectious organisms has been in the area of biological warfare. The information presented here was extracted from unclassified or declassified biological warfare documents, or derived from personal communications with or first hand experience of individuals involved in the subject. Some data, not singled out, had previously been classified or was extracted from classified sources and is now in the open literature, hence the open literature references.

The aerosolization of these wastes via wave action, or other agitation was clearly demonstrated by Claude Zobel (1946) and earlier. Additionally, it has been shown that the air travel and the subsequent dissipation of an aerosol from a given line source while approximating a function of an exponential decay pattern has nevertheless often retained its basic cloud structure and has in this form travelled hundreds of miles due to unique meteorological conditions. (U. S. Army 1966, and Report 219II) However, it must be recognized that due to the nature of the main sources of this data pool that some information has of necessity remained classified.

Data used in this section is from the following sources:

A. Fort Detrick, Maryland. A former United States Army installation dedicated to a variety of investigations dealing with many aspects of microbiological survival, metabolism, destruction and disease prevention.

B. Dugway Proving Grounds, Utah. A chemical warfare site still in existence, that has in the past been used for testing of biological and chemical agents in a variety of forms.

TABLE 13

MODEL INPUT PARAMETERS FOR CALCULATION OF TABLE 14

Cooling Tower Parameters

Cooling Tower Diameter (M)	16.6
Cooling Tower Height (M)	18.21
Plume Exit Velocity (m/sec)	9.35
Circulating Water Flow Rate	717900 gpm (2717.26 M^3/min)
Drift Rate (%)	.008
Plume Exit Temperature, dry bulb (^OK)	297.
Salt concentration (gm/cm^3)	.00135

Particle Diameter - Microns	% of Total Mass Drift
0 - 50	49%
50 - 100	20%
100 - 200	18%
200 - 300	7%
300 - 500	4%
500 & Larger	2%

Ambient Conditions

Wind speed (m/sec)	4.02
Temperature, dry bulb (^OK)	266.
Specific humidity (lbs moisture/lbs dry air)	.00158
Pasquill stability class	4
Frequency of wind direction which blows toward the sector	1

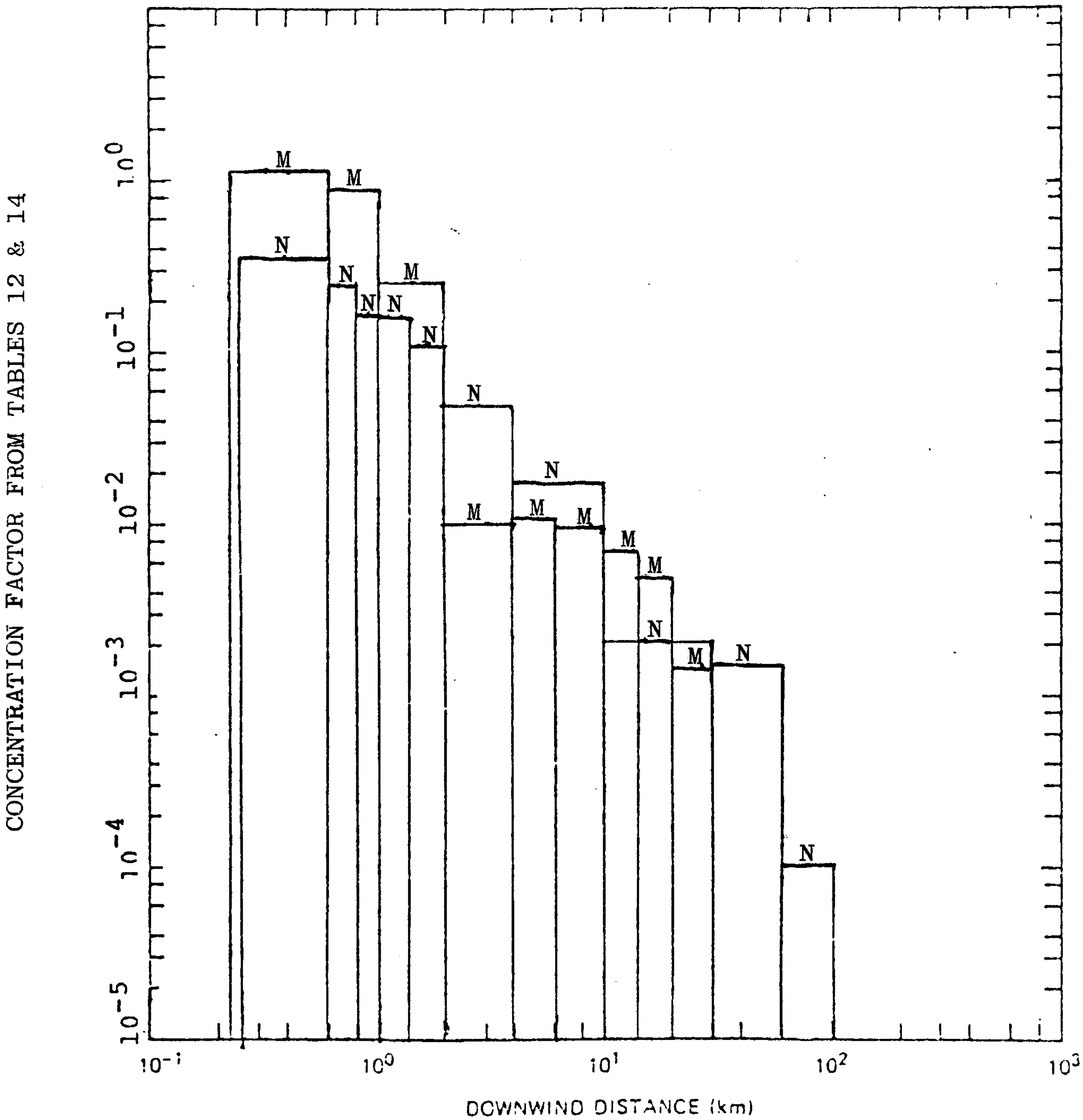
TABLE 14 EXAMPLE* OF GROUND LEVEL DISTRIBUTION OF DRIFT PARTICLES FROM A MECHANICAL DRAFT COOLING TOWER

Downwind Distance (Km)	Area of 22½° Sector (Km²)	Deposited** within Sector (Kg/month)	% of Total Deposition (%)	Concentration** within Sector (Kg/Km²-month)	Concentration*** Factor
.22 - .6	.0612	938.	7.2	15328.	1.1928
.6 - 1.0	.1257	1450.	11.2	11534.	.8836
1.0 - 2.0	.5890	1981.	15.3	3363.	.2617
2.0 - 4.0	2.3562	306.	2.4	130.	.0101
4.0 - 6.0	3.9270	565.	4.4	144.	.0112
6.0 - 10.0	12.566	1570.	12.1	125.	.0097
10.0 - 15.0	24.544	2160.	16.7	88.	.0068
15.0 - 20.0	34.361	2130.	16.3	62.	.0048
20.0 - 30.0	98.174	1865.	14.4	19.	.0015
Total	176.7	12965.	100.		

* Calculated from predictions of combined trajectory - Gaussian drift dispersion model for a round mechanical draft cooling tower.

** Frequency of wind direction which blows toward sector = 1

*** Multiply the total mass emission (Kg/month) from the tower by the concentration factor to immediately determine the ground level concentration (Kg/Km²-month) within the distance interval.



Calibration Factor vs. Downwind Distance For Examples of Natural (N) and Mechanical (M) Draft Cooling Tower Drift Deposition

FIGURE 10

The major mission was long range field testing in a relatively isolated part of the state.

C. Illinois Institute of Technology, Chicago, Illinois. Its research staff has contracts and grants from a large number of government and private sources. The research is variable and in some areas possibly classified.

D. Army Material Command, Washington, D.C. Involved with the logistics inherent in any aspect of the army mission.

E. Edgewood Arsenal, Edgewood, Maryland. At one time the research center for the study of gas, aerosol, and radiological and chemical properties, and the toxicity and protection from all forms of chemical agents.

F. United States Navy. Via direct or contracted efforts the USN was engaged in collaborative efforts with its sister services to investigate various aspects of biological warfare agents, dissemination, detection and protection.

G. Aberdeen Proving Grounds, Maryland. Primarily the army location for hardware testing.

H. Various contracts were in force at different times with organizations as diverse as Booz Allen Inc. and the University of Pennsylvania.

I. Foreign sources include the Canadian experimental station at Suffield, Canada and the British laboratories at Porton, England.

J. Wright Patterson Air Force Base, Ohio. Site of medical, physiological and toxicological testing in conjunction with the USAF mission. At one time it was involved in long range bacteriological tests from the point of view of detection and prevention of a microbiological attack.

The analysis within this task analyzes organisms in relation to attenuation due to dessication, solar radiation and ambient environmental conditions, and to protective chemical mechanisms. The organisms addressed in this task are listed in Table 15.

Results of Data Search

Serratia marcescens had been indicated as the causative agent in the deaths of individuals following a series of Biological Warfare (B.W.) tests. This occurred in two separate incidents, in 1950 near San Francisco and in 1952 near Fort McClellan, Alabama.

TABLE 15

ORGANISMS REVIEWED FOR AEROSOL SURVIVAL AND TRANSMISSABILITY

1. Rust spores
2. *Bacillus globigii*
3. *Pasteurella pestis*
4. *Pasteurella tularensis*
5. *Coccidioides immitis*
6. *Rickettsia burnetii*
7. *Serratia marcescens*
8. *Sarcina lutea*
9. Venezuelan equine encephalitis
10. *Vibrio cholerae*
11. Enterotoxin B
12. Simian virus
13. Toxic proteins
14. *Klebsiella pneumoniae*
15. *Escherichia coli*

lowered metabolic activity, permitting damaged cells to survive and even repair, lie dormant or even recuperate from the stress.

B. globiggi has also been used in field trials in the dried spore state, in a slurry and in liquid media. (U. S. Army, 1953).

Survial and Destruction

Levin (1966) has cataloged the persistence of a number of microorganisms in a spectrum of soils and climate. Tests of persistence and variability of persistence, have produced a variety of techniques designed to kill microorganisms. These range from extreme dry heat to the use of mustard gas on E. coli (U. S. Army 1965). Ultra violet light has of course been used against some organisms while other forms of radiation have permitted the ultimate recovery of the cell's capacity to produce DNA.

A study by Lighthart (1972) employed vegetative S. marcescens, Sarcina lutea and B. subtilis spores. The aerosols were challenged by varying humidities at 15°C for 6 hours in a carbon monoxide environment that approximated a high urban concentration. The survivability varied from lethal to protected. For example, S. marcescens was killed off four to sevenfold at low (1-25%) RH. Above this at 90% RH, protections was provided. S. lutea varied from protection during the first hour to death during the next 5 hours, topping a seventy fold increase in the RH range of 0 to 75%. The spores of B. subtilis proved to be hardy in almost all environments.

Viruses and bacteria have been inactivated by ozone (Burleson, 1975) but the truly effective result depends on the water being free of almost all organic waste. River water would be a difficult treatment media by this method, due to the ozone demand of the organic material.

Viruses

Virus aerosol survival studies have lagged behind bacteria or plant spores due to the inherent problems of tracing, trapping and identification. As techniques have improved we have learned that some viruses persist in the airborne state in good numbers for 6 or more hours. Using vesicular stomatitis virus (VSV) Watkins et. al. (1965) studied temperature and humidity variables. He concluded that maximum stability occurred at 20% and 80% RH while minimal stability was to be found at 50% RH. Temperature increments from 50°, 70°, 80° and 90°F all increased the decay rate.

Harper (1961) studied vaccinia, influenza and V.E.E. at temperature ranges of 7-12°C, 21-24°C and 32-34°C and concluded survival was inverse to temperature. Coxsackie A21 aerosols at 25°C and 50 to 60% RH experience a 50% decay rate in the first few seconds of aerosolization.

The persistence inherent in many aerosols of virus origin, depends greatly on the initial concentration. A dry cloud containing virus matter exhibits a longer survival. The medium in which the virus is suspended in prior to, and during aerosolization influences the subsequent behavior. The content has been studied but not the mechanism. Inositol for example decreases the sensitivity of viruses to relative humidity, U.V. light and X-ray, thereby artificially prolonging the viability.

Survivability and inactivation of viruses in air was examined at Wright Patterson Air Force Base, Ohio with the following conclusions. (1974).

Adenoviruses, enteroviruses and Newcastle virus were most stable at room temperature and 50% relative humidity. Para influenza and respiratory syncitial viruses were inactivated rapidly as relative humidity shifted. The decrease in relative humidity decreased the survival rate of the adenoviruses and enteroviruses within 2 hours. At moderate (50%) or high (90%) relative humidity the survival rate varied from 7-24 hours. The para influenza, respiratory syncitial and New Castle viruses were inactivated rapidly at high and medium RH and to a lesser degree at low RH.

In the realm of survival, Lefler and Kott (1974) noted the survivability of polio virus Type I in dry sand for 77 days. Wellings extracted Coxsackie B_4, Polio Type II and I, Coxsackie Type A, (Wellings, 1975) Echo (Snow, 1955; Goetz, 1954; Erlich & Miller, 1968) from ground water. The significance of these findings lies in the appreciation of the ubiquity, and persistence of these microbiological entities with regard to survival.

Inactivation had been attempted by Jensen when he exposed aerosols of Coxsackie, influenza, sindbis, and vaccinia to ultra violet during passage through a tube. The kill percentage is expressed in Table 16. Therefore, one may conclude that by avoiding U.V., as in a dust cloud or debris environment, to some degree, the viability of the aforementioned viruses would be protected.

A number of studies were directed at the behavior of organic entities such as viral nucleic acid from Simian Virus 40 (SV40) (U. S. Army, 1956; Akers, 1972) virus protein and RNA of Encephalomyocarditis Virus (EMV) (DeJong *et al*, 1974), stability of toxic proteins (U. S. Army, 1965), enterotoxin B (U. S. Army, 1967).

The results concerning the survivability and persistence of these viruses varied greatly so that no general conclusion can be drawn.

For example:

SV40 persisted well at 21°C throughout a spectrum of relative humidities from 22 to 88%. At 32°C viability was practically gone within 60 minutes.

At relative humidities of 50% or less the EMV entity lost its viability, yet the RNA of the virus retained its infectivity.

The same illogicity persists with enterotoxin B and other proteins. However, as long as the substance retains its allergenic or toxic property the debilitating effects common to the entity can occur.

Mycotic Sources

Coccidioides immitus is distinctly hydrophobic when in its arthrospore stage (Levine, 1977). As such, it survives well within the wide ranging termperatures, relative humidity, dessication and even light energies of an infinite variety. Soil conditions that provide Na^+, Ca^{++}, SO_4^-, and Cl^- encourage the survival and growth of this fungus. Therefore, any organic mass able to provide these ions can in turn harbor this pathogen. Moisture enhances the mycelial growth. Dispersion by air is easily accomplished since the intact arthrospore is extremely persistent in air and in soil from which it can be wafted.

Rickettsia

Rickettsia burnetii is linked to Q fever. Aerosols of this agent have infected at distances of over ten miles from the point source (Tigertt, 1961).

Many of the effects of variables on microbiological survival in aerosols are tabulated in Table 17. The effects were arrived at during B.W. tests and research. Some of the variables examined include exposure to U.V. light, temperature and relative humidity.

TABLE 16

KILL PERCENTAGE OF VIRUSES EXPOSED
TO ULTRA VIOLET RADIATION

100 $ft.^3$/min. flow		200 $ft.^3$/min. flow
99.9	coxsackie	97.5
99.9	influenza	99.9
99.9	sindbis	96.7
	vaccinia	99.9
96.8	adenovirus	91.3

TABLE 17

EVENTS INFLUENCING MICROBIOLOGICAL SURVIVAL

ORGANISM	TEMPERATURE °C	RELATIVE HUMIDITY	COMMENTS OR EFFECTS AND REFERENCES
Adenovirus			91.3% survival in an aerosol; exposed to U.V. light (Jensen, 1964).
	70°	50%	Stable at 22°C (USDOA, 1974).
		50-90%	Decay directly proportioned to rise in relative humidity (U.S. Army, 1974).
Bacillus globigii	4°		Increased count of organism 100% survival (Leif and Hebert, 1977).
	ambient	ambient	Carried 12 mi. remained viable in field aerosol (U.S. Army, 1953).
Bacillus subtilis	ambient	ambient	Survived in all environments (Lighthart, 1972).
Coccidioides immitis	10°-45°	5-85%	Arthrospore survives well in all exposures (Levine, 1977).
Coxsackie A21	25°	50-60%	Immediate 50% decay (Jensen, 1964).
		100%	Found in ground water. Aerosol passed through U.V. light at rate of 200'/min.; 97.5% decay (Akers, 1972).
Coxsackie B4		100%	Found in ground water (Wellings, 1975).
Echo 1, 7, 11		100%	Found in ground water (Wellings, 1975).

TABLE 17

EVENTS INFLUENCING MICROBIOLOGICAL SURVIVAL

ORGANISM	TEMPERATURE $^\circ C$	RELATIVE HUMIDITY	COMMENTS OR EFFECTS AND REFERENCES
Encephalomyo-caditis		50%	Virus loses viability (DeJong, 1974).
		50%	RNA retains infectibility.
Enterovirus	70°	50%	Stable at $22^\circ C$ (U.S. Army, 1974).
		50-90%	Direct relationship between increase in relative humidity and survival.
Escherichia coli	$24-30^\circ$	40-90%	Survives well; mustard gas affects growth (Dimmick, 1965 & U.S. Army, 1965).
Influenza	$7-12^\circ$ $21-24^\circ$ $32-34^\circ$		Survival is inverse to rise in temperature (Harper, 1961).
			When aerosol was exposed to U.V.; 99% decay (Jensen, 1964).
Klebsiella pneumonia	ambient	ambient	Presence is key to poor environment (Seidler, 1975).
		<50%	Only 1% survival after 24 hours (Goldberg, 1977).
		>50%	Survival increased as relative humidity increased (Goldberg, 1977).
Newcastle virus	70°	50%	Stable at $22^\circ C$ (U.S. Army, 1974).
		50-90%	Rapid deactivation of virus (U.S. Army, 1974).

TABLE 17

EVENTS INFLUENCING MICROBIOLOGICAL SURVIVAL

ORGANISM	TEMPERATURE °C	RELATIVE HUMIDITY	COMMENTS OR EFFECTS AND REFERENCES
Newcastle virus (Continued)		<50%	Increasing survival rate (U.S. Army, 1974).
Pasteurella Pestis		26-39%	Good survival rate (U.S. Army, 1965).
		61-87%	1 log death rate; actual 90% loss (U.S. Army, 1968).
Pasteurella tularensis	-40-24°	>75%	Survives well (U.S. Army, 1964).
	24-35°		Death rate increases linearly (Erlich, Miller, 1968).
	49°		Maximum kill temperature (Erlich, Miller, 1968).
Polio type I		0%	Survived for 77 days in sand (Leffler & KOH, 1974).
		100%	Found viable in ground water (Wellings, 1975).
Polio type II		100%	Found viable in ground water (Wellings, 1975).
Rickettsia burnetii			Proven to cause Q-fever 10 mi. from origin (Tigertt, 1961).
Sarcina lutea	15°	0-75%	Exposed to CO gas; survival varied (Lighthart, 1972).

TABLE 17

EVENTS INFLUENCING MICROBIOLOGICAL SURVIVAL

ORGANISM	TEMPERATURE °C	RELATIVE HUMIDITY	COMMENTS OR EFFECTS AND REFERENCES
Serrata marcescens		90%	Protected viability (Lighthart, 1972).
	-40-32°	20-80%	Increase in death over 32°
	-40-120°	20%	Decrease in relative humidity increased death rate (U.S. Army, 1968 and Dimmick, 1965).
	15°	1-25%	Survived for 6 hours while exposed to CO gas; then 4.7 fold death rate (Lightart, 1971).
		10%	Relative humidity not a factor in survival (Goetz, 1954).
Simian virus (SV)	21°	22-88%	Survived well (U.S. Army, 1965).
	32°	22-88%	Decayed within 1 hour (Akers, 1972).
Sindbis virus			96.7% survival when aerosol was exposed to U.V. light (Jensen, 1964).
Staphylococcus aureus	24-30°	<10%	Survives well (Dimmick, 1965).
Staphylococcus pullorum		15-80%	Survivability increases as relative humidity increases (Dimmick, 1965).
Streptococcus salivarius	24-30°	<10%	Survives well (Dimmick, 1965).

TABLE 17

EVENTS INFLUENCING MICROBIOLOGICAL SURVIVAL (5 of 5)

ORGANISM	TEMPERATURE °C	RELATIVE HUMIDITY	COMMENTS OR EFFECTS AND REFERENCES
Toxic Proteins	$25-32^\circ$		Retains potency (U.S. Army, 1965)
Vaccinia	$7-12^\circ$ $21-24^\circ$ $32-34^\circ$		Survival inverse to temperature (Harper, 1961).
			Aerosol exposed to U.V. light; 99% decay rate (Jensen, 1968).
V.S.V.	50°, 70°, 80°, 90°	20-80%	Increase in decay as temperature increases (Watkins, et. al.).
	$7-12^\circ$ $21-24^\circ$ $32-34^\circ$		Survival inverse to temperature (Harper, 1961).

RESULTS OF TASK III - DIRECT EFFECTS

The potential direct effects of pathogenic organisms and toxic substances on plants, animals and humans were evaluated under this task. The study of conventional epidemiology and pathology concerns itself with the routes by which infection is acquired, considers the transmission of disease from man to man, that arising from contact with environmental sources, as well as the essential nature of the disease and especially the structural and functional changes caused by it. The potential of a given agent to cause disease in any given population, and the existence and pattern of any ensuing epidemic rests upon a number of variables, but particularly the following:

1. Portal of entry for the disease-causing agent.
2. Portal of exit.
3. Incubation period.
4. Gradient of infection.
5. Mode of spread.
6. Survival in nature.
7. Susceptibility of the population at risk.

Portal of Entry

Since the material released from the tower may be carried in a variety of physical forms and in particles of varying size, with different agents being present in differing quantities, three potential portals of entry must be considered:

Inhalation: Inhalation of airborne or droplet-carried organisms may create invasive disease at any site within the respiratory tract. Large particles and droplets are restricted by normal host defenses to deposition on the mucous membranes of the nose, mouth, pharynx, and upper tracheo-bronchial tree. In this instance, high concentrations of the infecting organism are usually required to produce disease, and the mechanism is usually direct contact. In contrast, smaller particles, 1-5 microns in size, will be inhaled into the distal portions of the respiratory tract, including the terminal bronchioles and alveoli, and these can cause disease with very small numbers of particles, occasionally estimated to be as few as a single particle. This is true "inhalation disease". For those few organisms studied, a balance exists between size of inhaled droplet and numbers of organisms required to transmit disease, making specific quantitative estimates of disease risk impossible, except for the few microorganisms well-studied in defined laboratory models of infection.

Contact: Particles of any size on exposed surfaces may cause disease in several specific areas. Whereas contact of even large numbers of most organisms on normal skin or surfaces is unlikely to cause disease, certain exposed surfaces may be much more susceptible, particularly the following:

1. Abnormal skin or surfaces (sites of burns, abrasions, or open wounds).
2. Mucuous membranes of respiratory tract.
3. Conjunctiva.

Ingestion: Food or water supplies contaminated by cooling-device drift can cause disease in any population ingesting such contaminated materials. In considering the possible role of cooling device drift, primary contamination of food and water supplies, as well as secondary contamination via infection of plants or animals lower down in the food chain must be considered. The risk of both primary and secondary contamination is particularly important for any population ingesting untreated food or unchlorinated water.

Portal of Exit

This is a relatively unimportant facet of this task, and is pertinent to the discussion of secondary propagation of disease through a community. Portals of exit are relevant by providing a means of infecting cooling tower makeup water in the first place. While organisms excreted predominantly by fecal or urinary routes of exit may find their way most readily into polluted river or ground water, virtually any organism in any tissue of any susceptible host, excreted by any route, such as respiratory tract discharges, could, under some natural circumstances, be found there. What is more important, therefore, is the ability of the organism to survive or multiply in such settings.

Incubation Period

This period between first contact of the host with the infecting organism and the development of clinical symptoms plays a major role in determining the shape of epidemic curves, and hence, in the development of appropriate forms of epidemiologic monitoring of the effects of cooling towers. However, consideration of incubation periods is not relevant to this preliminary discussion.

Gradient of Infection

This reflects the proportion of those infected who become symptomatically affected by the disease. It is important in determining the magnitude of an epidemic and in evaluating the public health significance. It is largely determined by the susceptibility of the population and the size of the infecting inoculum. This will become important in determining modes of epidemiologic monitoring, in which the search for asymptomatic infections may become required.

Mode of Spread

The conventional modes of transmission of epidemic disease are:

1. airborne
2. droplet
3. contact
4. food and/or water
5. vector.

Direct or indirect contact with cooling-device drift will involve all these modes of spread, with the possible exception of vector-borne disease. In the discussion of individual infectious agents that follows, droplet-borne diseases are considered under the respective portals of entry of either contact or inhalation disease depending on the anatomic site of impact of the offending agent and the route by which specific disease might be best acquired.

Survival in Nature

This concept is perhaps the most important in determining the risk from exposure to pathogens in cooling device drift. Survival of the microorganisms includes an analysis of what is present in the water sources used to cool the towers, survival of the initial "inoculum" in the highly unnatural thermal conditions of the tower, and in the aerosol produced. These last two considerations will be the most important factors in determining whether or not disease will ensue from the use of water polluted with any potential pathogen. This was of course, discussed within Task II.

Susceptibility of the Population at Risk

This may be the most difficult variable to define quantitatively, as it will differ for each organism and for each population group. For humans the demographic and medical variable that will need to be considered include the following:

1. Age distribution of the exposed population.
2. Racial distribution of the exposed population.
3. Sex distribution of the exposed population.
4. Presence of malnutrition or exposure to other factors that will affect host defense (e.g., malaria, produc-

ing reticuloendothelial system blockade, and thereby increasing susceptibility to Salmonella infection).
5. Prior experience or exposure to the pathogens and toxins involved.
6. Presence of immunologic deficiency states.

Variables to be considered for animals include these:

1. Age distribution of the exposed population.
2. Sex distribution of the exposed population.
3. Presence of malnutrition or other factors that will affect host defense (e.g., weather conditions, breeding cycles, migration and hibernation patterns).
4. Prior experience or exposure to the pathogens and toxins involved.
5. Presence of immunologic deficiency states.
6. Relative position in the trophic levels, and feeding pattern (e.g., herbivore, carnivore, omnivore).

The environmental and physical variables which predispose vegetation to infection or intoxication are more numerous and varied than those for humans and animals. The factors include:

1. Biological variables; including age, stage of development, species and variety of the exposed population.
2. Edaphic variables; soil conditions such as moisture and nutrition content.
3. Climatic factors; e.g. wind speed, temperature, relative humidity, light intensity and quality.
4. Presence of a second pollutant or toxin, which may modify the effect of the first.
5. Quantity of precipitation.
6. Factors of exposure including the concentration of the toxin, duration and frequency of exposure. (Continuous and intermittant exposures of the same dosage will produce significantly different effects).

General statements as to the relative risk of specific organisms or toxins can be found in Appendix B, Aerosol Drift Direct Effects Assessment Catalogue. Analysis of the actual effects on humans, animals and vegetation is included for each specific toxin or pathogen.

Finally it should be recognized that the risk of cooling device drift to a given population involves not only the direct transmission of disease and toxicity but also indirect transmission (to be discussed under Task IV), and transmission of allergens.

Allergens of many types can be considered, but are generally beyond the scope of this report, although several biologic agents can be so involved. Some, by their ubiquity and because the unique environmental situation of the cooling tower might potentiate their growth or transmission, might be particularly important, including:

A. Allergic broncho-pulmonary aspergillosis
B. Thermophilic actinomycetes.

Under these conditions, high concentrations of many other organisms, or antigenic fragments of organisms, might also become important. Among these is transmission of toxic substances which might alter the susceptibility of the population to other organisms, and resultant long-term effects of prolonged contact with unusual chemical or biologic materials.

One particular organism which could not be addressed fully within the format of the Aerosol Drift Direct Effects catalog is Mycobacterium tuberculosis. The general effect of this organism is tuberculosis, a chronic infectious disease. It is normally characterized by the formation of avascular nodules of inflamatory tissue.

The organism is carried and transmitted via aerosol formites while infection may occur through inhalation, ingestion or directly through skin. Inhalation is the most frequent means of infection. The route of entry of the infectious fomites may usually be inferred from the location of the characteristic lesions. Further transmission of the disease may occur from discharges from these areas.

There are three common varieties of this organism, var. hominus, var. bovis, var. avium. Each has a different pathogenicity. The bovine type is progressive and sometimes fatal in cattle. Manifestation in horses is progressive and usually associated with infection in cattle. The disease is also progressive in swine who are highly susceptible and in cats, who are usually infected from tuberculous milk. This type rarely affects sheep, goats, dogs, humans and does not affect birds.

The avian type affects all birds. Due to their lowered resistance to disease, disease occurs mostly in domestic or captivated, wild birds. This type produces chronic symptoms in swine and is progressive in sheep. It is the most common form to affect these animals. Rarely are goats, horses, cattle, dogs or cats affected by the avian variety.

Cattle, swine and cats are resistant to the var. hominus. This type doesn't affect horses, sheep, goats or most birds. Only psittacines are not resistant and their infection is usually associated with tuberculous owners. Dogs may also contract the disease from their owners and it manifests itself in the pulmonary form. Var. hominus is of course, the most common form to affect man.

When large animals contract tuberculosis, cattle normally develop lesions in the lungs and in the cephalic and thoracic lymph nodes. Swine develop lesions in the cephalic and abdominal lymph nodes, and it is sometimes fatal. In sheep and goats, the affected areas are the lungs and thoracic lymph nodes.

In smaller animals, dogs are affected in the thoracic organs and cats, initially in the abdominal organs and later in the lungs. Poultry develop the disease slowly. Initially there is intestinal ulceration and then necrosis and ulceration of the spleen and liver.

Wild animals rarely contract the disease except when associated with humanity, zoos or cattle raising areas. Wild birds commonly develop lesions in the spleen and liver. However, outward signs of infection are variable and may be non-existent. Outbreaks among wild animals involving more than one individual, are usually associated with man. Infection stems from exposure to either infected farm animals or sewage outfall.

Humans are quite susceptible to tuberculous infections but rarely manifest tuberculous disease. Generally the route of entry determines the site of primary lesions. Inhalation produces lesions in lungs and tracheobronchial lymph nodes; ingestion: mouth, tonsils, neck lymph nodes, intestine; skin: ulceration at specific site and regional lymph nodes. After a period of days the infecting organisms spread to all parts of the body.

Most of the tubercle bacilli do not find suitable sites for development. Some remain microscopic foci and may promote infection of bones, joints, lungs and other organs as much as ten years later. Disease due to reinfection usually becomes the chronic pulmonary form. This form is the prime cause for morbidity and mortality.

Man may be regarded as the sole carrier. Animal infection stems directly and indirectly from man, and any residual foci of infection in cattle are eliminated through mild pasteurization.

RESULTS OF TASK IV - INDIRECT EFFECTS

The effects of cooling device drift are not limited to direct reactions to and manifestation of disease from toxins and pathogens. The infection of plant and animal and human populations may either be secondarily transmitted or spread to other members of the community or may lead to interruption of human and animal food sources.

The potential of a given agent to indirectly or secondarily cause disease in any given population and the insuring patterns of infection or intoxification relies on the same variables as discussed under Task III.

1. Portal of entry for the disease-causing agent
2. Portal of exit
3. Incubation period
4. Gradient of infection
5. Mode of spread
6. Survival in nature
7. Susceptibility of the population at risk

Essentially all discussion contained in the previous section holds true and only the exceptions will be noted here.

Portal of Exit

Under this task, discussion of this facet takes on new importance. Organisms excreted from infected individuals, predominantly by fecal or urinary routes of exit and perhaps respiratory tract discharges, may find their way quite readily into polluted river or ground water. Virtually any organism in any tissue of any susceptible host, excreted by any route, could be found in water sources or areas of food cultivation. The ability of the organism or disease to survive, multiply or remain virulent in such settings, determines the potential for its transmission to successive individuals.

Mode of Spread

The five conventional modes listed in the previous task are valid considerations within this section as well. The difference lies in the role of vectors as means of transmission. Vector transmission by definition accounts for one living organism carrying a disease to another non-infectious individual. Vectors act in events such as insect bites (mosquitos transferring malaria); food chain transmission (infected plants; low order animals; herbivores; carnivores; and predators). Other instances include contact with open lesions on infected individuals.

Fomites too, play a major role in indirect effects from cooling towers. Ingestion of water contaminated with waste from infected individuals could spread disease. Plants may harbor pathogens on its edible parts or concentrate toxins in its leaves, fruits or roots, as in tuberous plants. Many small wild animals concentrate toxins in their fatty tissue, or may simply be infected with the disease itself. Inclusion of any of these in a food supply would further spread the infection or offending agent. Prior to pasteurization, milk from infected cows was the major cause of the spread of tuberculosis.

Concentration of people in close quarters, such as in schools, encourages person to person transmission. In recent years winter bouts of influenza have reached epidemic proportions and there have been renewed outbreaks of "childhood diseases" (rubella, chicken pox, measles). Rapid transmission would also occur between animals in farm and breeding settings.

Susceptibility of the Population at Risk

Susceptibility to an infection may increase when transmitted from one animal, plant or human to a like individual due to potentiation. Like individuals are susceptible to like organisms, varieties, even concentrations or innocula. As each individual becomes infected the innocula become more refined to meet the specifications necessary to infect subsequent individuals. Populations are therefore more susceptible to the agent being transmitted.

RESULTS OF TASK V - RECOMMENDATIONS

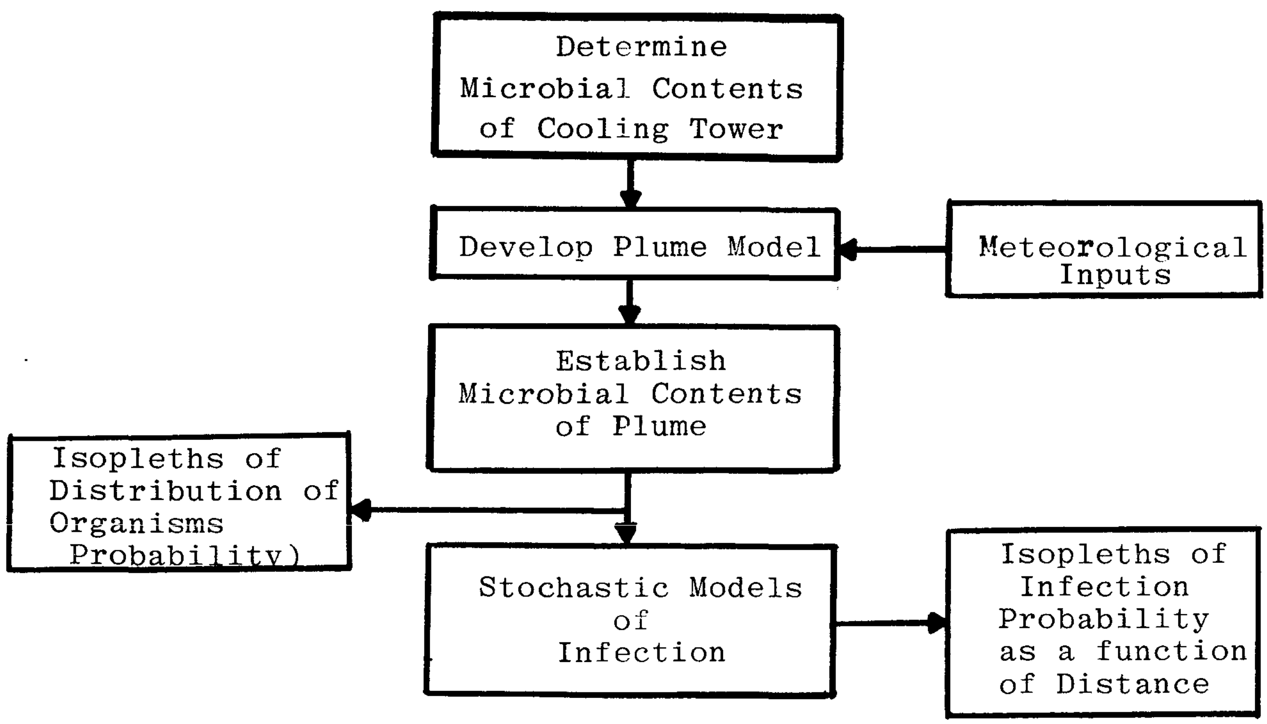
Discussion of the recommendations based on the results of this study, the results of Task V in the scope of the study, may be found in Section 3, Recommendations.

RESULTS OF TASK VI - COMPUTER SIMULATION

A. Introduction

The computer simulation is based on a combination of numerical and Monte Carlo modeling. Basically, the modeling is done in three serial parts for a cooling tower and associated ambient environment that are specified as input parameters. Part 1 developes the microbial environment in the cooling towers based on the data from the consultants. Part 2 develops and distributes the aerosols (micro-microbial environment) from the cooling tower into the environment. Part 3 calculates the microbial environment downwind from the cooling tower, evaluates the possibility of infections based on the results of Part 1 and 2, and prints out results. Figure 11 is a simplified flow chart for the simulation.

FIGURE 11
BASIC FLOW CHART



B. Development of Cooling Tower Microbial Environment

The consultants have developed a list of pathogenic organism that can occur in a polluted water source. This list was used as a basis to establish the microbial content of the cooling tower. To do this, a matrix was established listing each organism from the consultants list versus the following factors:

1. ability to produce disease (epidemiological significance)
2. survival in surface water
3. survival in treated effluent
4. survival in cooling device
5. survival in aerosols
6. integrity in fomites

For each factor a numerical value between 0 and 5 was assigned based on the consultants data. The definitions of these numerical constants are listed in Table 18. Table 19 shows the matrix and the numerical constants assigned for each category, for each organism considered. From the matrix a weighted product for each organism was found as follows:

$$W = \prod_{i=1} a_i f_i$$

Where W is the weighted product, a_i is the weighting factor (0 to 1) for the ith factor and f_i is the numerical constant from the matrix. As a practical initial matter, the weighting factors (a_i) were taken as unity, however, as more information becomes available and it is possible to refine the model, this should be changed. The products were grouped, that is, products with very similar numerical values were considered to be the same and normalized. From these normalized values a histogram was constructed and used as the distribution function for determining the probability that pathogens were present in the make-up water using Monte Carlo methods to evaluate the integral of the distribution function.

The number of organisms present in the make-up water (per unit volume) was modeled somewhat arbitrarily by using the probability from above as the mean of an exponential distribution limited to 10^6 maximum (personal conversation with Dr. H. Freudenthal). This was done by a modified Monte Carlo simulation. Thus, the number of pathogens entering the cooling tower per unit volume of make up water was established. This simulation, was further modulated by including only those results from the exponential distribution when a second selected uniform random variable exceeded the probability value found earlier.

TABLE 18

NUMERICAL CONSTANTS USED IN ESTIMATING PROBABLITIES

OCCURRENCE IN POLLUTED WATER SOURCE

(0) will not occur under any circumstances
(1) rarely occurs
(2) compromised - will occur only if concentration or frequency in surrounding environment significantly increases eg. epidemic, leak from toxic substance storage
(3) will occasionally occur
(4) will frequently occur
(5) will always occur
(x) unknown

SURVIVAL IN A PARTICULAR ENVIRONMENT (SURFACE WATER, TREATED EFFLUENT, COOLING DEVICE)

(0) will not survive under any circumstances
(1) rarely survives
(2) compromised - may survive in this environment only if conditions change eg. type of water treatment, presence of other toxins or pathogens
(3) will occasionally survive
(4) will frequently survive
(5) will always survive
(x) unknown

EPIDEMIOLOGICAL SIGNIFICANCE

(0) will never cause disease or direct effects
(1) rarely causes disease or direct effects
(2) compromised - host may contract the disease or become affected if its immune system has been weakened
(3) may cause non-transmittable effects or allergic responses
(4) usually causes disease
(5) always causes disease
(x) unknown

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aeroso-lization	integrity in fomites
Absidia corymbifera	4	1	4	4	3	5	4
Absidia ramosa	4	1	4	4	3	5	4
Actinomyces israeli	2	3	4	3	3	4	4
Actinomyces keratolytica	2	1	4	1	4	4	4
Actinomyces naeslundii	1	3	4	1	1	3	3
Actinomyces odontolyticus	1	3	4	1	1	3	3
Actinomyces viscosus	1	3	4	1	1	3	3
Arachina propionica	1	3	4	1	1	3	3
Aspergillus spp.	4	4	4	4	4	5	5
Aspergillus flavus	3	3	4	4	3	5	5
Aspergillus nidulans	2	4	4	3	3	5	5
Aspergillus niveus	2	4	4	3	3	5	5
Aspergillus restrictus	2	4	4	3	3	5	5
Aspergillus terreus	2	4	4	3	3	5	5
Bacillus anthracis	4	1	1	1	1	5	5
Bacillus cereus	4	4	4	3	4	4	5
Bacillus subtilis	2	4	4	2	3	4	5
Bacteriodes fragilis	4	4	4	4	4	5	5
Bacteriodes melaninogenicus	4	4	4	4	4	5	5
Basidiobolus haptosporus	4	1	4	4	3	5	4
Blastomyces dermatitidis							
Bordetella parapertussis	1	1	1	0	1	4	4
Brucella abortus	4	1	1	1	1	5	5
Brucella canis	4	1	1	3	3	5	5
Brucella melitensis	4	1	1	3	3	5	5
Brucella suis	4	1	1	3	3	5	5
Candida albicans	2	3	4	3	3	5	5
Candida guillermondii	2	3	4	3	4	5	5

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aerosolization	integrity in fomites
Candida krusei	2	3	4	3	4	5	5
Candida parapsilosis	2	3	4	3	3	5	5
Candida pseudotropicalis	2	3	4	3	4	5	5
Candida stellatoidea	2	3	4	3	4	5	5
Candida tropicalis	2	3	4	3	4	5	5
Candida utilis	2	3	4	3	5	5	5
Candida viswanthii	2	3	4	3	5	5	5
Candida zeylatoides	2	3	4	3	5	5	5
Cladosporium bantianum	1	1	3	3	3	5	3
Cladosporium carrionii	1	1	3	3	3	5	3
Clostridium botulism	4	1	3	3	3	5	5
Clostridium perfingens	3	4	4	3	5	4	5
Cocciodioides immitis	4	3	3	3	3	5	5
Cocynebacterium spp.	2	4	4	3	3	4	5
Conidiobolus coronatus	1	1	4	4	3	5	4
Corynebacterium diptheriae	2	1	3	3	3	4	5
Corynebacterium ulcerans	2	1	3	3	3	3	5
Cryptococcus neoformans	2	1	4	3	3	4	5
Dermatophilus congolensis	2	3	4	3	3	4	5
Enterobacteriae	2	1	5	1	3	5	5
Enterococci	4	4	4	3	3	5	4
Escherichia coli	3	4	4	3	4	4	5
Fuscobacterium spp.	4	4	4	4	4	5	5
Geotrichium candidium	2	1	3	0	3	5	5
Haemophilus aegyptius	2	4	4	3	4	4	5
Haemophilus influenzae	2	1	1	0	1	4	4
Histoplasma capsulatum	4	4	4	4	4	5	5
Klebsialla pneumonia	4	4	4	4	4	4	4

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in: surface water	Survival in: treated effluent	Survival in: cooling device	aeroso-lization	integrity in fomites
Listeria monocytogenes	2	1	4	1	1	5	4
Mucor spp.	2	1	4	1	1	5	4
Mucor pusillus	2	1	4	4	3	5	4
Mucor ramosissimus	2	1	4	4	3	5	4
Mycobacterium bovis	3	1	4	1	1	5	4
Mycobacterium chelonei	3	1	4	1	1	5	4
Mycobacterium fortuitum	3	1	4	1	1	5	4
Mycobacterium kansasii	3	1	4	1	1	5	4
Mycobacterium marinum	3	1	4	1	1	5	4
Mycobacterium scrofulaceum	3	1	4	1	1	5	4
Mycobacterium simiae	3	1	4	1	1	5	4
Mycobacterium tuberculosis	3	1	4	4	1	5	5
Mycobacterium ulcerans	3	1	4	1	1	5	4
Mycobacterium xenopi	3	1	4	1	1	5	4
Nocardia asteroides	2	1	4	1	1	4	5
Nocardia brasiliensis	2	1	4	1	1	4	5
Nocardia caviae							
Peptococcus spp.	4	4	4	4	4	5	5
Peptostreptococcus spp.	4	4	4	4	4	5	5
Phialophora dermatitidis	1	1	1	1	1	4	3
Phialophora gougerotii	1	1	1	1	1	4	3
Phialophora richardsiae	1	1	1	1	1	4	3
Phialophora spinifera	1	1	1	1	1	4	3
Phialophora verrucosa	1	1	1	1	1	4	3
Proteus mirabilis	4	4	4	1	4	4	5
Prototheca wickerhamii	1	1	4	1	1	0	0
Prototheca zopfi	2	1	4	1	1	0	0
Pseudomonas aeruginosa	2	1	4	1	1	4	4

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aeroso-lization	integrity in fomites
Pseudomonas mallei	4	1	3	3	3	4	5
Pseudomonas pseudomallei	4	1	4	3	3	3	4
Rhinocladiella compactum	1	1	1	1	1	5	3
Rhinocladiella perosoi	1	1	1	1	1	5	3
Rhizopus arrhizus	4	1	4	4	3	5	4
Rhizopus oryzae	3	1	4	4	3	5	4
Salmonella spp.	4	4	4	1	4	4	5
Salmonella typhi	4	4	4	3	4	4	5
Shigella spp.	4	4	4	1	4	4	5
Shigella boydii	4	4	4	1	4	4	3
Shigella dysenteriae	4	4	3	1	3	4	3
Shigella flexneri	4	4	3	1	3	4	3
Shigella sonnei	4	4	3	1	3	4	3
Sporothrix schenckii	2	3	4	1	1	4	4
Staphylococcus agalactiae	2	1	4	1	1	5	4
Staphylococcus aureus	4	4	4	4	4	5	5
Streptococcus spp.	2	1	1	0	1	4	4
Streptococcus agalactiae	2	1	1	0	1	4	4
Streptococcus faecalis	4	4	4	3	4	4	5
Streptococcus pneumoniae	2	4	4	1	3	4	5
Streptococcus pyogenes	2	1	4	1	1	5	4
Toruplopsis glabrata	2	1	4	1	1	5	4
Vibrio parahemolytica	4	4	4	1	5	4	5
Yersina enterocolitica	4	4	4	1	4	4	5
Yersina pestis	4	4	4	3	3	4	4
Yersina pseudotuberculosis	4	4	4	1	4	4	5
Zygomycetes	2	1	1	1	1	5	4

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aeroso-lization	integrity in fomites
Acenapthene	3	3	4	4	4	1	4
Acetone	3	4	2	3	1	5	4
Acrolein	3	4	1	4	1	5	1
Acrylonitrile	4	4	4	4	1	5	1
Aldrin	4	4	4	4	4	1	4
Antimony	4	3	4	4	4	1	5
Arsenic	4	4	4	4	4	5	3
Asbestos	4	4	5	4	4	3	5
Benzene	3	4	4	5	1	5	4
Benzidene	4	4	4	4	4	1	2
Beryllium	4	4	4	4	4	1	2
Biphenyl (Diphenyl)	4	3	4	4	4	1	4
Cadmium	3	4	4	4	4	4	1
Carbon Tetrachloride	3	1	4	4	1	5	4
Chlordane	4	4	4	4	4	3	4
Chlorinated Benzenes	1	4	4	5	4	1	4
Chlorinated Ethanes	1	4	5	5	1	3	4
Chlorinated Napthalene	3	4	4	4	4	1	2
Chlorine	4	5	1	5	4	4	1
Chloroform	3	4	4	5	4	4	1
Clorophenol	3	1	1	2	4	3	4
Chromium	4	3	4	4	3	2	5
Copper	4	3	4	4	4	2	1
Cyanides	4	3	4	4	4	4	1
DDT & metabolites	4	4	5	5	4	3	4
Diabyl Ethers	4					1	1
Dichlorobenzenes	3	2	5	4	4	2	4
Dichlorobenzidine	3	3	4	4	4	1	4

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aeroso-lization	integrity in fomites
Dichloroethylene	3	4	4	4	4	1	1
Dichlorophenol	3	4	x	x	x	3	4
Dichloropropane, Dichloropropene	1	3	4	4	4	1	4
Dieldrin	4	4	5	4	4	3	4
2,4, Dimethyl Phenol	2	4	3	5	1	3	3
Dinitrotoluene	3	1	x	4	x	1	1
Diphenylhydrazinr	1	3	4	4	4	1	4
Endosulfan	3	x	4	4	4	1	2
Endrin & metabolites	4	4	5	4	4	3	4
Ethylbenzene	3	3	5	4	4	2	4
Haloether	x	x	x	5	1	1	4
Halomethanes	3	3	2	4	4	4	4
Heptachlor & metabolites	4	4	5	4	5	3	4
Hexachloro 1,3 Butadiene	3	3	4	4	4	x	x
Hexachlorocyclohexane (Lindane)	3	1	5	4	4	1	4
Isophorone	3	3	5	4	4	3	4
Lead	4	3	1	4	4	1	1
Mercury & compounds	4	4	2	4	4	4	2
Methyl Ethyl Ketone (Butanone)	3	3	1	1	2	3	4
Napthalene	4	3	5	4	5	5	1
Nickel & compounds	4	4	5	4	4	2	4
Nitrites	3	4	1	4	4	4	2
Nitrobenzene	4	4	2	1	4	3	4
Nitrophenol	1	4	3	4	2	3	x

TABLE 19

SUMMARY OF PATHOGEN/TOXIN PROBABILITIES

PATHOGEN/TOXIN	produce disease	occurrence	Survival in surface water	Survival in treated effluent	Survival in cooling device	aeroso-lization	integrity in fomites
Nitrosamines	3	x	1	x	5	5	4
PCB's	x	x	4	5	4	x	x
Pentachlorophenol	3	3	5	4	4	3	4
Phenol	5	4	1	5	3	4	3
Phthalate Esters	3	3	2	x	4	x	x
Secondary Amines	1	3	4	1	1	5	1
Selenium & compounds	3	4	1	5	4	3	1
Silver & compounds	1	x	4	4	4	2	1
Styrene	3	3	3	4	4	3	1
Tetrachloroethylene	3	4	3	5	4	x	x
Thallium & compounds	4	4	5	4	4	1	1
Toluene	3	4	3	3	3	3	4
Toxaphene	4	4	5	4	4	1	4
Vinyl Chloride	3	3	4	4	4	3	1
Zinc & compounds	4	4	2	2	4	1	x

The value of make up water was estimated as equal to the sum of the evaporation loss and the droplet losses. These losses were calculated on the basis of the cooling tower design parameters and/or the cooling tower operating condition. For the present model, blow-down was assumed to restore the initial (steady-state) operating condition of the cooling tower periodically with respect to salt and the pathogen concentration. The time between blow downs was calculated as:

$$T=(CONC-1.)\ TVOL/_{UMW}$$

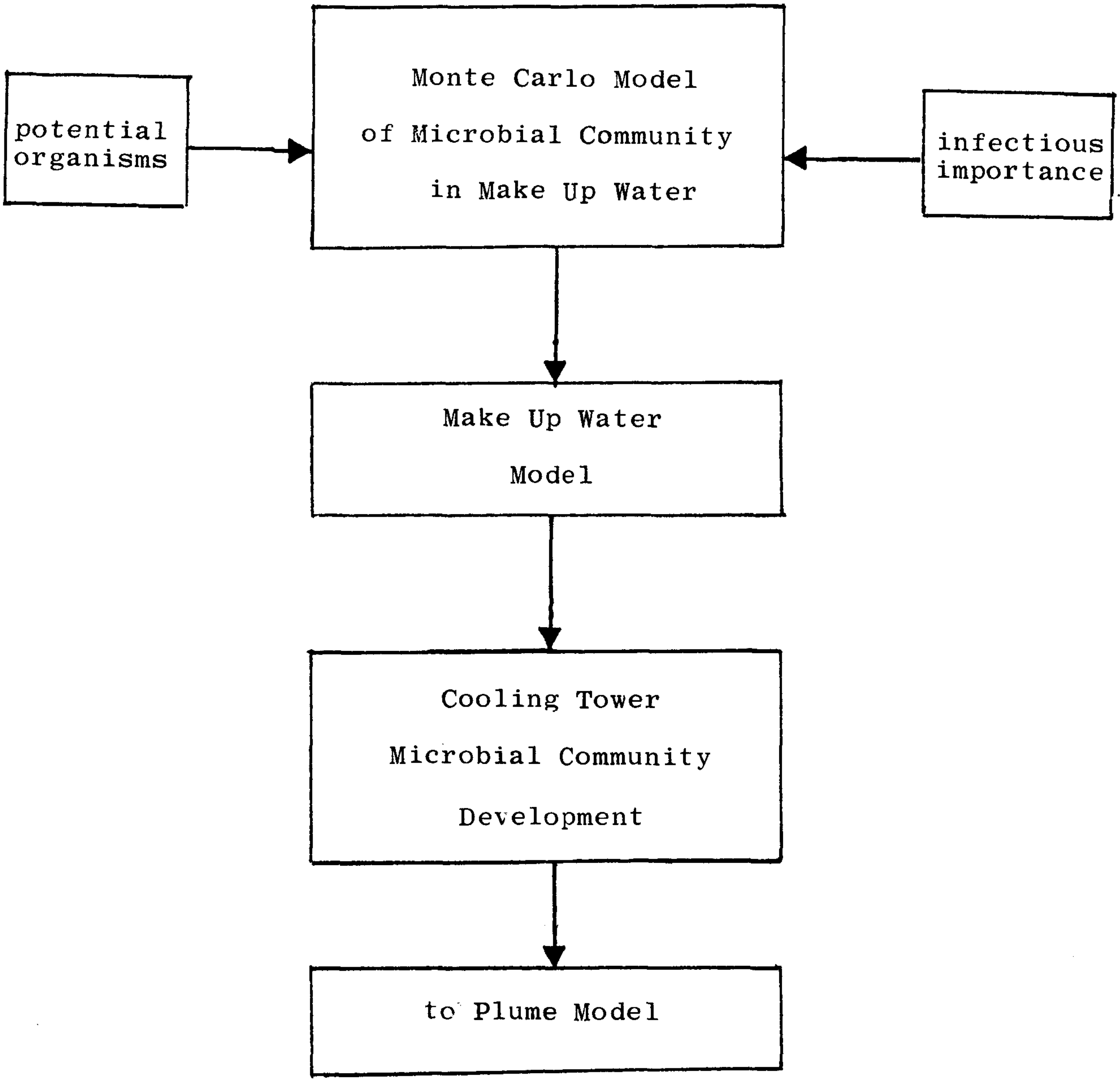
Where T is the time between blow downs, CONC is the maximum allowable concentration (input parameter), TVOL is the tower water value and UMW is the make up water input rates. The total average value of make up water taken in, then was calculated as:

$$BINVOL = UMW \times T/_2$$

where BINVOL is the total amount of water taken in between blow downs. This was multiplied by the number of organisms per unit volume derived earlier to establish the average microbial content of the cooling tower. As can be seen, the microbial content is then the average number of organisms taken in between blow downs diluted by the value of water carried by the tower. In the present model, no specific capability is included for growth or death of pathogenic organisms in the cooling tower. Their concentration is determined purely by input conditions and dilution factors. It is also assumed that the droplets are spherics and are homogeneous samples of the cooling tower microbial environment. Figure 12 shows a simplified flow chart of that portion of the simulation relating to the development of the microbial environment in the cooling tower.

FIGURE 12

MICROBIAL CONTENT OF COOLING TOWER



C. Aerosol Model - The Spatial Distribution of Organisms

The aerosol model that distributes the pathogens in the environment is based on the ORFAD Model (Oak Ridge fog and drift) (Wilson, 1975 & LaVerne 1977). The elements comprising the plume rise, the distribution of the aerosol droplet sizes and their physical distribution have been developed from this model. The model for this portion of the simulation takes cooling tower and environmental parameters (as inputs) and calculates the plume rise from the cooling tower and the plume environment. As in the ORFAD model, the aerosols are assumed to travel in ballistic trajectories set by the rise velocity of the plume centerline and the fall velocity of the droplet with respect to the plume centerline.

Plume rise is calculated as follows:

1. Determination of a buoyancy flux parameter (F)
2. Calculation of atmospheric stability (S)
3. Determination of the plume centerline (trajectory) (PR) based on F, S and wind conditions.

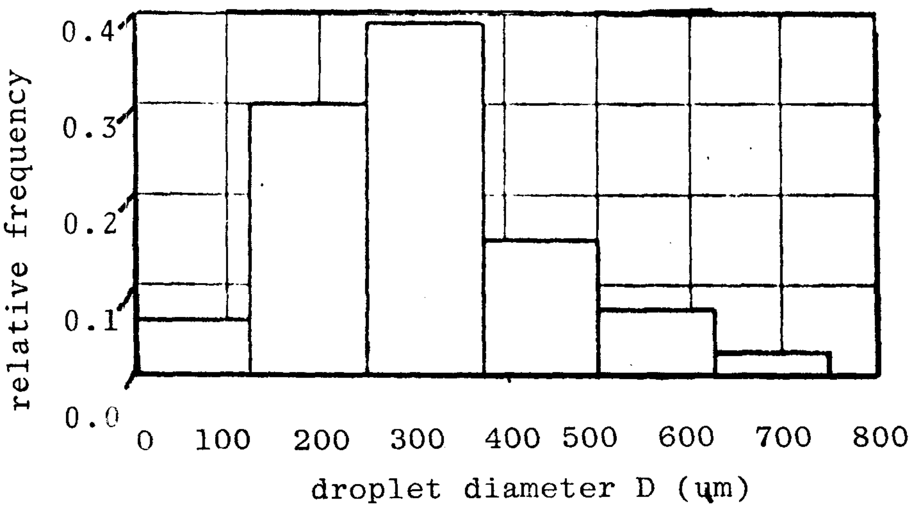
The flux buoyancy parameter (F) is that developed by Hanna (ref. 3). The atmospheric stability parameter is derived from the Pasquill stability class as determined from weather data (input parameters) that determine the atmospheric temperature gradient and the dry and wet bulk temperatures. Wind conditions (input parameters) are taken as 1 m/sec minimum, even for calm ground conditions since the wind velocity, generally is rarely less than this at typical tower heights. The plume is assumed to be disturbed over a 22.5^{o} angle downwind. Unlike ORFAD, this program computes for the downwind condition without regard to specific geographic direction. The day is broken into 4 hour segments starting at 0000 hours, and wind velocity, temperature (dry and wet bulb), stability and percent operating capacity of the plant are inputted for each time segment. Computations are done for each four hours and are summarized daily.

The aerosol drift deposition is based on ballistic ple as discussed by Laverne. This trajectory model assumes that all particles of a given original size (at the cooling tower) will fall to the ground at the same distance from the cooling tower for a given set of wind, stability and humidity conditions. This distance is such that the total trajectory is equal to the local plume height above the ground.

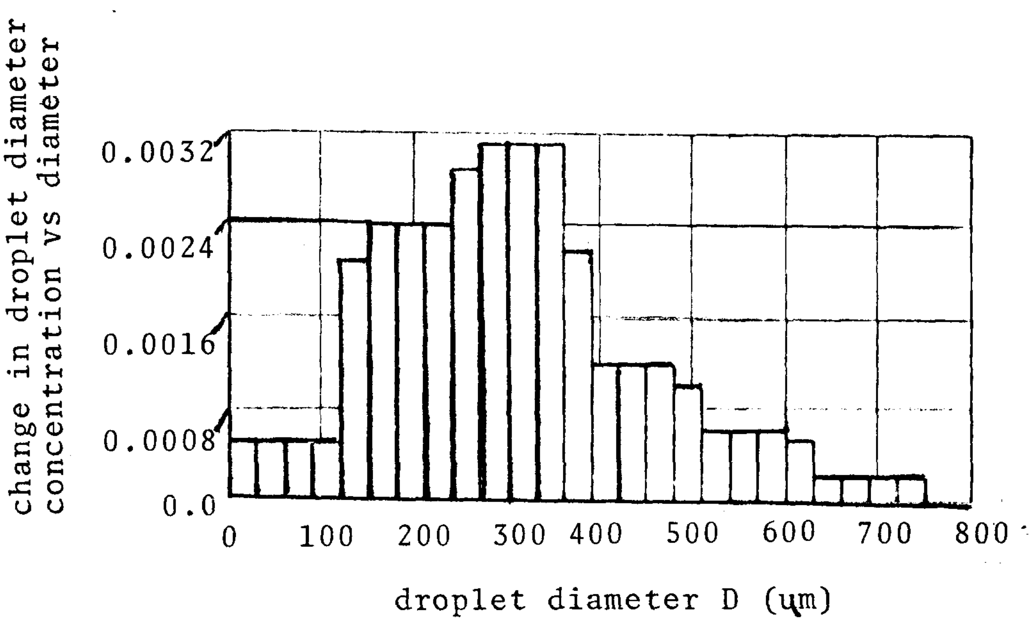
The distribution of aerosol particle sizes within the exit plume is shown in Figure 13(A). As in the ORFAD model, this distribution is recomputed in terms of the cumulative distribution function to obtain a refined droplet size distribution model (Figure 13 (B). Fall velocities are computed by using Stokes law for particles smaller than about 80 um and a relationship

FIGURE 13

DROPLET SIZE DISTRIBUTION



(A)

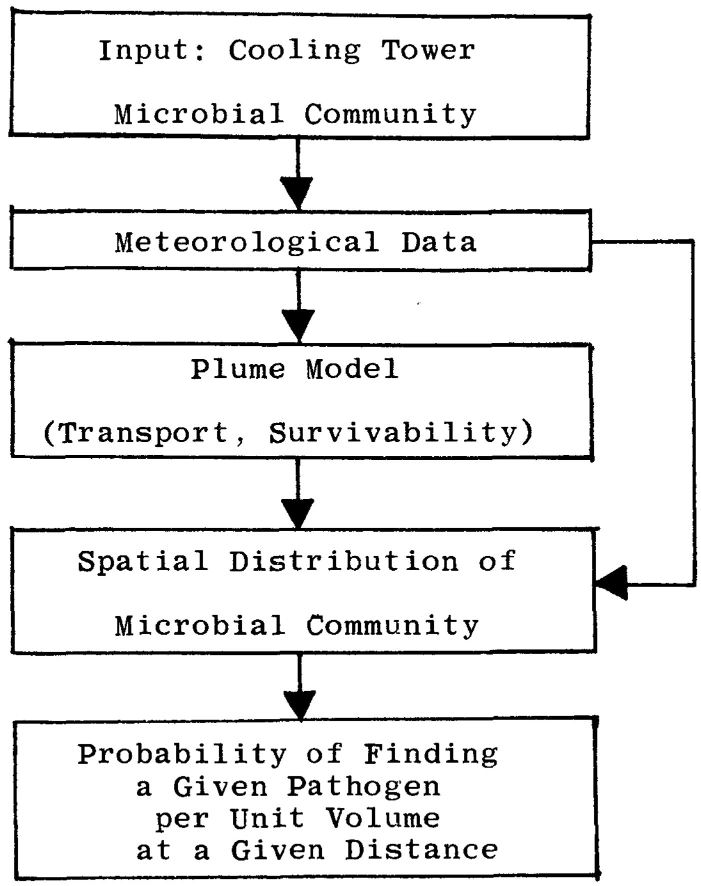


(B)

given in Letester (1966) for particles greater than about 80 μm. Particles in relative humidity environments greater than 76% are assumed not to evaporate, while particles in environments with less than 76% are assumed to evaporate, either to saturation (76%-50% R.H.) or dryness (R.H. 50%). Following the methods outlined in Laverne (1977), particles are distributed downwind in accordance with wind velocity, plume and weather condition. From these data, and the microbial input data from part 1 of the simulation, the total number of organisms impinged per unit area, per unit time, and present per unit volume (steady state), are easily calculated. The flow chart for this phase of the simulation is shown in Figure 14. It is assumed that the organisms that find their way into the aerosol will all survive if there is no evaporation (R. H. 76%) that 50% survive in the R. H. range of 76% to 50% and that 20% survive when the R. H. is 50%. These factors are further modified by 0.2 if there is direct sunlight (0800-0800) present or 0.5 with cloud cover. These factors are rather arbitrarily chosen and should be re-evaluated (perhaps dynamically simulated in further model developments. These results (organisms/M^3 and organisms/M^2) are tabulated for each four hour interval.

FIGURE 14

SPATIAL ORGANIZATION OF ORGANISMS



D. Estimation of Infection Probability

The previous elements of the simulation have established a potential microbial density for distances downwind from the cooling tower. It is now necessary to establish the extent to which these microbial densities are capable of producing infection. Two basic possibilities exist. In one case, inhalation of organisms can create an infection and in another, physical contact (touching or ingestion) will create an infection. In either case, a threshold level establishes a minimum below which nothing will happen. The estimation of this threshold is extremely difficult. Furthermore, the consequences of infection may vary from a general slight malaise to severe symptoms that require extensive care. The model developed here, does not consider the epidemiological affects of interaction between infected and non-infected individuals, but only considers the direct effect of the interaction between the microbial environment and the individual. Figure 15 is a simplified flow chart for Part 3 of the simulation.

The lifetime of deposited (or airborne) microbial particles has (again, rather arbitrarily) been taken to be 24 hours* on the average. The average ventilation value for a population is about 20,000 liters per day (Haup). Therefore, for the airborne organisms, the average number of organisms inhaled/day is calculated. A sticky problem is that of determining the number of organisms required to declare an infection. A randomly distributed variable, exponentially distributed with a mean of .1 X (3 X 10^6) was used to establish (in a Monte Carlo loop) the basis for estimating the number of organisms required to generate an infection. The same approach is used with respect to the number of particles injested with the assumption that an individual will ingest the microbial flora that falls on one square meter of surface in 24 hours. Results for 24 hours are obtained from the summation or averaging (as required) of the data accumulated for each four hours.

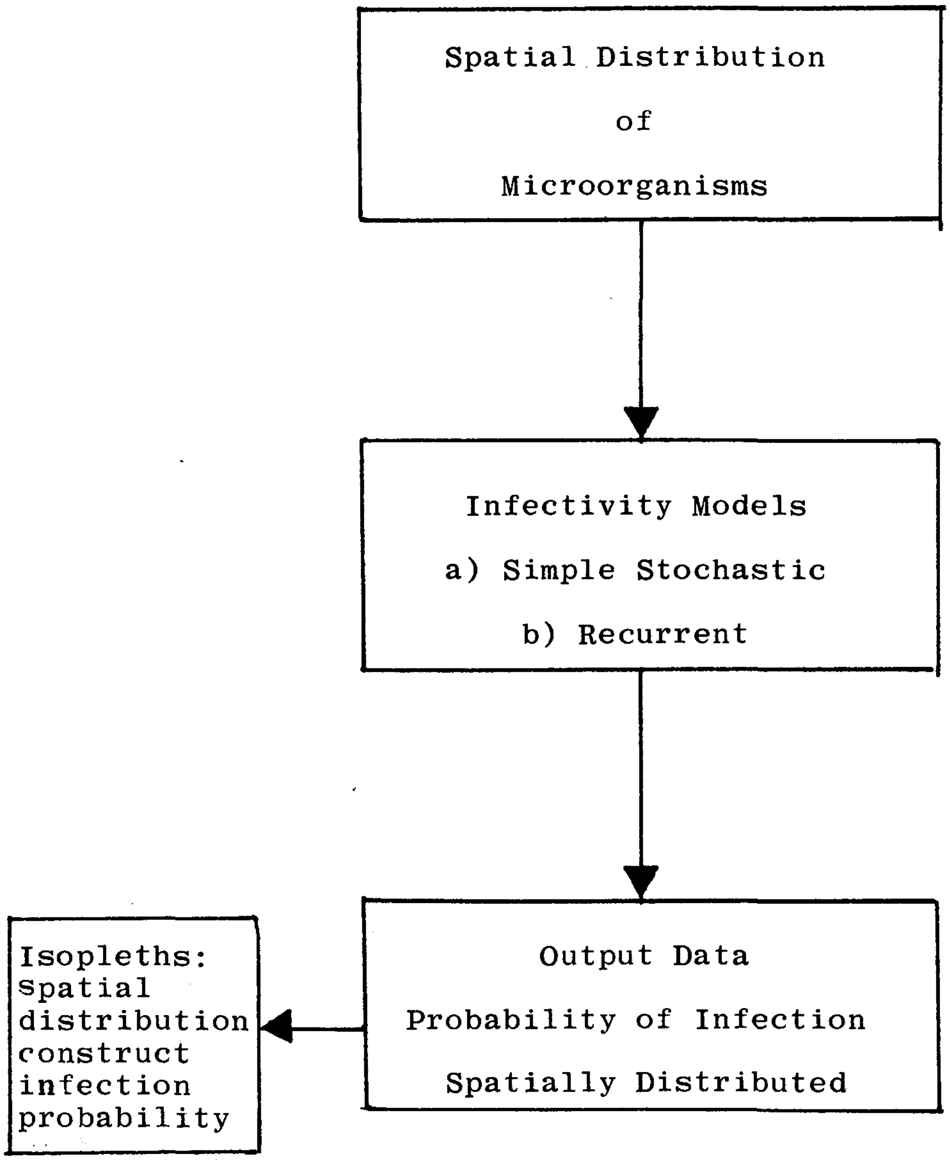
The above data is then used to generate infection probabilities, based on the number of times the infection threshold is pierced during the interval under consideration. This resultant is tabulated as the result for a particular simulation based on given input condition.

---

*It is recognized that many organisms remain viable for periods much longer than 24 hours, even years in some cases. However, it was assumed that the cooling tower, Figures 16-20, environment would not favor encystment or spore formation, and therefore, the cells would be susceptible to die-off due to uv, desiccation, etc. Twenty-four hours was picked as a working number for the purpose of modeling.

FIGURE 15

INFECTIVITY MODEL



E. Input Data Requirements

Table 20 lists the input data requirements and lists some typical values used in the simulations. These are printed for each simulation as part of the data file. Figure 16 shows a typical data file. Figures 17-21 shows the result of simulations under various conditions of cooling tower operation and environment.

Figure 17 simulates a typical summer day. Weather conditions represent the most significant difference in the simulations. Internal parameters on which the model is based, were previously discussed in Section 2. The fixed parameters were selected as typical for a large, natural draft tower. The day was divided into four (4) hour intervals as shown and the environmental parameters are varied as they might be for a summer day. The results of the simulation for each four hour interval are shown along with a summary of operating parameters for that interval. Also, listed for that interval are distance from the cooling tower, plume rise, the average number of organisms per cubic meter of air, the average number of organisms landing per square meter of surface area, all based on the output of the simulation. In addition, there is the Monte Carlo derived probability that the effluent will contain infectious organisms. Following the four hour listings are summaries for the 24 hour period detailing the number of organisms airborn per cubic meter, their incidence on surfaces per square meter, and the average 24 hour probability of effluent containing infectious organisms.

The second summary shows the results of exposure of a population to these infectious organisms with a maximum instantaneous susceptible population of 20%. The organisms are assumed to be ingested from both airborne particles and those picked up by contact with surfaces. This leads to the calculation of the average number of particles ingested assuming the population distributions described in the methodology. These averages are used in a simple infection model to derive the listing of the population fraction affected by the effluent.

The results support the concept that the potential for affecting a downwind population is present, unless measures are taken to control infectious organisms and toxins in the make-up water and the tower to suppress these effects. As pointed out in Section 2, many assumptions have been made because real data does not exist. These data, when available, could be used to considerably strengthen the model. However, even in its present form, the model clearly shows that if infectious organisms are present in the cooling tower environment, they will surely appear in the population downwind from the cooling tower.

Figures 18 and 19 represent the same operating parameters and environmental conditions. In Figure 18, 20% of the population is susceptible to infectious organisms and toxins. Figure 19 represents a worse case situation wherein 100% of the population is affected by transmitted pathogens and toxic particles. Figure 20 simulates conditions for a tower with a higher level of output, cooler environmental temperatures and a population which is 20% susceptible. Figure 21 represents a tower operating at 100% capacity with a 20% susceptible population.

TABLE 20
A TYPICAL INPUT PARAMETERS

PARAMETERS	UNITS	TYPICAL VALUES
Cooling tower height	ft	400
Tower inside diameter	ft	200
Temperature range (in tower)	^oF	25
Exit air velocity	ft/sec	0-50
Drift fraction	g/g	10^{-4} to 10^{-6}
Wind velocity	knots	50
Dry bulb temperature	^oF	-20 to +100
Wet bulb	^oF	-20 to +100
Pasquill Stability class	--	1 - 6

These data were inputted via a separated data file called FOR--.DAT. The program is now set to accept FOR28.DAT. These files are shown with each output run shown in Figure 6.

FIGURE 16

Typical Data File

```
TYPE (FILE) FOR26.DAT
450.,200.,5.E-5,12.,1.3,25.,1200.
50.,48.,10.,.8,4.
52.,45.,5.,.8,4.
60.,50.,20.,1.,5.
63.,50.,20.,1.,5.
58.,50.,5.,1.,4.
54.,50.,10.,1.,4.
3,5,7,9,13,223
@
```

FIGURE 17

***************COOLING TOWER FIXED PARAMETERS***************

TOWER HEIGHT (FEET)	450.00
TOWER DIAMETER (FEET)	250.00
HEAT LOSS (MEGACAL/SEC,MAX)	1000.00
TEMPERATURE RANGE (DEG F)	25.00
DRIFT FRACTION (G/G)	0.000050
CONCENTRATION RATIO (G/G)	1.30
EXIT VELOCITY (FT/SEC)	10.00

--COOLING TOWER ENVIRONMENTAL PARAMETERS--

TIME (HRS)	DRY BULB T	WET BULB T	WIND VEL.	OPER CAP	STABILITY
0- 400	70.00	65.00	5.00	.80	5.
400- 800	75.00	70.00	10.00	.90	4.
800-1200	80.00	72.00	8.00	1.00	5.
1200-1600	90.00	83.00	12.00	1.00	5.
1600-2000	80.00	75.00	9.00	1.00	5.
2000-2400	72.00	70.00	10.00	.90	5.

COOLING TOWER AND ENVIRONMENTAL PARAMETERS   0- 400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.53
HEAT LOSS (MEGACAL/SEC)	800.00
DRY BULB TEMPERATURE (DEG F)	70.00
WET BULB TEMPERATURE (DEG F)	65.00
WIND VELOCITY (KNOTS)	5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	271.9	0.0	0.0
0.15	356.3	0.0	0.0
0.20	392.9	2403.1	4753.7
0.30	392.9	1443.5	2186.2
0.50	392.9	1254.4	1245.0
0.75	392.9	1689.0	1305.1
1.00	392.9	1085.7	630.1
1.50	392.9	1600.5	665.1
2.00	392.9	1100.6	378.0
2.50	392.9	802.7	223.3
3.00	392.9	539.6	118.6
4.00	392.9	340.0	57.2
5.00	392.9	240.6	29.7
7.00	392.9	149.5	12.8
9.00	392.9	116.2	10.0
10.00	392.9	20.2	1.1
12.00	392.9	16.8	0.9
15.00	392.9	13.5	0.7
20.00	392.9	6.9	0.2
25.00	392.9	5.5	0.2

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 400- 800HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .55
HEAT LOSS (MEGACAL/SEC) 900.00
DRY BULB TEMPERATURE (DEG F) 75.00
WET BULB TEMPERATURE (DEG F) 70.00
WIND VELOCITY (KNOTS) 10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	136.4	0.0	0.0
0.15	178.7	144965.9	199142.1
0.20	216.5	38423.6	52783.1
0.30	283.7	11914.7	16367.4
0.50	398.8	3730.7	5125.0
0.75	522.6	1642.6	2256.5
1.00	633.0	945.4	1298.7
1.50	829.5	445.8	612.5
2.00	990.9	269.6	370.3
2.50	990.9	1636.7	1821.2
3.00	990.9	1276.9	1267.3
4.00	990.9	1973.4	1524.9
5.00	990.9	1370.0	795.1
7.00	990.9	2178.6	905.3
9.00	990.9	1556.4	534.5
10.00	990.9	1278.2	355.6
12.00	990.9	1065.2	296.3
15.00	990.9	687.6	151.1
20.00	990.9	433.2	72.9
25.00	990.9	306.3	37.9

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 800-1200HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .07
HEAT LOSS (MEGACAL/SEC) 1000.00
DRY BULB TEMPERATURE (DEG F) 80.00
WET BULB TEMPERATURE (DEG F) 72.00
WIND VELOCITY (KNOTS) 8.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	160.3	0.0	0.0
0.15	210.1	17714.7	0.0
0.20	254.5	4695.3	0.0
0.30	318.9	1456.0	0.0
0.50	318.9	4185.4	5749.6
0.75	318.9	2205.1	2188.6
1.00	318.9	3357.9	2594.7
1.50	318.9	1924.8	1117.1
2.00	318.9	2815.7	1392.5
2.50	318.9	2346.7	805.9
3.00	318.9	1955.6	671.6
4.00	318.9	1079.0	237.2
5.00	318.9	725.1	122.0
7.00	318.9	458.1	56.6
9.00	318.9	356.3	44.0
10.00	318.9	278.8	23.9
12.00	318.9	232.3	19.9
15.00	318.9	35.9	2.0
20.00	318.9	26.9	1.5
25.00	318.9	14.7	0.5

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1200-1600HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.16
HEAT LOSS (MEGACAL/SEC)	1000.00
DRY BULB TEMPERATURE (DEG F)	90.00
WET BULB TEMPERATURE (DEG F)	83.00
WIND VELOCITY (KNOTS)	12.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	110.4	0.0	0.0
0.15	144.7	34723.7	47700.6
0.20	175.3	9731.7	13368.5
0.30	229.7	3069.1	4216.1
0.50	289.6	1165.3	1600.7
0.75	289.6	3302.9	3675.2
1.00	289.6	4145.4	3644.5
1.50	289.6	2791.7	1879.1
2.00	289.6	1932.2	1121.4
2.50	289.6	3005.8	1486.5
3.00	289.6	2838.7	1179.6
4.00	289.6	1950.3	669.8
5.00	289.6	1421.7	395.5
7.00	289.6	688.2	115.8
9.00	289.6	535.3	90.1
10.00	289.6	426.2	52.7
12.00	289.6	355.2	43.9
15.00	289.6	247.2	21.2
20.00	289.6	35.8	2.0
25.00	289.6	28.6	1.6

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1600-2000HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .54
HEAT LOSS (MEGACAL/SEC) 1000.00
DRY BULB TEMPERATURE (DEG F) 80.00
WET BULB TEMPERATURE (DEG F) 75.00
WIND VELOCITY (KNOTS) 9.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	142.9	0.0	0.0
0.15	187.3	167370.7	207502.7
0.20	226.9	47063.3	58348.1
0.30	297.3	14858.2	18420.9
0.50	307.5	30438.8	33869.6
0.75	307.5	33611.3	29550.4
1.00	307.5	27496.8	21247.2
1.50	307.5	15536.7	9017.4
2.00	307.5	25613.6	10643.7
2.50	307.5	18759.0	6442.4
3.00	307.5	15632.5	5368.7
4.00	307.5	8613.3	1893.1
5.00	307.5	6890.6	1514.5
7.00	307.5	4135.8	696.0
9.00	307.5	2846.5	351.9
10.00	307.5	2229.6	191.4
12.00	307.5	1858.0	159.5
15.00	307.5	287.2	15.8
20.00	307.5	215.4	11.8
25.00	307.5	117.5	3.6

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 2000-2400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .21
HEAT LOSS (MEGACAL/SEC) 900.00
DRY BULB TEMPERATURE (DEG F) 72.00
WET BULB TEMPERATURE (DEG F) 70.00
WIND VELOCITY (KNOTS) 10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	135.7	0.0	0.0
0.15	177.9	742564.0	0.0
0.20	215.5	208802.9	0.0
0.30	282.3	65920.5	0.0
0.50	311.7	64452.4	184820.3
0.75	311.7	173105.7	330926.0
1.00	311.7	243932.9	349744.7
1.50	311.7	133611.9	127712.9
2.00	311.7	62840.0	45049.2
2.50	311.7	40217.6	23065.2
3.00	311.7	27928.9	13347.9
4.00	311.7	3567.1	1278.6
5.00	311.7	2282.9	654.6
7.00	311.7	963.1	197.3
9.00	311.7	1076.2	171.5
10.00	311.7	918.9	131.7
12.00	311.7	699.0	83.5
15.00	311.7	413.6	39.5
20.00	311.7	268.6	19.3
25.00	311.7	192.2	11.0

--------------- 24 HOUR TOTALS ---------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .34

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	0.0	0.0
0.15	1107339.0	454345.4
0.20	311119.8	129253.4
0.30	98662.0	41190.6
0.50	105227.0	232410.3
0.75	215556.6	369901.7
1.00	280964.0	379159.9
1.50	155911.4	141004.1
2.00	94571.7	58955.1
2.50	66768.6	33844.5
3.00	50172.2	21953.7
4.00	17523.1	5660.8
5.00	12931.0	3511.6
7.00	8573.2	1983.8
9.00	6487.0	1202.0
10.00	5151.9	756.5
12.00	4226.6	604.1
15.00	1685.0	230.4
20.00	986.8	107.6
25.00	664.9	54.7

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	0.0	0.000
0.15	1561684.4	18.135
0.20	440373.2	0.486
0.30	139852.6	1.223
0.50	337637.3	20.000
0.75	585458.3	9.244
1.00	660123.9	13.324
1.50	296915.5	18.221
2.00	153526.8	11.626
2.50	100613.1	10.064
3.00	72125.9	5.507
4.00	23183.9	0.486
5.00	16442.5	1.914
7.00	10557.1	0.318
9.00	7689.0	0.006
10.00	5908.4	0.000
12.00	4830.7	0.000
15.00	1915.4	0.000
20.00	1094.5	0.409
25.00	719.6	0.215

FIGURE 18

**************COOLING TOWER FIXED PARAMETERS**************

TOWER HEIGHT (FEET)	450.00
TOWER DIAMETER (FEET)	200.00
HEAT LOSS (MEGACAL/SEC,MAX)	750.00
TEMPERATURE RANGE (DEG F)	30.00
DRIFT FRACTION (G/G)	0.000050
CONCENTRATION RATIO (G/G)	1.40
EXIT VELOCITY (FT/SEC)	10.00

--COOLING TOWER OPERATING PARAMETERS--

TIME (HRS)	DRY BULB T	WET BULB T	WIND VEL.	OPER CAP	STABILITY
0- 400	72.00	68.00	5.00	1.00	3.
400- 800	70.00	66.00	2.00	1.00	2.
800-1200	72.00	67.00	3.00	.70	2.
1200-1600	75.00	71.00	5.00	1.00	3.
1600-2000	80.00	75.00	8.00	1.00	3.
2000-2400	77.00	74.00	5.00	1.00	4.

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 0- 400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .54
HEAT LOSS (MEGACAL/SEC) 750.00
DRY BULB TEMPERATURE (DEG F) 72.00
WET BULB TEMPERATURE (DEG F) 68.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	257.6	1157530.7	1753106.5
0.15	337.6	171767.8	260146.2
0.20	409.0	76052.8	115183.7
0.30	535.9	29332.3	44424.5
0.50	753.3	10220.6	15479.3
0.75	987.1	4696.3	7112.7
1.00	1195.8	2757.4	4176.2
1.50	1566.9	24301.0	33382.8
2.00	1788.3	15067.9	18680.9
2.50	1788.3	10665.2	10585.3
3.00	1788.3	16563.4	14562.2
4.00	1788.3	12922.4	8698.3
5.00	1788.3	18873.4	9333.6
7.00	1788.3	15355.8	6381.1
9.00	1788.3	10019.8	2787.3
10.00	1788.3	9017.8	2508.6
12.00	1788.3	6064.6	1333.0
15.00	1788.3	4074.8	685.7
20.00	1788.3	2700.9	333.9
25.00	1788.3	1877.2	161.2

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 400- 800HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.51
HEAT LOSS (MEGACAL/SEC)	750.00
DRY BULB TEMPERATURE (DEG F)	70.00
WET BULB TEMPERATURE (DEG F)	66.00
WIND VELOCITY (KNOTS)	2.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	653.5	418509.4	0.0
0.15	856.4	62103.3	0.0
0.20	1037.4	27497.2	0.0
0.30	1359.4	10605.2	0.0
0.50	1910.9	3695.3	0.0
0.75	2504.0	12797.4	23249.6
1.00	3033.4	2629.6	4777.4
1.50	3974.9	4516.2	6839.8
2.00	4589.6	5681.4	7804.6
2.50	4589.6	4086.2	4546.7
3.00	4589.6	6028.0	5299.7
4.00	4589.6	4735.4	3187.5
5.00	4589.6	3539.1	2054.1
7.00	4589.6	5657.6	2351.0
9.00	4589.6	3696.1	1028.2
10.00	4589.6	3326.5	925.4
12.00	4589.6	2237.4	491.8
15.00	4589.6	1503.2	253.0
20.00	4589.6	996.1	123.2
25.00	4589.6	692.1	59.4

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 800-1200HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .22
HEAT LOSS (MEGACAL/SEC) 525.00
DRY BULB TEMPERATURE (DEG F) 72.00
WET BULB TEMPERATURE (DEG F) 67.00
WIND VELOCITY (KNOTS) 3.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	418.6	182550.8	0.0
0.15	548.6	27089.0	0.0
0.20	664.6	11994.1	0.0
0.30	870.8	4625.9	0.0
0.50	1224.1	8503.4	16821.0
0.75	1604.1	4034.8	7330.1
1.00	1943.2	2357.0	3917.9
1.50	2546.3	1421.7	2153.2
2.00	2847.7	1748.1	2167.2
2.50	2847.7	1249.5	1240.1
3.00	2847.7	1947.8	1712.4
4.00	2847.7	1527.9	1028.5
5.00	2847.7	2239.0	1107.3
7.00	2847.7	1677.0	575.9
9.00	2847.7	1191.0	331.3
10.00	2847.7	1071.9	298.2
12.00	2847.7	720.9	158.5
15.00	2847.7	484.4	81.5
20.00	2847.7	321.0	39.7
25.00	2847.7	223.0	19.1

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1200-1600HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.33
HEAT LOSS (MEGACAL/SEC)	525.00
DRY BULB TEMPERATURE (DEG F)	75.00
WET BULB TEMPERATURE (DEG F)	71.00
WIND VELOCITY (KNOTS)	5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	245.7	230699.0	316915.1
0.15	321.9	37656.7	51729.6
0.20	390.0	16870.9	23175.8
0.30	511.0	6554.1	9003.4
0.50	718.4	2293.3	3150.3
0.75	941.3	1055.7	1450.2
1.00	1140.3	620.4	852.2
1.50	1494.3	298.6	410.2
2.00	1641.8	1629.6	1813.3
2.50	1641.8	2278.6	2003.3
3.00	1641.8	2111.1	1631.3
4.00	1641.8	1377.7	799.6
5.00	1641.8	2158.1	1067.2
7.00	1641.8	1613.0	554.0
9.00	1641.8	1145.0	318.5
10.00	1641.8	831.6	182.8
12.00	1641.8	693.0	152.3
15.00	1641.8	465.7	78.4
20.00	1641.8	308.7	38.2
25.00	1641.8	214.6	18.4

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1600-2000HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.54
HEAT LOSS (MEGACAL/SEC)	525.00
DRY BULB TEMPERATURE (DEG F)	80.00
WET BULB TEMPERATURE (DEG F)	75.00
WIND VELOCITY (KNOTS)	8.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	148.5	1462108.5	0.0
0.15	194.6	615833.1	763497.2
0.20	235.7	172227.6	213524.2
0.30	308.8	54280.5	67295.8
0.50	434.1	17112.9	21216.2
0.75	568.9	7553.8	9365.1
1.00	689.1	4352.6	5396.3
1.50	903.0	2055.0	2547.7
2.00	965.8	10592.2	11786.0
2.50	965.8	14689.5	12914.7
3.00	965.8	13568.4	10484.5
4.00	965.8	8817.5	5117.6
5.00	965.8	13793.2	6821.2
7.00	965.8	10293.2	3535.0
9.00	965.8	7304.5	2032.0
10.00	965.8	5304.7	1165.9
12.00	965.8	4420.6	971.6
15.00	965.8	2970.5	499.9
20.00	965.8	1969.5	243.5
25.00	965.8	1369.3	117.6

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 2000-2400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.11
HEAT LOSS (MEGACAL/SEC)	525.00
DRY BULB TEMPERATURE (DEG F)	77.00
WET BULB TEMPERATURE (DEG F)	74.00
WIND VELOCITY (KNOTS)	5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	240.7	52706921.0	0.0
0.15	315.4	22199903.0	0.0
0.20	382.1	6208559.4	0.0
0.30	500.7	1956733.1	0.0
0.50	703.9	1160041.0	3116082.4
0.75	922.3	1011519.6	2281934.3
1.00	1117.3	1120061.6	2243878.1
1.50	1464.1	547435.4	933247.5
2.00	1582.6	1343405.2	1844744.9
2.50	1582.6	1462743.0	1606894.3
3.00	1582.6	905710.1	829138.8
4.00	1582.6	477745.8	328016.9
5.00	1582.6	305757.3	167944.6
7.00	1582.6	155998.6	61204.3
9.00	1582.6	21427.3	6538.6
10.00	1582.6	17356.1	4766.6
12.00	1582.6	9966.6	2281.0
15.00	1582.6	6378.6	1167.9
20.00	1582.6	7138.4	980.2
25.00	1582.6	4223.7	464.0

-------------- 24 HOUR TOTALS --------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .38

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	56158319.0	2070021.5
0.15	23114353.0	1075373.0
0.20	6513201.9	351883.8
0.30	2062131.1	120723.7
0.50	1201866.5	3172749.3
0.75	1041657.6	2330441.9
1.00	1132778.7	2262998.0
1.50	580027.9	978581.2
2.00	1378124.3	1886996.8
2.50	1495712.0	1638184.5
3.00	945928.8	862828.9
4.00	507126.7	346848.4
5.00	346360.0	188328.0
7.00	190595.2	74601.3
9.00	44783.8	13035.9
10.00	36908.7	9847.5
12.00	24103.2	5388.1
15.00	15877.0	2766.3
20.00	13434.6	1758.7
25.00	8599.9	839.7

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	58228341.0	20.000
0.15	24189726.0	18.613
0.20	6865085.7	6.878
0.30	2182854.8	12.173
0.50	4374615.7	20.000
0.75	3372099.4	3.674
1.00	3395776.8	7.069
1.50	1558609.1	20.000
2.00	3265121.2	18.308
2.50	3133896.4	20.000
3.00	1808757.8	9.432
4.00	853975.1	6.754
5.00	534688.0	5.787
7.00	265196.5	14.795
9.00	57819.7	1.351
10.00	46756.2	1.133
12.00	29491.3	0.325
15.00	18643.3	0.112
20.00	15193.2	0.420
25.00	9439.6	0.312

FIGURE 19

***************COOLING TOWER FIXED PARAMETERS***************

TOWER HEIGHT (FEET)	450.00
TOWER DIAMETER (FEET)	200.00
HEAT LOSS (MEGACAL/SEC,MAX)	750.00
TEMPERATURE RANGE (DEG F)	30.00
DRIFT FRACTION (G/G)	0.000050
CONCENTRATION RATIO (G/G)	1.40
EXIT VELOCITY (FT/SEC)	10.00

--COOLING TOWER OPERATING PARAMETERS--

TIME (HRS)	DRY BULB T	WET BULB T	WIND VEL.	OPER CAP	STABILITY
0- 400	72.00	68.00	5.00	1.00	3.
400- 800	70.00	66.00	2.00	1.00	2.
800-1200	72.00	67.00	3.00	.70	2.
1200-1600	75.00	71.00	5.00	1.00	3.
1600-2000	80.00	75.00	8.00	1.00	3.
2000-2400	77.00	74.00	5.00	1.00	4.

COOLING TOWER AND ENVIRONMENTAL PARAMETERS   0- 400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .54
HEAT LOSS (MEGACAL/SEC)   750.00
DRY BULB TEMPERATURE (DEG F)   72.00
WET BULB TEMPERATURE (DEG F)   68.00
WIND VELOCITY (KNOTS)   5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	257.6	1157530.7	1753106.5
0.15	337.6	171767.8	260146.2
0.20	409.0	76052.8	115183.7
0.30	535.9	29332.3	44424.5
0.50	753.3	10220.6	15479.3
0.75	987.1	4696.3	7112.7
1.00	1195.8	2757.4	4176.2
1.50	1566.9	24301.0	33382.8
2.00	1788.3	15067.9	18680.9
2.50	1788.3	10665.2	10585.3
3.00	1788.3	16563.4	14562.2
4.00	1788.3	12922.4	8698.3
5.00	1788.3	18873.4	9333.6
7.00	1788.3	15355.8	6381.1
9.00	1788.3	10019.8	2787.3
10.00	1788.3	9017.8	2508.6
12.00	1788.3	6064.6	1333.0
15.00	1788.3	4074.8	685.7
20.00	1788.3	2700.9	333.9
25.00	1788.3	1877.2	161.2

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 400- 800HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .51
HEAT LOSS (MEGACAL/SEC) 750.00
DRY BULB TEMPERATURE (DEG F) 70.00
WET BULB TEMPERATURE (DEG F) 66.00
WIND VELOCITY (KNOTS) 2.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	653.5	418509.4	0.0
0.15	856.4	62103.3	0.0
0.20	1037.4	27497.2	0.0
0.30	1359.4	10605.2	0.0
0.50	1910.9	3695.3	0.0
0.75	2504.0	12797.4	23249.6
1.00	3033.4	2629.6	4777.4
1.50	3974.9	4516.2	6839.8
2.00	4589.6	5681.4	7804.6
2.50	4589.6	4086.2	4546.7
3.00	4589.6	6028.0	5299.7
4.00	4589.6	4735.4	3187.5
5.00	4589.6	3539.1	2054.1
7.00	4589.6	5657.6	2351.0
9.00	4589.6	3696.1	1028.2
10.00	4589.6	3326.5	925.4
12.00	4589.6	2237.4	491.8
15.00	4589.6	1503.2	253.0
20.00	4589.6	996.1	123.2
25.00	4589.6	692.1	59.4

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 800-1200HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .22
HEAT LOSS (MEGACAL/SEC) 525.00
DRY BULB TEMPERATURE (DEG F) 72.00
WET BULB TEMPERATURE (DEG F) 67.00
WIND VELOCITY (KNOTS) 3.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	418.6	182550.8	0.0
0.15	548.6	27089.0	0.0
0.20	664.6	11994.1	0.0
0.30	870.8	4625.9	0.0
0.50	1224.1	8503.4	16821.0
0.75	1604.1	4034.8	7330.1
1.00	1943.2	2357.0	3917.9
1.50	2546.3	1421.7	2153.2
2.00	2847.7	1748.1	2167.2
2.50	2847.7	1249.5	1240.1
3.00	2847.7	1947.8	1712.4
4.00	2847.7	1527.9	1028.5
5.00	2847.7	2239.0	1107.3
7.00	2847.7	1677.0	575.9
9.00	2847.7	1191.0	331.3
10.00	2847.7	1071.9	298.2
12.00	2847.7	720.9	158.5
15.00	2847.7	484.4	81.5
20.00	2847.7	321.0	39.7
25.00	2847.7	223.0	19.1

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1200-1600HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .33
HEAT LOSS (MEGACAL/SEC) 525.00
DRY BULB TEMPERATURE (DEG F) 75.00
WET BULB TEMPERATURE (DEG F) 71.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	245.7	230699.0	316915.1
0.15	321.9	37656.7	51729.6
0.20	390.0	16870.9	23175.8
0.30	511.0	6554.1	9003.4
0.50	718.4	2293.3	3150.3
0.75	941.3	1055.7	1450.2
1.00	1140.3	620.4	852.2
1.50	1494.3	298.6	410.2
2.00	1641.8	1629.6	1813.3
2.50	1641.8	2278.6	2003.3
3.00	1641.8	2111.1	1631.3
4.00	1641.8	1377.7	799.6
5.00	1641.8	2158.1	1067.2
7.00	1641.8	1613.0	554.0
9.00	1641.8	1145.0	318.5
10.00	1641.8	831.6	182.8
12.00	1641.8	693.0	152.3
15.00	1641.8	465.7	78.4
20.00	1641.8	308.7	38.2
25.00	1641.8	214.6	18.4

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1600-2000HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .54
HEAT LOSS (MEGACAL/SEC) 525.00
DRY BULB TEMPERATURE (DEG F) 80.00
WET BULB TEMPERATURE (DEG F) 75.00
WIND VELOCITY (KNOTS) 8.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	148.5	1462108.5	0.0
0.15	194.6	615833.1	763497.2
0.20	235.7	172227.6	213524.2
0.30	308.8	54280.5	67295.8
0.50	434.1	17112.9	21216.2
0.75	568.9	7553.8	9365.1
1.00	689.1	4352.6	5396.3
1.50	903.0	2055.0	2547.7
2.00	965.8	10592.2	11786.0
2.50	965.8	14689.5	12914.7
3.00	965.8	13568.4	10484.5
4.00	965.8	8817.5	5117.6
5.00	965.8	13793.2	6821.2
7.00	965.8	10293.2	3535.0
9.00	965.8	7304.5	2032.0
10.00	965.8	5304.7	1165.9
12.00	965.8	4420.6	971.6
15.00	965.8	2970.5	499.9
20.00	965.8	1969.5	243.5
25.00	965.8	1369.3	117.6

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 2000-2400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .11
HEAT LOSS (MEGACAL/SEC) 525.00
DRY BULB TEMPERATURE (DEG F) 77.00
WET BULB TEMPERATURE (DEG F) 74.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	240.7	52706921.0	0.0
0.15	315.4	22199903.0	0.0
0.20	382.1	6208559.4	0.0
0.30	500.7	1956733.1	0.0
0.50	703.9	1160041.0	3116082.4
0.75	922.3	1011519.6	2281934.3
1.00	1117.3	1120061.6	2243878.1
1.50	1464.1	547435.4	933247.5
2.00	1582.6	1343405.2	1844744.9
2.50	1582.6	1462743.0	1606894.3
3.00	1582.6	905710.1	829138.8
4.00	1582.6	477745.8	328016.9
5.00	1582.6	305757.3	167944.6
7.00	1582.6	155998.6	61204.3
9.00	1582.6	21427.3	6538.6
10.00	1582.6	17356.1	4766.6
12.00	1582.6	9966.6	2281.0
15.00	1582.6	6378.6	1167.9
20.00	1582.6	7138.4	980.2
25.00	1582.6	4223.7	464.0

-------------- 24 HOUR TOTALS --------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .38

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	56158319.0	2070021.5
0.15	23114353.0	1075373.0
0.20	6513201.9	351883.8
0.30	2062131.1	120723.7
0.50	1201866.5	3172749.3
0.75	1041657.6	2330441.9
1.00	1132778.7	2262998.0
1.50	580027.9	978581.2
2.00	1378124.3	1886996.8
2.50	1495712.0	1638184.5
3.00	945928.8	862828.9
4.00	507126.7	346848.4
5.00	346360.0	188328.0
7.00	190595.2	74601.3
9.00	44783.8	13035.9
10.00	36908.7	9847.5
12.00	24103.2	5388.1
15.00	15877.0	2766.3
20.00	13434.6	1758.7
25.00	8599.9	839.7

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	58228341.0	100.000
0.15	24189726.0	93.064
0.20	6865085.7	34.390
0.30	2182854.8	60.866
0.50	4374615.7	100.000
0.75	3372099.4	18.371
1.00	3395776.8	35.344
1.50	1558609.1	100.000
2.00	3265121.2	91.542
2.50	3133896.4	100.000
3.00	1808757.8	47.158
4.00	853975.1	33.772
5.00	534688.0	28.933
7.00	265196.5	73.977
9.00	57819.7	6.753
10.00	46756.2	5.667
12.00	29491.3	1.625
15.00	18643.3	0.561
20.00	15193.2	2.101
25.00	9439.6	1.559

FIGURE 20

***************COOLING TOWER FIXED PARAMETERS***************

TOWER HEIGHT (FEET)	450.00
TOWER DIAMETER (FEET)	200.00
HEAT LOSS (MEGACAL/SEC,MAX)	1200.00
TEMPERATURE RANGE (DEG F)	25.00
DRIFT FRACTION (G/G)	0.000050
CONCENTRATION RATIO (G/G)	1.30
EXIT VELOCITY (FT/SEC)	12.00

--COOLING TOWER OPERATING PARAMETERS--

TIME (HRS)	DRY BULB T	WET BULB T	WIND VEL.	OPER CAP	STABILITY
0- 400	50.00	48.00	10.00	.80	4.
400- 800	52.00	45.00	5.00	.80	4.
800-1200	60.00	50.00	20.00	1.00	5.
1200-1600	63.00	50.00	20.00	1.00	5.
1600-2000	58.00	50.00	5.00	1.00	4.
2000-2400	54.00	50.00	10.00	1.00	4.

COOLING TOWER AND ENVIRONMENTAL PARAMETERS   0- 400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .53
HEAT LOSS (MEGACAL/SEC) 960.00
DRY BULB TEMPERATURE (DEG F) 50.00
WET BULB TEMPERATURE (DEG F) 48.00
WIND VELOCITY (KNOTS) 10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	147.7	0.0	0.0
0.15	193.6	0.0	0.0
0.20	234.5	0.0	0.0
0.30	307.3	0.0	0.0
0.50	431.9	0.0	0.0
0.75	566.0	33588.6	100577.0
1.00	685.6	23065.9	60616.2
1.50	898.4	19152.6	42232.9
2.00	1088.4	21190.9	41473.5
2.50	1144.0	33167.7	54289.9
3.00	1144.0	62080.0	84678.8
4.00	1144.0	43036.0	44026.6
5.00	1144.0	24558.1	20098.8
7.00	1144.0	11749.6	6868.6
9.00	1144.0	7107.8	3231.7
10.00	1144.0	5757.3	2355.9
12.00	1144.0	907.8	309.6
15.00	1144.0	581.0	158.5
20.00	1144.0	270.2	55.3
25.00	1144.0	315.2	51.6

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 400- 800HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .44
HEAT LOSS (MEGACAL/SEC) 768.00
DRY BULB TEMPERATURE (DEG F) 52.00
WET BULB TEMPERATURE (DEG F) 45.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	287.4	0.0	0.0
0.15	376.6	0.0	0.0
0.20	456.3	0.0	0.0
0.30	597.9	0.0	0.0
0.50	840.4	0.0	0.0
0.75	1101.3	6755.1	0.0
1.00	1334.1	4638.8	0.0
1.50	1748.1	3851.8	0.0
2.00	2117.7	4261.7	0.0
2.50	2177.6	6670.4	0.0
3.00	2177.6	12485.0	0.0
4.00	2177.6	785.1	647.6
5.00	2177.6	1390.9	855.8
7.00	2177.6	896.2	441.4
9.00	2177.6	1466.0	562.2
10.00	2177.6	1240.0	414.3
12.00	2177.6	967.3	278.6
15.00	2177.6	1737.2	358.3
20.00	2177.6	1199.8	204.5
25.00	2177.6	877.3	121.1

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 800-1200HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.26
HEAT LOSS (MEGACAL/SEC)	768.00
DRY BULB TEMPERATURE (DEG F)	60.00
WET BULB TEMPERATURE (DEG F)	50.00
WIND VELOCITY (KNOTS)	20.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	67.4	0.0	0.0
0.15	88.3	0.0	0.0
0.20	107.0	0.0	0.0
0.30	140.2	2930.3	2642.1
0.50	197.1	504.6	455.0
0.75	243.9	212.0	191.2
1.00	243.9	159.0	143.4
1.50	243.9	484.0	363.8
2.00	243.9	703.4	479.6
2.50	243.9	507.8	280.4
3.00	243.9	401.2	197.6
4.00	243.9	565.1	246.6
5.00	243.9	476.8	159.3
7.00	243.9	319.4	92.0
9.00	243.9	560.2	115.5
10.00	243.9	504.2	104.0
12.00	243.9	387.9	66.1
15.00	243.9	284.4	39.3
20.00	243.9	172.7	18.8
25.00	243.9	116.4	9.7

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1200-1600HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .56
HEAT LOSS (MEGACAL/SEC) 768.00
DRY BULB TEMPERATURE (DEG F) 63.00
WET BULB TEMPERATURE (DEG F) 50.00
WIND VELOCITY (KNOTS) 20.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	66.1	0.0	0.0
0.15	86.6	12773.5	12540.5
0.20	104.9	4682.3	4596.9
0.30	137.5	1635.0	1605.2
0.50	193.3	540.3	530.4
0.75	239.6	262.3	257.5
1.00	239.6	196.7	193.1
1.50	239.6	687.9	567.5
2.00	239.6	1190.6	811.7
2.50	239.6	905.7	557.3
3.00	239.6	716.8	395.8
4.00	239.6	957.3	417.7
5.00	239.6	858.2	329.1
7.00	239.6	540.7	155.7
9.00	239.6	947.5	195.4
10.00	239.6	852.8	175.9
12.00	239.6	655.8	111.8
15.00	239.6	480.5	66.3
20.00	239.6	291.7	31.8
25.00	239.6	196.4	16.4

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1600-2000HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .29
HEAT LOSS (MEGACAL/SEC) 768.00
DRY BULB TEMPERATURE (DEG F) 58.00
WET BULB TEMPERATURE (DEG F) 50.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	278.8	0.0	0.0
0.15	365.4	15757.6	0.0
0.20	442.6	5776.2	0.0
0.30	580.0	2016.9	0.0
0.50	815.3	666.5	0.0
0.75	1068.3	323.5	0.0
1.00	1294.1	242.6	0.0
1.50	1695.8	848.7	0.0
2.00	2054.3	1468.7	0.0
2.50	2061.7	1117.3	0.0
3.00	2061.7	320.1	314.3
4.00	2061.7	263.3	197.9
5.00	2061.7	390.5	240.2
7.00	2061.7	472.4	206.1
9.00	2061.7	386.8	129.2
10.00	2061.7	348.1	116.3
12.00	2061.7	533.8	131.0
15.00	2061.7	487.7	100.6
20.00	2061.7	336.9	57.4
25.00	2061.7	246.3	34.0

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 2000-2400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.01
HEAT LOSS (MEGACAL/SEC)	768.00
DRY BULB TEMPERATURE (DEG F)	54.00
WET BULB TEMPERATURE (DEG F)	50.00
WIND VELOCITY (KNOTS)	10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	142.5	667715.0	1213064.7
0.15	186.8	93190.5	169303.0
0.20	226.2	40975.7	74442.2
0.30	296.5	15737.4	28590.8
0.50	416.7	5470.4	9938.3
0.75	546.1	2511.0	4561.9
1.00	661.5	1473.6	2677.2
1.50	866.9	6882.1	11439.3
2.00	1050.1	5025.6	7611.4
2.50	1072.7	7100.4	8803.0
3.00	1072.7	5563.2	6190.2
4.00	1072.7	8119.3	6273.9
5.00	1072.7	6069.6	4085.6
7.00	1072.7	7910.5	3912.1
9.00	1072.7	6439.5	2211.5
10.00	1072.7	5795.5	1990.3
12.00	1072.7	4408.2	1226.3
15.00	1072.7	2845.9	625.5
20.00	1072.7	1792.7	301.7
25.00	1072.7	1267.5	156.7

-------------- 24 HOUR TOTALS --------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .35

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	667715.0	1213064.7
0.15	121721.7	181843.5
0.20	51434.2	79039.1
0.30	22319.7	32838.1
0.50	7181.8	10923.7
0.75	43652.5	105587.5
1.00	29776.7	63629.8
1.50	31907.0	54603.6
2.00	33841.0	50376.2
2.50	49469.3	63930.6
3.00	81566.3	91776.7
4.00	53726.0	51810.4
5.00	33744.1	25768.8
7.00	21888.9	11676.0
9.00	16907.8	6445.6
10.00	14498.0	5156.7
12.00	7860.7	2123.4
15.00	6416.7	1348.5
20.00	4064.0	669.5
25.00	3019.2	389.6

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	1880779.7	20.000
0.15	303565.1	5.182
0.20	130473.2	0.000
0.30	55157.8	1.640
0.50	18105.4	1.041
0.75	149240.0	7.946
1.00	93406.6	0.127
1.50	86510.6	1.380
2.00	84217.3	0.195
2.50	113399.9	1.183
3.00	173342.9	0.473
4.00	105536.4	5.531
5.00	59513.0	2.343
7.00	33564.9	1.877
9.00	23353.5	1.702
10.00	19654.7	1.159
12.00	9984.1	0.172
15.00	7765.2	0.344
20.00	4733.5	0.001
25.00	3408.7	0.789

FIGURE 21

***************COOLING TOWER FIXED PARAMETERS***************

TOWER HEIGHT (FEET)	450.00
TOWER DIAMETER (FEET)	200.00
HEAT LOSS (MEGACAL/SEC,MAX)	1200.00
TEMPERATURE RANGE (DEG F)	25.00
DRIFT FRACTION (G/G)	0.000100
CONCENTRATION RATIO (G/G)	1.40
EXIT VELOCITY (FT/SEC)	20.00

--COOLING TOWER OPERATING PARAMETERS--

TIME (HRS)	DRY BULB T	WET BULB T	WIND VEL.	OPER CAP	STABILITY
0- 400	55.00	52.00	20.00	1.00	5.
400- 800	55.00	51.00	25.00	1.00	5.
800-1200	60.00	55.00	10.00	1.00	3.
1200-1600	65.00	50.00	20.00	1.00	5.
1600-2000	63.00	61.00	5.00	1.00	6.
2000-2400	58.00	54.00	10.00	1.00	6.

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 0- 400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .56
HEAT LOSS (MEGACAL/SEC) 1200.00
DRY BULB TEMPERATURE (DEG F) 55.00
WET BULB TEMPERATURE (DEG F) 52.00
WIND VELOCITY (KNOTS) 20.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	82.1	0.0	0.0
0.15	107.5	0.0	0.0
0.20	130.3	0.0	0.0
0.30	170.7	0.0	0.0
0.50	239.9	10434.8	14334.5
0.75	296.0	2174.1	2986.6
1.00	296.0	3504.0	3898.9
1.50	296.0	3857.4	3391.3
2.00	296.0	3152.4	2435.9
2.50	296.0	2319.1	1561.1
3.00	296.0	1778.7	1032.4
4.00	296.0	2589.1	1280.4
5.00	296.0	2344.2	974.1
7.00	296.0	1395.9	388.3
9.00	296.0	875.6	192.4
10.00	296.0	788.0	173.2
12.00	296.0	551.8	92.9
15.00	296.0	441.5	74.3
20.00	296.0	293.0	36.2
25.00	296.0	204.0	17.5

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 400- 800HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.55
HEAT LOSS (MEGACAL/SEC)	1200.00
DRY BULB TEMPERATURE (DEG F)	55.00
WET BULB TEMPERATURE (DEG F)	51.00
WIND VELOCITY (KNOTS)	25.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	65.6	0.0	0.0
0.15	86.0	0.0	0.0
0.20	104.2	451920.5	620810.7
0.30	136.5	96629.8	132741.9
0.50	191.8	26797.7	36812.4
0.75	251.4	11319.1	15549.2
1.00	274.6	7428.3	10204.4
1.50	274.6	24613.5	27387.7
2.00	274.6	16962.5	16835.5
2.50	274.6	27216.1	21030.3
3.00	274.6	20955.4	14105.5
4.00	274.6	14516.9	8425.5
5.00	274.6	22598.8	11175.9
7.00	274.6	16770.9	5759.6
9.00	274.6	11887.8	3306.9
10.00	274.6	10699.0	2976.2
12.00	274.6	7191.8	1580.7
15.00	274.6	4834.0	813.5
20.00	274.6	3207.3	396.5
25.00	274.6	2565.8	317.2

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 800-1200HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .55
HEAT LOSS (MEGACAL/SEC) 1200.00
DRY BULB TEMPERATURE (DEG F) 60.00
WET BULB TEMPERATURE (DEG F) 55.00
WIND VELOCITY (KNOTS) 10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	164.1	0.0	0.0
0.15	215.1	0.0	0.0
0.20	260.5	86868.0	0.0
0.30	341.4	18574.1	0.0
0.50	479.9	5151.0	0.0
0.75	628.8	2175.7	0.0
1.00	761.8	1427.9	0.0
1.50	998.2	2106.5	3827.0
2.00	1209.2	443.7	806.2
2.50	1382.8	865.1	1437.9
3.00	1382.8	1638.4	2250.7
4.00	1382.8	1030.9	1023.2
5.00	1382.8	1539.4	1353.4
7.00	1382.8	1069.4	620.7
9.00	1382.8	1630.3	806.3
10.00	1382.8	1672.1	694.8
12.00	1382.8	1281.0	439.9
15.00	1382.8	935.6	260.3
20.00	1382.8	566.3	124.5
25.00	1382.8	380.5	64.0

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1200-1600HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.04
HEAT LOSS (MEGACAL/SEC)	1200.00
DRY BULB TEMPERATURE (DEG F)	65.00
WET BULB TEMPERATURE (DEG F)	50.00
WIND VELOCITY (KNOTS)	20.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	76.9	126221.7	123919.0
0.15	100.7	34704.2	34071.1
0.20	122.0	17073.7	16762.2
0.30	159.9	7061.8	6933.0
0.50	224.7	2567.6	2520.8
0.75	279.0	1287.4	1263.9
1.00	279.0	965.5	947.9
1.50	279.0	643.7	632.0
2.00	279.0	2950.7	2434.2
2.50	279.0	5455.8	3719.6
3.00	279.0	4325.4	2661.4
4.00	279.0	2922.2	1439.4
5.00	279.0	4919.6	1886.7
7.00	279.0	3097.5	892.2
9.00	279.0	4741.9	1163.8
10.00	279.0	4881.4	1006.7
12.00	279.0	3751.9	639.5
15.00	279.0	2747.9	379.4
20.00	279.0	1667.2	181.9
25.00	279.0	1122.4	93.7

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 1600-2000HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .02
HEAT LOSS (MEGACAL/SEC) 1200.00
DRY BULB TEMPERATURE (DEG F) 63.00
WET BULB TEMPERATURE (DEG F) 61.00
WIND VELOCITY (KNOTS) 5.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	302.2	425005.7	0.0
0.15	321.0	116853.8	0.0
0.20	321.0	57489.4	0.0
0.30	321.0	921603.3	2247629.7
0.50	321.0	1649865.0	2414239.9
0.75	321.0	903697.7	881584.5
1.00	321.0	425025.1	310968.6
1.50	321.0	188900.0	92138.8
2.00	321.0	24126.3	8826.0
2.50	321.0	15440.8	4518.9
3.00	321.0	8866.7	2162.4
4.00	321.0	4987.5	912.3
5.00	321.0	6152.0	900.2
7.00	321.0	3071.0	321.0
9.00	321.0	2106.5	171.2
10.00	321.0	1798.6	131.6
12.00	321.0	1368.2	83.4
15.00	321.0	979.0	47.8
20.00	321.0	635.9	23.3
25.00	321.0	455.0	13.3

COOLING TOWER AND ENVIRONMENTAL PARAMETERS 2000-2400HRS

PROBABILITY OF EFFLUENT CONTAINING ORGANISMS	.53
HEAT LOSS (MEGACAL/SEC)	1200.00
DRY BULB TEMPERATURE (DEG F)	58.00
WET BULB TEMPERATURE (DEG F)	54.00
WIND VELOCITY (KNOTS)	10.00

DIST(MI)	PLUME RISE(M)	ORG/M3/4HRS	ORG/M2/4HRS
0.10	155.9	878180.6	1459709.3
0.15	204.3	133648.3	222149.8
0.20	247.4	59352.9	98656.2
0.30	261.9	34801.3	57846.7
0.50	261.9	196764.4	243944.4
0.75	261.9	109327.0	108508.1
1.00	261.9	163549.8	126377.5
1.50	261.9	92746.8	53829.8
2.00	261.9	135216.3	66869.6
2.50	261.9	122557.0	50928.5
3.00	261.9	93545.9	32126.4
4.00	261.9	63924.4	17782.4
5.00	261.9	41248.0	9066.1
7.00	261.9	24755.7	4165.9
9.00	261.9	17035.9	2106.2
10.00	261.9	13340.6	1145.4
12.00	261.9	11117.1	954.5
15.00	261.9	1717.9	94.4
20.00	261.9	1288.4	70.8
25.00	261.9	702.8	21.7

-------------- 24 HOUR TOTALS --------------

DAILY PROBABILITY OF EFFLUENT CONTAINING ORGANISMS .37

DIST(MI)	ORG/M3/DAY	ORG/M2/DAY
0.10	1429408.0	1583628.4
0.15	285206.3	256220.9
0.20	672704.5	736229.1
0.30	1078670.3	2445151.2
0.50	1891580.5	2711851.9
0.75	1029981.0	1009892.3
1.00	601900.6	452397.4
1.50	312868.0	181206.7
2.00	182851.9	98207.3
2.50	173853.9	83196.3
3.00	131110.6	54338.8
4.00	89971.1	30863.2
5.00	78802.0	25356.5
7.00	50160.4	12147.7
9.00	38278.0	7746.9
10.00	33179.6	6128.0
12.00	25262.0	3790.9
15.00	11655.8	1669.5
20.00	7658.1	833.2
25.00	5430.5	527.5

------------ SUMMARY OF RESULTS ---------------

DIST(MI)	AVG NO. PART. INGESTED/IND.	PERCENT AFFECTED BY EFFLUENT
0.10	3013036.4	20.000
0.15	541427.2	11.257
0.20	1408933.6	19.958
0.30	3523821.4	20.000
0.50	4603432.4	0.311
0.75	2039873.3	7.159
1.00	1054298.0	4.150
1.50	494074.6	7.704
2.00	281059.2	1.682
2.50	257050.1	15.002
3.00	185449.4	15.660
4.00	120834.3	1.400
5.00	104158.4	2.561
7.00	62308.1	6.319
9.00	46024.9	1.991
10.00	39307.6	3.284
12.00	29052.9	1.169
15.00	13325.3	2.601
20.00	8491.2	1.955
25.00	5958.0	0.000

F. Program History

Figure 22 is a listing of the simulation program. The program is written in Fortran IV for use with the DEC-20 system. Data is inputted via a data file (e.g. FOR 28. DAT) that contains the input data in free format.

FIGURE 22

```
@TYPE (FILE) PLUMOD.FOR
C        PROGRAM PLUMOD --A. UZZO-- 10/25/78
C        THIS PROGRAM SIMULATES THE PROBABILITY OF OCCURRENCE
C        THE DOWNWIND DISTRIBUTION AND POSSIBLE INFECTION IN
C        A POPULATION BY POTENTIALLY INFECTIOUS ORGANISMS FROM
C        COOLING TOWER DRIFT.  THE DISTRIBUTION AND POTENTIAL
C        EFFECTS OF THESE ORGANISMS ARE BASED ON DATA FROM
C        THIS REPORT.  THE DRIFT COMPUTATIONS ARE BASED ON THE
C        ORFAD MODEL AS DESCRIBED BY M. E. LAVERNE IN REPORT
C        ORNL/TM-5201 (OAK RIDGE NATIONAL LABORATORY).

         DIMENSION TBL(6,5),DIAM(7),R(1),XM(21),VI(25),VF(25,2)
         DIMENSION DF(25,2),CUMUL(25),DRFRAC(7),TGI(6),ISED(6)
         DIMENSION DRIFT(20),DR(20),IK(20),PRR(20),A(6),P(4),B(4)
         DIMENSION TOMS(20),TOMC(20),TOTC(20),TOTS(20)
         DIMENSION ARY(20),TOPP(20)

         DATA TGI/-.0263,-.0173,-.0146,-.01,.0046,.0263/
         DATA A/-7.9,5.03,-1.38E-7,11.3,8.13E-3,-3.49/
         DATA B/-9.1,-3.57,.88,.006/
         DATA DIAM/70.,175.,300.,425.,550.,700.,0./
         DATA DRFRAC/.06,.3,.39,.15,.07,.03,6./
         DATA G,PI,CUBRT,FTM/9.81,3.1416,.33333,.3048/
         DATA XM/.1,.15,.2,.3,.5,.75,1.,1.5,2,2.5,3.,
         14.,5.,7.,9.,10.,12.,15.,20.,25.,0./
         AB(Y)=255.37+.5555*Y
         OPEN(UNIT=7,ACCESS='SEQOUT',FILE='PLUM.DAT')
         LR=26

         PROBA=0.
         DO 8 I=1,20
         TOTS(I)=0.
         TOTC(I)=0.
8        CONTINUE

C        READ INPUT DATA AND WRITE FIXED DATA
         READ(LR,*)HTO,DIATO,FRACDR,EXSPDO,CONC,TMPR,HEATO
C        WRITE FIXED PARAMETERS
         WRITE(7,1000)
         WRITE(7,1003)HTO
         WRITE(7,1005)DIATO
         WRITE(7,1007)HEATO
         WRITE(7,1030)TMPR
         WRITE(7,1031)FRACDR
         WRITE(7,1032)CONC
         WRITE(7,1033)EXSPDO
         WRITE(7,1012)
         DO 5 I=1,6
         READ(LR,*)(TBL(I,J),J=1,5)
5        CONTINUE
         READ(LR,*)(ISED(I),I=1,6)
         LTIME=0
         NTIME=400
         WRITE(7,1034)
         WRITE(7,1035)
```

```
          MTIME=0
          KTIME=400
          DO 3 JK=1,6
          WRITE(7,1036)MTIME,KTIME,(TBL(JK,JL),JL=1,5)
          MTIME=MTIME+400
          KTIME=KTIME+400
3         CONTINUE
          DO 800 NCY=1,6


          DBT=TBL(NCY,1)
          WBT=TBL(NCY,2)
          WINDO=TBL(NCY,3)
          PCAP=TBL(NCY,4)
          STAB=TBL(NCY,5)
          HEATO=HEATO*PCAP
          LSTAB=STAB

C         CALCULATE TOWER PARAMETERS
          HT=HTO*FTM
          DIAT=DIATO*FTM
          EXSPD=EXSPDO*FTM
          WIND=WINDO*.514
          RAD=DIAT/2
          TAREA=PI*RAD*RAD
          EXVOL=EXSPD*TAREA
          CWFR=1.8E6*HEATO7)
          UMW=EVLOS+ARLOS
          APP=2.7
          FRACON=0.

C         CALCULATE DILUTION FACTOR TIME--INPUT VOLUME
          TAU=(CONC-1.)*TVOL/UMW
          ATAU=TAU/2
          BINVOL=UMW*ATAU

C         CALCULATE PROB. OF ORG PRESENT
          C=0.
          DO 30 I=1,2000
          Y=GGUBF(ISED(1))
          IF (Y-.064)10,11
11        IF(Y-.1380)12,13
13        IF(Y-.2686)14,15
15        IF(Y-.3158)16,17
17        IF(Y-.4444)18,19
19        IF(Y-.4722)20,21
21        IF(Y-.5833)22,23
23        IF(Y-.6944)24,25
25        IF(Y-.7963)26,27
27        IF(Y-.9074)28,29
10        Z=0.;GO TO 40
12        Z=.1;GO TO 40
14        Z=.2;GO TO 40
16        Z=.3;GO TO 40
```

```
18      Z=.4;GO TO 40
20      Z=.5;GO TO 40
22      Z=.6;GO TO 40
24      Z=.8;GO TO 40
26      Z=.8;GO TO 40
28      Z=.9;GO TO 40
29      Z=1.
40      C=C+Z
30      CONTINUE
        PROB=C/2000.
        XY=ABS(GGNOF(ISED(3)))
        IF(XY.GT.1.)GO TO 2
        PROB=XY*PROB
2       PROBA=PROBA+PROB

C       CALCULATE INPUT PARAMETERS
        CTORG=0.
        NTRY=Y*20
        DO 210 I=1,NTRY


        CALL GGEXP(ISED(2),PROB,1,R(1))
        CNORG=R(1)*1.E5
        RV2=GGUBF(ISED(3))
        IF(RV2-PROB)200,205
200     CNORG=0.
205     CTNORG=CNORG+CTNORG
210     CONTINUE
      -SEE ORFAD MODEL
        DIAMAX=DIAM(IDRCL)*1.5-.5*DIAM(IDRCL-1)
        DIAM(IDRCL+1)=DIAMAX
        D=0.
        DD=DIAMAX/25.
        F=0.
        X1=0.
        X2=.5*(DIAM(1)+DIAM(2))
        K=1
        CONR=.01
        FAC=1.E-4*((1.+.7*CONR)*CONR/.3112)**CUBRT
        DO 240 J=1,25
        D=D+DD
        DIM=FAC*D
        VFJ2=3519.2*DIM*DIM
        VFJ1=.4963*VFJ2
        VIJ=D*D/33414.
        IF(D.GT.74.36)VIJ=.00445*(D-37.18)
        DFJ=7.415E-6*D**2.667
        DFJ1=DFJ*((VIJ-VFJ1)/(VIJ+VFJ1))
        DFJ2=DFJ*(VIJ-VFJ2)/(VIJ+VFJ2)
        VF(J,1)=VFJ1
        VF(J,2)=VFJ2
        VI(J)=VIJ
        DF(J,1)=DFJ1
```

```
            DF(J,2)=DFJ2
      215   IF(D-X2)220,220,230
      220   CUMUL(J)=F+DRFRAC(K)*(D-X1)/(X2-X1)
            GO TO 240
      230   F=F+DR5,232
      232   K=IDRCL
            F=F-DRFRAC(IDRCL)
      235   X2=DIAMAX
            IF(J.LT.25)GO TO 215
            CUMUL(J)=1.
      240   CONTINUE
            DO 250 J=1,24
      250   CUMUL(26-J)=CUMUL(26-J)-CUMUL(25-J)

      C     CALCULATE RELATIVE HUMIDITY
            TEO=AB(DBT)
            TEB=AB(WBT)
            JFLAG=0
            T=TEO
            GO TO 110
      130   JFLAG=1
            T=TEB
      110   CONTINUE
            IF(TEO.LT.273.16)GO TO 265
            Z=373.16/T
            P(1)=A(1)*(Z-1)
            P(2)=A(2)*ALOG10(Z)
            Z1=A(4)*(1.-1./Z)
            P(7)=A(7)*(10**Z1-1)
            Z1=A(6)*(Z-1)
            P(4)=A(5)*(10**Z1-1)

            GO TO 245
      265   Z=273.16/T
            P(1)=B4))
      245   SUM=0.
            DO 244 I=1,4
      244   SUM=SUM+P(I)
            PVSF=14.696*10**SUM
            IF(JFLAG)120,120,140
      120   PVSD=PVSF*2.063
            GO TO 130
      140   PVSW=PVSF*2.036
            PV=PVSW-(7.67E-4*29.84*(DBT-WBT)*(1.+(WBT-32.)/1571.))
            RH=PV/PVSD
            IF(RH.LE.0.)RH=.01
            RHFAC=(1.-RH)**1.079
            IRH=2
            IF(RH.LT.0.5)IRH=1

      C     CALCULATE TOWER EFFLUENT TEMPERATURE
            IF(WBT.LT.80)ENTAL=(WBT+4.31)/(7.92-.0248*WBT)
```

```
                IF(WBT.GE.80.)ENTAL=(WBT-13.85)/(2.77-.016*WBT)
                RAPP=TMPR*APP
                ENTAL=ENTAL+RAPP
                IF(ENTAL.GT.43.7)TS=(2.766*ENTAL+13.85)/(1.+.016*ENTAL)
                IF(ENTAL.LE.43.7)TS=(7.92*ENTAL-4.31)/(1.+.0248*ENTAL)
                TPO=AB(TS)
                DELQ1=EVLOS/(753130*EXVOL)
                DELQ=DELQ1*TPO
                U=WIND
                FC=0.
                DO 361 IX=1,20
2STAB)
                TEHT=TEO+TG*HT
                S=G*(TG+.01)/TEO
        300     CONTINUE
                FR=G*EXSPD*RAD*RAD*(1.-TEHT/TPO+DELQ*(.61+2545.*FC/TPO))
                IF(FR.GE.0.) GO TO 310
                TEHT=TPO
                GO TO 300
        310     CONTINUE
                IF(LSTAB.GT.4) GO TO 362
                F4=FR**.4
                H=AMIN1(HT,304.8)
                XS=2.16*F4*H**.6
                X=AMIN1(XME,3.*XS)
        320     CONTINUE
                H=1.6*(FR*X*X)**CUBRT/U
                PR=H
                GO TO 340
        330     CONTINUE
                PR=5.*SQRT((SQRT(FR/(S*SQRT(S)))))
        340     CONTINUE
                PRR(IX)=PR
                IF(PR.GT.0.) GO TO 350
                GO TO 361
         C       CALCULATE DRIFT AND DRIFT PARAMETERS
                K=25
                OR=0.
                OPR=0.
                OXME=0.
                INCR=1
                DO460 IX=1,20
                DRIFT(IX)=0.

                XME=XM(IX)*1609.3
                PR=PRR(IX)
                DPR=PR-OPR

        C       CALCULATE DRIFT
                DXME=XME-OXME
                OPR=PR
                OXME=XME
```

```
                IF(RH.LT.0.76) GO TO 410

C               NO EVAPORATION
                VFALL=(HT+PR)*U/XME
                DIA=37.18+VFALL/.00445
                IF(VFALL.LT.0.1655) DIA=SQRT(73414.*VFALL)
                IDIA=DIA/DD+1.
                IK(IX)=IDIA
                IF(IDIA.GT.25)GO TO 491
                DVDR=(VFALL-U*DPR/DXME)/XME
                DDDR=DVDR/.0045
                IF(VFALL.LT.0.1665)DDDR=.5*DIA*DVDR/VFALL
                DCDD=CUMUL(IDIA)/DD
                GO TO 440

C               EVAPORATION
      410       CONTINUE
                H=HT+PR
      420       RY=DF(K,IRH)/RHFAC
                IF(H.LT.RY) GO TO 450
                XR=U*(H-RY)29600          K=K-1
                OR=XR
                IF(K)491,491,420
      430       DCDD=CUMUL(K)
                IK(IX)=K
                IF(K.GE.25) GO TO 491
                VFALL=VF(K,IRH)
                DDDR=1./(XR-OR)
      440       CHI2=ARLOS*DDDR*DCDD*INCR*8./(XME*PI)
                DR(IX)=CHI2/VFALL
                DRIFT(IX)=CHI2
      491       CONTINUE
      460       CONTINUE
                IF(NCY.LE.2)AMOD=1.
                IF(NCY.GT.2 .AND. NCY.LT.6)AMOD=.2
                RANV=GGUBF(ISED(4))
                IF(RANV.LT.0.1)AMOD=.5
                IF(NCY.GT.5)AMOD=1
                IF(RH.GT.0.76)BMOD=1
                IF(RH.LE.0.76.AND.RH.GE.0.5)BMOD=.5
                IF(RH.LT.0.5)BMOD=.2
                DO 470 IY=1,20
                TUMS(IY)=DRIFT(IY)*CAORG*AMOD*14400.*BMOD
                TUMC(IY)=DR(IY)*CAORG*AMOD*14400.*BMOD
                TOTC(IY)=TOTC(IY)+TUMC(IY)
                TOTS(IY)=TOTS(IY)+TUMS(IY)
      470       CONTINUE
                WRITE(7,1012)
                WRITE(7,1001)LTIME,NTIME
                WRITE(7,1002)PROB
                WRITE(7,1006)HEATO
                WRITE(7,1008)DBT
                WRITE(7,1009)WBT
                WRITE(7,1010)WINDD
```

```
          WRITE(7,1011)
          WRITE(7,1016)
          DO 600 IR=1,20
600       WRITE(7,1015)XM(IR),PRR(IR),TOMC(IR),TOMS(IR)
          LTIME=LTIME+400
          NTIME=LTIME+400
800       CONTINUE
          PROBB=PROBA/6
1001      FORMAT('1','     COOLINMS',F4.2)
1003      FORMAT(1X,'TOWER HEIGHT (FEET)                    ',F10.2)
1005      FORMAT(1X,'TOWER DIAMETER (FEET)                  ',F10.2)
1006      FORMAT(1X,'HEAT LOSS (MEGACAL/SEC)                ',F10.2)
1007      FORMAT(1X,'HEAT LOSS (MEGACAL/SEC,MAX)            ',F10.2)
1008      FORMAT(1X,'DRY BULB TEMPERATURE (DEG F)           ',F10.2)
1009      FORMAT(1X,'WET BULB TEMPERATURE (DEG F)           ',F10.2)
1010      FORMAT(1X,'WIND VELOCITY (KNOTS)                  ',F10.2)
1011      FORMAT(//)
1000      FORMAT('1',//,'****************COOLING TOWER FIXED PAR
          1AMETERS****************'//)
1015      FORMAT(2X,F7.2,10X,F8.1,5X,F12.1,5X,F12.1)
          WRITE(7,1012)
          WRITE(7,1018)
          WRITE(7,1020)PROBB
          WRITE(7,1019)
          DO 700 IM=1,20
700       WRITE(7,1017)XM(IM),TOTC(IM),TOTS(IM)
1012      FORMAT(////)
1016      FORMAT(1X,'DIST(MI)',5X,'PLUME RISE(M)',6X,'ORG/M3/4HRS'
          1,6X,'ORG/M2/4HRS')
1018      FORMAT('1',///,'---------------    24 HOUR TOTALS  --
          1-------------'/)
1017      FORMAT(2X,F7.2,5X,F12.1,5X,F12.1)
1019      FORMAT(1X,'DIST(MI)',7X,'ORG/M3/DAY',7X,'ORG/M2/DAY')
1020      FORMAT(1X,'DAILY PROBABILITY OF EFFLUENT CONTAINING ORGA
          1NISMS',F4.2,/)
          DO 750 J=1,20
          TOPP(J)=20.*TOTC(J)+TOTS(J)
          PL=0.
          PK=0.
          DO 650 M=1,100
          CALL GGEXP(ISED(5),.1,1,R(1))
          DORG=3.E6*R(1)
          IF(TOPP(J).GT.DORG)PK=PK+1.
          PL=PL+1.
650       CONTINUE
          AND=ABS(GGNOF(ISED(6)))
          ARY(J)=AND*PK*20./PL
          IF(ARY(J).GT.20.)ARY(J)=20.
750       CONTINUE
          WRITE(7,1025)
          WRITE(7,1026)
```

```
      WRITE(7,1026)
      WRITE(7,1028)
      DO 770 N=1,20
      WRITE(7,1027)XM(N),TOFF(N),ARY(N)
  770 CONTINUE
 1025 FORMAT('1',///,'---------------    SUMMARY OF RESULTS
     1  ------------------')
 1026 FORMAT(1X,//,2X,'DIST(MI)',7X,'AVG NO. PART.',7X,'PERCEN
     1T AFFECTED')
 1028 FORMAT(19X,'INGESTED/IND.',10X,'BY EFFLUENT',/)
 1027 FORMAT(2X,F7.2,8X,F12.1,16X,F7.3)
 1030 FORMAT(1X,'TEMPERATURE RANGE (DEG F)          ',F10.2)
 1031 FORMAT(1X,'DRIFT FRACTION (G/G)               ',F10.6)
',F10.2)


 1034 FORMAT(12X,'--COOLING TOWER OPERATING PARAMETERS--')
 1035 FORMAT(1X,'TIME (HRS)'4X,'DRY BULB T',4X,'WET BULB T', 4X
     1,'WIND VEL.',4X,'OPER CAP',4X,'STABILITY')
 1036 FORMAT(1X,I4,'-',I4,2X,F10.2,4X,F10.2,4X,F9.2,7X,F4.2,
     16X,F4.0)
      END
@
```

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-79-251a	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Effects of Pathogenic and Toxic Materials Transported Via Cooling Device Drift-- Volume 1. Technical Report		5. REPORT DATE November 1979 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) H.D. Freudenthal, J.E. Rubinstein, and A. Uzzo		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS H2M Corporation 375 Fulton Street Farmingdale, New York 11735		10. PROGRAM ELEMENT NO. INE624A 11. CONTRACT/GRANT NO. 68-02-2625
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Final; 1/77 - 9/79 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Michael C. Osborne, Mail Drop 61, 919/541-2915.

16. ABSTRACT The report describes a mathematical model that predicts the percent of the population affected by a pathogen or toxic substance emitted in a cooling tower plume, and gives specific applications of the model. Eighty-five pathogens (or diseases) are cataloged as potentially occurring in U.S. waters, but there is insufficient data to predict the probability of occurrence or relate their occurrence to public health, population, or pollution. Sixty-five toxic substances are cataloged as potentially occurring in U.S. waters, but the actual number is probably many times the EPA-supplied list. Toxic concentrations to persons, animals, and plants are known for only a few of the chemicals: most toxic levels can be only inferred from animal studies. In the population as a whole, the epidemiological impact of a pathogen is a function of age, sex distribution, racial (genetic) distribution, general health and well-being, prior exposure, and immunological deficiency states. While cooling device drift may not be directly responsible for epidemics, it may potentiate the burden in an already weakened population, raising a segment of the population into the clinical state. The effect of toxic substances is difficult to evaluate because of inadequate data on humans. The effect is a function of concentration in susceptible tissue, and is much less dependent than pathogens on host resistance.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Water	Pollution Control	13B	07B
Cooling Towers	Epidemiology	Stationary Sources	13A,07A	
Drift	Mathematical Models		14B	12A
Plumes			21B	
Pathology			06E	
Toxicity			06T	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 215
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

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