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ABSTRACT

This publication includes several activities regarding the use of nuclear power plants and possible effects on the environment. The materials are designed for secondary school students and include reference materials and masters for transparencies. (RH)

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THERMAL POLLUTION BY NUCLEAR POWER PLANTS

A Learning Experience for
Coastal and Oceanic
Awareness Studies

Produced by

MARINE ENVIRONMENT CURRICULUM STUDY
MARINE ADVISORY SERVICE
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POPULATION-ENVIRONMENT CURRICULUM STUDY
COLLEGE OF EDUCATION
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as part of a

PLAN FOR ENVIRONMENTAL EDUCATION

Fall 1974

Please send evaluations

of learning experiences

to

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TITLE: THERMAL POLLUTION BY NUCLEAR POWER PLANTS

* CONCEPT: V.B.2.d.

V. The activities of human populations may degrade the environment and restrict the quality of human life.

B. Human activities cause pollution.

2. Pollution reduces the quality and usefulness of the environment.

d. ECOSYSTEMS MAY BE ALTERED BY POLLUTION.

** MARINE CONCEPT: 4.22

4. Man is part of the marine ecosystem.

4.2 Man's activities may deplete and degrade marine ecosystems.

4.22 MAN IS CHANGING MARINE ECOSYSTEMS BY ADDING POLLUTANTS TO AIR AND WATER.

GRADE LEVEL: 10-12

SUBJECT: Biology, Social Studies

CLASS PERIODS: Various

AUTHOR: Dillner

* From A Conceptual Scheme for Population-Environment Studies, 1973. Cost $2.50.

** From Marine Environment Proposed Conceptual Scheme, 1973. No charge.

Both conceptual schemes are available from Robert W. Stegner, Population-Environment Curriculum Study, 310 Willard Hall, University of Delaware, Newark, DE 19711.

R276

Background material:

One of the most useful characteristics of water is its high specific heat. This ability to slowly absorb and release heat makes water an excellent medium for heat exchange. Man has used water for thousands of years as a coolant, but as industries grew and diversified increased demands were made on cooling water.

One of the principal users of water for cooling is the electric power industry. In 1968 electric power generation accounted for about three-quarters of the total of 60,000 billion gallons of water used in the U.S. for industrial cooling.

At the present time the amount of heat being discharged into bodies of water poses few problems except in some local situations. A comprehensive study of warming in the lower Connecticut River has revealed no apparent drastic biological consequences. However, when projections are made of increased future demands for electrical power, which are likely to be met by nuclear plants, it is evident that heat discharge may be of great consequence. Nuclear plants, being less efficient users of steam than fossil-fuel plants, require almost a fifty per cent increase in coolant water. Experts have estimated that within 30 years the electric power industry will be producing nearly two million megawatts of electricity which will require the disposal of about 20 million BTUs of waste heat per day. They have further estimated that removal of this heat by way of natural waters would require a flow through power plants of approximately one-third of the average daily fresh water runoff in the United States. The enormity of the predicted heat discharge has many scientists worried about the adverse effects of waste heat on aquatic and estuarine ecosystems.

It is because of the potential to disrupt ecosystems that the discharge of waste heat is called thermal pollution. Other terms such as calefaction and thermal loading may also be used. These terms are less biased than the term thermal pollution since they do not imply that all waste heat is harmful.

If electric power demands are to be met using existing nuclear and fossil fuels and if thermal pollution of natural bodies of water prove to be too disruptive of ecosystems, then alternate means of waste heat disposal must be used. The use of wet and dry cooling towers is one alternative already in use. In a wet cooling tower, heat is removed from coolant water by evaporation. A drawback to the wet tower is the large amount of surface water released into the atmospheric circulation. This water may form fog or ice in the vicinity of the tower depending on weather conditions. The dry cooling tower overcomes the problem of water loss by keeping the coolant water in a closed system much like an automobile radiator. Dry towers, however, are more expensive than wet towers which in turn are more expensive than dumping waste heat into natural bodies of water.

Radical new sources of power may be the only answer to the thermal pollution problem. Possibilities being actively studied include the use of fuel cells (a cell which produces energy directly form the controlled electrochemical oxidation of fuel), magnetohydrodynamics (a generator which produces energy directly from thermal energy), and fusion (the combining of light atomic nuclei which results in energy production). The value of these potential power sources is that they produce electricity and avoid the inefficient energy conversion and thermal loading which characterize present sources. The proliferation of power needs demands that efforts be made to explore alternate means of generation power in order to avoid environmental degradation.

Classroom procedures:

It is suggested that the drawings included with this teacher resource packet be prepared either as overhead transparencies or handouts.

THERMAL POLLUTION

1. List various activities of man which produce waste heat.

The list should include steel and chemical industries and nuclear and fossil fuel power plants.

2. Show Figure 1, a drawing of a nuclear power station. Why is waste heat produced?

In a nuclear reactor heat is generated from a radioactive source. The heat produces steam, which turns turbine blades, which runs a generator, which produces electricity. This process is very similar to electrical production by fossil fuel plants which use coal or oil as the energy source. An advantage of nuclear plants is the elimination of the combustion products of fossil fuels; however, a negative aspect is about a 50% increase in demand for cooling water. As water moves through a nuclear power plant, its temperature may be increased as much as 20°F.

3. What parts of the environment are affected by waste heat?

The aquatic and estuarine environments are obvious answers, but the atmosphere may also be affected.

4. What are the effects of adding heat to bodies of water?

Responses may include:

1. *raises water temperature.*
2. *affects stratification.*
3. *reduces oxygen concentration.*
4. *affects individual organisms.*
5. *affects ecosystems.*

Students are not expected to suggest this complete list. Items not suggested should be added to the list as the lesson progresses.

5. Show Figure 2 which shows water temperature on the Monongahela River. What could account for the various peaks in water temperature?

Students may reply that industries could be located at points on the river where temperature peaks occur. Showing Figure 3 which indicates the location of cities along this portion of the River should confirm this idea. It should be noted that the total rise in temperature along the 40 miles of river is about 5°F.

6. Show Figure 4, an aerial perspective drawing of a nuclear power plant on the Connecticut River at Haddam Neck (B).

The plant (A) is located at the head of a canal (C) which was dug to carry warm water back to the river.

7. Show Figure 5 which shows an aerial thermogram of the Haddam nuclear plant.

The hot effluent (white area) is about 93°F., while normal river temperature (stippled area) is 77°F. The power plant empties 370,000 gallons of coolant water per minute into the river. At slack tide heated water tends to spread across the river. At ebb tide the water moves downstream. When the tide rises, warm water is carried upstream as is shown in Figure 5. The warming effect can be detected as far as 2 miles upstream and 2.2 miles downstream.

STRATIFICATION

8. Ask "Is water uniformly affected at all depths by heated effluent?"

Discussion should include density properties of water in relation to stratification. At temperatures above 37°F., warmer water is less dense than cooler water, hence it tends to rise to the surface.

9. Show Figure 6, which shows the hot-water plume that would result from a nuclear power plant on the Hudson River as predicted by an engineering study. What information does the drawing contain? Numbers across the surface of the river indicate water temperature in Fahrenheit degrees.

Water at the surface is heated more than water at depths. The lines on the graph are 1°F. contour lines. The depth to which water is heated as well as the linear distance through which it is heated is shown.

OXYGEN CONCENTRATION

10. Show Figure 7, The Relationship between Dissolved Oxygen and Temperature. What effect does increased water temperature have on dissolved oxygen?

As temperature increases the amount of dissolved oxygen decreases. A laboratory activity concerning this relationship could be included in the inquiry.

EFFECT ON INDIVIDUAL ORGANISMS

11. Name various ways in which increased temperature could affect the physiology of aquatic and estuarine organisms.

Answers should include: increased breathing, increased heartbeat, faster growth, and shorter lifespan. It is generally true that respiration and oxidation rates double for every 50°C. rise in temperature. Warm-water fish require at least 5 ppm oxygen during 16 of every 24 hours.

Oxygen content for most fish should not fall below 3 ppm. Carp, with very low oxygen requirements, need 0.5 ppm oxygen at 33°F. and 1.5 ppm at 95°F.

Temperature affects the spawning of aquatic and estuarine organisms. An oyster's temperature regulation is so sensitive that it spawns within a few hours when surrounding water reaches a critical temperature. The eggs of trout hatch at 37°F. in 165 days, but at 54°F. only 32 days are required. Life span is generally shortened by temperature increases. At 46°F. Daphnia live for 108 days, but at 82°F. they live only 29 days. A rapid rise or fall in temperature may lead to thermal shock and be fatal. However, if temperature change is gradual, acclimation is possible. Temperature also affects distribution and migration patterns, competition between species, predation, parasitism, and disease transmittal.

12. Show Figure 8, which shows shad populations in the Connecticut River. Is there any relation between shad populations and temperature? (The Haddam power plant began operation in July 1967.)

    Apparently there were no ill effects due to the power plant. The large number of shad in 1965 was due to an above-average spawning success in 1960. Shad are the most important natural resource of the river in terms of economics.

    Students should realize that not all temperature increases are harmful. Warmer waters could provide for faster growth in shellfish and could even provide better fishing for sport fishermen. A scientific study concluded that industrial warming had no drastic effects on the Connecticut River.

13. Figure 9 shows an aquatic ecosystem. How will a change in water temperature affect this ecosystem?

    The large fish at the top of a food chain are dependent on smaller fish, invertebrates, algae, and dissolved nutrients. The smaller organisms are apt to be affected first by a temperature change. A change which affects any one of the lower links in the food chain may seriously affect the population of large fish.

14. Show Figure 10, The Effect of Temperature on 3 Groups of Freshwater Algae. What does the graph show?

    All three types of algae are eaten, but most consumers prefer diatoms to green or blue-green algae. Only a few consumers eat blue-green algae which can be toxic to some organisms. The graph shows that these algae differ in their temperature tolerances. As the temperature rises, biological succession occurs which eventually changes the species composition from primarily diatoms to primarily blue-green algae. Consumers that depend on diatoms and green algae would then be adversely affected.

Daphnia, for example, which may survive temperatures as high as 95°F., would starve if the diatoms on which it feeds could not survive a 95°F. temperature. Consumers depending on Daphnia for a source of food would be similarly affected.

Cooling systems, which divert a considerable portion of a stream's flow through intake pipes where water temperature is raised as much as 20°F., have drastic effects on organisms. This sudden rise in temperature may cause thermal shock followed by death for plankton. At some cooling stations 95% of living things may be killed. Chlorine, added to cooling systems to retard the growth of microorganisms in pipes, tends to sterilize the cooling water.

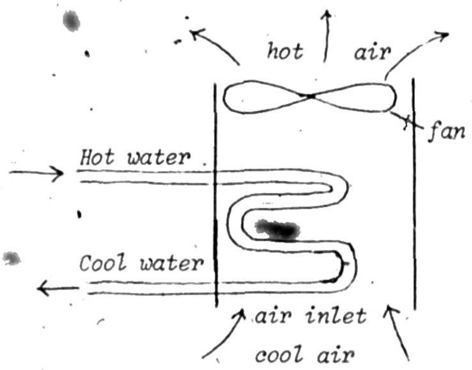
ALTERNATIVES

15. Are there alternate means of disposing of waste heat besides adding it to bodies of water?

Students familiar with the problem may answer that cooling towers can be used; however, if students do not know the answer it should not be volunteered by the teacher. It will be developed later in the lesson.

16. At this point in the inquiry students are asked to develop models (drawings) of alternate cooling methods - ones which would dispose of waste heat into the air.

Coaching by the teacher should lead to a drawing similar to the following:

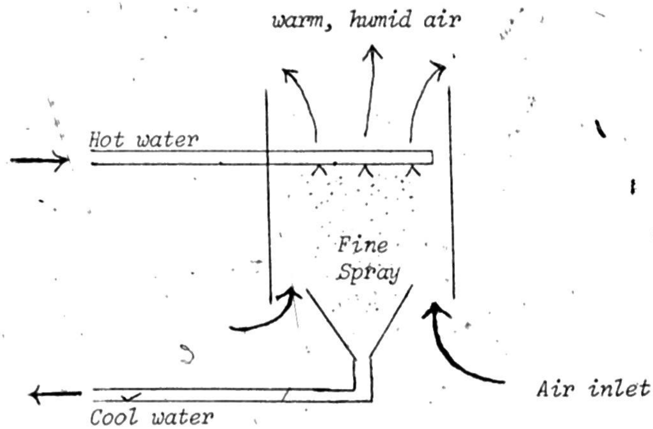


MODEL OF DRY TOWER

In this type of system hot water passes through a series of pipes as cool air is passed over the pipes. Water temperature drops but air temperature increases. This is the basic design of an automobile engine radiator.

17. Discussion should proceed to the development of a second model based on evaporation as a method of heat dissipation.

If students are not aware that evaporation causes cooling, saturate a piece of cotton with alcohol and rub it on the skin of a student's arm. He should feel coolness. The model constructed should approximate the following:



MODEL OF WET TOWER

A fan is not necessary for a wet tower but is sometimes used. Updrafts created by the temperature differential may cause sufficient air circulation. Large surface areas for the evaporation of water are achieved either by spraying the water or by passing it over baffles which break it into small droplets. Show Figure 11, which illustrates the effect of baffles.

18. Show Figures 12 through 15, drawings of actual cooling towers. Students should compare their models with these illustrations.

19. Do wet and dry cooling towers pose any threat to the environment?

The chief shortcoming of the wet tower is the large amount of water vapor discharged into the atmosphere. A 1000-megawatt power plant utilizing wet towers would discharge 20,000-25,000 gallons of evaporated water per minute. This amount is equivalent to a daily rainfall of one inch over an area of two square miles. Fog and ice would occur on cold days. If salt water was being used as the coolant, salt spray would destroy vegetation over a large area. Dry towers do not have these drawbacks.

20. Discussion should lead to the economics of heat disposal. List in order the various types of cooling methods according to their cost of installation and operation.

21. Show Figure 16 which shows costs of various cooling systems for 800,000 kilowatt power stations using nuclear fuel. Students can compare their ordering with this chart. Discuss the economics involved.

A CASE STUDY - THERMAL POLLUTION IN THE DELAWARE ESTUARY

22. Show Figure 17, which is a map of the Delaware Estuary with major points of thermal discharge numbered.

23. Table 1 lists the 15 major cooling water users in the Delaware Estuary. The following questions should be asked:

What type of industry uses the Estuary to the greatest extent for cooling purposes?

What effect will the Salem nuclear plant have on total usage?

24. Look at Table 2, which lists data for the electric utilities on the Delaware Estuary. Of major concern here is a comparison of heat discharge from fossil fuel plants with the expected discharge from the Salem nuclear plant.

The Salem plant will have two pressurized water reactor units, each capable of generating 1,050 megawatts. Each unit will use water at an average rate of 1 million gallons per minute. Average total usage will be 2.88 billion gallons per day. The heat output is estimated at 15.25 x 109 BTU/hr. The temperature rise across the condensers will be 13.6°F. The power company claims that the temperature rise in the bay will be less than 5°F. An outfall 500 feet from the shoreline will produce a 40-acre zone for heat dissipation where temperature increases will exceed a 5°F. rise. Power companies have applied to the Atomic Energy Commission for permission to build a nuclear plant at Newbold Island near Trenton. The proposal is for cooling towers which will probably evaporate 25 million gallons of water per day in the vicinity.

25. Additional case studies could be made by students as research projects.

The following locations and sources of information would be helpful:

A. Cayuga Lake - Cornell Scientists...Aug.-Sept. 1968, p. 2-36
Wagner, 1971, p. 145-147
Thermal Pollution...8 Nov. 1968, p. 649-650

B. Connecticut River - Merriman, May 1970, p. 42-52
Clark, March 1969, p. 18-27

TABLE 1

Major Cooling Water Uses in the Delaware Estuary in Million Gallons a Day

1.	Public Service Gas & Electric Co. (Mercer)	630
2.	U. S. Steel	250
3.	Public Service Gas & Electric Co. (Burlington, New Jersey)	288
4.	Philadelphia Electric (Richmond)	568
5.	Philadelphia Electric (Delaware)	265
6.	Philadelphia Electric (S. Wark)	363
7.	Philadelphia Electric (Eddystone)	726
8.	Philadelphia Electric (Chester)	109
9.	EP - Sinclair (Trainer)	120
10.	Sun Oil (Marcus Hook)	115
11.	DuPont (Deepwater)	113
12.	Delmarva Power and Light (Edgemoor)	408
13.	Atlantic City Power Co. (Deepwater)	139
14.	Delmarva Power and Light - Getty (Delaware City)	325
15.	Salem nuclear power generation plant* (under constr.)	2880

* Owned by a consortium of power companies.

Source: Delaware Estuary Comprehensive Study. 1966. Department of Natural Resources and Environmental Control, Dover, Delaware.

TABLE 2

Electric Utilities on the Delaware Estuary

	Installed Power 1000 Kw	Heat Rejection Rate 10^6 BTU/Hr.
1. Public Service Gas & Electric Co.		
(a) Mercer	660	1200
(b) Burlington	550	3150
2. Philadelphia Electric Company		
(a) Richmond	483	45
(b) Delaware	468	NA
(c) South Wark	378	NA
(d) Schuykill	333	1927
(e) Eddystone	726	NA
(f) Chester	284	798
3. Delmarva Power & Light Company		
(a) Edgemoor	386	1438
(b) Delaware City	116	NA
4. Atlantic City Power Company		
(a) Deepwater	308	1250
5. Salem Nuclear Power Generation Plant (under construction)	2010	15250

Source: Delaware Estuary Comprehensive Study. 1966. Department of Natural Resources and Environmental Control, Dover, Delaware.

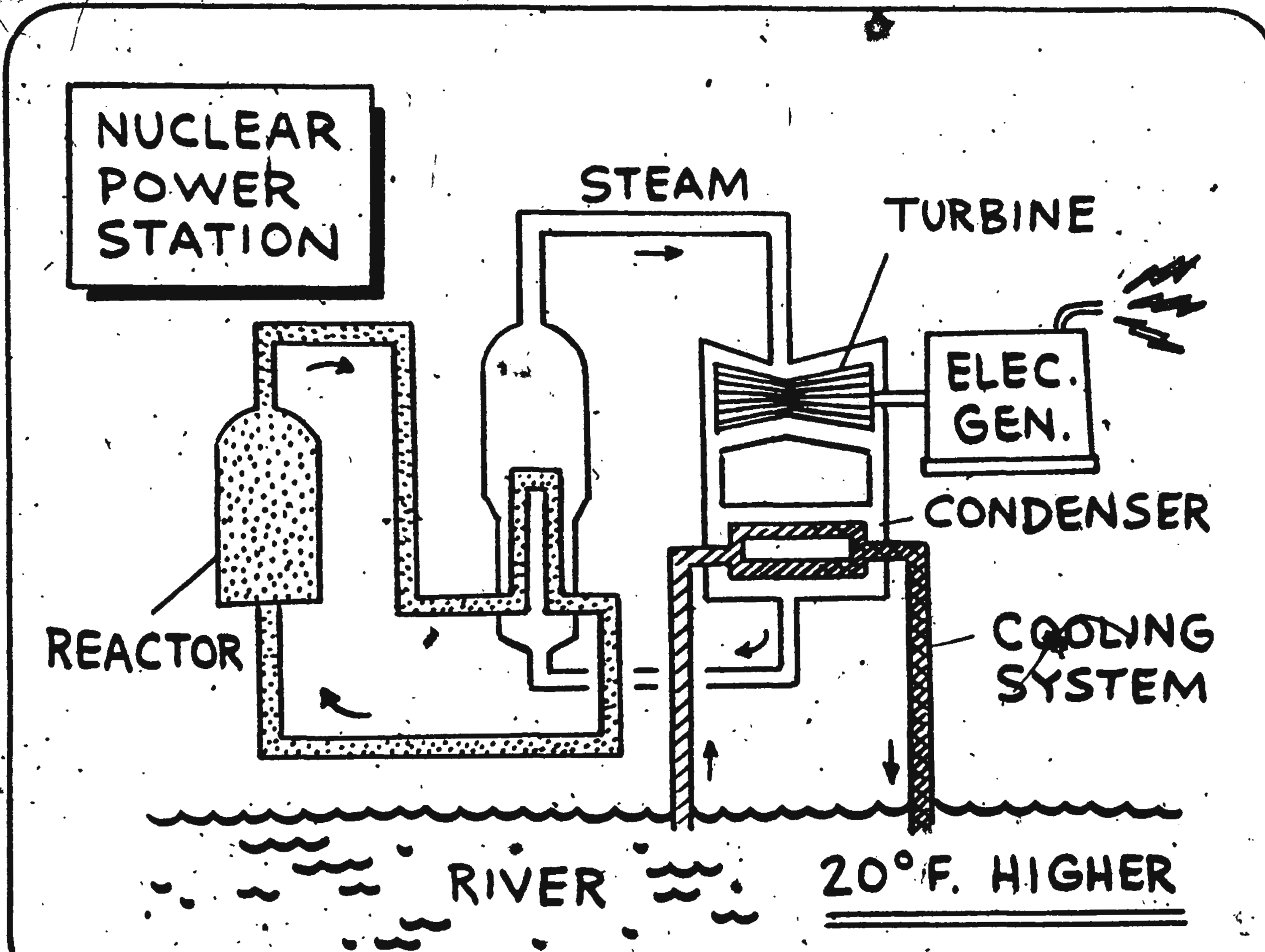


Fig. 1

V.B.2.d. (Mar. 4.22) P. 11

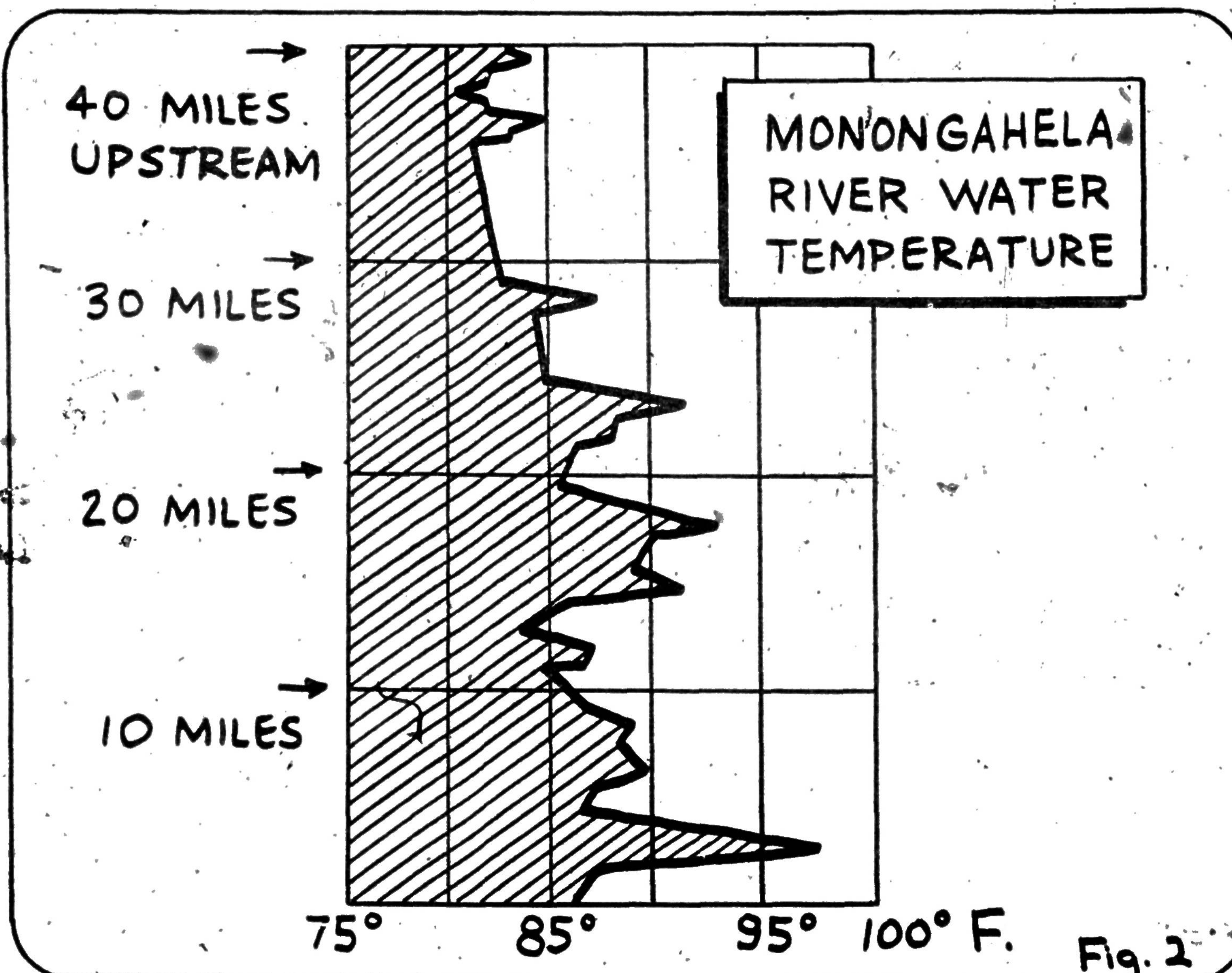


Fig. 2

V.B.2.d. (Mar. 4.22) p. 12

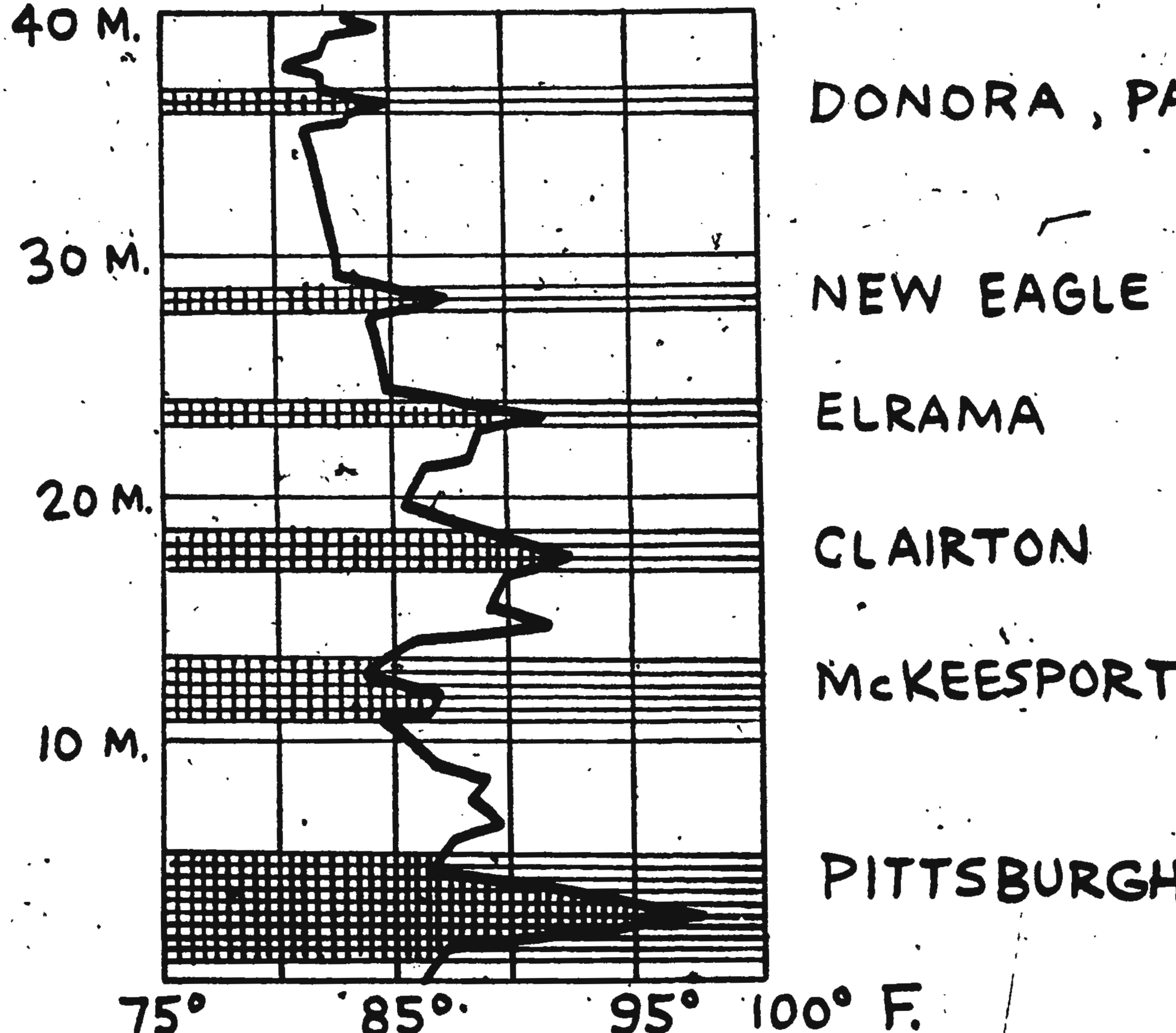


Fig. 3

V.B.2.d. (Mar. 4.22) p. 13

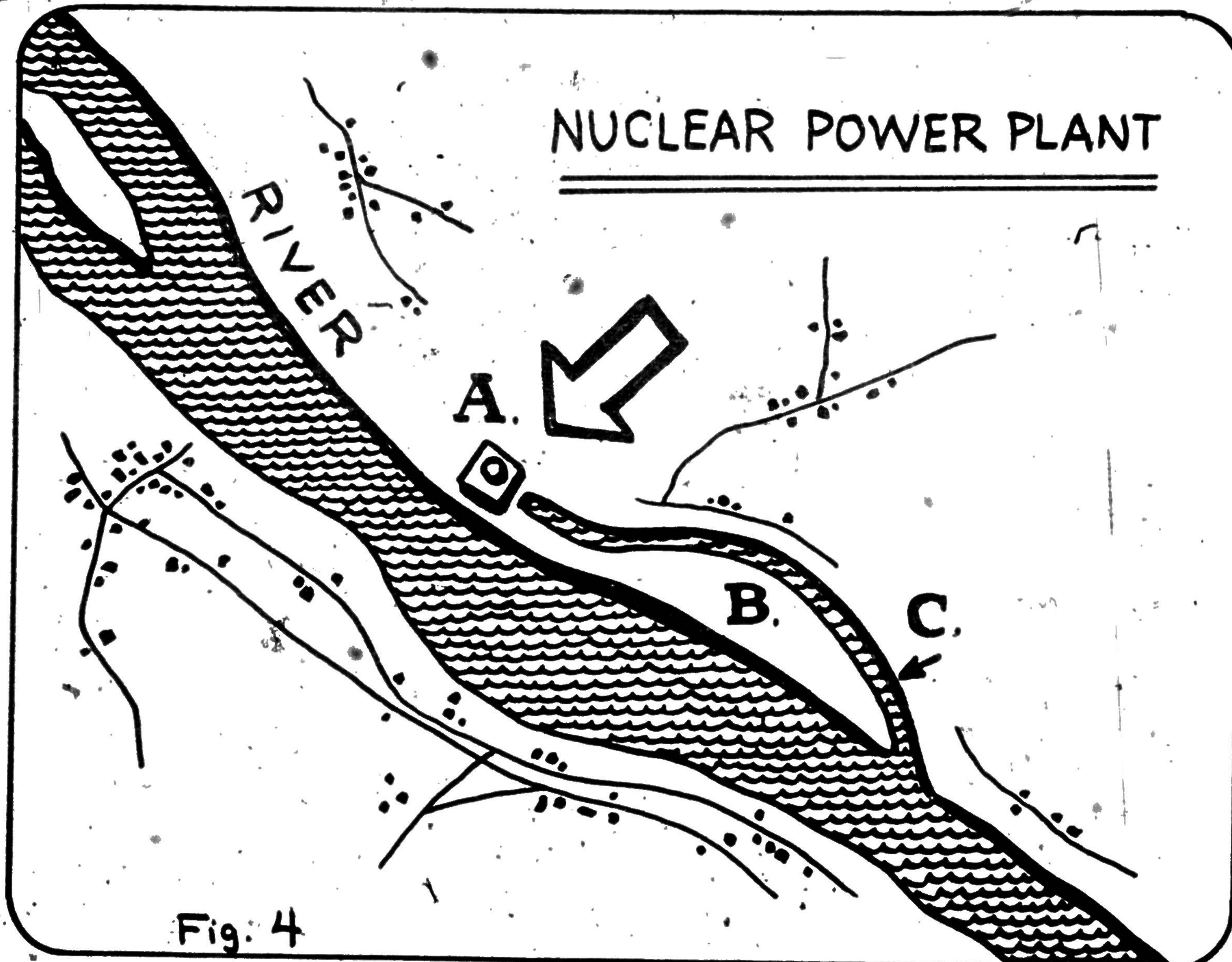
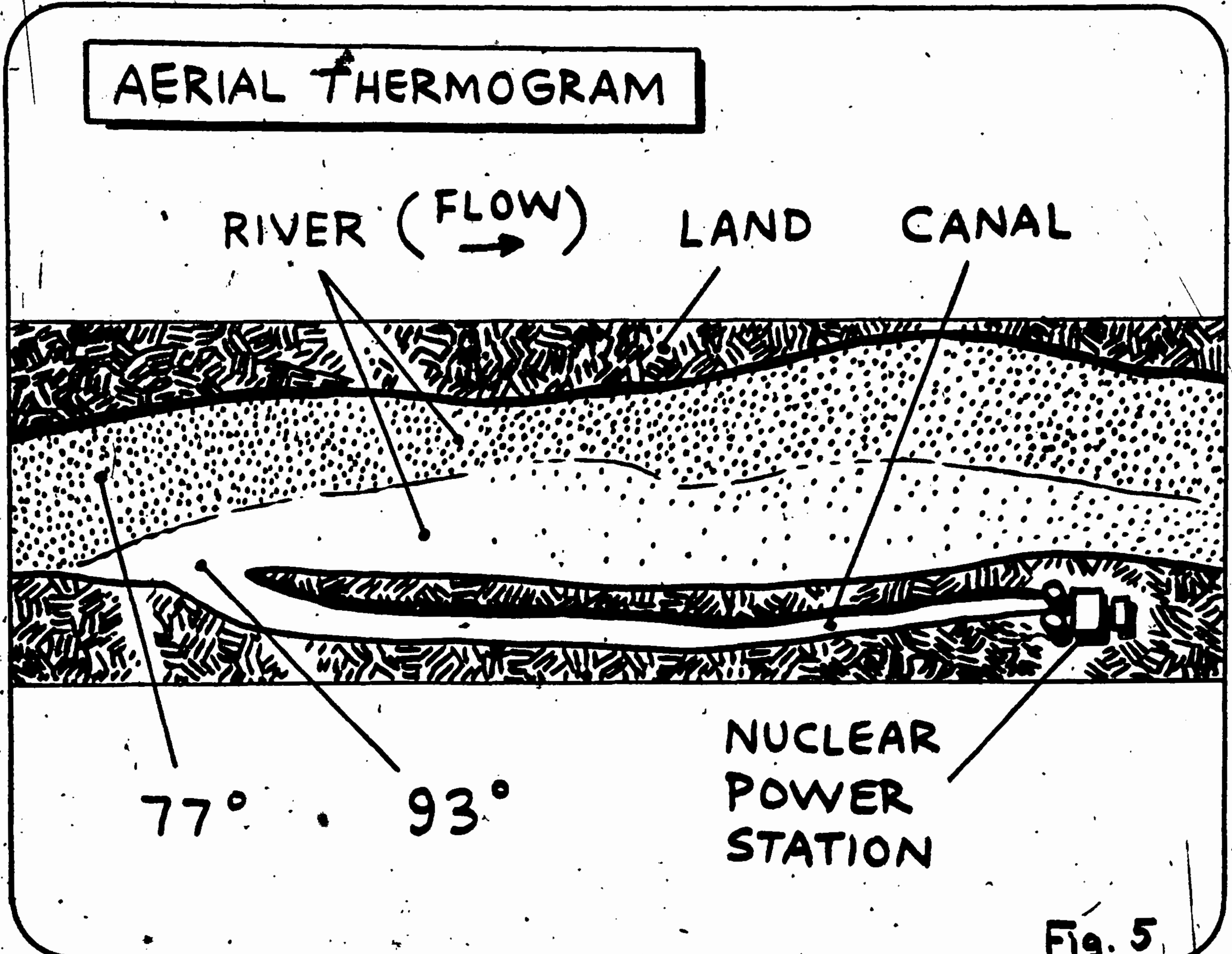
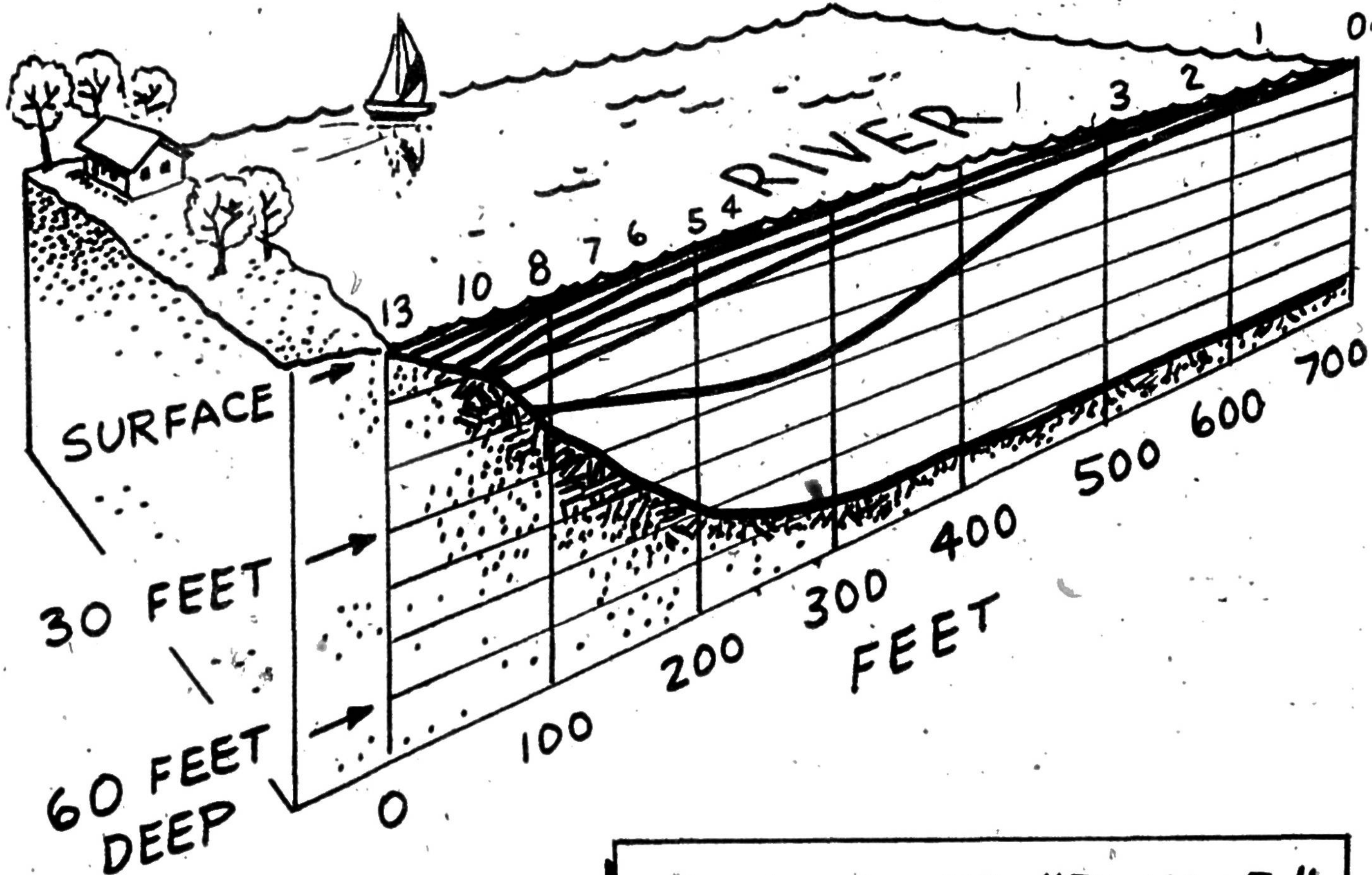


Fig. 4

V.B.2.d. (Mar. 4.22) p. 14



V.B.2.d. (Mar. 4.22) p. 15



HOT WATER "PLUME"

Fig. 6

V.A.2.d. (Mar. 4.22) p. 16

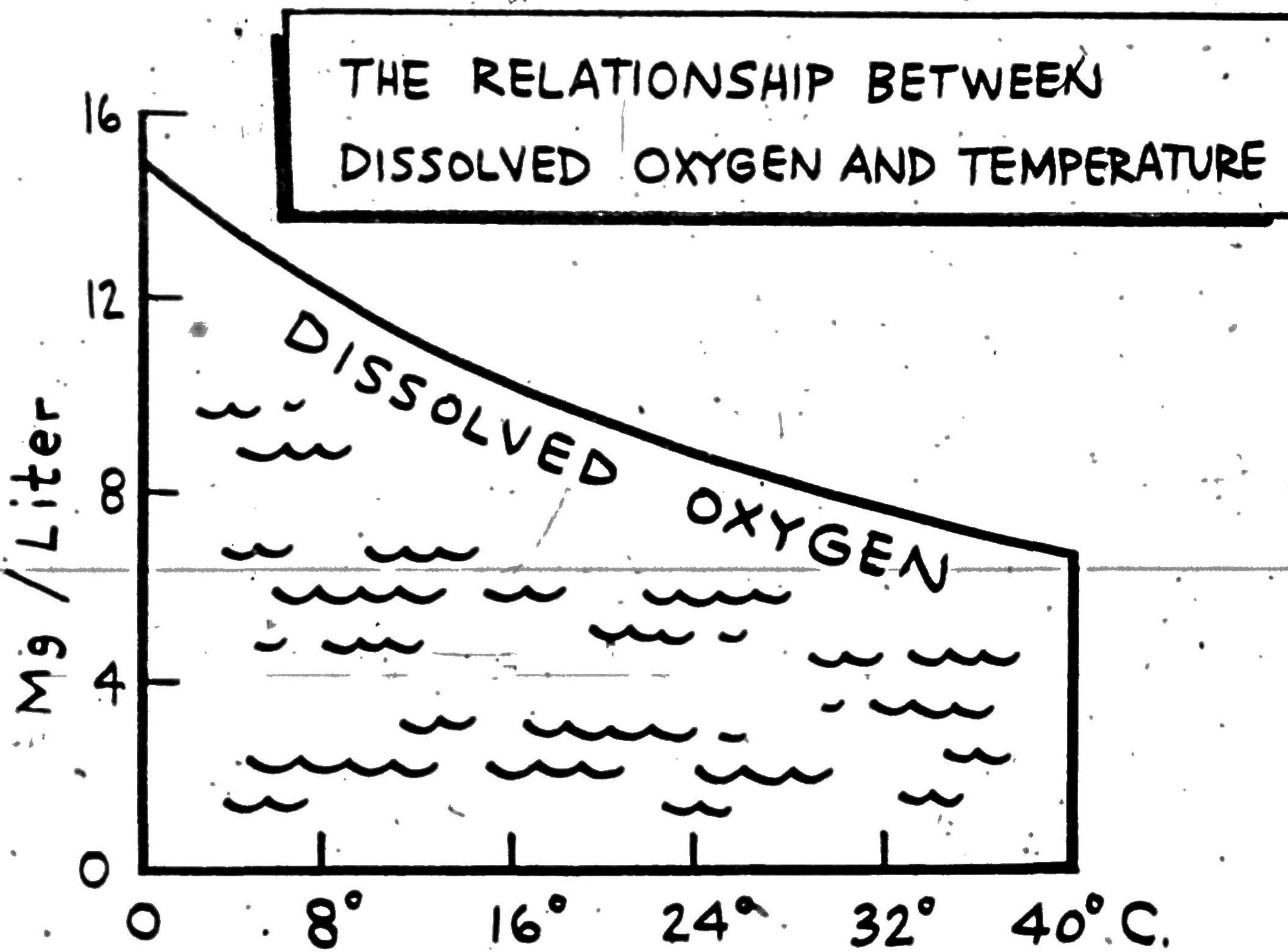


Fig. 7

V.B.2.d. (Mar. 4.22) p. 17

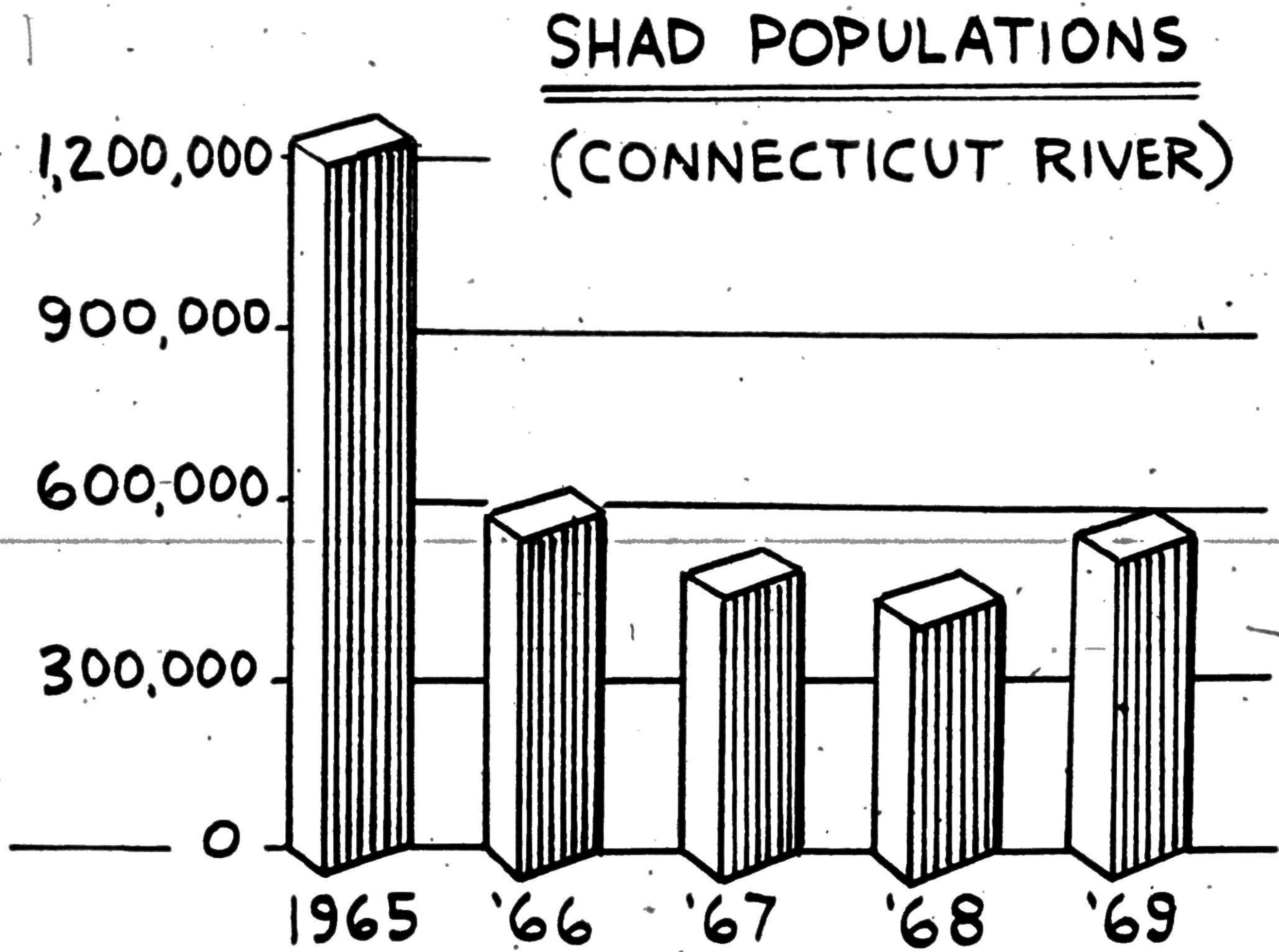

SHAD POPULATIONS
(CONNECTICUT RIVER)
1,200,000
900,000
600,000
300,000
0
1965
'66
'67
'68
'69

Fig. 8

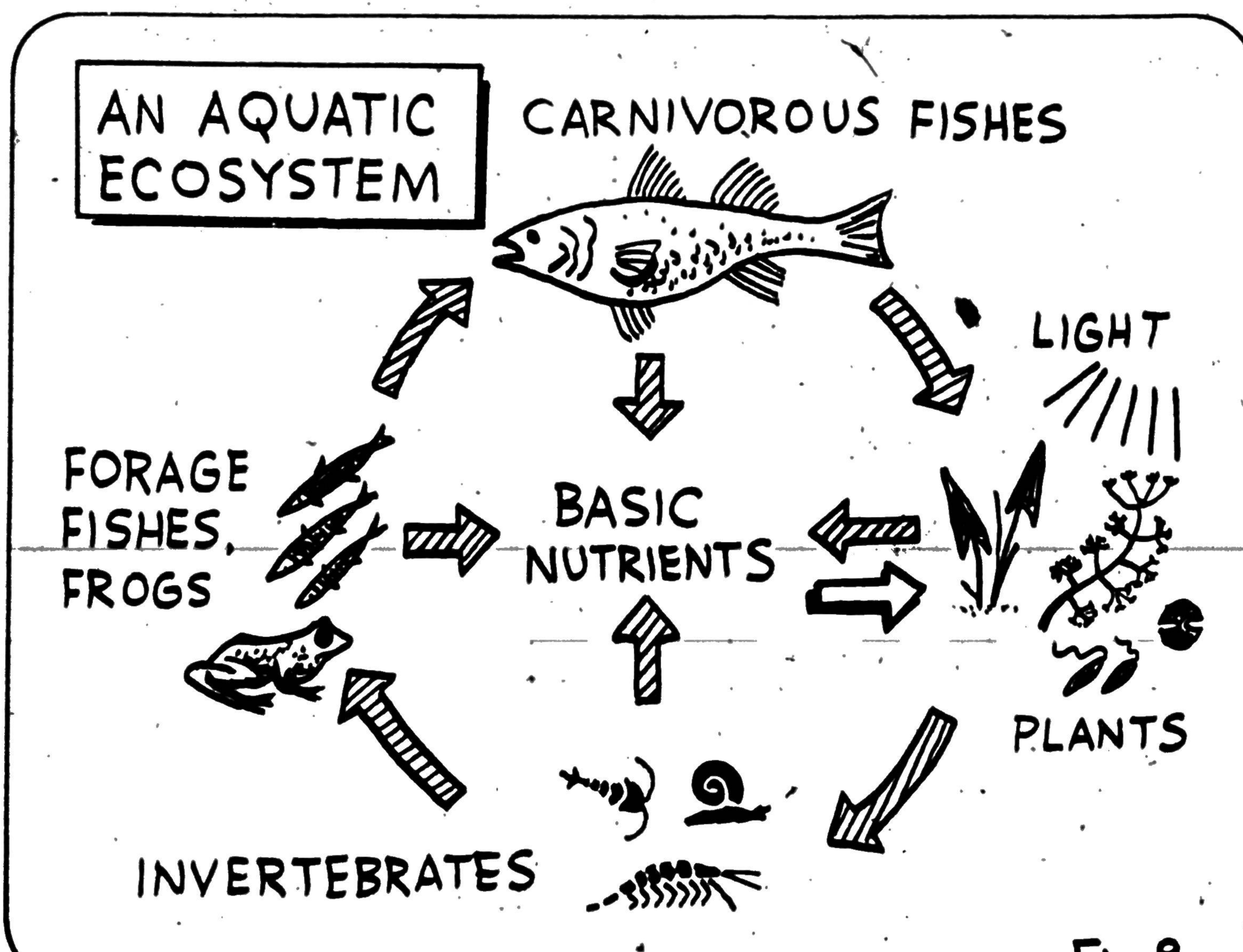

AN AQUATIC ECOSYSTEM
CARNIVOROUS FISHES
LIGHT
FORAGE FISHES, FROGS
BASIC NUTRIENTS
PLANTS
INVERTEBRATES

Fig. 9

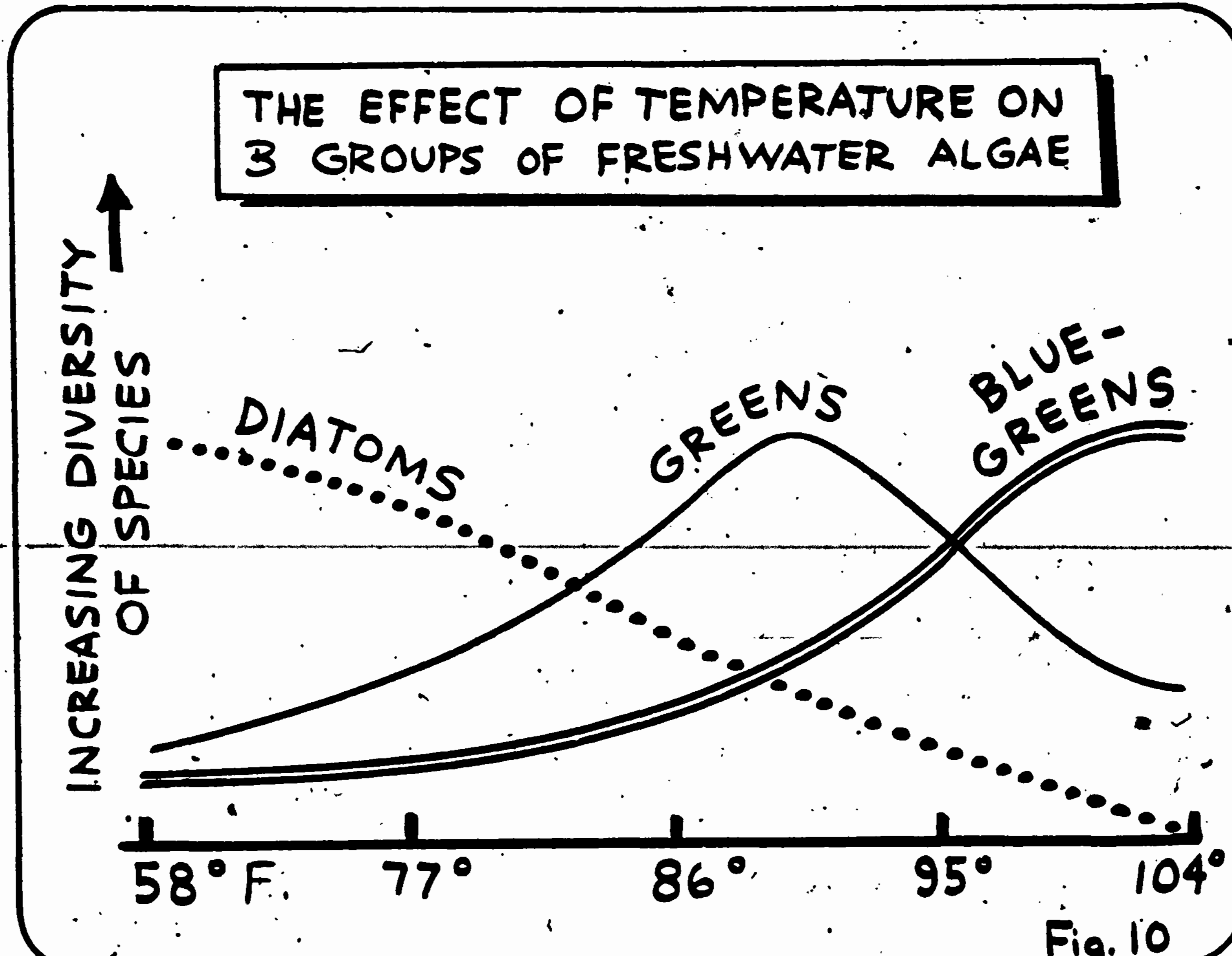


Fig. 10

V.B.2.d. (Mar. 4.22) p. 20

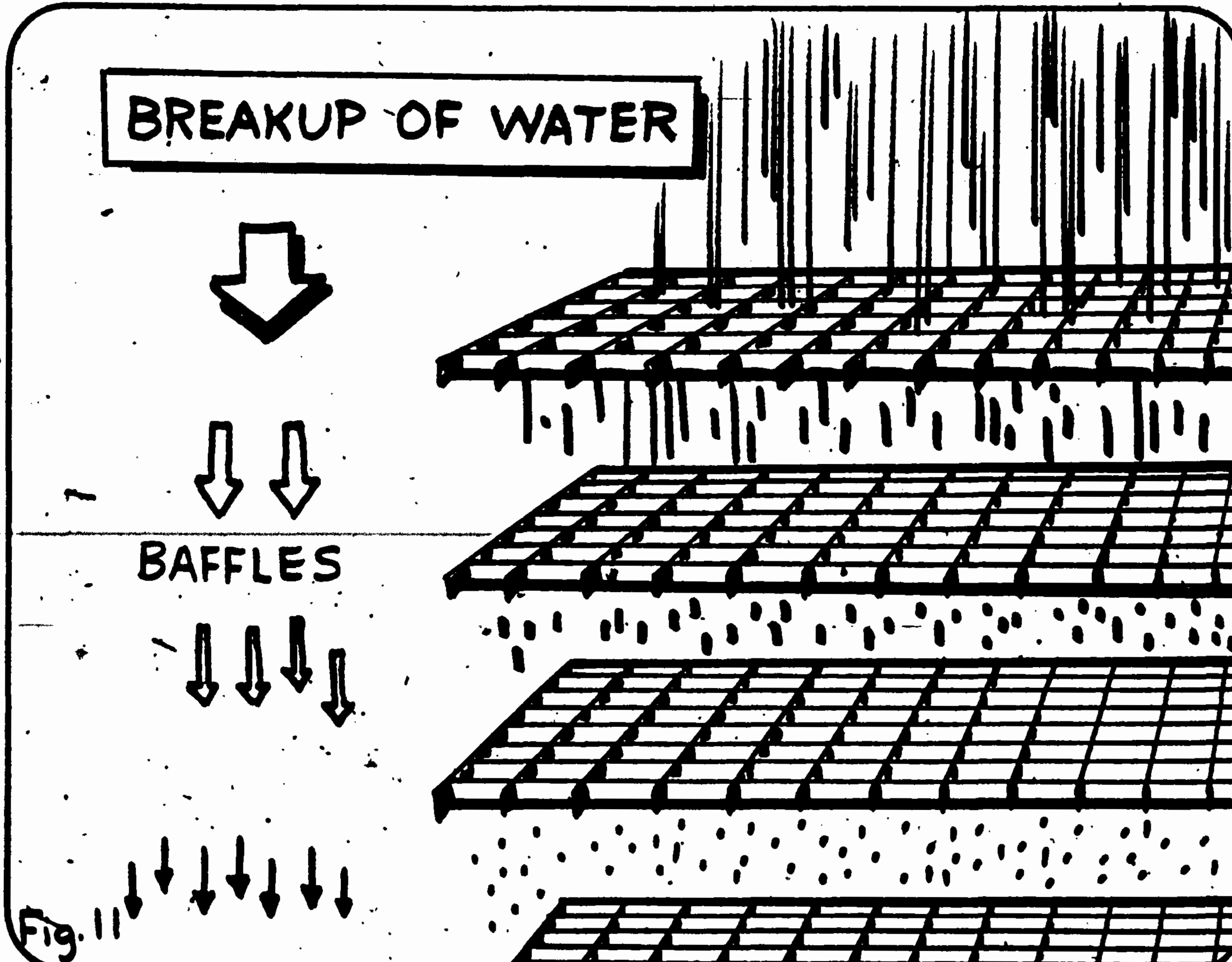


Fig. 11

V.R.2.d. (Mar. 4.22) p.21

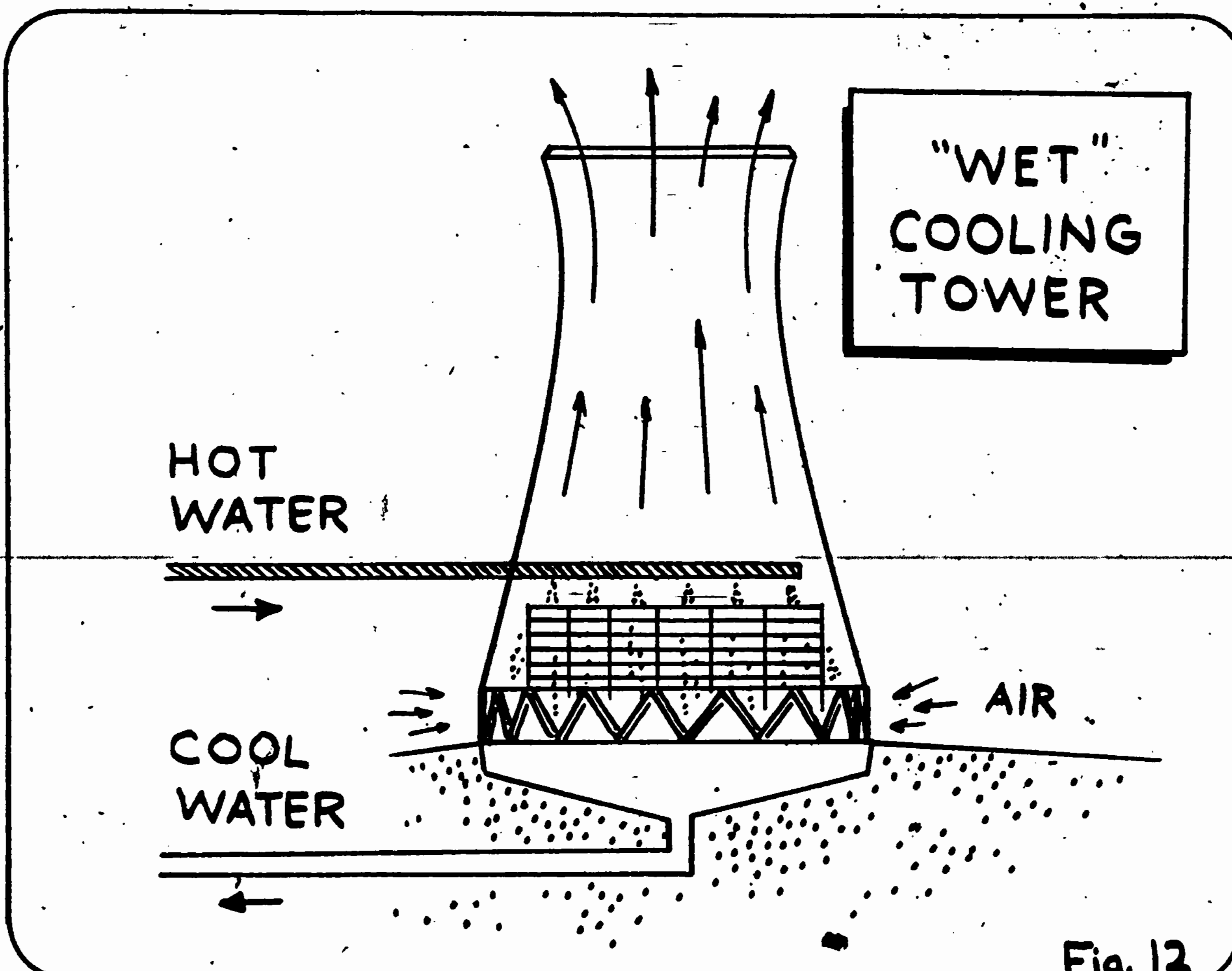


Fig. 12

V.R.2.d. (Mar. 4.22) p. 22

WET TOWER - INTERNAL STRUCTURE

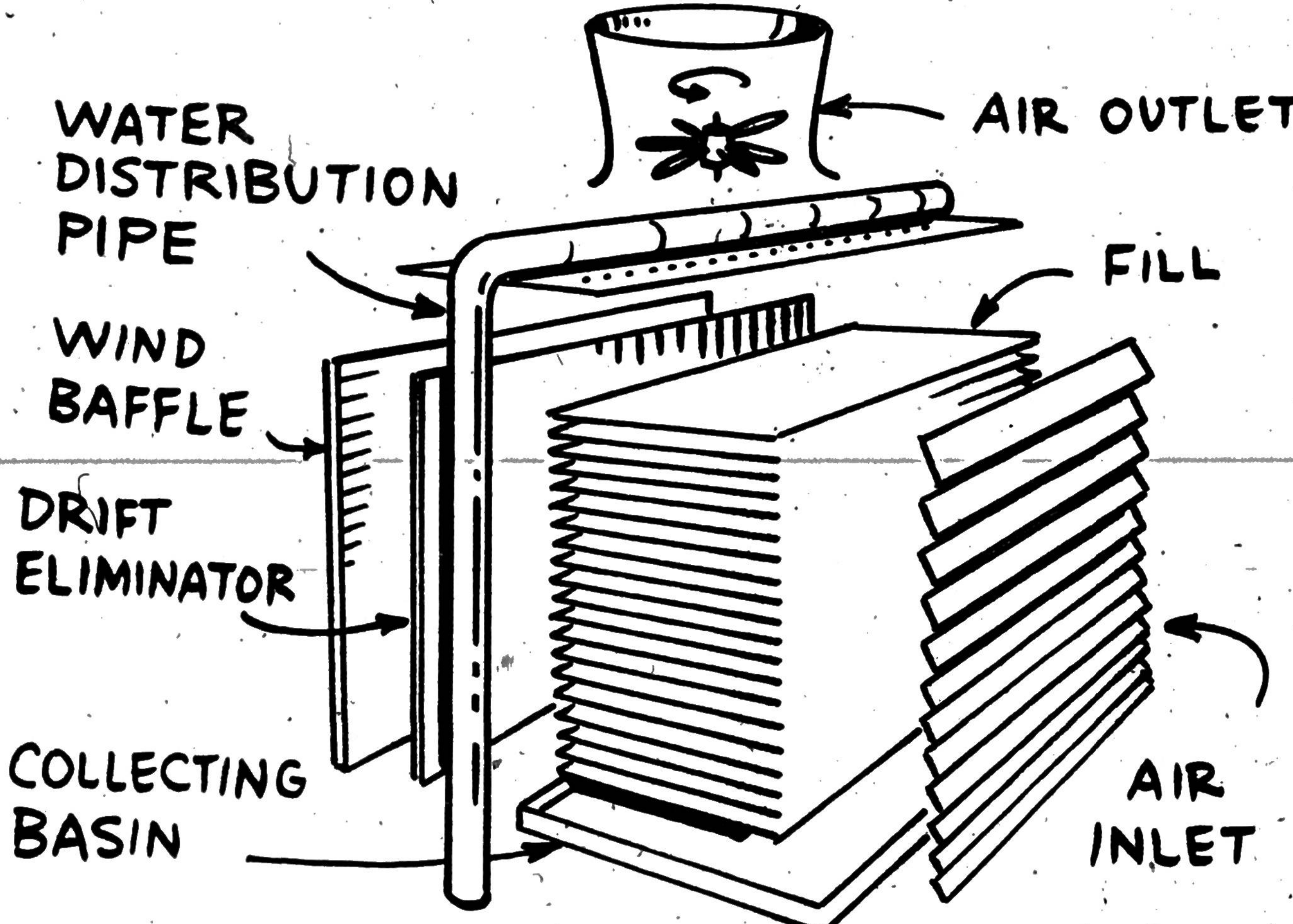


Fig. 13

V.R.2.d. (Mar. 4.22) p. 23

WET TOWER - EXTERNAL STRUCTURE

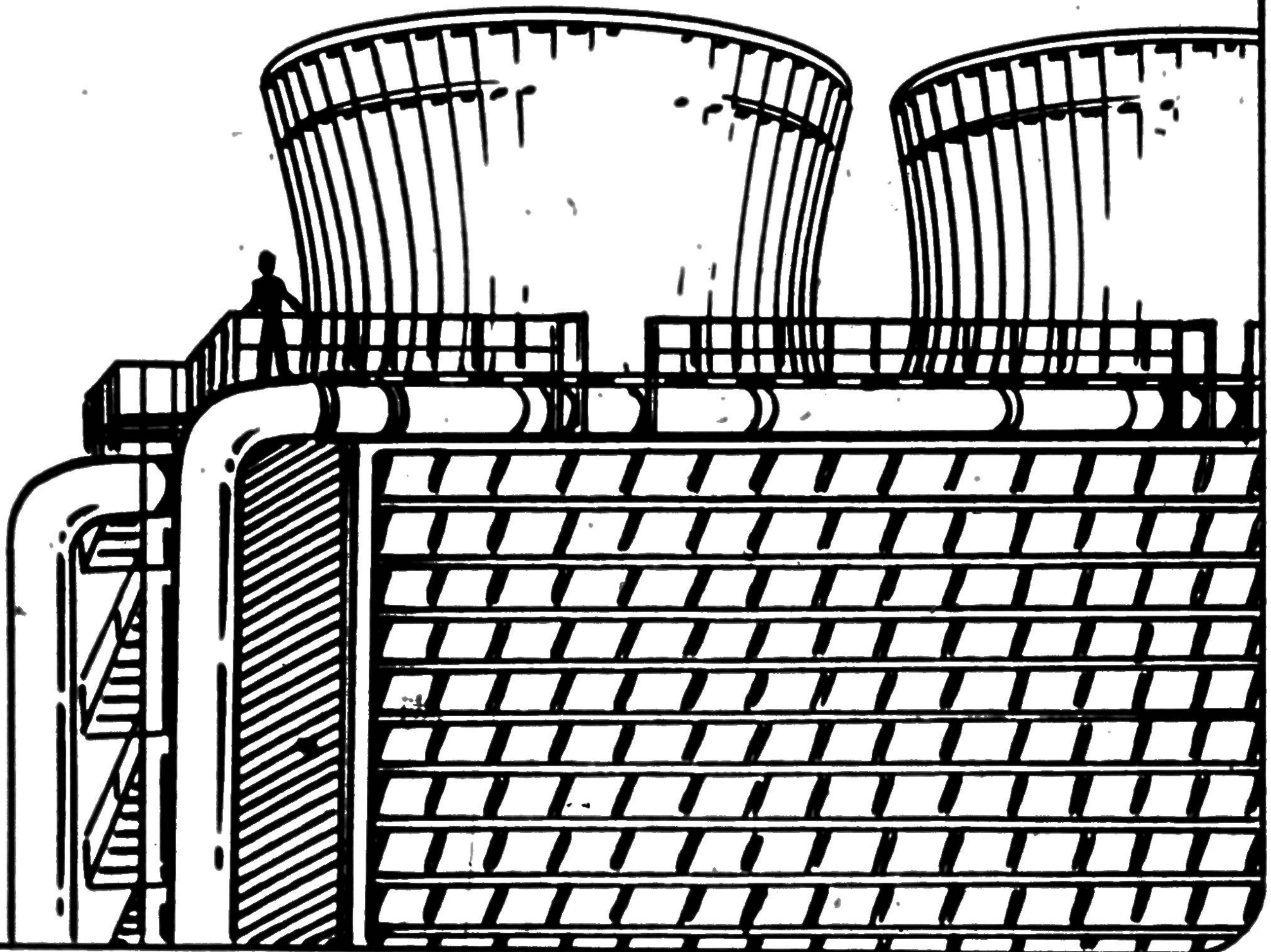


Fig. 14

V.R.2.d. (Mar. 4.77) p. 24

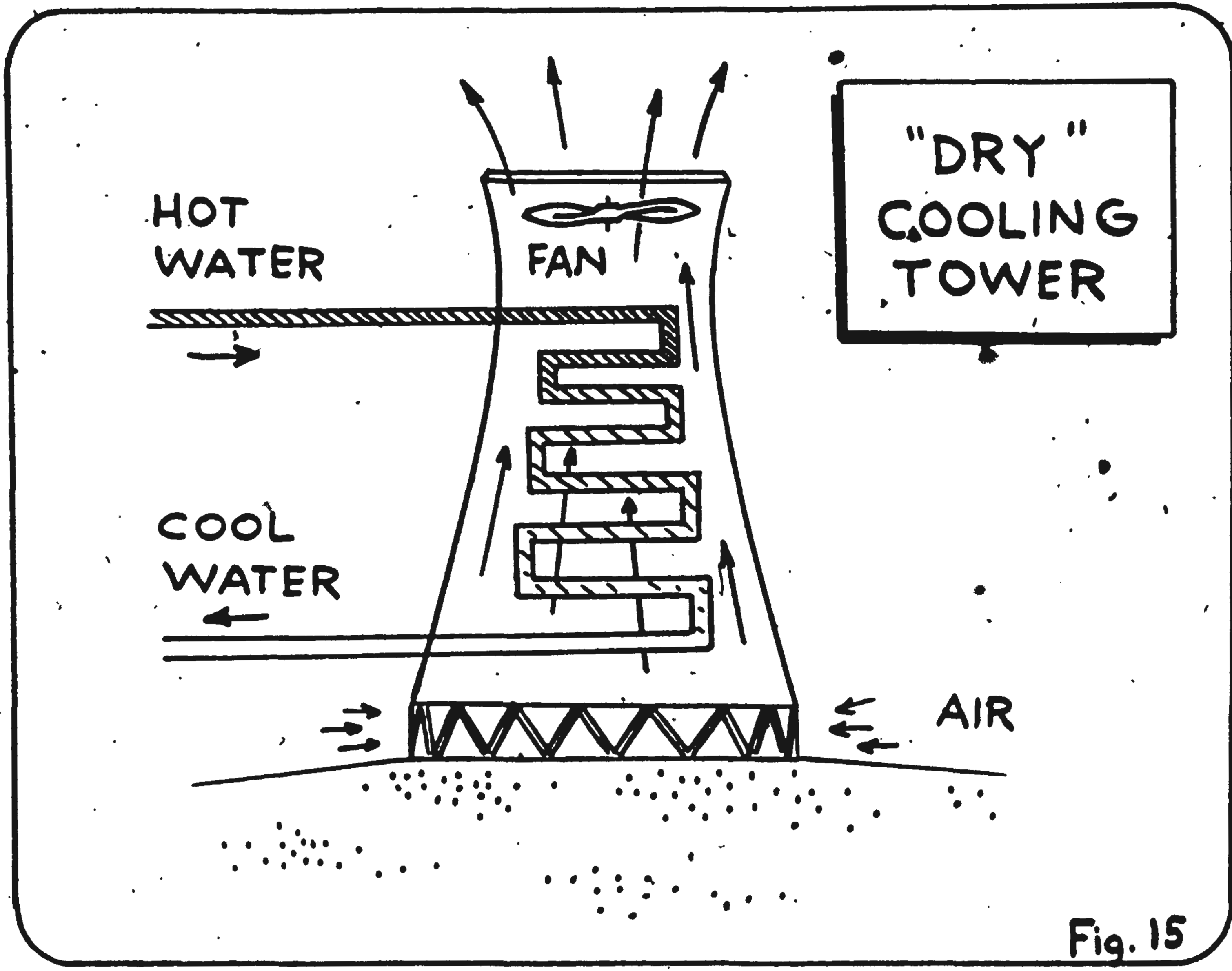


Fig. 15

V.R.2.d. (Par. 4.22) p. 25

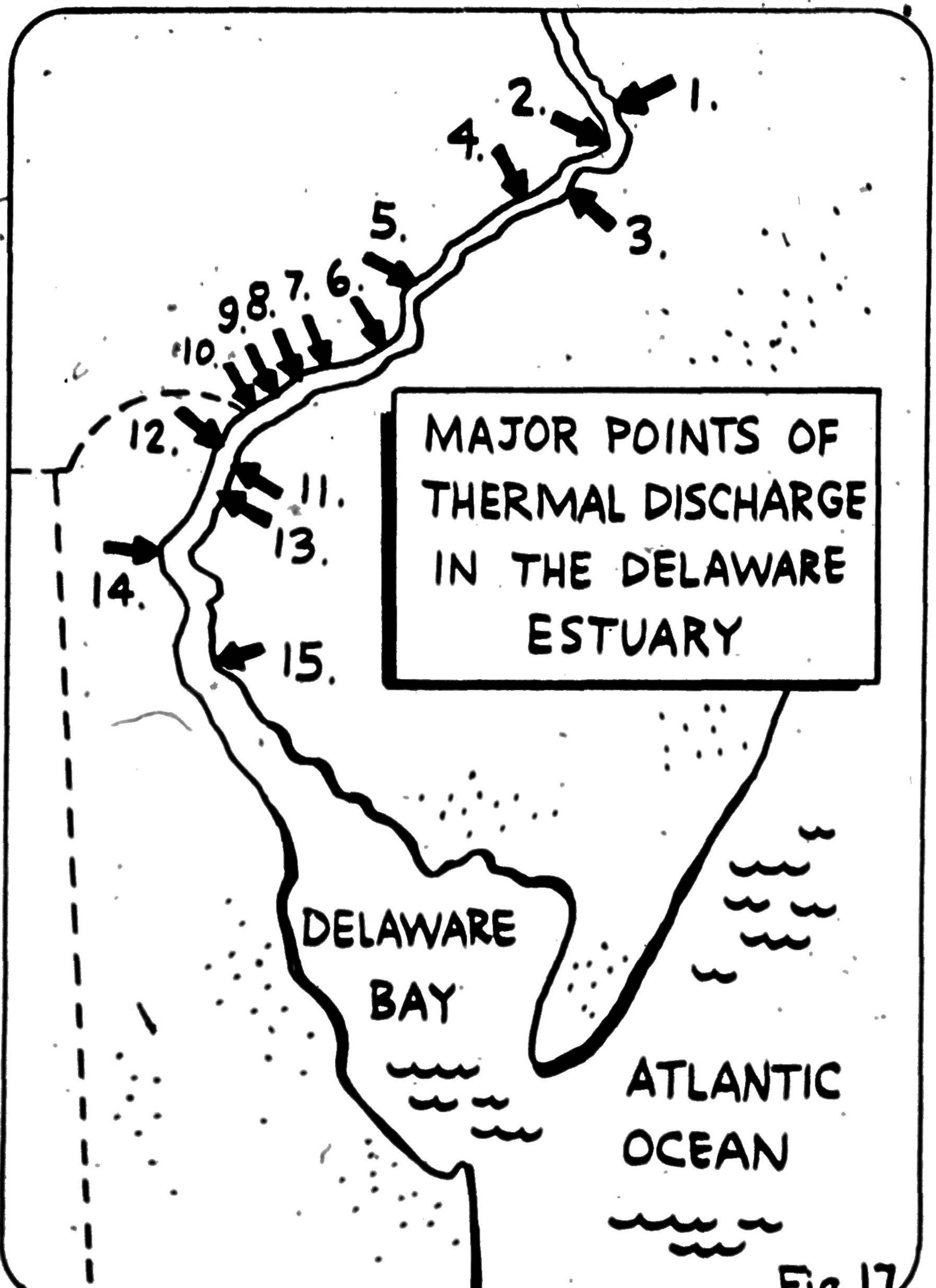
COST OF COOLING SYSTEMS

800,000 KW NUCLEAR
1970 $

	OCEAN WATER	RIVER	LAKE	WET TOWER (MECH. DRAFT)	WET TOWER (NAT. DRAFT)	DRY TOWER (MECH. DRAFT)	DRY TOWER (NAT. DRAFT)
CONDENSER:	2.4	2.6	2.3	2.8	2.8	1.7	1.7
TOWERS:	-	-	-	2.6	7.1	19.3	45.0
PUMPS, ETC:	4.8	4.8	7.3	4.0	4.1	3.4	3.4
TOTAL:	7.2	7.4	9.6	9.4	14.0	24.4	50.1

(IN MILLIONS $)

Fig. 16


1.
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15.
MAJOR POINTS OF THERMAL DISCHARGE IN THE DELAWARE ESTUARY
DELAWARE BAY
ATLANTIC OCEAN

Fig. 17