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Nuclear Power on Cayuga Lake

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NUCLEAR POWER ON CAYUGA LAKE*

*By Alfred W. Eipper***

Controversy over threats to Cayuga Lake, New York, from a proposed electric power plant has aroused national interest. This attests to the concern over the increasing seriousness and difficulty of allocating fixed water resources among demands that are proliferating, both in kind and in quantity. Escalating population and competition for resources are forcing us to a new awareness of concepts like sharing, compromise, and multiple use. The Cayuga Lake case is a prime example of the ecological problems involved in a nuclear power plant proposal, and the complex of scientific, social, and political questions closely associated with them. It demonstrates the variety of interests and attitudes that are involved in today's natural resource controversies, and some of the impediments to framing legislation that would promote equitable solutions. The complex decisions about uses of a natural resource must be public decisions in the truest political sense, and can no longer be made exclusively by any one special-interest group, be it a citizens' committee, a regulatory agency, or a "public" utility.

Demands on natural resources are increasing much faster than the population. In the case of water, per capita use in the United States, excluding transportation and recreation uses, appears to be doubling every 40 years.[1] This means that in the 50 years it will take our United States population to double, *total* water use will more than quadruple. According to the U.S. Department of the Interior, under existing use patterns, the total amount of water needed just to sustain the present U.S. population for the remainder of their lives is greater than all the water that has been used by all people who have occupied the earth to date.[2] And although we tend to think of water supplies as fixed, increasing amounts of water are being rendered unusable through various forms of pollution.

Steam electric stations pose some of the most crucial problems to future allocation of water resources in the United States. Electrical needs in this country are doubling every 10 years at present.[3] This is the result of population increase combined with rapid increases in per capita consumption of electricity. These needs will be met largely by construction of steam electric stations now that most sites suitable for hydroelectric generation have been utilized.

Generation of Electric Power

Steam electric stations operate by turning water into high-pressure steam to spin a turbine which drives an electric generator. In a fossil-fueled plant the combustion of coal, oil, or gas produces the heat that creates the steam. In a nuclear plant, the heat is derived from a self-sustaining nuclear fission chain reaction in the fuel (usually enriched uranium) of the reactor. In any steam electric plant the spent steam must be cooled immediately beyond the turbine to lower the back-pressure on it; the difference between the pressures on the two sides of the turbine is what makes the turbine spin. As the steam is cooled, it condenses to water, and the water is cycled back to the boiler. The spent steam is cooled in a condenser by coming in contact with pipes containing cold water (coolant). During this process the coolant is heated 10° to 30° F, depending on plant design.

All steam electric plants require large amounts of coolant water for the condensers. The colder this water is, the more efficient the plant's operation. There are basically three ways of obtaining cooling water for the plant: one is to take it from some natural body of water. The problem here is that returning the coolant to its water body source some 20° F warmer than when it left can produce various kinds of ecological upsets in the receiving water. To avoid such problems the warmed water can be cooled again before returning it to the river, lake, or estuary from which it was taken, using one of the cooling devices described in the next paragraph. A second source of condenser cooling water is a cooling pond—a small "lake" impounded for the purpose. Cooling water is withdrawn from the impoundment, and discharged directly back into it without cooling. Here cooling is achieved largely by evaporation from the pond surface, and about 1½ surface acres are required for each megawatt of electricity generated. A third source of condenser cooling water is a "closed circuit" system in which the coolant, after leaving the condensers, passes through a cooling device, thence back to the condenser, and so on, in a cycle analogous to the cooling system of an automobile engine.

Cooling devices are usually towerlike structures in which the water is spread out and cooled by radiation or evaporation. In "dry" towers the water is dispersed in pipes which are cooled by fans. Dry towers are the most expensive to operate, but water loss is negligible. In evaporative cooling towers the water trickles down through series of baffles and cools by evaporation. Natural draft evaporative towers rely on air convection produced by their lamp-chimney shape, and may be 200 to 400 feet high. They are expensive to build but relatively inexpensive to operate. In mechanical (induced) draft evaporative towers, air is forced up through the baffles by fans. These "towers" are typically very low and arranged in series. They are much less conspicuous and are cheaper to build than natural draft towers, but more expensive to operate. An exceptionally lucid and detailed description of steam electric stations and cooling methods is given by Tor Kolflat.[4] Zeller *et al.* have surveyed environmental effects of cooling facilities.[5]

Roughly two-thirds of a steam electric station's total energy output is in the form of waste heat. Because nuclear-fueled plants must be large to be economically efficient and because no appreciable amount of their waste heat is dissipated to the atmosphere (in contrast to a fossil-fueled plant), nuclear plants pose more serious thermal pollution problems for water bodies. Furthermore, nuclear plants produce more waste heat per kilowatt-hour of electricity generated because, for safety reasons, they are required to operate at lower steam pressures and temperatures than fossil-fueled plants, and this lowers the nuclear plant's efficiency.[6]

Nuclear power plants have certain definite advantages. They do not pollute the atmosphere with particulate matter or oxides of sulfur and nitrogen, as do plants using fossil fuels such as natural gas, coal, and oil. Because they operate for months without refueling, they are especially useful in areas where fossil fuel would have to be transported great distances to the plant. They *may* also provide more economical production than fossil fuel plants. On the other hand, nuclear power plants routinely release small amounts of radionuclides to the water and to the atmosphere.

Although nuclear power accounted for less than 1 percent of the nation's total electrical output in 1967, it is expected to provide over half our total capacity by the year 2000, at which time the total cooling water requirements of the United States' steam electric industry are expected to approximate one-third of the country's entire yearly supply of runoff water.[7]

Cayuga Lake

Cayuga and several similar Finger Lakes nearby are quite unusual among lakes of the United States. Exceptionally long, narrow, and deep, they were formed during the Pleistocene when glacial scouring straightened and deepened a preexisting group of adjacent valleys in soft shale. Cayuga is 38 miles long, has a mean width of 1.7 miles, and a surface area of about 66 square miles.[8] It has a maximum depth of 435 feet, a mean depth of 179 feet, and a volume of 331 billion cubic feet. The mean flushing time (average length of time required for a drop of water to move all the way through the lake) is 9 years or more.

During summer months the lake is thermally stratified: the upper layer (epilimnion) and lower layer (hypolimnion) differ so much in temperature—and hence in density—that they do not mix, even under the influence of strong winds. During the period of stratification (May to November) temperatures in the epilimnion range from 50° to 73° F; temperatures in the hypolimnion range from 40° to 43° F, just above the temperature at which water reaches its maximum density (about 39° F). The epilimnion layer becomes thicker as summer progresses, usually extending to depths of 35 to 50 feet below the surface. In autumn this layer begins to cool and consequently to increase in density. This process continues until late October or November, when density of the water in the epilimnion has increased to a point where it is near enough that of the hypolimnion so that the next strong wind causes the two layers to mix. The lake then becomes essentially the same temperature throughout and remains so (generally without ice cover) until May, when warming and density reduction of the surface layer reach a point where stratification is reestablished.

During the period of stratification, biological production, particularly of single-celled algae, is largely confined to the epilimnion, where light is available in combination with nutrients and warmer temperatures. Dead plant cells and planktonic animals sink to the hypolimnion. While stratification persists, there is no source of additional oxygen for the hypolimnion. Animals confined to the hypolimnion—such as lake trout (a major resource in Cayuga)—use the oxygen there in respiration, and additional oxygen is consumed by bacterial decay of the dead plant and animal matter continually sifting down from above. Thus oxygen in the hypolimnion decreases throughout the summer until that time in the fall when the epilimnion cools to a point at which winds can mix the entire lake again, and rejuvenate oxygen supplies in the deeper water.

Most lakes gradually become more fertile with the passage of time by a process known as eutrophication. Nutrients, including nitrogen and phosphorus in various forms, are continually being added from the surrounding watershed. As the concentration of nutrients increases, so does biological production. Also, as a lake becomes greener from the proliferation of single-celled algae, it absorbs more solar radiation and reflects less. This creates higher temperatures, and added heat speeds biological production. Thus biological production, tends to be self-accelerating.

Lakes vary in their rates of aging, depending on nutrient load, temperature, area, and depth. The activities of man, moreover, can speed eutrophication considerably. Lake Erie is one of the most recent and extreme examples of the acceleration of natural eutrophication with all its attendant problems. Greater use of the Cayuga Lake watershed for housing, industry, and agriculture will continue to increase the influx of nutrients and to advance eutrophication. Heating the water will hasten these changes and possibly produce some others.

The Utility Company Plan

In the summer of 1967 New York State Electric and Gas Corporation (NYSEG), a private utility with some half million customers in the south-central area of the state, announced plans to construct an 830-megawatt nuclear-fueled steam electric station next to the 290-megawatt coal-fired plant (Milliken Station) they had been operating on the lake for about 10 years. The new installation was to be named Bell Station. Clearing and excavation of the site, 12 miles northwest of Ithaca (and Cornell University), was scheduled to begin in April 1968, and the plant was expected to begin operating in mid-1973.

In October of 1967 several Cornell staff members and one representative of the State Conservation Department were invited to an informal meeting by several officials of the utility and a representative of the construction engineering firm that was to build the plant. At this meeting the utility company's representatives briefly described to us their needs and plans for developing the site, and solicited comments. The State Conservation Department representative discussed the possibility that by using some of the warm water from the plant, it might be possible to operate a large fish hatchery for coho salmon on the lake, and utility personnel replied that such a program might have great public relations benefits for the company. Cornell staff members asked the company representatives what possible ill-effects the new power plant's operation might have on the lake ecosystem as a whole, and were told that the company had retained a biological consultant to study some of those aspects, and hoped to engage additional consultants from the Cornell staff. Apparently the company was at this time working to compile data for its voluminous Bell Station Preliminary Safety Analysis Report (1968), an Atomic Energy Commission prerequisite to filing for an AEC construction permit. At this meeting it was also suggested to the company that, before actual work on the site was started, it would be desirable to hold public hearings or the equivalent to settle any possible differences or misunderstandings in advance.

In February 1968 the Cornell Water Resources Center held a meeting for all interested University staff members at which NYSEG officials and consultants made an elaborate presentation of their plans for Bell Station. They described the company's need for more electrical power, and the desirability of locating the plant adjacent to the present Milliken Station. Advantages included a centralized location in the company's power grid, capability of using already owned transmission facilities and rights-of-way, and an abundant year-round supply of cold water. In the company plan, 45° F cooling water would be obtained from a depth of about 100 feet, warmed 20 to 25 degrees in the nuclear plant's condensers, and returned to the surface waters at a rate of 1100 cubic feet per second (500,000 gallons per minute), year-round. About one-tenth of the lake's total volume would thus be "processed" each year. Heat from the plant would add approximately 6 billion Btu per hour to the water, over and above the reported 1.3 billion Btu per hour heat rejection from Milliken.

The water that cools a power plant by passing through its densers will obviously get heated up. It is a quite straightforward matter to estimate the amount that the water is heated, given three things: (1) the capacity of the power plant (usually stated in megawatts), (2) the thermal efficiency of the power plant (the ratio of the electric power output to the total power input), and (3) the rate at which cooling water passes through the condensers (usually stated in cubic feet per second). We shall do this calculation for the proposed Bell Station nuclear power plant. A capacity of 830 megawatts and a rate of flow of cooling water of 1100 cubic feet per second are planned. The thermal efficiency of nuclear power plants being built at this time is typically 32 percent; thus only 32 percent of the total energy becomes electrical energy and 68 percent becomes heat.

Almost all the heat goes into the water passing through the condensers. Hence, at Bell Station, while the water flows by at 1100 cubic feet per second, it will be heated at a rate of $(68/32) \times 830 = 1780$ megawatts. The production of one megawatt of power for one second is identical to the production of 947 Btu of energy, so $1780 \times 947 = 1{,}680{,}000$ Btu of energy are put into 1100 cubic feet of water every second. Finally, since 1 Btu is defined as that amount of heat that will raise the temperature of one pound of water by 1° F, and 1 cubic foot of water weighs 62.4 pounds, the water will be heated $1{,}680{,}000/(62.4 \times 1100) = 25°$ F while passing through the condenser.

The calculation is almost identical for a fossil fuel plant, except that (1) typical efficiencies are higher, generally about 40 percent and (2) about one-fourth of the heat escapes through the stacks in the form of hot gases, instead of going out through the condensers.

One of the loose statements that one sees these days is that such and such a river or lake will be heated, say, 25° F by a proposed power plant. What is meant, of course, is that the water is being heated 25° F *in the condensers.* The amount of heat being added to the body of water, rather than the amount the water heated in the condensers, is the crucial quantity for most considerations, since, for example, by doubling the rate at which water is passed through the condensers, the same power plant will heat the condenser water only half as much, while heating the lake or river almost exactly as before. However, if you were a limnologist trying to keep the nutrients in the hypolimnion from being transferred to the biologically productive epilimnion, or a fishery biologist trying to keep the number of small aquatic organisms entering the condensers to a minimum, you would prefer the smaller condenser, which transfers less water (and fewer organisms) from the bottom to the top of the lake. On the other hand, the greater temperature change will be more devastating to those aquatic organisms which *are* transported through the condensers. Moreover, the smaller the condensers, the higher the *average* temperature of the coolant while passing through the condensers. With a higher temperature coolant the plant will operate at a lower efficiency, and more heat will be put into the lake for each megawatt of electric power.

A number of people at this meeting raised questions about possible ill-effects on the lake's ecology from the operation proposed by the utility. Although discharging water to the lake surface at 60° to 75° F might seem harmless, in fact, adding the predicted amount of heat could reasonably be expected to produce changes in any aquatic ecosystem, and there was good reason to expect that some if not all such changes would be deleterious (these changes will be discussed later). Not surprisingly there was a wide divergence of opinion between the questioners and the utility personnel regarding what sorts of possible changes constituted harmful changes. When company officials were asked what attention they had given to use of available technology for cooling the condenser water before returning it to the lake, it was obvious—from the amount of "fielding" which that particular query received within the company team present—that the matter had received little if any serious consideration. This meeting left many of us unsatisfied. It served a very useful purpose in raising and defining questions about possible effects of the proposed operation on the lake. But the utility's answers to some of these questions, and nonanswers to others, were distinctly disquieting.

Scientists' Concerns Take Shape

By March 1968 we had learned that in additon to studies by its private consultant, NYSEG was planning to delegate investigations of the lake to independent research organizations. One of these was a heat budget study to be conducted by engineers of Cornell Aeronautical Laboratory at Buffalo, New York. The other was a study of the ecology of Cayuga Lake to be conducted independently by certain biologists and limnologists (fresh water ecologists) at Cornell appointed by—and solely responsible to—the Cornell Water Resources Center. Several of these were scientists who had previously conducted research on the lake.

In the weeks following the utility "briefing" for the Cornell community, the nagging questions left unanswered at that meeting intensified and proliferated among some two dozen of us who had been present. More unsettling still were the growing indications that these questions were to be left in limbo, with most of the action at Cornell being directed toward development of the Water Resources Center's research program for the lake. By this time a few of the more detached scientists were even referring to the desirability of studying ecological effects of one or more large power plants on Cayuga Lake, and using its adjacent "twin," Seneca Lake, as a control.

By March 1968 increasing numbers of us were articulating our unanswered questions about the power plant's effects on the lake in the form of letters to local editors and legislators, the utility was preparing to break ground for Bell Station (as planned), and it appeared unmistakably clear that a unilateral industrial decision about use of a needed resource was beginning to be implemented.

In reaction to this, about 20 of us met in early April to discuss the possibility of collaborating on a position paper delineating our questions about Bell Station's effects on Cayuga Lake and available technology for avoiding these threats. We felt impelled to give concrete expression to our conviction that natural resource decisions of this sort must have input from more than one special-interest group. We hoped that publication of a position paper might provide the focal point or catalyst needed by those in the area who were unsatisfied with the narrow course being followed in the lake issue but did not know how to modify it. After three successive drafts, each one of which was worked on by nearly all of the 21 coauthors involved, we submitted a review draft of the paper to officials of some state and federal regulatory agencies, the University, and NYSEG. All reactions were favorable except (not surprisingly) those of the utility. Company officials, it appeared, were particularly concerned that 4 of the 21 authors were men also involved in the Water Resources Center's research project that NYSEG was funding. Presumably the company took the position that it would give too much the appearance of conflict of interest for a scientist to appear as an author of our position paper and later of a research report for the utility. At any rate, the 4 authors in question withdrew their names, and we went to press with 17 remaining. Eight fields were represented by these authors: limnology—3, fishery biology —6, aquatic botany—2, natural resources—2, and 1 each from aquatic microbiology, water resources engineering, electrical engineering, and geology. We obtained a loan from the Environmental Defense Fund to pay for the printing of 5,000 copies of our position paper and by June 1968 had mailed copies to a list of several hundred individuals and organizations who we hoped might be interested in the issue and/or influential in disseminating the paper or its thoughts more widely. By the end of the summer we had received enough voluntary contributions to repay the Environmental Defense Fund, and our supply of the paper was nearly exhausted.

The position paper described Cayuga Lake and drew attention to limnological data, gathered periodically since 1928, which suggested that Cayuga Lake was becoming measurably more eutrophic, particularly in recent years. The paper discussed NYSEG's proposed operation on Cayuga Lake:

> The total volume of water withdrawn from the hypolimnion during a 6-month period of summer stratification would be 18.5 billion cubic feet, or roughly 10 percent of its average volume during the May-October period.
>
> Every 24 hours, year-round, 100 million cubic feet of heated water (65–70°F) would be added to the epilimnion. Spread uniformly over the entire lake, this would be an addition of about one-half inch per day to its 66-square-mile surface.
>
> The large, continuous addition of heated water throughout the stratification period would increase the epilimnion's normal October volume some 20 percent.

The paper stressed certain effects of the power plant operation on the lake—effects which were entirely predictable from company data and limnological data available now, although the precise magnitude of these effects was less predictable.

> 1. The onset of thermal stratification will occur earlier in the spring and, because volume of the epilimnion will be increased during the course of the summer, stratification will extend longer into the fall.
>
> 2. The length of the growing season for plants and animals in the upper layer will, therefore, be extended.

3. Water brought up from the lower layer and flushed into the surface where most biological production (growth and reproduction of plants and animals) takes place, will contain nutrients previously unavailable to plants in the lighted portion of the upper layer.

4. A longer growing season and more nutrients in the surface layer of the lake will result in greater capacity for biological production.

5. Prolonged stratification will extend the period of oxygen depletion in the large underlying layer of cooler water, where trout live, during the summer. Thus oxygen levels will become lower than they do at present, before being replenished by the delayed fall mixing of the upper and lower layers.

The position paper then described the applicable state and federal permit-granting procedures, and the different sorts of cooling systems available and in use, noting that operation of the power plant on the lake, but with appropriate cooling technology, represented a reasonable and very inexpensive compromise.[9] Our report concluded:

> Our society has often indicated its ability and willingness to pay for maintaining environmental quality, therefore a negligible power cost increase to meet the higher construction and operation expenses of closed-circuit cooling should be acceptable. The momentum of public opinion increasingly obliges those individuals or firms who are polluting our air, water, and land to include as part of their operating cost satisfactory solutions to their waste disposal problems. This should be the case with thermal pollution of Cayuga Lake at Bell Station.
>
> In summary, the proposed plant threatens a great many of Cayuga Lake's primary values. We believe no utility company or other single-interest group has any right to impose such a threat to a resource so valuable to so many.

During the summer of 1968 Professor Clarence Carlson, a fishery biologist at Cornell with training and experience in aquatic radioecology, became increasingly aware of the possible dangers from the small quantities of radionuclides that could (within AEC permissible limits) be discharged from Bell Station into Cayuga Lake and then concentrated because, among other reasons, of the lake's slow flushing characteristics (approximately as much water would go through the plant in a year as goes through the lake in the same period). Thus the equilibrium concentrations of radionuclides that would be attained in the lake could be considerably higher than the concentrations of those radionuclides in the water entering the lake from the plant at the beginning of plant operations. This is unlike the situation in a river or tidal estuary, where the radionuclide concentration in the power plant effluent would be higher than that in the adjacent receiving waters. Dr. Carlson was joined in this concern by 11 other scientists (including others conversant with aquatic radioecology, several physicists, a medical doctor, and 5 authors of the thermal pollution paper, myself included), who published in November 1968, a second position paper, "Radioactivity and a Proposed Power Plant on Cayuga Lake."[10] Using available data on radioactivity decay rates and the rates at which particles would be added to and flushed out of the lake, Dr. Carlson, aided by nuclear engineers and limnologists, calculated equilibrium concentrations and total amounts of various radionuclides that would be accumulated in Cayuga Lake if "typical expected" releases and if AEC maximum permissible concentrations were continuously discharged into the lake.

In addition to concentration of radionuclides caused by Cayuga Lake's slow-flushing characteristics, Dr. Carlson and his colleagues stressed that

> There will . . . be concentration of radionuclides in aquatic organisms. Many plants and animals concentrate specific radionuclides in certain organs or tissues. For example, iodine is concentrated in the thyroids of higher animals and strontium in bones, scales, and shells. . . . The extent to which different radionuclides are concentrated under various conditions by different organisms varies widely. The scientific literature contains reports of concentration factors for strontium-90 by freshwater organisms up to 500,000 for filamentous green algae, 100,000 for insect larvae, and 20,000 to 30,000 for fishes. Each element can be expected to behave differently in different organisms. Though radionuclide levels in human diets may not be significantly increased or exceed "permissible" levels, no one can accurately predict the effects such accumulations might have on aquatic organisms. Additions of radionuclides and the resulting increase in radiation exposure may be particularly damaging to aquatic organisms, because they are normally subjected to relatively small amounts of ionizing radiation.

The authors made special efforts to avoid invoking nuclear hobgoblins or similar scare tactics, and tried to be as factual as possible. It is interesting to note that the authors succeeded in avoiding an emotional reaction to the radionuclide issue in this case. Indeed, the general public's reaction to the radioactivity paper was far more subdued than it was to the thermal pollution bulletin. Additional points made in summarizing the radioactivity paper were the following:

1. The proposed Bell Station is an "experimental" nuclear power station in the sense that no plant of such large capacity or of the precise design proposed here has ever been operated elsewhere. No nuclear power station has been sited on or discharged liquid radioactive wastes to a relatively small, slow-flushing lake like Cayuga.
2. The quantity of radioactive waste discharges from the proposed plant cannot be accurately predicted in advance.
3. Radiation exposure of every person who will use the lake will be slightly increased as a result of normal plant operation.
4. An accident in the plant which could result in greatly increased exposure of the local population is possible, though highly unlikely.
5. Any exposure to radiation involves some biological risk to ourselves and our descendants.
6. If operating procedures other than those proposed by the company were used, it would be possible to reduce or prevent routine discharges of radionuclides to the environment.
7. The local public has not been informed of the risks to itself and its environment inherent in the operation of Bell Station or of the cost necessary to avoid at least some of those risks.

Public Response

Reactions to the two position papers ranged from anger through apathy to acclaim. This spectrum of response was manifest within the University as well as outside it, although among the academicians there was less neutrality as anyone who has ever attended a faculty meeting could guess. Identifiable disapproval of our activities included feelings that we were doing something that violated propriety, academic decorum, and/or the scientist's pristine role. Others felt that we were against nuclear power, progress, and new concepts, despite our continuing and completely sincere contentions that we did not oppose the plant—only the proposed method of operating it. In short, we were damned by some for being radicals, by others for being reactionaries, and still others likened us to "the little old lady in tennis shoes who never goes near the lake, but wants to know in her heart that it is pure."

Although there was certainly no wild outburst of public acclaim when our first position paper appeared, as the weeks went by it became obvious that a growing number of people in the Cayuga Lake area felt that the questions we had raised should be widely considered and discussed before a decision was made to let the utility operate the power plant with a once-through cooling system. Requests for copies of the position paper gradually accelerated, and increasing numbers of these came from other states—even a few from other countries. By late July 1968 there was at least one request per week to speak to some sportsmen's, fraternal, or college organization around the lake. We were especially gratified to learn that two remarkably conscientious local legislators, Assemblywoman Constance Cook and Senator Theodore Day, and also the League of Women Voters, were devoting serious study to the issues that had been raised.

NYSEG's blasting and excavation for Bell Station proceeded rapidly through the summer of 1968, until by November the company had over 2 million dollars invested in the site, which was clearly visible from points on the lake three miles away. Company press releases tended to be bland, reassuring—and repetitive. I was receiving increasingly strong and frequent inquiries about the possibility of forming some sort of citizens' group to provide a vehicle for unified expression of the mounting number of individual concerns about the plant. Finally, in early August, we held a meeting in a local grocery store that was attended by some 30 members of the community, including several authors of the first position paper. I reviewed the current status of the controversy, handed out packets of background information, and tried to explain my view that the role of the scientists in such an issue is to make available information on pollution hazards and alternatives that will help the voter in making his own decision without telling him how to vote. Such decisions must be broadly based public decisions. Furthermore, from the standpoint of political strategy (and ethics) the most important factor is not *who* speaks, but *how many*. I therefore felt that if people in the community wished to take some sort of action on this issue, they must make the decision on whether—and how—any action group should be organized, but it should not be by the people who wrote the position papers. After the meeting was over, a young man I didn't know—a Mr. David Comey—introduced himself and said he might be able to help get some sort of organization started, or at least determine if one was wanted. Dr. Carlson and I gave him our files of reprints, mailing lists, and correspondence on the Cayuga Lake case.

Mr. Comey proved to be an unusually dynamic individual, and he became deeply committed to this issue. He rapidly attained an astonishing level of expertise in scientific and technical areas relating to the power plant controversy, and his organizational activity was prodigious. Within a few weeks he formed the Citizens' Committee to Save Cayuga Lake. The number of paid members grew to 300 within three months and over 800 within six months, and affiliation with the Cayuga Lake Preservation Association, sportsmen's clubs, and property-owner associations brought in more than 2000 associate members.

Informative, hard-hitting newsletters soon appeared, state and federal legislators were made aware of the problem, and news releases went out to a variety of newspapers and radio stations. The Citizens' Committee printed the position paper on radioactivity, and reprinted the thermal pollution paper. In October Mr. Comey and his capable committee arranged a large civic luncheon which featured a powerful address by Barry Commoner entitled "The Hidden Costs of Nuclear Power." The local radio station rebroadcast it several times.

The Utility's Response

NYSEG's actions in the Cayuga Lake case seemed to follow a behavior pattern fairly common in resource preemptions by industry. The strategy was to announce the proposal *after* plans for implementing it were already well under way, and to keep things moving ahead rapidly thereafter. Company officials consistently refused invitations to debate their critics in public. The company's numerous publicity releases stressed progress, electrical needs, a tradition of good neighborliness, electric rates that had not been raised in 15 years, monetary benefits of the plant to the community, and the enticing possibility of a large salmon hatchery on the lake—courtesy of NYSEG and the New York State Conservation Department.

The company would never allow its second plant to "harm" the lake, it reiterated, and was conducting contact research programs which it expected would demonstrate that its operations would not damage the lake.[11] That the company did indeed contract at least two lake studies to highly qualified independent research teams is to its credit. Needless to add, the researchers did not share the company's preconception of what the results might show. Company officials' reactions to the position papers, as given in various press releases, indicated that the authors were "jumping to conclusions before the facts are in." They stated that plans for design of the plant were still flexible, pending conclusion of the company-sponsored research on the lake.

The utility's posture that it was not already committed to a once-through flushing design for the plant's condenser cooling water seemed a little ridiculous to the Citizens' Committee. In the summer of 1968 a company official had told a large audience that if the company were required to employ a system for cooling the water before returning it to the lake, financial considerations might force the company to consider moving its plant elsewhere. Since several million dollars had already been invested in this project, it seemed obvious that the company planned on *not* moving elsewhere, and hence planned on not being required to employ a cooling system in the plant design. We subsequently learned that NYSEG had already contracted to sell about two-thirds of Bell Station's power output to Consolidated Edison in New York City—this while "research to assure no harming of the lake by the plant" was under way and before a half year's data were available for analysis.[12] Law Professor Harold P. Green has caricatured the attitude of such utilities (and some regulatory bodies) toward risk-taking as a four-step process:

> (i) we do not have enough scientific knowledge to tell us whether or not the risks are really significant, but out present judgment is that the risks are insignificantly small; (ii) as the project goes forward, further research will be undertaken to verify our judgment that the risks are insignificantly small; (iii) whatever risks do exist can be reduced to tolerable dimensions through technological devices; (iv) if the risks indeed are found to be, and remain, significant, the program will of course be abandoned or drastically restricted or controlled to protect the public interest. *QED.*[13]

Legislators' Response

By September 1968 citizens' expressions of concern to their legislators about Bell Station had become a rising groundswell. They realized that the AEC would not, as a matter of policy, take thermal effects into account and based its licensing solely on radioactivity criteria. Moreover, as observed above, even these criteria were designed for flushing situations, rather than essentially nonflushing waters like Cayuga. The New State Health Department was the only permit-granting agency that could by law take thermal effects into account, and the many citizens who wrote the Health Department about thermal problems were not reassured by the standard reply they received, which read in part:

> The State Health Department looks on Cayuga Lake as a valuable asset to the State and, therefore, is interested in protecting it. On the other side of the coin, the State Health Department is involved with industrial development of the state.

Doubts about the Health Department's true role were subsequently reinforced by this announcement in the December 19, 1968 Ithaca *Journal*:

> Dr. Hollis S. Ingraham, the State Health Commissioner [Head of the Health Department] has been elected chairman of the New York State Atomic Energy Council. . . . The council is charged with encouraging the development of atomic energy in the State and at the same time protecting the health and safety of the public.

It appeared the State had installed a "closed-circuit cooling system" of its own.

Accordingly State Assemblywoman Constance Cook and State Senator Theodore Day took actions that led the Joint Legislative Committee on Conservation, Natural Resources, and Scenic Beauty to hold an all-day hearing in Ithaca on November 22, 1968 to help determine whether existing State licensing criteria and their current interpretation by the agencies involved were adequate to protect Cayuga Lake from damage by the power plant's proposed operation.

The hearing opened with a number of presentations by utility officials. They described their activities to date and their intentions. These were followed by presentations from five of the authors of the position papers, Drs. Clifford Berg, Clarence Carlson, Lawrence Hamilton, John Kingsbury, and myself, each speaking about threats of the proposed operation to Cayuga Lake from the standpoint of his own particular discipline. David Comey added information on cooling devices now being used by more progressive electric companies in the Northeast and the deficiency of current regulations to protect the citizens' interests here.

In the afternoon Professor Leonard Dworsky, director of the Cornell Water Resources Center, stated his conviction that current legislation and limitations on functions of regulatory agencies were such that "under these circumstances we believe that all available technology should be utilized in connection with the Bell Station plant so as to eliminate any further deterioration of the Cayuga Lake environment." It was obvious that the utility people were taken aback by Professor Dworsky's testimony. That they clearly had expected him to testify more on their side implied to us that they had failed to grasp the full meaning of scientific integrity. The afternoon ended with the legislators asking the utility vice-president to reiterate, for the record, his earlier estimate (subsequently found high by a factor of about 2) that technology to eliminate most possibilities of thermal or radionuclide pollution to Cayuga Lake would add not more than fifty cents to the monthly household electric bill of the average NYSEG customer.[14] In retrospect it was a clear victory for the Citizens' Committee and its allies, although at the end of that long day many of us were too exhausted to be sure.

In late January 1969 the Citizens' Committee announced its intention to seek legal designation as an intervenor in hearings that would be prerequisite to an AEC permit for construction of Bell Station, stated that it had engaged Harold P. Green, a Washington attorney of national prominence in such matters to act on its behalf, and was now seeking to raise $10,000 to cover costs of this proceeding.

In early March Mrs. Cook, supported by Mr. Day and other legislators, introduced three bills to provide environmental safeguards for lakes in nuclear power plant cases such as the one pending on Cayuga Lake. One of these bills provided restrictions on the place and aggregate amount of heat additions to the epilimnion, another restrained a utility from making any expenditures on a site (after simply acquiring it) until the New York State Health Department discharge permit and Atomic Energy Commission construction permit had been obtained, and the third bill limited the concentration of radioactive waste discharges from a plant to not more than 50 percent higher than the intended maximum discharge stated in the plant's Preliminary Safety Analysis Report. These bills seemed to us eminently sound, reasonable, fair, and not unduly restrictive. All three of them passed the State Assembly—and the first two the Senate also—unanimously.

In this same period the State Health Department proposed a set of thermal discharge criteria for New York waters and held a series of hearings on them. These criteria were sharply criticized by the Cornell Water Resources Center administrators, biologists working on its Cayuga Lake study, Cornell engineers working independently on the problem, the Citizens' Committee, and others because they failed to provide any scientifically sound basis for regulating thermal discharges in stratified lakes. The criteria were also criticized by Associated Industries of New York State as being too restrictive—an interesting sidelight.

On April 11, 1969, NYSEG announced an indefinite postponement in company plans for construction of Bell Station "to provide more time for additional research on cooling systems for thermal discharge from the plant, and for consideration of the economic effect of such systems." Presumably the favorable outlook for Mrs. Cook's three bills, and uncertainty as to what thermal discharge criteria the state would adopt, were factors in the company's decision. Commenting on this action, the trade journal *Nucleonics Week* stated: "Observers suggest, also, that the postponement decision may have been influenced by NYSE&G aversion to a court battle over A.E.C. licensing."[15]

The scientists, the citizens, and the legislators had acted conscientiously in their appropriate roles. This is the way resource allocation problems should be solved, and the outlook for a reasonable decision in the Cayuga Lake case was bright.

Disappointments from the State Capitol

One of Mrs. Cook's three bills (the one limiting radionuclide discharges to 50 percent more than the stated concentration) was killed in the Rules Committee of the State Senate as a result of heavy pressure from utilities in the state. Then in May 1969 Governor Rockefeller vetoed the other two bills. In turning down the thermal discharge bill, he stated legislative action at this time was premature because the State Water Resources Commission was now developing thermal discharge criteria which would supply the needed safeguards. In vetoing the bill to restrict heavy investment in site development until permits had been granted, he said: "It would not be reasonable to expect the Public Service Commission to evaluate and balance against one another the myriad of factors involved in selecting sites. . . . [The bill] would be detrimental to the State's power program and would seriously retard the economic growth of the State."

A second blow came on July 25, 1969, when the State Water Resources Commission approved the much-criticized thermal discharge criteria in their originally proposed form. It seemed that the lengthy series of statewide hearings on these proposals had been a meaningless exercise. The criteria were forwarded to

Washington for evaluation by the Federal Water Pollution Control Administration.

Later Developments

In November 1969 the Water Resources Center's study of Cayuga Lake was published. It covered a 9½ month sampling period. The data comprised a valuable increment to the store of information on the lake. However, as the director of the Center pointed out, the data from such a short-term study did not—and could not have been expected to—provide definitive answers about the safety of the company's proposal for using Cayuga Lake.

In August 1970 NYSEG president William A. Lyons announced that construction of Bell Station was contingent on what thermal discharge criteria New York State adopts, adding "It now appears that an optimistic estimate of the earliest possible on-line date for a nuclear plant at our site on Cayuga Lake would be late in 1977. It more likely would not be until 1978." The utility recently sold the reactor vessel for the proposed Bell Station to the Long Island Lighting Company.

It is now two years since the first position paper on Cayuga Lake was written, and at this writing, Bell Station remains dormant—a multimillion-dollar excavation on Cayuga's shoreline. The increase in cost of the completed plant that has taken place through price rises during the two years the company has been resisting compromises has been estimated at $100 million. One wonders how the company can reconcile this with the relatively small additional cost (perhaps $15 million total) of accepting these compromises in the first place.

The Citizens' Committee remains viable, and is expanding its activities. In the Cayuga Lake region, in Cornell University—and indeed throughout the nation—there is noticeable increased concern with environmental quality, the management of natural resources, and the development of controls to prevent pollution before it happens.

Editor's Postscript: How Radioactive Waste Builds Up in a Lake

by John Harte and Robert H. Socolow

If a factory or power plant discharges a fixed amount of waste every day into a lake, the concentration of that waste in the lake will build up to an equilibrium level at which the waste leaves the lake at the same rate as the waste enters the lake. The concentration of the waste at equilibrium and the length of time required to reach, say, one-half the equilibrium concentration, both depend on the rate at which the lake is flushed. Other things being equal, the slower the lake is flushed, the longer the time during which the concentration of waste keeps increasing substantially and the higher the final equilibrium concentration.

Wastes can leave a lake in ways other than by being flushed out. For example, nutrients can react chemically to form insoluble salts, falling to the bottom of the lake, or a waste may pass through the food chain into birds or land animals. All of these arguments apply whether or not the particular waste is radioactive. If the waste *is* radioactive, this provides another mechanism by which the substance can leave the lake, because a radioactive substance decays. The waste may be said to have "left" the lake if, as is usually the case, the decay products are not radioactive.

The decay of a radioactive waste and the flushing of a uniformly mixed waste out of a lake have one property in common: for each process, the rate at which waste leaves the lake at any instant is proportional to the amount of waste in the lake at that instant. When there is more than one way ("channel") for waste to escape, there will be a characteristic rate associated with each exit channel, and if these channels are *independent*, these rates will *add* to give the total exit rate. In the case of radioactive waste, the two most important exit channels, radioactive decay and getting flushed out, are clearly independent.

Let $N(t)$ be the amount of waste in the lake at time t. Then the rate at which waste leaves the lake by flushing is $N(t)/L$ where L, the mean flushing time for the lake, is the time by which a volume of water equal to the volume of the entire lake will have flowed through the lake. The rate at which the radioactive waste decays is $N(t)/R$, where R is the mean-life of the radioactive isotope in question.

If we let

$$\frac{1}{T} = \frac{1}{R} + \frac{1}{L} \tag{1}$$

then, because the rates add, the total rate at which waste leaves the lake is $N(t)/T$; T is the mean time for waste to exit from the lake.

Now suppose that a waste product is being added to the lake at a constant rate B. Then at *equilibrium*, the rate at which waste is *removed*, N/T, *equals* the rate at which it is *added*, B, and so the equilibrium amount is $N = BT$. In words, BT is the amount of nutrient which will enter the lake at the rate B within the mean time T. Other things being equal, a slow-flushing lake means a large value of the mean flushing time L, hence a large value of the mean exit time T, and hence large equilibrium concentrations.

For Cayuga Lake, L is about 10 years. The time R, of course, depends on the isotope; for strontium-90, with a half-life of 28.1 years, R is 40.6 years, so that $T = 8.0$ years. This means that the equilibrium amount of strontium-90 in Cayuga Lake will equal the total amount of strontium-90 discharged (at a constant rate) into the lake in 8.0 years. The equilibrium *concentration* will equal this amount divided by the volume of the lake.

The detailed way in which the amount of waste product builds up, under these assumptions, is given by the solution of the differential equation

$$\frac{dN}{dt} = -\frac{N(t)}{T} + B \tag{2}$$

Each side of this equation is an expression for the net rate of change of waste in the lake. If the discharge of waste begins at a time $t = 0$, then the solution is

$$N(t) = BT(1 - e^{-t/T}) \tag{3}$$

After a time T, the amount of waste product has reached $(1 - 1/e) = 0.63$ of its equilibrium value. A graph of $N(t)$ versus t is shown below. In equilibrium, $dN/dt = 0$.

In view of this discussion, it is clear that proper standards for radioactive waste disposal from nuclear power plants built on lakes must be based on equilibrium concentrations, rather than on the concentration of radioactive waste in the water passing into the lake from the condensers. The latter type of standard, however, is easier to administer and has the advanture of being independent of the properties of the body of water being used for cooling. An example of this kind of standard is the AEC upper limit for strontium-90 discharge, set at 3×10^{-7} *microcuries per cubic centimeter of cooling water.* Let us work out an example which illustrates the relation between these two types of standards.

For the proposed Bell Station plant, where 1100 cubic feet (or

3.1×10^7 cubic centimeters) of cooling water are emitted every second, the AEC standard just quoted permits 9.3 microcuries to enter Cayuga Lake every second. The equilibrium amount of strontium-90 in Cayuga Lake is the amount entering the lake in 8.0 years, which works out to be 2.3×10^9 microcuries. Since the volume of Cayuga Lake is 9.4×10^{15} cubic centimeters, the equilibrium *concentration* in the lake is 2.5×10^{-7} microcuries per cubic centimeter. By a set of coincidences which can be summed up by saying that water is drawn through the Bell Station condensers at nearly the same rate that it is flushed through Cayuga Lake, this equilibrium concentration is very close to the concentration of isotope which is first emitted in the condenser cooling water. The reader will note, however, that the *concentration* of the radioactive waste in the cooling water had nothing directly to do with the equilibrium concentration; only the *amount* of radioactive waste discharged per second enters into the calculation.

The reader should be reminded that an equilibrium concentration in no sense implies a uniform distribution of radioactive waste in the lake; in particular, biological concentration of particular wastes in particular organisms must be included in any complete assessment of the hazards involved in a particular rate of release of radioactive waste to a lake.

Footnotes

❖ The following selection, copyright © 1971 by Holt, Rinehart and Winston, Inc., is from the forthcoming book, *Patient Earth*, edited by John Harte and Robert H. Socolow, who are both Assistant Professors of Physics at Yale University. *Environmental Affairs* presents this selection with the special permission of Holt, Rinehart and Winston, Inc., which will publish the book (544 pages, $4.50 paperbound) in May.

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1 U.S. Water Resources Council, *The Nation's Water Resources*, Washington, D.C.: U.S. Government Printing Office, 1968.

2 U.S. Department of the Interior, *Quest for Quality*, U.S.D.I. Conservation Yearbook, Washington, D.C.: U.S. Government Printing Office, 1965, p. 10.

3 Joint Committee on Atomic Energy, *Selected Material on Environmental Effects of Producing Electric Power*, Joint Committee Print, 91st Congress, 1st Session, Washington, D.C.: U.S. Government Printing Office, 1969.

[4] *Thermal Pollution–1968*, Part I, Hearings before the Subcommittee of the Committee on Public Works, U.S. Senate, 90th Congress, 2nd Session, February 1968, Washington, D.C.: U.S. Government Printing Office, 1968.

[5] R. W. Zeller *et al.*, *A Survey of Thermal Power Plant Cooling Facilities*, Pollution Control Council, Pacific Northwest Area, Portland, Oregon, 1969.

The future role of cooling towers in electric power generation is not easy to predict at the moment. As with many other technological devices which reduce an environmental problem, there will be side effects which must be assessed. For example, cooling towers will increase local fog formation; whether at any particular site the extent of that effect is negligible or not will require research which takes into account regional climatic conditions. Cooling towers should be considered as one among a spectrum of possible solutions to the problem of thermal pollution. Other alternatives, in addition to those suggested by Professor Eipper, are (1) to build power plants near bodies of water such as the oceans which are so vast that the heat increase to the water may be ecologically insignificant, (2) to develop ways of utilizing the "waste" heat from the power plant for practical purposes such as heating homes, melting snow on roads, or prolonging the growing season of irrigated crops, and (3) to halt the growth of electric power consumption and stop building additional power generating plants. Each of these alternatives involves costs and benefits which must be evaluated. [Editors' note]

[6] Joint Committee on Atomic Energy, *op. cit.*

[7] J. F. Hogerton, "The Arrival of Nuclear Power," *Scientific American*, Vol. 218, No. 2, pp. 21–31 (1968); J. E. McKee, "The Impact of Nuclear Power on Air and Water Resources," *Engineering and Science*, Vol. 31, No. 9, pp. 19–22, 31–32 (1968); J. R. Clark, "Thermal Pollution and Aquatic Life," *Scientific American*, Vol. 220, No. 3, pp. 18–27 (1969).

[8] The following description of Cayuga Lake is slightly modified from A. W. Eipper *et al.*, *Thermal Pollution of Cayuga Lake by a Proposed Power Plant*, Ithaca, N.Y.: Authors, Fernow Hall, Cornell University, 1968.

[9] The Alabama Power Company recently announced its intention to install induced-draft cooling towers at its proposed 829-megawatt SEALA nuclear generating plant at a cost of about $4 million (just over 2.4 percent of the total plant cost). The Georgia Power Company has announced that it will use closed-circuit cooling at its planned nuclear power stations on the Altamaha River and elsewhere. (R. H. Stroud, *Nuclear-Fuel Steam-Electric Stations*, Bulletin No. 202, pp. 1–2, Washigton, D.C.: Sport Fishing Institute (1969).

[10] C. A. Carlson *et al.*, *Radioactivity and a Proposed Power Plant on*

Cayuga Lake, Ithaca, N.Y.: Authors, Fernow Hall, Cornell University, 1968.

[11] This approach was documented in the company's Preliminary Safety Analysis Report to the Atomic Energy Commission.

[12] From the January 16, 1969, issue of the trade journal *Nucleonics Week*.

[13] Quoted by L. J. Carter, "Technology Assessment," *Science*, Vol. 166, No. 3907, pp. 848–852 (1968).

[14] In a more detailed analysis on January 20, 1969, the company vice-president, Albert Tuttle, estimated the total construction and operating costs for cooling the plant's thermal discharge by natural draft evaporative towers at $21.3 million or (prorated) $2.4 million per year. This would amount to a cost of slightly less then $5 per year to each of the company's half million customers. Subsequently a careful analysis by Cornell economist Jeffrey Romm indicated actual cost to be $12.8 million ($1.4 million per year). Mr. Romm's estimates are in good agreement with cost estimates for comparable facilities at comparable-size plants elsewhere. (Jeffrey Romm, "The Cost of Cooling Towers for Bell Station," Manuscript, mimeo., Ithaca, N.Y.: Reprint Department of Agricultural Economics, Cornell University, 1969.)

[15] Vol. 10, No. 6, p. 2 (April 17, 1969).

Suggestions for Further Reading

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