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ENVIRONMENTAL ASSESSMENT AND RESEARCH

The Laboratory's involvement in environmental assessment and research began in 1972 and continued for two decades. Core support was provided by the State of Maryland Power Plant Siting Program. The work involved a wide range of disciplines including air-quality transport modeling, aquatic toxicology and fisheries dynamics, chemistry of aquatic and air pollutants, electromagnetic field effects, cooling-tower plume dynamics, groundwater transport modeling, radiological safety, noise pollution, waste-disposal technology, environmental regulatory law, and socioeconomics. The efforts provided a sound basis for the resolution of many environmental issues and contributed substantial fundamental knowledge in several disciplines.

EVOLUTION

In the late 1960s and early 1970s, a sensitivity to environmental and resource problems emerged. At APL, some felt that work on such problems was consistent with the primary mission of the Laboratory to work on threats to our national security, and they were looking for opportunities to contribute.[1]

At about the same time, the Baltimore Gas and Electric Company was seeking approval from the Maryland Public Service Commission for the Calvert Cliffs, Maryland, Nuclear Power Plant. It became clear in those proceedings that the Commission did not have a sound basis for resolving the environmental issues raised in the hearings. In response, the Legislature of the State of Maryland passed the Power Plant Siting Act, which placed an environmental surtax on electricity generated in Maryland and created a program, administered by the Department of Natural Resources, to monitor environmental influences of existing power plants, to evaluate the potential impact of proposed plants, and to conduct research that would improve the ability to predict environmental effects.

The Power Plant Siting Program under Lee Zeni awarded a contract for the evaluation of potential impacts to a team from three components of The Johns Hopkins University: the Chesapeake Bay Institute, the Department of Geography and Environmental Engineering, and APL. The program objective was to support the evaluation of power plant impacts at specific sites, complemented by research in supporting technical disciplines and the development of broadly useful impact assessment techniques such as databases and models.

The Chesapeake Bay Institute team, under the direction of Donald Pritchard, was responsible for hydrological work; aquatic and estuarine biology efforts were under the direction of Loren Jensen of the Department of Geography and Environmental Engineering. The APL team, led by Alvin Schulz, was responsible for a broad range of other disciplines including air quality, chemistry of air and aquatic pollutants, radiological safety, electromagnetic field effects, noise pollution, cooling-tower plume dynamics and impacts, waste-disposal technology, groundwater modeling, environmental regulatory law, socioeconomics, and terrestrial ecology and aesthetics.

The Laboratory's responsibility for power plant site evaluation for the State of Maryland continued until 1985. Annual funding from the Power Plant Siting Program, typically in the range of $1 million to $1.5 million, provided core support that permitted the development of a multidisciplined team. The interest of the group broadened with time to include research on alternative energy sources, safety and risk assessment, and site and route selection methods using multiobjective optimization techniques. During the middle years of the Laboratory's environmental work, about forty-five APL staff members were involved.

From 1972 to 1985, leadership of APL's Environmental Assessment Group passed from Milton Moon to Lawrence Kohlenstein to Edward Portner. In 1974, Jensen left The Johns Hopkins University and Robert Otto assumed responsibility for the biological work. In 1980, Otto left the University and APL established an Aquatic Ecology Section under the leadership of Dennis Burton in the Environmental Assessment Group.

The Aquatic Ecology Section provided expertise in fisheries ecology, behavior, and toxicology, as well as aquatic chemistry. The section was located at the Chesapeake Bay Institute at the University's Shady Side, Maryland, location. That location provided a continuous-flow bioassay laboratory that was used to evaluate acute, chronic, and sublethal effects of various environmental factors and toxic substances on aquatic organisms. In 1985, when reductions in funding led APL to discontinue its other environmental work and the Environmental Assessment Group was disbanded, the Aquatic Ecology Section was transferred to the Submarine Technology Department, where it continued to conduct basic research and address applied environmental problems in the Chesapeake Bay and its tributaries, as well as other aquatic ecosystems throughout the United States. The Aquatic Ecology Section was dissolved in 1991 after the University decided to close the Chesapeake Bay Institute and sell the Shady Side property.

Thus ended two decades of environmental work by APL staff. During that period, the staff made numerous contributions to the fundamental understanding of environmental effects and provided a sound basis for resolving issues and mitigating impact for more than eight proposed power plant sites.

SITE EVALUATION HIGHLIGHTS

The role of the Power Plant Siting Program is to ensure that the electrical generation capacity needed by the State receives regulatory approval with appropriate environmental safeguards. Ultimately, the program provides guidance to the Public Service Commission in hearings generally involving utilities and intervenors. Much of the value of the program comes from resolving issues outside the formal regulatory process.

The Issues

Our activities for most sites included air-quality and cooling-tower studies and models, prediction of emissions (e.g., sulfur dioxide, total suspended particulates, salt, visible plumes, fogging and icing, fugitive dust, and chlorination), noise assessments, waste-disposal evaluations, aquatic impact prediction, transmission-line impacts (e.g., shock effects, television interference, health effects, and fuel ignition), terrestrial characterizations, transportation and construction effects, shoreline erosion, hydrological and groundwater evaluations, land-use studies, and aesthetic evaluations. A few of these topics are discussed in this article from a site evaluation perspective. We also provide examples of our research that complemented and supported the site evaluations.

Once-through cooling systems are not suitable for most locations because of the entrainment of fish eggs and larvae and the impingement of fish on intake screens. Even with cooling towers that reduce the withdrawal and discharge of cooling water to a small percentage of that of once-through systems, safeguards to protect aquatic life are needed. In the 1970s, when large facilities were still being proposed, the sites tended to be on substantial bodies of water, often in estuaries just at the boundary between fresh and brackish water where striped bass spawn. Within a few years, utilities proposed large-scale development in three of the four largest striped bass spawning grounds in Maryland: Douglas Point on the Potomac, Summit on the Chesapeake and Delaware Canal, and Vienna on the Nanticoke. At the same time, the striped bass population began a serious decline, eventually reaching levels that resulted in bans on striped bass fishing not only in Maryland, but throughout most of the East Coast. This coincidence led to a great deal of study of striped bass by the Power Plant Siting Program; the studies contributed much to the fundamental understanding of striped bass population dynamics and to fisheries management decisions in general.[2] Plans for the development of the Douglas Point and Summit sites have been dropped completely, and substantial mitigating measures have been identified in the event that development ever proceeds at Vienna.

In contrast to most of the issues examined, air quality is regulated by explicit standards. The Power Plant Siting Program devoted considerable effort to gathering meteorological data and modeling to ensure that proposed emissions would meet standards. This issue was most constraining and demanding in areas where uneven terrain enhanced the potential for violations either because of elevated locations (e.g., Sugarloaf Mountain at the Dickerson site) or because of complex air circulation (e.g., Western Maryland).

Cooling-tower systems require internal treatment to prevent biological growths; chlorine is generally used. The location of generating stations in sensitive aquatic areas raises issues associated with the effect of discharges from cooling towers. Our staff conducted research on the dynamics of chlorine in estuarine waters and on the toxicity of chlorine residuals to estuarine biota. This work contributed much to the understanding of the effect of chlorine from other sources (e.g., sewage treatment plants and other industries).

Acoustic noise on a power plant site comes from various sources, including turbines, generators, cooling towers, coal operations, and vehicles such as ash-removal trucks. Typically, a new power plant will be located in a rural area where noise can annoy nearby residents if it is not adequately controlled. In our studies of noise effects, we characterized the noise sources found on power plant sites, predicted off-site noise levels, and evaluated the potential for annoyance. We also recommended limitations on noise emissions, with consideration of noise-abatement technology.

We also considered electromagnetic effects from electrical transmission facilities. Transmission lines in Maryland are designed with voltages up to 500 kV. These lines produce electric and magnetic fields that can have undesirable effects under some conditions. At the time of our studies, researchers were just beginning to consider the possible human health implications of chronic exposure to transmission-line electric fields. Today, more than a decade later, this issue is still being hotly debated, and we still lack a consensus on what constitutes a potentially hazardous level of chronic exposure to electric and magnetic fields.

Acute shock effects caused by transmission-line fields are much better understood. Electric shock can result from the influence of the intense electric fields generated by high-voltage lines (500-kV lines produce electric fields greater than 5 kV/m near the Earth's surface). Although these shocks could conceivably be a hazard in rare and unusual circumstances, they can be an annoyance to nearby residents.

Major Site Evaluations

Since the Power Plant Siting Program began, major changes have occurred in electricity conservation, safety concerns, changing electricity usage patterns, new electricity generation technology, and the economics of energy sources. The changes have profoundly affected the demand for power plant sites. No utilities have proposed new nuclear stations for many years. Indeed, they are proposing no large central generating units of any type. The need for small units suited for responding to peaks in demand has dominated. Even base-load demand is being met by modular units brought on-line as slowly rising demand requires. Independent companies are now empowered by law to generate electricity while producing steam for other industrial processes and to sell it to electric utilities, provided that the price is competitive with that of the utilities. This situation is further fragmenting and distributing electricity generation in Maryland.

Today, most utility-owned sites being considered for future development are the same ones that were identified in the early 1970s and evaluated by the Power Plant Siting Program. For these sites, baseline environmental studies have been done, potential environmental impacts have been evaluated, and, for the most part, measures to mitigate the impacts have been identified. Remaining issues have more to do with establishing the need for additional generating capacity, determining whether industry or utilities should generate the power, and identifying the technology that should be used. Evaluations for sites on which major development has occurred, or for which development is still being considered, are summarized in the following paragraphs.

Brandon Shores, located on the Baltimore harbor, was one of the first site evaluations. Two generating units totaling 1200 MW were eventually developed by the Baltimore Gas and Electric Company. Brackish water cooling towers were used to mitigate the aquatic impact. We addressed air quality, the effects of salt fallout from the cooling tower, and the effects of noise on residential areas.

Perryman is a site owned by Baltimore Gas and Electric on the Bush River. It has been the subject of a series of studies in response to several generating-station proposals over the years. Perryman was initially evaluated as a nuclear site and later as a site for a coal-fired plant. If the site is developed, cooling towers will be used, but the source of water to replenish the evaporated water remains a subject of contention. The Bush River has been ruled out, but the State of Maryland wants to require that effluent from an adjacent sewage-treatment plant be used. The utility wants an option to use water from the Baltimore City aqueduct drawing from the Susquehanna. Measures to protect wetlands have shrunk the developable size of the site. The current plans of Baltimore Gas and Electric to develop several combined-cycle generating units have been delayed by an industrial intervenor proposing to provide the utility with electricity from cogeneration at a plant in Curtis Bay.

In the late 1970s, Delmarva Power and Light proposed to build several large coal-fired generating units at its site in Vienna, Maryland, on the Nanticoke River. Following three years of study, Public Service Commission hearings were held on numerous issues. The principal concern was that the site is located by one of the primary striped bass spawning grounds. After study and analysis, the Power Plant Siting Program concluded that to mitigate the impact on the striped bass stock, wedge-wire intake screens should be used. Other issues considered by the Program involved solid-waste disposal and fugitive dust emissions from coal-handling operations. Related studies were conducted on the interaction of cooling-tower plumes, stack plumes, and a proposed new bridge; cancer rates in the town of Vienna; and fugitive dust emissions from barge operations. Delmarva Power and Light has subsequently revised its plans for the site several times, diverting its new-capacity development to peaking units and gas combined-cycle units located outside of Maryland. When the Vienna site is eventually used, it is likely that a sound foundation will remain from the site evaluation work for the resolution of most environmental issues.[3-8]

The Potomac Electric Power Company (PEPCO) has proposed expansion at its Dickerson site on the Potomac several times—first, in 1973, when we did studies on air quality, water budget, cooling-system impacts, noise, and visual effects. This work contributed to the environmental hearing a few years ago when PEPCO proposed a combined-cycle facility for the site. Development has again been postponed as PEPCO seeks alternative generation sources through competitive bids.

In addition, we did studies at sites in Douglas Point,[9] Summit, Easton, Sollers Point, Bainbridge, Still Pond Neck, and Hagerstown; at six candidate sites in Western Maryland; and at two candidate sites on the Eastern Shore.

Another significant application of the capabilities developed under the Power Plant Siting Program occurred during the Three Mile Island accident. Because of work on nuclear safety, our staff members were able to evaluate various contingencies and provide estimates of potential consequences to the State of Maryland as they evaluated the need for evacuation.

RESEARCH HIGHLIGHTS

Striped Bass Migration

For close to half a century, the migratory behavior of striped bass spawned in tributaries to the Chesapeake Bay confounded fisheries managers in Maryland and Virginia, and along the Northeast Coast. Chesapeake Bay spawning grounds appeared to be the only sources of striped bass strong enough to support the extensive coastal fishery in New York and New England. All of the major tagging studies, however, seemed to indicate that a very small percentage of the Chesapeake Bay stock migrated to coastal waters. It was clear that such a small migratory fraction could not account for the coastal harvest. The uncertainty fueled debate and impaired fisheries management decisions.

Our research was based on age-specific sex ratios of stock within the Chesapeake Bay, and age-specific sex ratios as a function of position along spawning rivers where stock used for the tagging studies was taken.[10] We showed that the great majority of tagged fish were males and confirmed that very few males migrate from the Bay at any time in their lives. They remain a Bay resource. We also showed that about 50% of females migrate into coastal waters when they are three years old. A smaller proportion migrates from the Bay at age two and age four.

Once migrated, they remain in coastal waters until mature, typically at age six, when they return to their native waters to spawn. Subsequently, many migrate to and from the Bay repeatedly. This level of migration of female stock is sufficient to explain how the Bay spawning grounds can be the primary support of coastal fisheries. These results provided an important insight for fisheries managers trying to deal with the dramatic decline of striped bass stocks that occurred in the late 1970s and throughout the 1980s.

Striped Bass Contaminant Studies

Over-fishing and adverse water quality and contaminants were generally considered to be major reasons for the decline of striped bass. In 1983, APL's Aquatic Ecology Section initiated a study for the U.S. Fish and Wildlife Service to evaluate the effects of contaminants on the species. The studies were designed to evaluate the *in situ* effects of organic contaminants (chlorinated insecticides and herbicides, polynuclear aromatic hydrocarbons, etc.), inorganic contaminants (heavy metals), nutrients (ammonia, nitrate, nitrite, and phosphorus), and general water-quality conditions (temperature, salinity, conductivity, pH, dissolved oxygen, alkalinity, and hardness) on the survival of early-life stages of striped bass. Sublethal effects on yearlings were evaluated using histological and hematological parameters. Laboratory studies were also conducted to control various parameters.

Four major conclusions resulted from the six-year study. First, acidic conditions may have been responsible for mortality of striped bass prolarvae in the Nanticoke River. Second, trace metals and sudden decreases in water temperature were responsible for mortality of striped bass prolarvae in the Potomac River. Third, low water hardness and various inorganic contaminants were responsible for mortality of striped bass prolarvae in the Choptank River. Fourth, no acutely harmful water-quality or contamination conditions were detected in several areas of the Chesapeake Bay, including the Chesapeake and Delaware Canal. Thus, several chemical and physical factors were found to affect the survival of early-life stages of striped bass.[11]

Effects of Acid Deposition and Episodic Habitat Acidification on Migratory Fishes

In 1985, a six-year program of laboratory and field studies was initiated to determine the effects of acid deposition on habitat quality in spawning and nursery areas used by several migratory fish species of the Chesapeake Bay. The studies were stimulated by chemistry surveys that revealed that about 70% of the streams in the Coastal Plain physiographic province possessed limited acid neutralizing capacities. In addition, many streams exhibited short-term acidic pulses during storm-associated periods of high surface runoff. The sensitivity of these streams to acidic inputs generally reflected the limited ability of many Coastal Plain soils to neutralize acidity.[12]

Laboratory studies showed that larval stages of several Chesapeake Bay fish species (striped bass, blueback herring, white perch, and yellow perch) were very sensitive to moderately acidic pH depressions that had been measured in many Coastal Plain streams. The studies suggested that acidic pulses in spawning and nursery areas may decrease reproductive success and be at least partially responsible for the depressed status of these migratory Bay fish populations. Field toxicity tests were designed to corroborate the laboratory study results. The field studies showed that larvae of yellow perch and blueback herring were more sensitive to acidic pulses in the field than during laboratory experiments, presumably because of the interaction with other environmental factors such as current velocity and suspended sediments.

In 1986, we initiated field studies to evaluate the chemical and biological effectiveness of automated lime-slurry dosers in Maryland Coastal Plain streams as a short-term mitigation strategy for acid deposition effects. The technology had been used successfully in Sweden and Norway to neutralize acidic pulses in streams and rivers to protect anadromous fish spawning habitats. Stream liming is of interest to Maryland's Department of Natural Resources as one of several short-term mitigation strategies that can be used to maintain suitable pH levels in Coastal Plain streams until adequate controls on coal-burning industries and motor vehicles can be implemented through recent amendments to the Clean Air Act.

Past and present study results show that lime-slurry dosers can effectively neutralize acidic pulses in Maryland Coastal Plain streams. Limestone additions during high-flow periods also decrease the concentration of dissolved aluminum, a metal that is often mobilized during acidic pulses and that can reach concentrations toxic to larval fish. The results of the field and laboratory studies are being used by the Department of Natural Resources to select Coastal Plain streams that will be good candidates for lime dosers or other mitigation approaches.

Tributyltin Environmental Studies

Tributyltin (TBT) is a highly toxic pesticide that was used until recently in antifouling paint on boat hulls. It was used in antifouling paint because it is extremely toxic to fouling organisms, has a long half-life, and does not cause corrosion problems. The toxic properties of TBT, however, can cause severe detrimental effects on non-target organisms at part-per-trillion concentrations. It is one of the most toxic chemicals ever introduced into the aquatic environment. The Aquatic Ecology Section began to study the material in 1984 because of several observations that showed that several benthic organisms normally found in the Chesapeake Bay were not present in many boat marinas and harbors. Analytical methods development, monitoring studies, and aquatic toxicity tests with TBT were initiated in 1984 and continued through 1989. The research was initially supported by APL Independent Research and Development funds, followed by support from the Navy, Maryland Department of Natural Resources, and Maryland Department of the Environment.

The following findings were made during the studies.[13] Analyses of vertical water profiles showed that TBT occurred in the surface microlayer of Chesapeake Bay water primarily during the spring of each year. Bubble collapse by rectified diffusion and film collapse by surface stresses converted TBT-enriched microlayer organic matter into particulate phases that could enter the food web by detrital feeders. Concentrations of TBT in the water column were higher in boat marinas and harbors than in the main stem of the Bay. Peak TBT concentrations occurred during the early part of the boating season (May and June) when freshly painted boats entered the water. Significant quantities of TBT were found in the dissolved fraction of sediments primarily in marinas and harbors. It also appears to adsorb to suspended materials (such as resuspended Chesapeake Bay sediment). Toxicological studies with Chesapeake Bay organisms confirmed the acute and chronic toxicity of the material to several trophic levels.

Data generated from our studies were used to pass environmental legislation prohibiting the use of TBT as an antifouling paint. Both the State of Maryland and the Commonwealth of Virginia passed legislation in 1988 prohibiting the use of TBT on all recreational boats less than twenty-five meters in length, with the exception of aluminum hull boats. Legislative actions in both jurisdictions banned the sale or possession of TBT, except in commercial boat yards where TBT with acceptable leach rates can be used on vessels larger than twenty-five meters or those that have aluminum hulls. An acceptable leach rate is defined as 5.0 $\mu g \cdot cm^2 \cdot d^{-1}$ at steady state. Both bills permitted the sale and use of TBT paints having acceptable leach rates if they were sold in 16-oz. spray cans for use on outboard motors and lower units.

Toxicity Evaluation of Effluent Discharges in Maryland

In recognition of the problem that many aquatic ecosystems were adversely affected by human activity, Congress passed the Federal Water Pollution Control Act amendments of 1972. These amendments require that any person wishing to discharge any pollutant from a fixed location must first obtain a National Pollution Discharge Elimination System (NPDES) permit. Initially, NPDES permits focused on the control of conventional and known nonconventional pollutants thought to be toxic. By 1977, it was apparent that many discharges still contained significant quantities of pollutants; thus, the Federal Water Pollution Control Act was further amended to address the problem of individual toxicants present in an effluent. Effluent limitations based on individual chemicals, however, did not always provide adequate protection for aquatic life when multiple mixtures of pollutants were present. In 1984, the U.S. Environmental Protection Agency issued a national policy statement that required biological testing of effluents to determine toxicity.[14]

The Aquatic Ecology Section initiated a program in 1986 for the Maryland Department of the Environment to develop toxicity procedures for evaluating the toxicity of NPDES-permitted discharges to the waters of the State. The Laboratory was also directed to develop standard operating procedures for conducting freshwater and saltwater bioassays of both an acute and a chronic nature. Supplies of several freshwater and saltwater crustaceans and fish were developed for testing.[15]

To date, 196 discharges have been tested for acute toxicity (some have been tested several times), and more recently, 29 discharges were tested for chronic toxicity. Of 133 industrial and 63 municipal discharges tested for acute toxicity, 33% and 11%, respectively, were found to be toxic. Several effluents found to be acutely toxic were retested later. Many of those retested showed an improvement and/or elimination of acute toxicity. Of 15 industrial and 14 municipal discharges that were suspected to be chronically toxic, 73% and 86%, respectively, were found to be toxic. It is uncertain what the potential impact of the chronically toxic discharges will be to the receiving waters of the State because Maryland has not made a final decision on mixing zones for chronic toxicity.

Chlorine Dynamics

The use of chlorine to control biofouling of condenser tubes and other parts of the cooling system of power plants led to concern over the environmental effects of the chlorinated effluents. A research program on the lifetimes of chlorinated residuals was initiated to address the problem. An area of particular interest was the decay of organic chloramines and bromamines formed by the reaction of chlorine with naturally occurring organic nitrogen compounds in fresh and saline waters. These compounds were less stable than inorganic chloramine and formed a possible pathway for the decay of the oxidizing residuals. The resulting kinetic studies[16–18] were the first to document the rates and probable mechanisms of destruction of these compounds. In the course of the investigations, many of these same compounds were found to constitute a reservoir of oxidizing residual even in the presence of the commonly used dechlorinating agent sulfur dioxide.[19,20] This fact had been obscured in previous studies by the interference of the excess sulfur dioxide with the usual analytical methods for determining chloramine. This fact was discovered here only by the novel adaptation of a fluorescent technique normally used in clinical laboratory applications.

Electric Shock Research

The electric field around a high-voltage installation can induce currents and voltages in nearby vehicles, fence wires, rain gutters, and other metallic objects. The induced potentials near transmission lines can reach several thousand volts in an object that is well insulated from ground. Such an object acts as a capacitor on which voltage and charge are induced by the action of the electric field. A person touching the object may unwittingly supply a ground path for electrical discharge and feel an unpleasant electric shock.

To define the limits of possible undesirable electric field influences, we conducted a research program on human reactions to electrical stimulation. A summary of some of our research is given by Reilly and Larkin[21] and is illustrated in the following paragraphs.

We developed a research laboratory that featured a high-voltage stimulator to deliver shocks similar to those induced by ac or dc electric fields. We recruited subjects who participated in a variety of experiments designed to understand the variables and conditions governing electrical sensation.

Figure 1 is an example from our research with capacitor discharges and shows threshold sensitivity curves for four ways of delivering the stimulus: a touch with the fingertip, a discharge to a large 1.27-cm-diameter electrode held against the skin, a discharge to a small 0.11-cm electrode, and a discharge to a needle piercing the skin. The minimum threshold charge ranges from 0.07 μC for the subcutaneous needle electrode to 0.3 μC for the finger-tapped electrode.

Sensitivity measurements at levels above the thresholds of detectability are important in defining the conditions under which people may be annoyed or disturbed by electric shock. Measurements were made near the perception threshold to the tolerance limit. Table 1 lists average response thresholds as multiples of the mean perception threshold for shocks delivered to the fingertip and forearm. The dynamic range may be compared with hearing or pressure sensitivity, both of which have dynamic ranges of about 100,000 to 1.

We studied a large sample of subjects to investigate the statistical distribution and correlates of electrical sensitivity. Figure 2 shows statistical distributions of perception and annoyance thresholds pertaining to 124 adults, including 25 college women, 24 college men, 25 female office workers, and 50 male maintenance workers. The distributions have a lognormal form and show significant differences in sensitivity between men and women. Further breakdown showed that the maintenance workers had higher thresholds than any other subgroup.

It might seem that a factor related to sex and occupation could partially account for individual sensitivity differences, but a multiple regression analysis showed that the apparent sex and occupation differences are artifacts of an underlying body-size dependency: the women in our sample group tended to be smaller than the men, and the maintenance workers were larger than the college men. When these size differences were taken into account, no statistically significant differences in sensitivity between the groups remained.

Another aspect of our research was to develop computational models to define the electrical factors responsible for nerve stimulation. This work led to a neuroelectric model.[22] With the aid of the model, we were able to explain the underlying basis for the various threshold curves shown in Figure 1. The model has since been used in many other medical applications of electrical stimulation.

Other Studies

Although space does not permit summaries of all the noteworthy research conducted, the following list provides some sense of the scope of our work.

1. The likely distributions of coal-fired and nuclear power generating stations for different growths in electrical energy demand were determined by a series of studies over many years using multi-objective optimization techniques.[23]
2. The location of radiological waste storage facilities away from reactors was evaluated using multi-objective techniques.
3. Safety risks of the liquefied natural gas facility at Cove Point on the Calvert Cliffs nuclear plant were evaluated.[24]
4. The behavior of mechanical draft cooling-tower plumes was studied at the Benning Road power plant.

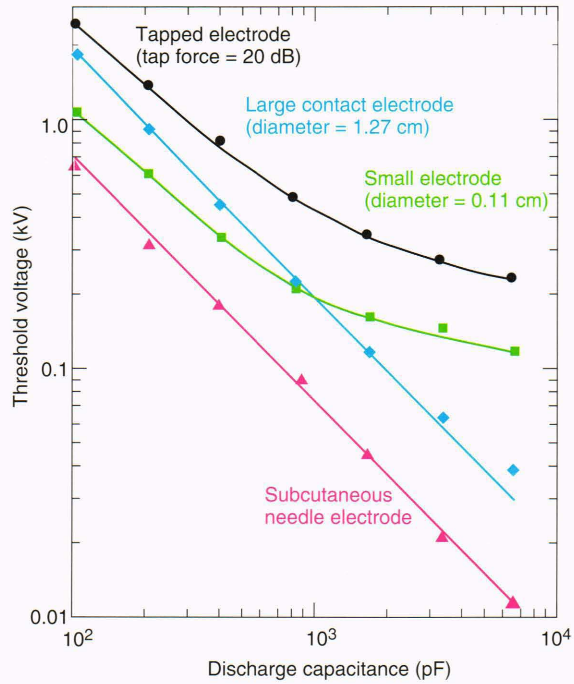

Figure 1. Threshold sensitivity curves for four methods of stimulation using capacitive discharges of positive polarity. The measured data were slightly adjusted to conform to a large sample result.

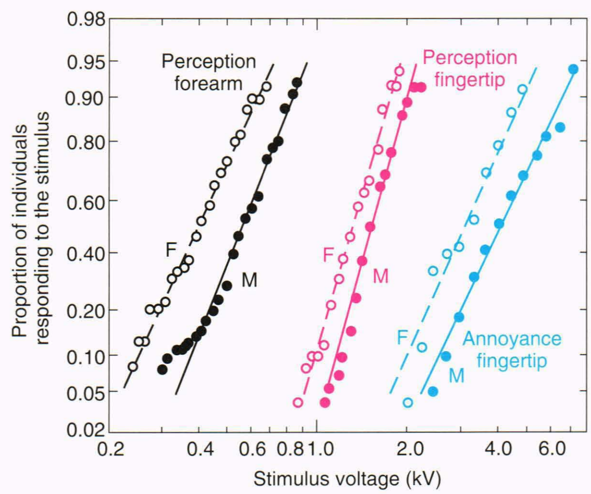

Figure 2. Cumulative probability that a capacitive discharge (+ polarity, 200 pF) exceeds perception or annoyance thresholds. Samples consisted of 74 males (M) and 50 females (F). Discharges on the fingertip were given via a tapped electrode; discharges on the forearm were given via a 0.5-cm-diameter contact electrode.

Table 1. Average response thresholds as multiples of the mean perception threshold for shocks delivered to the fingertip and forearm.

Response category	Fingertip		Forearm	
	100–1600 pF	6400 pF	100–1600 pF	6400 pF
Unpleasant	2.3	1.7	3.5	2.5
Painful	3.5	2.5	5.5	4.0
Tolerance	7.1	5.1	11.0	7.9

5. A model of cooling-tower thermodynamics was developed.[25]

6. A highly reliable meteorological tower was developed and put into operation at the Bainbridge site.

7. A computer model for cooling-tower plume and saline drift was developed.[26]

8. An acoustic sounder to characterize upper-air meteorology was evaluated.[27]

9. A major experiment at Chalk Point was concluded involving the development and use of a dye tracer technique to measure cooling-water saline drift emissions and fallout.[28]

10. The effect of transmission lines on property values was evaluated.[29]

11. A model for the prediction of leachate generation from coal combustion wastes was developed.[30]

12. The rate constant for the decomposition of N-bromoalanine was determined.

13. Methods for determining arsenic and selenium speciation were evaluated.

14. The effects of arsenic and selenium on striped bass eggs, larvae, and juveniles were evaluated.

15. Macrofouling control in power stations by free-field ultrasonic radiation was studied.[31]

16. The toxicological effects of various munitions on aquatic organisms were determined by a study funded by the U.S. Army.[32]

17. Five aspects of fugitive coal dust were studied: emissions from a rail car dumper, emission reduction by watering, particle-sizing techniques, coal-pile dust emissions, and fugitive dust emission models.[33]

CONCLUSIONS

Much of the progress against environmental degradation must be established in the trenches, ensuring that decisions on individual actions are sound and that a valid scientific basis exists for those decisions. In this light, APL's two decades of involvement in environmental and energy work are an outstanding example of how science and technology can provide an informed basis for environmental policies and decisions. Although we can be proud of our past accomplishments, the importance of environmental issues is at least as great today, and many important technical problems remain unresolved. Under appropriate circumstances, the staff and facilities of the Laboratory could again make major contributions in environmental areas.

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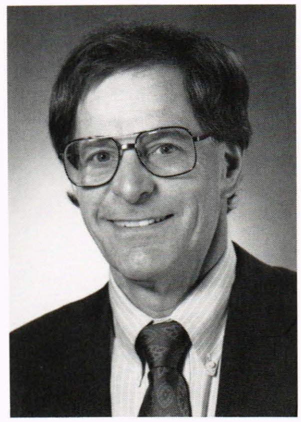

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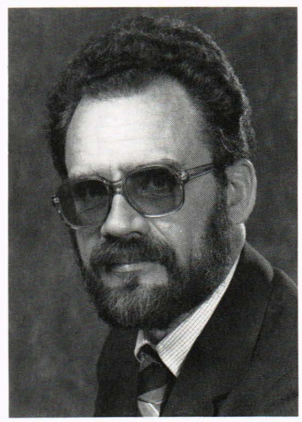

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