MEASURING THE ENVIRONMENTAL
EFFECTS OF THERMAL DISCHARGES

Raymond S. Harvey and Duncan Randall

Savannah River biologists have launched an expanded program at their new Thermal Effects Laboratory to evaluate the ecological consequences of warm water discharges from industrial processes and power plants.

For more than twenty years, scientists at the Savannah River Laboratory have studied the environmental effects of both radioactive and thermal discharges accompanying nuclear reactor irradiations and chemical separations at the Savannah River Plant. All studies, both by Du Pont scientists and by other organizations, indicate that operation of the Savannah River Plant has had minimal effects beyond plant boundaries, and only very localized effects within the plant site itself.

As part of this continuing program, a special Thermal Effects Laboratory was constructed in 1971 to study quantitatively the long-term effects of slightly heated effluents on the ecology of plant and animal life in natural streams. Fundamental investigations of subtle effects of slight temperature rises on aquatic biota will improve our ability to predict reliably the ecological consequences of new enterprises.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Description of SRP

The Savannah River Plant (SRP), built and operated for the U. S. Atomic Energy Commission by Du Pont, was established in 1950 to produce plutonium-239 and tritium for national defense. Since then, the number of products has been increased to include many radionuclides for civilian use, such as plutonium-238 for self-contained power sources for space exploration and cardiac assist devices (*Du Pont Innovation* Vol. 2 No. 3, Spring 1971, p. 13); cobalt-60 for possible use in X-radiography and food preservation and as a power source; and californium-252 for neutron radiography, industrial process control, mineral exploration, and possible cancer therapy (*Du Pont Innovation* Vol. 1 No. 3, Spring 1970, p. 4).

SRP occupies 300 square miles in rural South Carolina along the Savannah River, 25 miles southeast of Augusta, Georgia. The site includes three operating nuclear reactors, two chemical separations plants, a heavy-water production facility, a fuel and target fabrication plant, the Savannah River Laboratory (SRL), a local unit of the U. S. Forest Service, and the Savannah River Ecology Laboratory (operated since 1961 by the University of Georgia).

These facilities occupy only a small portion of the site. The remainder, from most of which the public is also excluded, has become a natural preserve for plants and animals indigenous to the southeastern Coastal Plain. Radioactive releases are limited to extremely low levels and have no significant effect on wildlife. In June 1972, SRP was designated as the nation's first National Environmental Research Park, to encourage investigators from universities and research organizations to pursue environmental studies.

Environmental Monitoring at SRP

Programs to assess and minimize environmental effects of SRP operations were initiated before the first cubic yard of concrete was poured. The scope of these programs has steadily expanded; for fiscal year 1973 alone, about \$10 million is being spent for environmentally oriented activities. The variety of past and present programs can only be suggested by mentioning a few activities.

Du Pont chemists and health physicists maintain constant surveillance of the slightest radioactive emissions to the atmosphere, to ground water, and to the Savannah River. Non-radioactive pollutants such as mercury, sulfur, fly ash, etc., are closely monitored. Air is routinely analyzed as far away as 120 miles from SRP. Drinking water, vegetation, animals, fish, milk, and farm produce are regularly sampled in a 1200-square-mile area around SRP.

Surveillance of the Savannah River has detected only minute traces of six of 400 radionuclides formed in SRP reactors, principally tritium, strontium-90, and cesium-137. Thermal and biological monitoring of the river, including six comprehensive surveys by the Limnology Department of the Philadelphia Academy of Natural Sciences between 1951 and 1972, has revealed no evidence of any detrimental temperature effect on algae, insects, invertebrates, or fish due to SRP operations.

These findings have been confirmed by other independent agencies, including biologists from the Universities of South Carolina and Georgia (who conducted surveys of birds and ecosystems at SRP during 1951-1960), the U. S. Geological Survey (which has monitored river water temperature since 1951), the Environmental Protection Agency, and pollution control authorities of both Georgia and South Carolina. All indications are that SRP has had minimal effect on the off-site environment and on the health of both employees and off-site populations.

Thermal Discharges from SRP Reactors

The slight temperature increase in the Savannah River caused by SRP operations averages 1.1°F and has never exceeded 2.5°F; this is well within the 5°F allowed by South Carolina Water Quality Standards. In fact, solar heating as the river flows past the plant site is usually greater than SRP's contribution.

Practically all of the heat discarded to the environment arises from current operation of three of SRP's five nuclear reactors; two have been mothballed for several years. Utilization of this waste heat for electric power generation is not economically feasible, because the reactor effluent cooling water is not hot enough. Instead, the effluent from one reactor is cooled by recirculation through a 2640-acre water impoundment, Par Pond, from which no heat reaches the Savannah River. Effluent from the other two reactors flows through miles of natural streams and swamps, shielded from solar heating by heavy vegetative growth; little of this waste heat reaches the river, most being dissipated by evaporation and air cooling en route. Consequently, the highest temperature ever measured in the Savannah River at SRP was 84.9°F, even with all five reactors operating, which is well below the maximum 90°F allowed by South Carolina.

Within SRP boundaries, however, there are some localized effects. Downstream from reactor coolant outlets, many trees in or near the natural streambeds have died from thermal effects of flooding. Although fish no longer thrive near coolant outlets, bass are attracted to warm waters farther downstream during the winter; growth rates and body size of some turtles are increased. These effects diminish with distance from the coolant outlets, but persist down to and partly into the 7470-acre swamp along the Savannah River. Where streams receiving coolant finally enter the river, plant and animal populations are almost unaffected.

About 100 acres of Par Pond average 2-7°F warmer than the natural pond temperature. Eutrophication* has resulted from evaporative concentration of pond water accompanied by influx of minerals from the Savannah River during reactor cooling. As a result, plankton photosynthesis increased fivefold between 1965 and 1970; but the increased mass of plankton was consumed by fishes and turtles, which grew faster and larger than usual. No deleterious bloom of algae and plankton appeared, and the concentration of dissolved oxygen was diminished only in deeper water. Par Pond has now become a beautiful lake inhabited by a large variety of aquatic animals and used as a refuge by thousands of migratory birds.

These observations suggest the complex interplay of many factors when the environment is thermally stressed. The gross effects of thermal discharges from SRP operations are acceptably low. But even small temperature increases may have subtle ecological consequences; and thermal discharges from power plants situated closer to rivers or lakes might cause larger temperature increases and therefore significantly greater effects. SRL's Thermal Effects Laboratory provides advanced research facilities for evaluating whatever long-term ecological consequences might follow even small temperature increases.

The Thermal Effects Laboratory

This new aquatic research establishment was built on the bank of Upper Three Runs Creek, the longest of four streams on the plant site that flow into the Savannah River. It includes a greenhouse enclosing six experimental flowing streams, three outdoor fish ponds, and a laboratory equipped with sophisticated instruments for biological studies. Water for these streams is pumped from the main channel of Upper Three Runs; part of this water may be heated in a thermal headtank before introduction into the streams.

*An increase of mineral and organic nutrients that reduces the concentration of dissolved oxygen, producing an environment that favors plant over animal life.

The Parent Stream. Upper Three Runs Creek was chosen as the source of water for the experimental streams and ponds because (1) most of its 190-square-mile drainage area lies within SRP boundaries; (2) it has never received heated discharges of cooling water from production reactors; (3) its water quality is excellent; and (4) it has a wide diversity of plant and animal species.

The streambed is moderately to heavily shaded by thick stands of alder, gum, hickory, and oaks along the banks. Adjacent to the laboratory, the creek is about 50 feet wide and 3 feet deep, with an average current of about 1 mph. Water temperature varies from 41°F in winter to 74°F in summer.

Pumping and Temperature Adjustment. Two 400-gpm centrifugal pumps, operating alternately, supply creek water to the experimental streams and ponds. The standby pump starts automatically whenever the operating pump stops or is turned off.

The temperature of part of the incoming creek water can be raised 20°F in an 800-gallon thermal headtank containing twenty-six 10-kilowatt electric immersion heaters. This warm water can be mixed with unheated creek water flowing into the experimental streams to maintain the desired temperature differentials between the creek and the streams. At present, water to all six streams is still unheated, allowing aquatic biota to stabilize at natural levels.

With the exception of the concrete intake in Upper Three Runs and the carbon-steel pumps, all materials contacting the creek water are polyvinyl chloride (PVC) plastic or stainless steel, to minimize contamination of the experimental streams. The intake is covered by 2" x 2" mesh screening to keep large organisms and detritus from fouling the pumps, yet permit smaller organisms to enter the experimental streams.

The Greenhouse. The 25 x 62-foot glass greenhouse admits natural illumination to the six experimental streams. Screens over each stream provide shading comparable to that in Upper Three Runs. Air conditioning prevents the streambeds and substrates from becoming warmer than those in the creek during the hot summer months. Light intensity and water velocity, turbidity, and nutrient concentration are identical in all six streams.

These experimental streams differ from artificial stream systems studied at other sites in that (1) the greenhouse streams receive natural illumination with the same diurnal and seasonal patterns of sunlight as the parent stream; (2) organisms are seeded naturally by parallel, once-through flow of creekwater through each stream; and (3) the influent water to four of the six streams will be heated to simulate conditions near thermal discharges of nuclear power plants.

Construction and Colonization of the Streams. Each of the six streams consists of two U-shaped PVC channels 9 feet long, 1 foot wide, and 1 foot deep connected to a small intervening pool 4 feet long, 2 feet wide, and 2.5 feet deep. Flexible PVC joints permit channels to be raised or lowered to adjust the slope for the desired water velocity and riffing. Flow in each stream is 50 gpm, approximating the 1-mph current in the creek. Feed waters from the cold and warm water headers flow across a measuring weir into the inlet channel, through the pool, into the outlet channel, and back into one of the outdoor fish ponds or directly into the creek.

Streambeds were prepared for colonization by adding substrate materials from Upper Three Runs to simulate niches and habitats in which algae, insects, and other invertebrates live naturally. A 4-inch layer of smooth rocks was placed in the bottom of each stream and covered with 3 inches of sand and occasional mud to simulate the loose, sandy, porous bottom of Upper Three Runs. Small sticks and limbs were inserted between the rocks and across the sand to represent logs and fallen trees in the creek. Two species of aquatic plants were rooted after substrates were stabilized by stream flow. Natural

habitats are thus simulated by patches of black swamp mud, ripple areas formed by smooth pebbles and broken branches, small pools of slack water, and a deeper, quiet pool for organisms that need a darker, undisturbed environment.

Organisms in the influent creek water attach themselves to these substrates and become part of the experimental stream community. Although attached algae and insects became common in all streams after only one month, about a year was required before species diversity became comparable with that in the creek.

Fish Ponds. Three 20-foot-long, 15-foot-wide, 4.5-foot-deep concrete ponds between the greenhouse and the creek will be used to study the effects of temperature on productivity of freshwater fish. These ponds can be heated by effluent from three of the six experimental streams when stream temperature studies start; or they can be heated directly with water from the thermal head-tank, as in the preliminary bacterial study described below.

Test Objectives. The experimental streams will allow precisely controlled, long-term ecological studies of the effects of slight elevations in water temperature, while maintaining most of the characteristics of natural streams.

Although construction of the Thermal Effects Laboratory was completed in October 1971, the experimental streams will not be heated until late fall 1974. This allows time for establishment of stable populations in the streams, testing of control systems, and determination of seasonal variations in diversity, population density, and productivity of various species of algae and insects under natural conditions. When these reference conditions have been established, four of the streams will be warmed by mixing influent creek water with water from the thermal headtank, simulating the effect of coolant effluent from a power plant. Two streams will be heated 10°F and two will be heated 5°F above creek water temperature; two unheated streams will serve as controls.

Effects of this heat stress will be determined in several ways. Shallow trays of rock, sand, and sticks buried at intervals in the streams will be removed temporarily to measure the respiration rates of attached organisms and

estimate their numerical abundance. Species diversity and stream productivity will be measured with fine-mesh insect traps and plastic boxes containing microscope slides installed in the streams. Water quality will be monitored by periodic chemical and bacterial analyses.

Studies will not only determine the gross effects of small temperature changes on the general health of a nonpolluted stream, but will also measure in detail the effects on:

- o The number of individual organisms per species.
- o The diversity of species.
- o The relative dominance of various species.
- o The population structure of species -- do young plants or animals grow faster, and is their life span affected?
- o The metabolic rates of both individuals and communities of organisms.
- o The standing crop (total amount of organic matter) in a given area of streambed.

Preliminary Studies

Several studies have been carried out in Upper Three Runs and the fish ponds while waiting for colonization and population stabilization in the experimental streams.

Temperature Effects on Bacteria. Aquatic bacterial populations vary with geographical location, current velocity, chemical content of the water, circulation or stratification, and temperature. Cooperative investigations with Clemson University biologists showed that temperature increases up to 20°F in three flowing, non-polluted aquatic systems increased total culturable bacterial populations as much as 20-fold, but decreased species diversity.

Figure 1 shows seasonal fluctuations in total bacteria population in Upper Three Runs Creek and in two of the three fish ponds. Bacteria counts for the six experimental streams (not shown) agreed closely with counts for the creek,

indicating that natural conditions have been duplicated in the laboratory. Bacterial populations in the ponds were generally higher than in the creek, because of excrement from about 50 fish in each pond. The bacterial population of Pond 2 rose above that of Pond 3 after Pond 2 was heated 5-9°F above ambient; before heating, the Pond 2 population was somewhat lower than in Pond 3 because Pond 2 is more heavily shaded from solar heating.

Figure 1 also shows that bacterial species diversity increased initially with increasing temperature, but then declined as the temperature approached lethal levels for some species. Other studies suggest that the genus *Brevibacterium* is the major group stimulated by heating in this temperature range; *Bacillus* is more or less unaffected; and *Sarcina*, *Micrococcus*, and other groups are inhibited.

Effect of Temperature on Growth and Radionuclide Uptake. Aquatic plants and animals living in reactor effluent streams at SRP are chronically exposed to microscopic traces of radioactivity as well as elevated water temperatures. The ability of algae, midge larvae, and freshwater shrimp to accumulate radionuclides was measured, because these organisms are important in the foodchains of fish, water fowl, and ultimately man.

The table shows that moderate increases in water temperature generally increase, then decrease, organism growth rates. Radionuclide uptake depends not only on the particular organism, but also on the particular nuclide and the temperature. No easy generalization appears possible.

Effect of Temperature on Growth and Respiration. Respiration rates of mayfly nymphs, *Dolania americana*, were measured to determine how water temperature affects oxygen consumption of benthic organisms.* The nymphs burrow into the

* Plants and animals that attach themselves to substrate materials, and depend on water currents to bring them food and oxygen.

sandy substrate of black-water streams;** although common in Upper Three Runs, *Dolania* have been reported in only three other streams in the U. S.

Growth rates increased with seasonal increases in creek water temperature until the two-year-old nymphs emerged in June and July. Respiration rates also increased, in keeping with the lower concentration of dissolved oxygen in water at higher temperatures. Figure 2 shows that respiration rates are about 15% higher for nymphs in water baths operated 9°F above creek water temperatures, but the seasonal pattern of respiration was not altered by the higher temperatures.

Implications for the Future

Results of studies at the Thermal Effects Laboratory will be applicable to the soft, black-water streams of the Atlantic Coastal Plain because of similar physical, chemical, and biological characteristics. Long-term studies of the effects of small increases in water temperature on lake and river biota will lead to a better understanding of the environmental effects of power generation from both nuclear and fossil fuel.

The tangible benefits of the production of power and industrial products must always be weighed against less immediately evident costs -- possible degradation of the beauty and healthfulness of our surroundings, and reduction of our natural resources heritage. Our present knowledge of ecology is far from adequate to assure that a proper balance can always be achieved; for lack of information, we must frequently assume the worst. Research at the Thermal Effects Laboratory will contribute significantly to the growing body of hard, factual knowledge that is necessary for any *realistic* evaluation of the environmental effects of present and future industrial operations.

** Streams whose waters have been darkened by colloidal suspensions of tannins and lignins from decomposing leaves and other vegetation.

TransparencyCaption

1. Augusta College Biology Professor Harvey Stirewalt (left) and Savannah River Laboratory biologist Ray Harvey examine new plant growth in the middle pond section of one of the six experimental streams in the greenhouse.
2. Savannah River Laboratory Technologists Al Parrott (left) and Jim Foreman collect aquatic insects from the middle of Upper Three Runs Creek. In the background are the greenhouse (left) and the analytical laboratory; also shown (right) is the water intake structure in the creek that supplies water to the experimental streams and the fish ponds.
3. Ray Harvey measures the concentration of dissolved oxygen in one of the three fish ponds between the greenhouse and the creek. In the center background is the analytical laboratory.
4. In the analytical laboratory, Ray Harvey identifies algae with a Unitron phase-contrast biological research microscope.
5. Ray Harvey (right) and Professor Stirewalt measure oxygen consumption by insects with a Gilson Medical Electronics differential submarine respirometer.

Figure 1. Effect of Water Temperature on Bacterial Growth and Diversity

Figure 2. Effect of Water Temperature and Season on the Respiration Rate of the Mayfly *Dolania Americana*

Figure 1.

Respiration rate (microliters of oxygen consumed per hour per milligram of body weight) at
 ambient temperature ●——●
 ambient temperature + 9 °F ○---○

Figure 2.

Aquatic Organism Growth and Radionuclide Uptake

Organism	Max. Concentration Factor ^a at any Temperature for		Effect of Temperature Increase from 73° to 104°F on Radionuclide Uptake			
	⁸⁵ Sr	¹³⁷ Cs	Growth Rate	Decreases for	Little Effect for	Increases for
Green Alga, <i>Stigeoclonium lubricum</i>	1300	980	max. at 84°F	---	⁵⁷ Co, ⁶⁵ Zn, ⁸⁵ Sr	⁵⁴ Mn, ⁵⁹ Fe, ¹³⁷ Cs
Blue-Green Alga, <i>Plectonema boryanum</i>	3000	1100	max. at 86°F to 95°F	⁵⁷ Co	¹³⁷ Cs	⁵⁴ Mn(max. at 95°F), ⁵⁹ Fe, ⁶⁵ Zn, ⁸⁵ Sr
Diatom, <i>Navicula seminulum</i>	7500	1400	max. at 79° to 84°F	---	⁸⁵ Sr, ¹³⁷ Cs	⁵⁴ Mn, ⁵⁷ Co, ⁵⁹ Fe, ⁶⁵ Zn
Midge Larva, <i>Glyptotendipes paripes</i>	35	55	max. at 88°F (97° lethal)	⁵⁹ Fe, ¹³⁷ Cs	⁵⁷ Co	⁵⁴ Mn, ⁶⁵ Zn, ⁸⁵ Sr
Midge Larva, <i>Chironomus plumosus</i>	50	30	max. at 73°F	--	---	⁵⁴ Mn, ⁵⁷ Co, ⁵⁹ Fe, ⁶⁵ Zn(max. at 79°F), ⁸⁵ Sr, ¹³⁷ Cs
Freshwater Shrimp, <i>Palaemonetes paludosis</i>	1600	620	half die at 84°F	⁶⁵ Zn, ⁸⁵ Sr, ¹³⁷ Cs	---	---

a. Picocuries of radionuclide per gram of body weight divided by picocuries of radionuclide per gram of laboratory culture solution. One picocurie of any radionuclide is that amount which yields 2.2 disintegrations per minute.

Biographies

Raymond S. Harvey, a biologist in the Environmental Sciences Division of the Savannah River Laboratory, received his B.S. in Biology from Emory University in 1949. He was employed in pharmaceutical sales by Merck Sharp and Dohme before joining Du Pont at the Savannah River Plant in 1954, where he served as a health physicist and later as a supervisor of biological monitoring and associated research. He transferred to SRL in 1965, where his studies shifted from radioecology to thermal ecology. He is currently in charge of aquatic research at the Thermal Effects Laboratory. Duncan Randall joined Du Pont in 1941 after receiving a B.A. degree from Brooklyn College. He left to take graduate work, received the M.A. degree from Columbia University and, in 1950, the Ph.D. in Physical Chemistry from Fordham University, and returned to Du Pont's Photo Products Department. The same year, he transferred to the Explosives Department and was temporarily assigned to the Knolls Atomic Power Laboratory, Schenectady, N.Y. In 1954, he moved to the Savannah River Laboratory's Theoretical Physics Division, working primarily on isotope separations, reactor kinetics and stability, and reactor charge design. He has worked in SRL's Technical Information Service since 1970.