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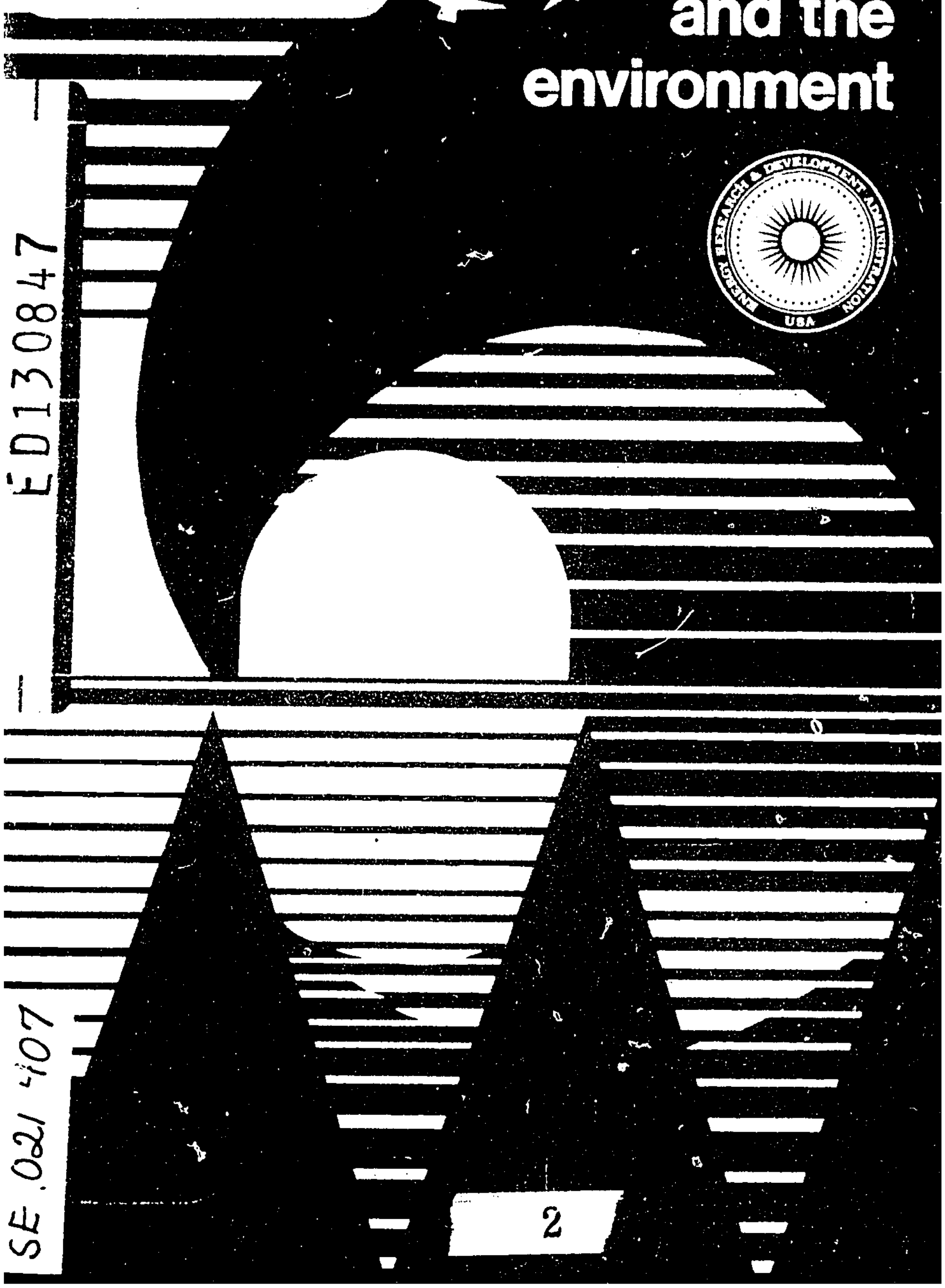
ABSTRACT

Described are the major environmental effects resulting from the production of electricity by nuclear power plants. Discussed are effects of waste heat, radioactivity, radioactive waste elimination, costs, and future prospects. Included are diagrams illustrating cooling tower operation, effects of thermal discharge into water systems, radioactive waste disposal facilities, and a reading list. (SL)

nuclear power and the environment



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Nuclear Power and the Environment

by Joseph M. Dukert

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Getting Down to Basics

"Environment" is a word that's used a lot these days, but it's hard to define. Literally, it means "surroundings", and so the term must signify quite different things to a Missouri farmer and to a lifelong resident of Manhattan. Yet they could agree on some general goals for protecting (or improving) the extremely complex thing that everybody calls "*the* environment." We all prefer clean air, water that's safe for both fish and people, and an uncluttered land, whose resources are used wisely. That sounds simple and logical, but it adds up to a big order—especially when progress toward one such goal may not automatically help to reach the others. Where do we even begin?

"Energy" is probably as good a starting place as any. Energy is the ability to do work, and it comes from muscles, steam engines, electric motors, etc. This country requires more energy today than ever before in its history. Despite conservation measures prompted by a potential energy shortage, Americans will use more energy of all kinds during the next 12 months than they did during the entire 19th century. This is partly because of an expanding population, partly because of changed life styles in an industrial society, and partly because a prodigious amount of energy will go into cleaning up the environment. More power is needed now for the recycling of solid wastes, for water treatment plants, and for all sorts of pollution abatement systems. In one sense, at least, energy is clearly a tool that can be used to protect the environment.

However, there could be a catch!

Movements of warmwater game fish in natural environments and in thermally affected areas are monitored by battery-powered "beeper" tags that sense temperature.

The fastest growing form of useful energy in this country is electricity, but electricity-generating plants tend to be polluters themselves. Coal-burning power stations, for instance, can't avoid releasing some combustion products. Nuclear plants, although they avoid the latter problem, add a certain amount of radioactivity to the natural background radiation. In fact, any means of producing energy is subject to criticism: Some day, for instance, it may be possible to tap "geothermal energy" (the heat of the earth itself) on a moderately large scale, but that prospect arouses the opposition of some people who fear that chemical contamination of the surrounding area could be a side effect. Solar energy and fusion power may produce environmental problems too, when they finally reach the stage where they can be implemented on a large scale—perhaps late in this century.

None of these worries can be overlooked, and new steps are being taken continually to make sure that power generating stations of all kinds will do their job in the way that's best for public health and welfare. Still, many questions have to be answered before citizens in any particular community can appreciate the balance between costs and benefits as they apply to their own environment and their own energy needs. Case-by-case details are needed for intelligent decisions about the types of power plants that can best produce the energy that is needed. In every case, the total environment ought to be considered: Air, water, land, and other vital, limited resources.

This booklet will explore and help answer some of the major questions about effects on the environment that might be produced by just one increasingly important energy source—nuclear power plants. It won't try to get into the specifics of the 200 or so commercial power reactors that are already operating, being built, or definitely planned in various parts of the U. S. That would be impossible in the space available. Before each new plant is finally licensed to begin operation, many thousands of pages must be filled with studies, reports, and data about its potential environmental effects. In fact, environmental analyses begin well before construction gets underway. Depending on the site, each plant might have to be reviewed by dozens of different government departments, commissions, and agencies at the local, state, and federal level. Testimony at various public hearings could easily add more thousands of pages.

What a brief booklet like this can do is to help its readers understand what they hear or learn about those individual cases. Knowing the basics makes it easier to evaluate specifics.

During the next few years, many decisions will have to be made about how additional electricity is to be produced. Utilities and their customers will face various choices, and nuclear power will be one of them.

Electricity and Waste Heat

People who argue either for or against nuclear power plants often try to oversimplify the problem of thermal effects, which are the results of temperature changes in the water near a generating station. A difference of only a few degrees may seem slight, yet there are circumstances in which this could make a vital impact. On the other hand, a person who talks about a "steam plant" might make it sound like something that will boil fish alive. Unfortunately, technical terms like "condenser" and "cooling tower" don't always help. They may even add to the confusion at times, because many people don't really know what such things are or why they are needed. Certain other terms such as "efficiency" seem simple enough, but actually have several different meanings.

Where Does the Heat Come From?

In principle, all large power plants are remarkably similar. Despite success with other methods on a small scale, the only practical way of producing large amounts of electricity on a continual basis is to rotate a big magnet rapidly inside coils of wire. The shaft of the magnet is usually linked directly to the shaft of a turbine, which is sort of a sophisticated paddle wheel. The only basic difference among the major types of power plants is the energy source each one starts with—that is, its means of spinning the turbine.

Sometimes the force of falling water does the trick, and that eliminates the problem of thermal effects completely. The number of such "hydroelectric" plants will always be limited, however. There are relatively few places where suitable natural waterfalls exist or where dams can be built

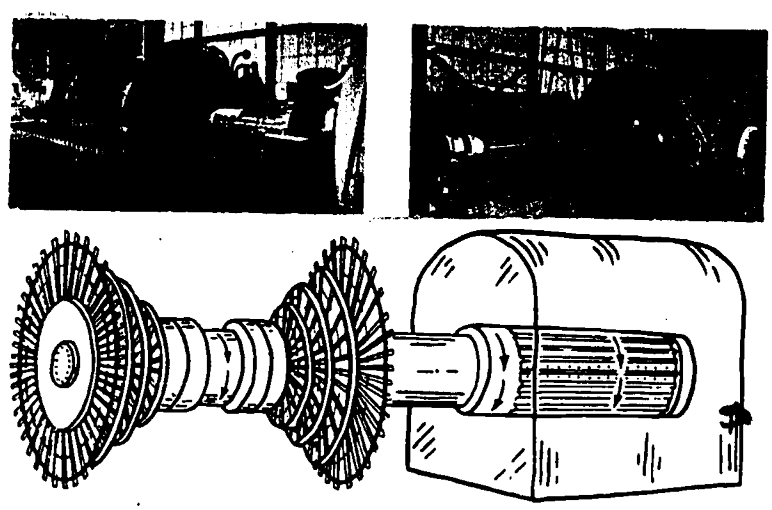
The Trojan Nuclear Power Plant near Prescott, Oregon, is on the shores of the Columbia River. The plant, shown under construction, will have a capacity of 1,130,000 electrical kilowatts. On the right is the 499-foot-high cooling tower. The facility will include a recreation lake, boating facilities, a reflecting pool, and a whistling swan lagoon.

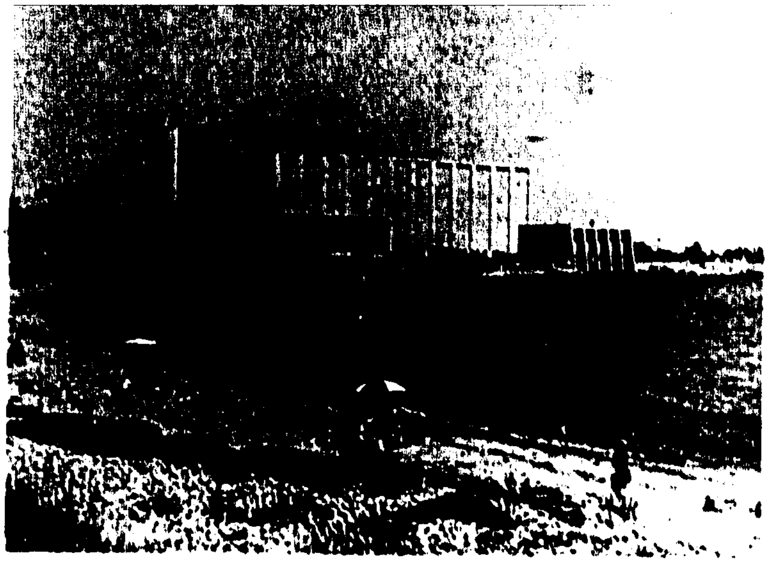
effectively. A much more common method of spinning the turbine is to force a gas across its blades at high velocity. The gas used most often is ordinary steam. In a nuclear power plant, fissioning atoms supply the heat to turn water into steam for this purpose. In a fossil-fuel, steam-electric plant the heat comes from burning coal, oil, or natural gas.

In any case, it's important to remember that the steam involved is not released after passing through the turbines. Instead, it changes back to liquid form in a *condenser*. As water, it then flows back into the plant's steam source to be reused. This is a continuous closed cycle: Water to steam, steam to water, water to steam, etc. The steam has no direct effect on the outside environment, because it never leaves the plant.

Nevertheless, no generating plant succeeds in converting all this energy into electricity. If a plant burns fossil fuel, part of the heat is lost up the smokestack. In either a fossil-fuel or a nuclear plant, some heat is necessarily given off through the condensers. (See illustration on page 8.)

In all large power plants, electricity is generated when a spinning turbine (left) rotates a magnet inside coils of wire within a generator (right). The force that drives the turbine may come from falling water or from combustion gases, but in all nuclear plants and in most nonnuclear ones it comes from steam. Inset photos show real equipment during assembly.



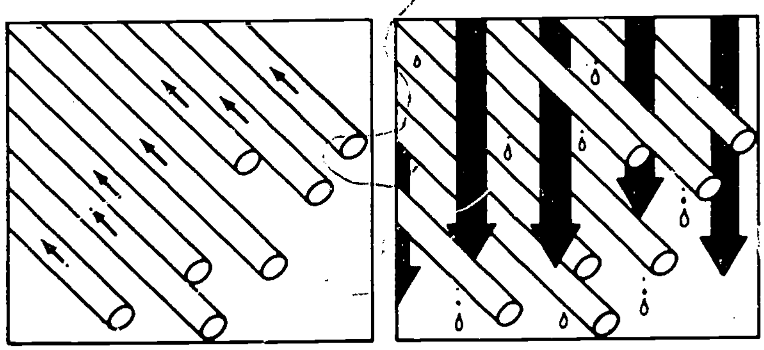


The Millstone Nuclear Power Station Unit 1, which has a 652,100-kilowatt capacity, is on Long Island Sound at Waterford, Connecticut.

Steam is produced in a power plant at very high temperatures and under extremely high pressure. It cools quickly, however, because most of its heat energy is transformed into "energy of motion" as it spins the turbines. Its pressure drops as it cools, and the steam finally enters a partial vacuum inside the condenser. At that point, the steam has "spent" all its usable energy, but it must lose more heat in order to reenter the liquid state. (That's a fundamental rule of physics.) A typical condenser design may consist of several thousand metal tubes through which relatively cool water from a separate source is constantly pumped. As the "spent" steam passes over the outside surfaces of these pipes, it loses the necessary amount of heat energy to the water flowing through them and finally condenses to liquid. This last transfer of energy represents "waste heat", because it doesn't contribute anything to the plant's electrical output.

As both fossil-fuel and nuclear plants have grown in size, they have released larger amounts of waste heat to the rivers, lakes, and other bodies from which they draw cooling water for their condensers. The increased use of nuclear power has focused more attention on thermal releases, however, because

The figures on this page show the source of most waste heat in a steam-electric plant. This photo of a condenser gives a "cutaway" view that will be hidden later when the huge inlet pipe for cooling water covers the face. During operation, steam will enter from the top of the condenser shell, condense on the relatively cool surfaces of the long horizontal tubes inside, and fall like rain to a collecting basin below. The cooling water never touches the steam and passes through the condenser in a few seconds, but its temperature may rise between 10° and 30°F during the quick trip. In some systems the temperature of the steam itself may be only about 100°F, however, as it moves through a partial vacuum.



On the left, cooling water passes through the metal tubes continuously to absorb "waste heat" through the tube walls. On the right, steam, which has already used up most of its heat driving turbines, condenses on the outside of the tubes.

of two factors: (1) It is much cheaper and more convenient to build a few large nuclear plants than many smaller ones; and (2) A typical nuclear power plant rejects about half again as much heat through its condensers as the most advanced fossil-fuel plants of the same generating capacity. One reason is that fossil-fuel plants discharge about 20% of their waste heat directly into the atmosphere via their stacks—thus "splitting the load". But it is also true that current nuclear plants are slightly less efficient in using heat than the best coal plants built to date.

The increased size of modern generating plants—nuclear *and* fossil-fuel—isn't a totally negative factor from the standpoint of environmental protection. Larger plants generally release less heat in proportion to the amount of electricity they deliver, and this improvement is more marked in the case of nuclear plants as their size increases.* Nevertheless, a single large plant tends to concentrate the thermal effects more than several scattered, smaller ones would. And, as for the difference in operating efficiency between nuclear and nonnuclear plants, it's worth explaining in a bit more detail. Efficiency in this case has nothing to do with either reliability or economics; in certain ways nuclear power holds the edge on both those counts. Thermal efficiency is simply a measure of electrical output from the generators, compared with the plant's basic heat output.

For example, if the heat source produces 3000 megawatts of heat and the plant ultimately generates 1000 megawatts of electricity, its efficiency (in this sense) is 1000 MW† divided by 3000 MW, or 33.3%. For the most part, commercial nuclear power plants in the United States have thermal efficiency ratings of about 32%. This is far better than many

*In addition, new *types* of nuclear plants will be able to match the thermal efficiency of today's fossil-fuel plants. Those prospects will be discussed later in this booklet.

†MW stands for megawatts. To distinguish between heat energy and electrical energy, the abbreviations MWt (megawatts—thermal) and MWe (megawatts—electrical) are also used.

fossil-fuel plants, and it is close to the national average; but it's not quite as good as the small group of 38 to 40% plants that have been built to use fossil fuel in recent years. The major difference has been that the steam in nuclear plants isn't produced at temperatures and pressures as great as those in fossil-fuel plants. Nuclear power is closing the gap, however, and more will be said about this later on (see pages 63-69).

What's To Be Done?

There are several ways of handling the thermal problem for either a fossil-fuel or a nuclear plant; and it's impossible to say which will be best in any given situation until that particular case is studied. In fact, the problem itself may vary from serious to insignificant—depending on the plant site. Only one thing is certain: The owners of a new nuclear generating plant will not be permitted to operate it (or even to start building it) until they have shown convincing evidence that waste heat from this specific plant arrangement won't do any substantial environmental damage in this location.

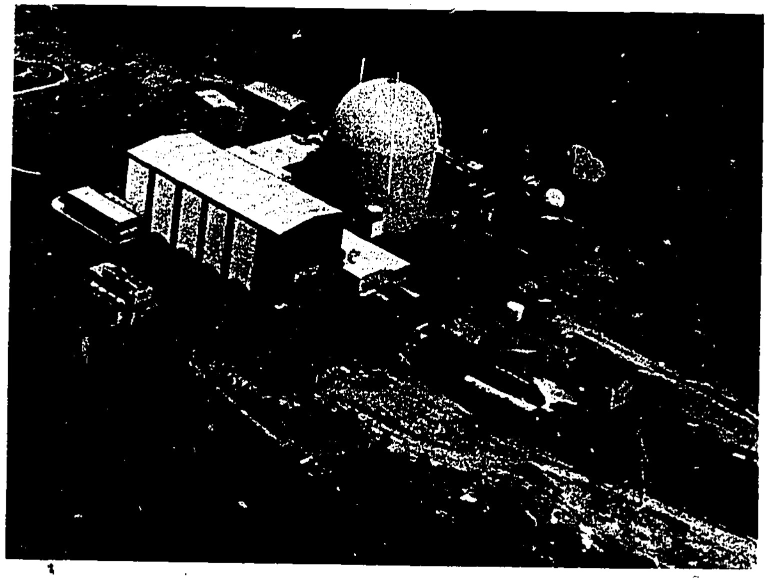
Several million gallons of cooling water per minute may flow through a plant's condensers, but obviously it makes a big difference whether this is taken from a narrow river or a deep, wide bay. Will the temperature of the entire water supply be affected, or is the condenser outflow "a drop in the ocean"? Relative volumes are important. Also, are there tides and currents that help remix the waters?

The natural temperature range of the water is important too. How warm would the water around the site be during the summer if no plant were operating? How much do maximum and minimum temperatures change over a period of several years? Are other power plants already being built nearby, so that effects could add up?

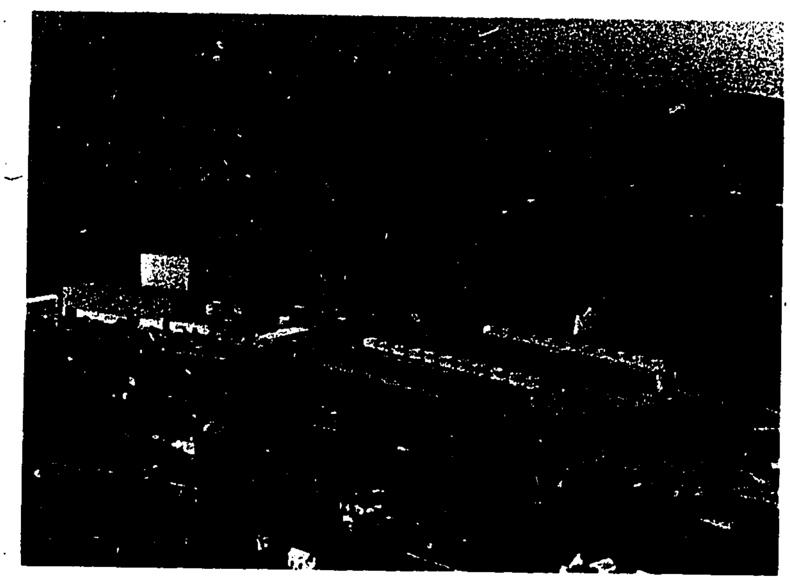
The simplest way of using any water source is to pump the water through the condenser and then return it directly to the river, lake, estuary, or ocean from which it came. This is sometimes called "once-through cooling" and it is cheaper than building cooling towers such as those described on pages 14-19. If a large supply of water is available, however, many experts have argued that this "once-through" method may actually produce the least disruption to the natural environment. Furthermore, this technique involves many variations of its own that make a difference. Often, water for a plant's condensers is drawn in from far below the surface—perhaps 20 to 70 feet down. Water at such depth is likely to contain fewer of the microscopic organisms that can be so important to the whole ecological cycle,* and it is usually cooler. When it is discharged near or at the surface at the end of a once-through cycle, it produces less of a warming effect than might otherwise be expected.

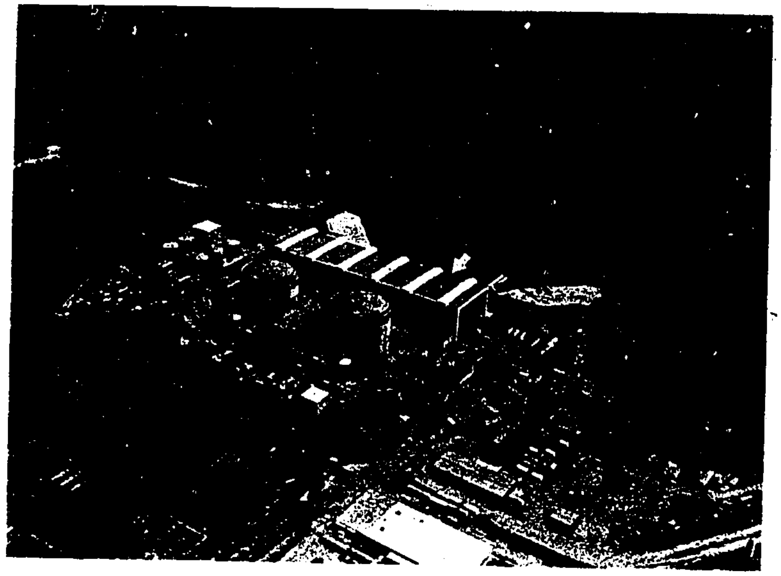
Furthermore, the effects of once-through cooling can be limited by the design of the condensers themselves. These can be built with additional pumping capacity, so that they do their job without ever raising the temperature of the cooling water by more than, say, 10°F. Use of such special condensers is limited too, however. First, they require a generous water supply, because more water must be pumped through them to accomplish the same task. Secondly, such condensers may be used only in connection with once-through cycles, because they can be economically impractical in places where cooling towers are also required. The towers need a temperature differential of between 15° and 45°F to operate effectively. Nevertheless, recent rulings by the Environmental Protection Agency indicate that supplementary cooling systems will be required for virtually all electric generating stations from now on. With rare exceptions, the days of "once-through cooling" appear to be numbered.

*Differences in the water's oxygen content must be considered also. Oxygen normally dissolves in a liquid more readily as temperature goes down, but both proponents and opponents of some power plant cooling systems have learned that this can be misleading. Bottom water may be poor in oxygen because it is too dark for photosynthesis to take place there or too rich in oxidizable materials. On the other hand, researchers have occasionally discovered that subsequent agitation and aeration produce a net increase in the oxygen content of water that has been warmed by passing through a plant's condensers.

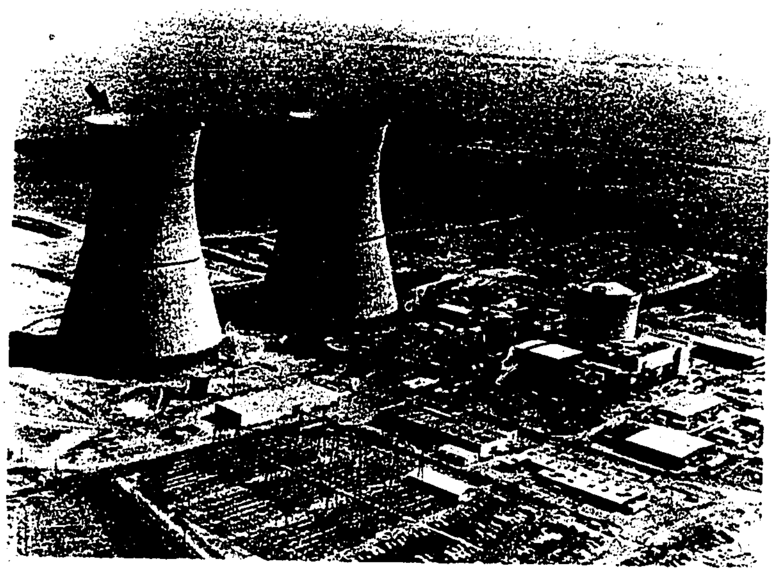


Four types of cooling apparatus: Above left, the Connecticut Yankee Atomic Power Plant sends water downstream in a mile-long open channel and discharges it into the Connecticut River. Above right, the Calvert Cliffs Nuclear Power Plant in Maryland is on the shore of the





deep, 6-mile wide Chesapeake Bay and uses low rise condensers. Below left, the Vermont Yankee Nuclear Power Station uses mechanical draft cooling towers. Below right, the Rancho Seco Nuclear Generating Station in California uses large natural draft cooling towers.



Then there is the question of how any cooling water—even the limited discharge from a cooling tower system—is to be returned to its source. Should it be pumped back under high pressure, so that mixing will take place rapidly? Or should a larger mixing zone be set aside? In some cases the water from a plant is allowed to flow for more than a mile in an open discharge canal before it returns to the main body downstream. In other cases, a cooling pond may be constructed so that water discharged from the condenser can give up almost all its excess heat directly to the atmosphere before it goes back to its source. That sometimes brings objections because of the large amount of water it removes from the area as a result of natural evaporation. Furthermore, this system will probably always have limited use, because it requires a specific kind of topography and takes up so much space. A 1000-MWe plant may need an artificial lake area of more than 3 square miles. In populated and fast-developing areas—where new power plants are especially needed—sites that would be large enough are often unavailable at any price.

Cooling towers are not all alike. For instance, they may be classified as either wet or dry. Air may move through them by means of a natural draft, or it may be forced through by mechanical means. The basic combinations are shown on pages 16-19.

Inside a wet tower, water discharged from a plant's condensers is sprayed over a latticework where it breaks into droplets and cools as it falls. Its excess heat is transferred to air; and either the air rises naturally as its temperature increases (and its density decreases) or it is helped upward by fans. In contrast, water from a condenser passes through a dry tower in pipes. Here the cooling is again done by a flow of air, but the process takes place without having the water exposed to the air. No water is lost into the atmosphere.

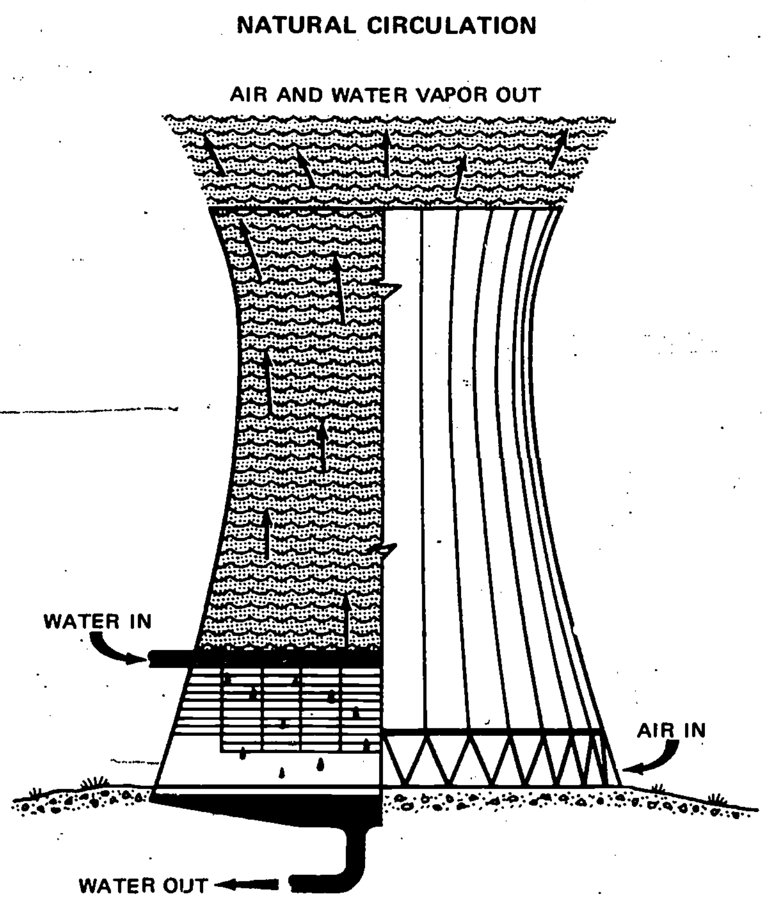
Dry mechanical-draft towers are usually the most expensive to operate. The pumps and piping in either type of dry tower are far more elaborate, and both pumps and fans need electricity to operate, so using them reduces the net amount of power that a generating plant can supply to its customers. The hyperbolic-shaped, natural-draft towers are larger than those using induced draft, but more of the mechanical towers are normally used at each site.

One disadvantage of wet towers is that their cooling effect comes mostly from evaporation. The warm moist air that rises from them may cause fog and ice in winter as it cools and condenses. This danger has often been exaggerated, but it should at least be considered. There are also special technical and environmental problems when salty or brackish water is involved. For example, mineral residues of any kind from inside a tower can spread over trees and plants in the neighborhood if special precautions are not taken.

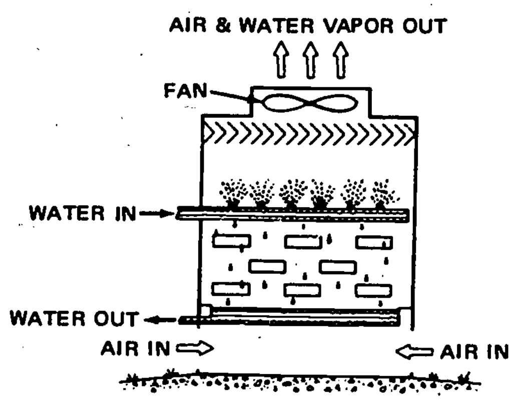
A plant's cooling system may employ also either a closed cycle or an open cycle, and this adds to the complexity of choices. In a closed cycle, water goes from the condensers to some sort of atmospheric heat exchanger (either an artificial lake or a cooling tower) and then comes back to a plant for reuse. In a case like this, the installation of natural-draft, closed-cycle towers may make it necessary to heat the water in the condensers more than 30°F; but the overall result might be considered acceptable even in a naturally warm area because only a very small portion of the condenser discharge would ever reach the natural aquatic environment. In an open cycle, heat is removed by one of the techniques described above, but then the water is returned to some natural body of water. This would normally require that more concern be given to effects on the cooling water itself. Finally, some plants are designed to vary their cooling techniques as the natural water temperature changes. During hot weather, an additional cooling step, such as the spray system shown on page 20 can be used, but at other times it may be skipped.

Which way is best for a given situation? There is no quick, absolute answer. Like so many of the decisions that must be made in order to meet power needs without unduly disturbing the environment, these choices require a reasonably thorough knowledge of many factors, including the life patterns in the area.

Wet Cooling Towers

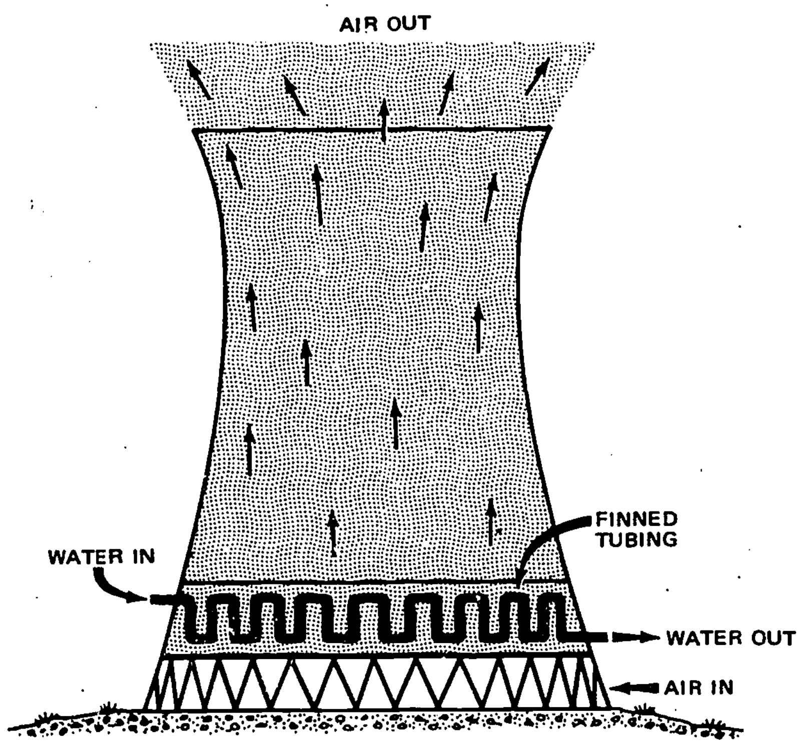


MECHANICAL CIRCULATION



Dry Cooling Towers

NATURAL CIRCULATION



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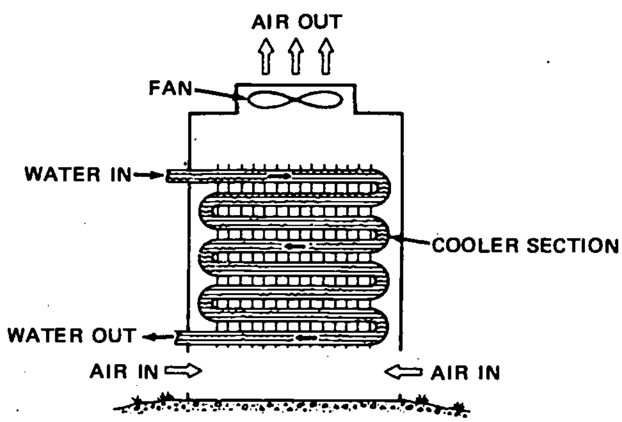
MECHANICAL CIRCULATION



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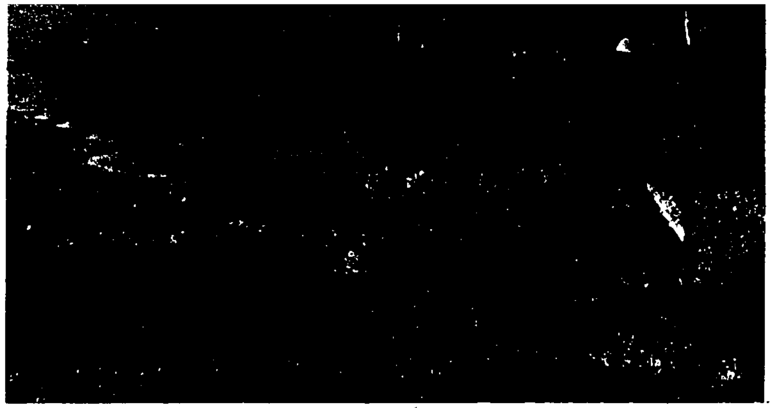


By increasing surface contact between the water and air, a spray system can reduce the necessary area of a cooling pond by a factor of 20.

Look for Little Things

A fisherman may be aware of only a few of the hundreds of species in a river or estuary. One feeds on another, and the whole web of life among aquatic plants and animals may never be fully understood. Occasionally, however, a natural or artificial change in conditions for some obscure organism will produce good or bad effects on another species that will be noticed immediately.

Thermal effects can be subtle. Spawning patterns, feeding habits, and growth rate are often related to temperature. Competing species may react in opposite ways—or at least to a different degree—to changes. Thermal shock, which is the adverse effect of sudden variations in temperature, can take place whether the change is up or down on the thermometer. But nature's own changeability and adaptability shouldn't be overlooked. The most violent fluctuations are usually those over which man has no control: a sudden summer shower, a cold snap, or high winds and tides.*

*Observations of Lake Michigan showed that its temperature had dropped by 2°F in a period of 40 years, despite being used as a heat sink by various forms of industry—including power plants. Nuclear plants with a combined capacity of 7000 MWe are now planned along the Lake's shores; and calculations show that the heat they would add by operating at full power *for an entire year* is only equivalent to the energy Lake Michigan absorbs from the summer sun in *2 hours*.

This is one reason why laboratory studies have been supplemented by field research. Another is that temperature can't always be considered in isolation from other factors. Dissolved chemicals and bacteria play a related role, for example, whether they are washed into a body of water by a heavy rain or dumped there by polluters.*

Today the U. S. Energy Research and Development Administration (ERDA), which absorbed the research and development programs of the U. S. Atomic Energy Commission in January 1975, sponsors and otherwise encourages a considerable variety of research on the thermal effects of both fossil-fuel and nuclear power plants in all parts of the country. This is not new. More than 25 years ago, the forerunner of the AEC began the very first studies on the effects of reactor heat upon an adjacent body of water, which, in this case, was the Columbia River. Since then, hundreds of reports have been published about the continuing investigations in that single area alone.† Long-term comparisons are especially valuable, and the pioneering work there has helped in the continual refinement of research techniques for other regions.

Studies of the Columbia River system began as early as 1943, while wartime secrecy still concealed this country's decision to build the vast Hanford reactor complex near Richland, Washington. Hanford was designed to produce plutonium for the Manhattan Project, the national program that developed the atomic bomb. Unlike the commercial

*The sudden and unsightly growth of blue-green algae is one example. It normally depends on both temperature and chemical pollutants, as well as the supply of carbon dioxide. Muddiness produced by heavy rain or man-made discharges, on the other hand, may limit the water plants' ability to carry on photosynthesis.

†Many of these are summarized in *The Columbia River Estuary and Adjacent Ocean Waters: Bioenvironmental Studies*, University of Washington Press, Seattle, Washington, 1972, 857 pp., $22.00.

power plants that were eventually built all over the country, those first reactors along the Columbia River were not connected to turbines or condensers.

None of the reactor heat was used, so the Columbia's water was allowed to pass directly through the Hanford reactors and then return to the river. This meant that eight of the nine reactors built at Hanford were bound to release more heat and radioactivity to the environment than commercial power plants of comparable size, yet years of study showed no harmful effects on the river's highly prized salmon. In fact, nesting sites for salmon increased on the Hanford reservations; and it appears that the construction of dams along the Columbia affects fish populations far more than Hanford's operations did at their peak.

Steelhead trout, oysters, and other aquatic organisms have also been involved in the Columbia River studies, but the reactions of the cold-loving salmon are especially interesting. One reason why thermal kills have not taken place is that the salmon simply avoid the problem areas on their own. Warmer water discharged by the reactors forms a thermal plume that is limited to a relatively small part of the river which is near the middle of the channel. Migrating salmon just swim around it.

The Columbia River, of course, is not typical of all river systems. It is a relatively large, fairly clean, and swift-moving river, fed by snows that keep its natural temperature low. But intensive studies of other reactor sites show that it is possible to minimize adverse thermal effects in practically any region by the right combination of ecological and engineering studies. The twin keys to success seem to be advance preparation and an effective program for continuous monitoring.

Many utilities have financed new efforts by universities, academies, and private research groups to supply needed data about biological patterns. Some of these are producing the first comprehensive scientific portrait of life in our country's

A scientist lifts a plankton canister, containing millions of microscopic organisms, from Lake Michigan. The plankton, which are the base of the aquatic food chain, will be examined in a laboratory for quantity, variety, and quality, as part of a Federal Government project to assess the effect that warm-water discharges from nuclear and fossil fuel power plants have on the life in the lake.

major waterways—ranging from algae and plankton to shellfish and sharks. Like all materials submitted by utilities in connection with license applications, the reports of these studies are made available in public reading rooms—including at least one in the vicinity of the plant site in question.

The patterns of water movement are being examined more closely too. Huge hydraulic models are built and computer programs are developed to simulate the effects of wind, tide, and currents on heat dissipation in specific areas. The predictions are checked by measurements on the spot, and any number of cooling designs can be "tried out" before construction finally begins. Once a plant is built and put into service, of course, its operations can be monitored to make sure that thermal pollution is avoided.*

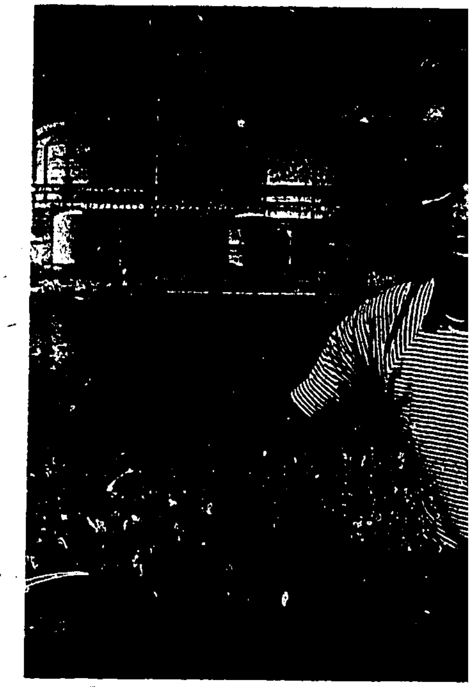
In evaluating thermal effects, it's a good policy to avoid jumping to conclusions. On one hand, the fish kills blamed on heated discharges from generating plants have almost invariably been traced to other causes. On the other hand, the common sight of fish congregating in the slightly warmer waters near a power plant doesn't prove that the plant's operation is actually benefiting them. Many species tend to congregate in areas of optimum temperature, but there are always exceptions. As a matter of fact, casual observations by non-specialists (including fishermen) rarely prove anything.

The Ground Rules

In compliance with the National Environmental Policy Act of 1969, any applicant for a permit to build a nuclear power plant must give the Nuclear Regulatory Commission (NRC), which absorbed the regulatory functions of the U. S. Atomic Energy Commission in January 1975, a detailed

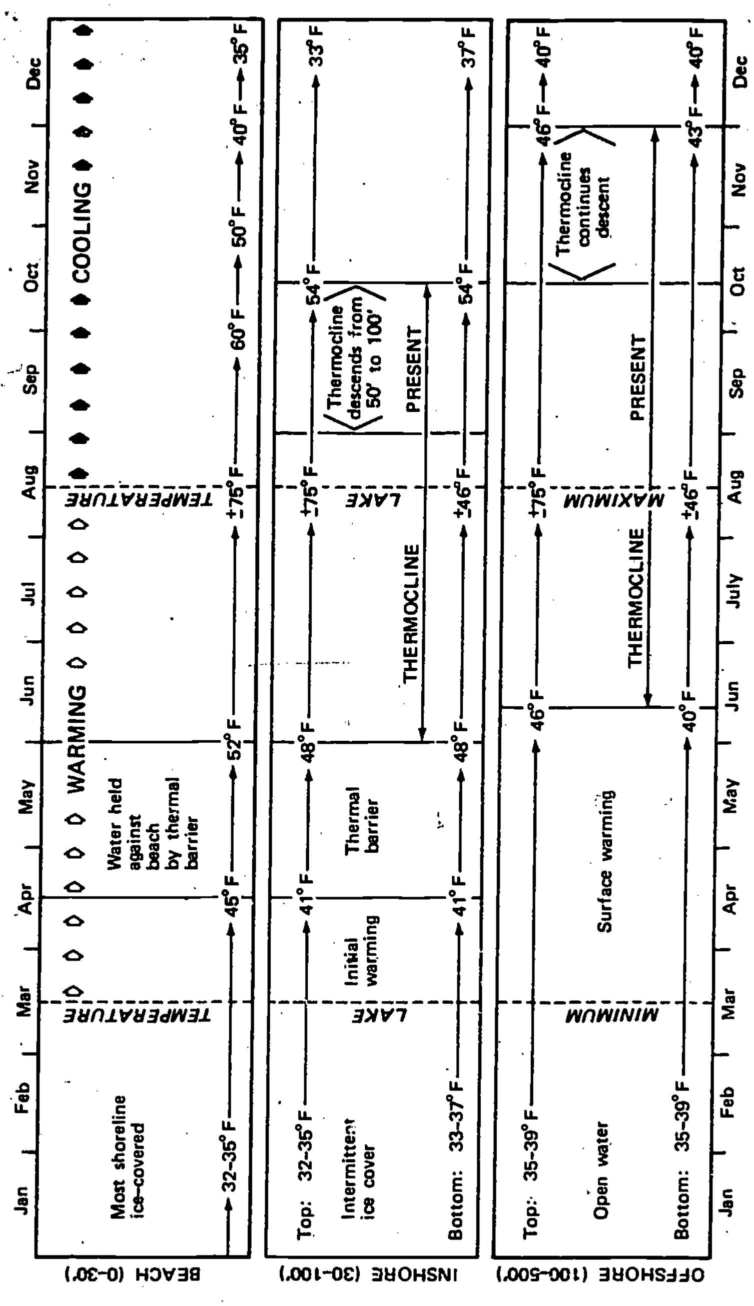
*Not all thermal effects should be considered thermal pollution. A broad but fair definition of thermal pollution might be "the causing of unreasonable damage to some further human use of water by changing its temperature". That still doesn't settle the definition of "unreasonable", but there's usually a point where common sense simply has to be applied.

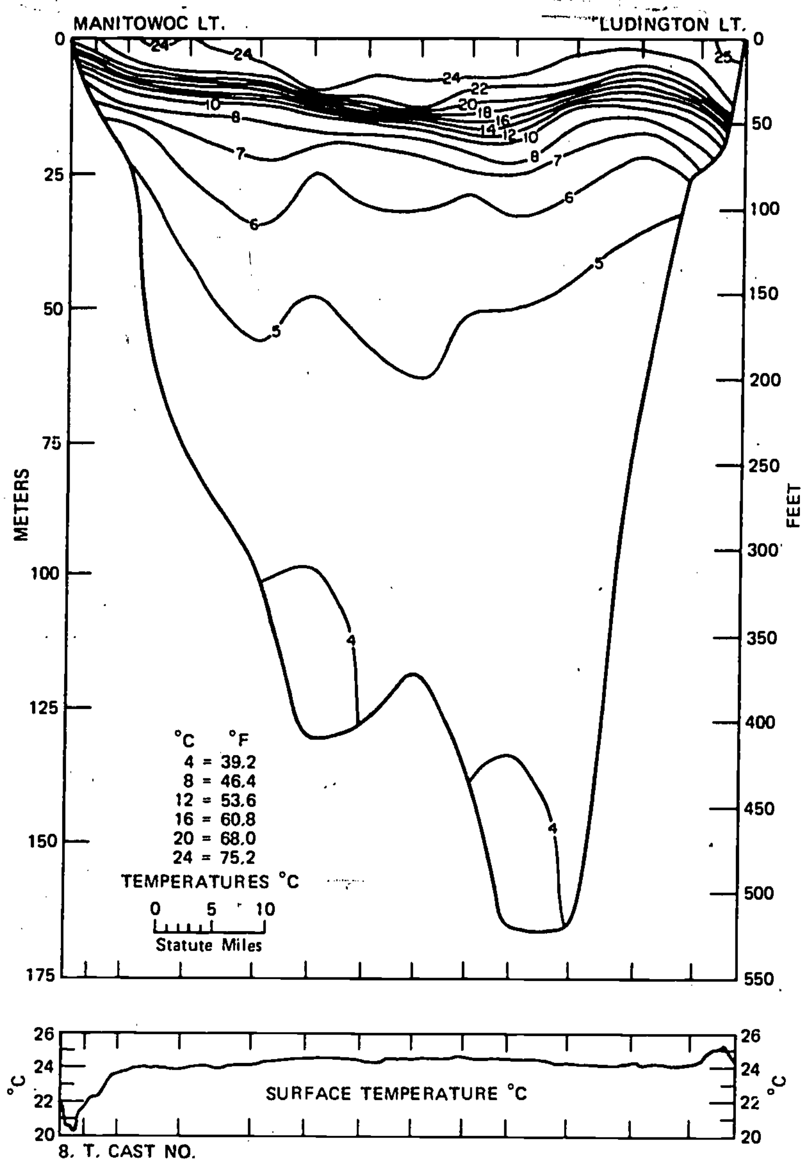
University of Miami scientists have raised millions of shrimp and thousands of trout, pompano, scallops, crabs, and clams in the warm water of the Turkey Point Nuclear Power Plant cooling canal systems. All these species have grown faster in the warm water. The University hopes that such "seafood farming" in cooling water discharged from power plants could help meet the world's increasing need for high-protein foods. On the right, a researcher holds a large sea trout from one of the canals. Two nuclear units are in the background.



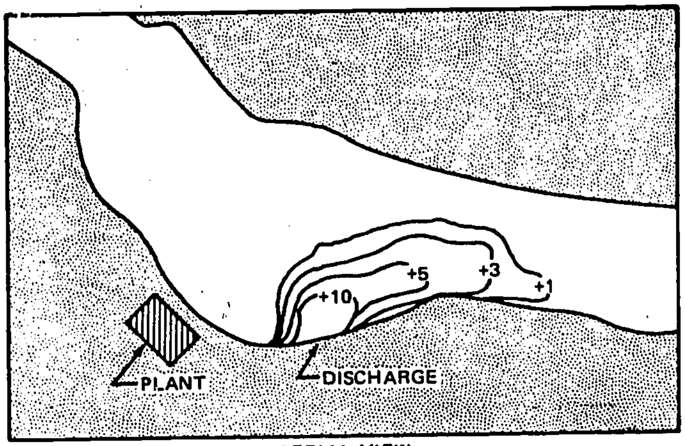
environmental report that includes pre-operational studies, citations of applicable thermal-effect research, schedules for additional studies, and a summary of the extent and nature of the environmental impact expected from the plant.* Copies of the statement are sent to any government agencies that are likely to have a special interest and expertise in commenting on the proposal. For example, copies go to the Environmental Protection Agency and to the Department of the Interior. State and local government bureaus are also invited to examine it, and a public announcement is made that the document (which usually contains hundreds of pages, including maps, diagrams, and photographs) is available for interested individuals and groups to peruse. Based on information in this report and on other information as well, NRC officials prepare a draft environmental statement.

*Of course the environmental analyses required by the NRC also consider possible radiation effects, as well as esthetics, preservation of historic sites, etc.


BEACH (0-30')
INSHORE (30-100')
OFFSHORE (100-500')
Jan
Feb
Mar
Apr
May
Jun
Jul
July
Aug
Sep
Oct
Nov
Dec
WARMING
COOLING
TEMPERATURE
LAKE
MINIMUM
MAXIMUM
Most shoreline ice-covered
32-35° F
45° F
Water held against beach by thermal barrier
52° F
±75° F
60° F
50° F
40° F
35° F
Top: 32-35° F
Intermittent ice cover
Bottom: 33-37° F
Initial warming
41° F
Thermal barrier
48° F
THERMOCLINE
PRESENT
Thermocline descends from 50' to 100'
54° F
33° F
37° F
±46° F
Top: 35-39° F
Open water
Bottom: 35-39° F
Surface warming
46° F
40° F
Thermocline continues descent
43° F

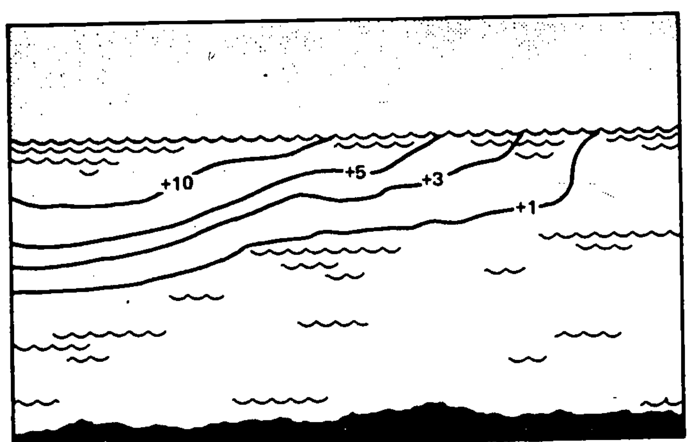


Charts show how Lake Michigan's temperature changes naturally as one moves across it in profile (above) and as the seasons change (left). The thermocline is a layer of water below the surface in which the temperature drops very sharply and suddenly.

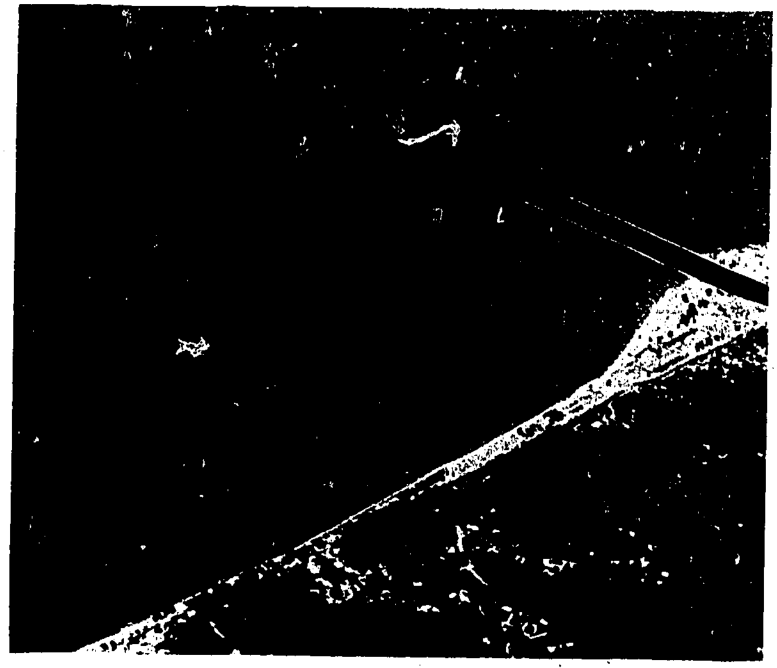


AERIAL VIEW

Two ways of looking at a thermal plume. A thermal plume from power plant discharges does not always extend from shore to shore, and it may not reach the bottom. Infrared aerial photography (often with "false color" added to emphasize minor temperature differences) shows effects at the surface fairly well, but a three-dimensional view requires the use of thermistors at various depths in the water. Wind, currents, tides, etc., may modify the plume's shape continually.



SIDE VIEW



The "plume" of the Grand River as it enters Lake Michigan at Grand Haven, Michigan.

No two environmental reports are alike, because each is tailored to answer questions about a specific plant design and a specific site. However, the law requires that every report must cover five basic points, with an adequate amount of supporting evidence for each:

1. The total environmental impact of the proposed action.

2. A discussion of any adverse effects on the environment that apparently cannot be avoided under the plan submitted.

3. Possible alternatives to this particular plan.

4. A comparison of short-term and long-term results, weighing social and economic factors as well as changes to the local environment.

An air and water sampling program at the Gaseous Diffusion Plant in Tennessee assures compliance with all Federal, State, and local water

5. A separate discussion of any resources that could not be recovered after the project under consideration was carried out (e.g., destruction of a natural rock bridge).

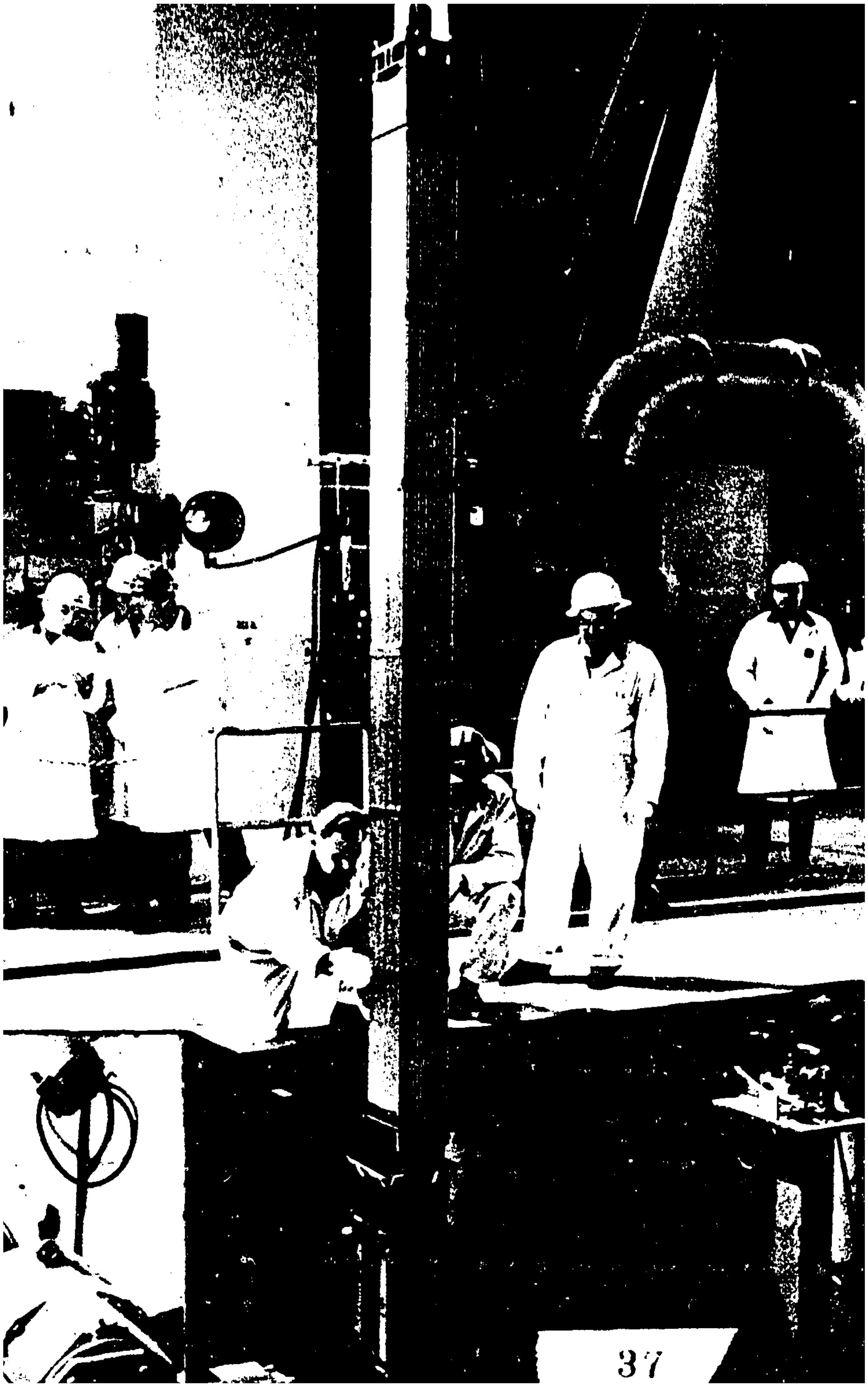
Almost every part of the environmental report involves a cost-benefit analysis, but in this instance cost involves more than money alone. There is never any doubt that the construction and operation of a power plant will affect the land, air, and water in some way; the same is true of houses, factories, schools, and shopping centers. Adverse effects are offset by beneficial effects, but the results are almost always mixed. In the case of a power plant, the use of various kinds of cooling systems might produce different sets of advantages and disadvantages. Their cost (both financial and environmental) is matched against the benefits they offer. When it comes to detailed specifications, many minor trade-offs usually are necessary to come up with the best overall solution.

It's almost always possible to reduce an undesirable effect (thermal or any other kind) by more expensive design and construction. The tough decision comes in determining how

quality standards. The program also provides background data useful in the preparation of environmental impact statements for new facilities.

far to go. Time is important, as we'll see in the fuller discussion of cost-benefit analyses that begins on page 55. Dollars and cents have to be involved in part because the cost of producing electricity always affects its selling price. It is hardly in the public interest to insist on a large expenditure that will produce only a minor change unless the change is a necessity. Overall, the U. S. has decided as a nation that it is worth some extra expense and inconvenience to eliminate any serious environmental damage from power plants.* The cost-benefit analysis spells out the options. It makes it easier for a company, a regulatory agency, or the public at large to appreciate all the conflicting factors at once and in reasonable perspective.

*Standards vary from state to state, but federal legislation on water quality has been interpreted to require some limit on man-caused increases to water temperature plus a maximum temperature above which no heat can be added. Often the regulations allow greater increases in cool weather than in warm weather, but occasionally nature manages to break through the maximum limits in summer without any help from man.



How About Radioactivity?

"Radiation" is another term that can be confusing.

First of all, it may denote the emission of heat such as that from a radiator in your home. In that sense, the waste heat from any sort of generating plant is dissipated partly by being *radiated* to the atmosphere. But when the term is used in connection with nuclear power, it generally refers to a special kind of radiation produced in nuclear reactions. Strictly speaking, this special kind should be called ionizing radiation (because of its ability to convert ordinary atoms into electrically charged particles or ions). It has existed in nature since the beginning of time, but today it can also be produced by man. Ionizing radiation can be extremely valuable in many fields, including medical diagnosis and medical treatment. When nuclear radiation is discussed in relation to power plants, however, it is usually because people are worried about the harmful effects it may also have.

Nontechnical people find it hard to think of ionizing radiation in specific measurable amounts. They can't see it or weigh it, and this bothers them. Yet fairly simple instruments can detect fantastically tiny quantities of radioactivity*; this makes it possible to measure and regulate the increase of radiation in the environment much more precisely than the increase of any chemical pollutant.

Federal government regulators have tried to be purposely conservative in the ground rules laid down for radiation

*Despite this fact, the increases in surrounding radiation levels that result from nuclear power plant operations are sometimes too small to be measured.

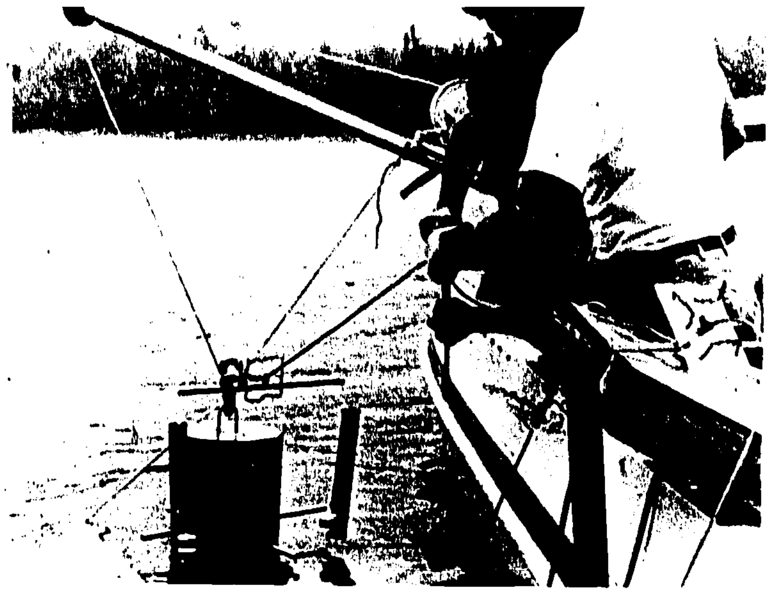
The cladding on a reactor fuel element keeps most radioactive material sealed inside until reprocessing begins. Here a fresh fuel element is lowered into the core of the San Onofre Nuclear Generating Station in California.

exposures resulting from the operation of nuclear power plants. For many years, licensees were regularly admonished to keep the radioactivity in reactor effluents "as low as practicable" and to make certain in each case that this would be well within the standards recommended by the National Council on Radiation Protection and Measurements and the Federal Radiation Council—groups of experts separate from the basic nuclear regulatory body. In mid-1971, however, the AEC went further. It prescribed much more specific design objectives for water-cooled reactor power plants.* These spell out a firm commitment to keep their radiation releases to a fraction of recommended standards. Persons who live right at the boundary of a power plant site will thus generally be exposed to *only about 1%* of the limit for man-made radiation specified by the Environmental Protection Agency† for individual members of the public.‡ This did not mean that the AEC disagreed with the EPA standards that apply to the total of exposures from all sorts of radiation other than natural background and medical procedures. It's just that the underlying policy had always been to keep radiation expo-

*Companion guidelines for other reactor types will presumably be issued by the new Nuclear Regulatory Commission as experience with the other types increases.

†For more than a decade before 1970, these radiation protection guides were developed and recommended by the Federal Radiation Council which was created by the Atomic Energy Act. The duties of the Council have now been assumed by EPA. That agency gets advice from the National Academy of Sciences and the National Council on Radiation Protection and Measurements, which works in turn with the International Commission on Radiological Protection. Physicians, geneticists, biologists, physicists, and other scientists are involved in establishing the standards.

‡The EPA guides for persons who work in the nuclear industry are not as strict as they are for members of the public, because a worker's exposure to radiation is monitored far more closely and he knowingly accepts occupational risks. The guides for *average* public exposure, on the other hand, are more strict than for *individual* members of the general population. Under current nuclear regulatory concepts, the annual exposure of any sizable population group near an operating nuclear power plant should be kept to *less than 1%* of the federal guides for average population exposure, which are the strictest of all.



A dosimetry buoy is placed in Lake Michigan by a research team from ERDA's Argonne National Laboratory as part of a study to determine if measurable amounts of radioactivity are put into the lake by nuclear power plants.

sures to a practical minimum, and technological advances made the new, very low numerical guidelines reasonable.

Although the amount of radiation exposure is small, a logical question to ask is: "Why should there be any at all in normal operations?" The answer requires an explanation concerning the reactor coolant, from which the radioactivity released largely originates. Incidentally, this radioactivity is almost always released indirectly, and it emerges under controlled conditions.

The primary coolant for most U. S. reactors is water, but it should not be confused with the plant's condenser cooling water. The primary coolant is a separate fluid (either gas or liquid) that comes into contact directly with the fuel elements in a reactor core. It is reused continuously inside a sealed system, but gradually it accumulates some radioactivity in various ways:

1. Stable elements in water become activated.
2. Chemicals added to reduce corrosion or dampen nuclear reactions are activated by radiation.

3. The corrosion that does take place adds microscopic activated particles from the fuel element cladding.

4. Occasionally, a small leak in one of the fuel elements itself can allow fission products and other contaminants to escape.

On a slow but continuous basis, the coolant is drawn off and purified. The reasons for this are varied and complicated, but they have to do with normal plant operations. There are various ways of removing the radioactive material from a coolant, whether the material is solid or gaseous. The vast majority of the radioactive impurities removed in this way are then stored long enough for the radioactivity to decay to very low levels; or else they are concentrated and sealed in waste containers to be handled elsewhere, as described on pages 45-53. Once the traces of radioactivity in the water stored at a power plant have dwindled to a certain point, it is safe to add to the waters of a nearby river, lake, or bay.* There, of course, it will quickly be diluted even more. Minor amounts of liquid waste collected from laboratory sinks, the laundering of laboratory coats, etc., are handled in the same careful way as the reactor coolant.

Operating rules, which are a part of each plant's license, have the effect of limiting the permissible concentration of each specific radionuclide or type of radioactive material, and this automatically controls the possible biological effect. By all commonly accepted standards, the liquid effluent from a modern power reactor should be quite safe to drink from a radiological standpoint.

Nuclear power plants are not by any means the only source of radioactivity in everyday life. Fossil fuel, in fact,

*The alternative is to return the very mildly radioactive liquid to the reactor tank as "make-up water" to replace what has been drawn off for various purposes or (in the case of some types of reactors) what is lost through evaporation. However, this merely postpones the problem of eventual disposal, and radioactivity inevitably builds up within the coolant. The engineering decision between the two approaches at any particular plant is an example of the trade-offs that are always involved in a specific plant design.

contains some radioactivity, which is released to the environment when the fuel burns. Some radioactivity is present in every human body too. There is radioactive potassium in the soil and in the fertilizer farmers spread on fields. The exact level of "natural background radiation" varies with the altitude, latitude, local geology, and time of year, among other factors.

Yet there is no place in the United States where the natural background radiation is not many, many times as great as the amount of exposure that will be added annually for the closest neighbor of any nuclear power plant operating under current guidelines. There is no sizable community whose average radiation exposure is likely to increase more than 1% as a result of all the nuclear power plants that are planned for the foreseeable future. This is clearly much less radiation exposure than a person would get simply by moving from an area having low natural background radiation levels to one having high levels.*

Naturally, each utility that applies for a power plant construction permit has the responsibility of demonstrating that its proposed plant can operate within these strict ground rules. It must begin this process with the environmental analysis already outlined. Details of the proposed plant design must be submitted at the same time in a "Preliminary Safety Analysis Report" and, eventually, in a "Final Safety Analysis Report."† They must indicate, among other things, the amounts and types of radioactive material that may be released to the environment. This is important because not all types of radioactivity are alike.

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*This booklet treats such a broad subject that it cannot include as much detail about radiation as do several others in this series. Among those most closely related to the subjects discussed here are *Nature's Invisible Rays, Your Body and Radiation, The Genetic Effects of Radiation,* and *Atoms, Nature and Man.*

†The PSAR and FSAR must also deal with the extremely remote possibility of a major accident at the power plant. NRC licensing procedure takes into account the results of the "maximum credible accident", which is explained in the booklet entitled *Atomic Power Safety.*

		ALTERNATIVES		
		A	B	C
INCREMENTAL GENERATING COST				
ENVIRONMENTAL COSTS[1,2]				
Primary Impact	Population or Resource Affected			
1. Heat Discharged to Water Body	1.1 Cooling Capacity			
	1.2 Aquatic Biota			
	1.3 Migratory Fish			
2. Effects on Water Body of Intake Structure and Condenser Cooling System	2.1 Primary Producers and Consumers			
	2.2 Fisheries			
3. Chemical Discharge to Water Body	3.1 People			
	3.2 Aquatic Biota			
	3.3 Water Quality–Chemical			
4. Consumption of Water	4.1 People			
	4.2 Property			
5. Chemical Discharge to Ambient Air	5.1 Air Quality–Chemical			
	5.2 Air Quality–Odor			
6. Salts Discharged from Cooling Towers	6.1 People			
	6.2 Plants			
	6.3 Property Resources			
7. Chemical Contamination of Ground Water (excluding Salt)	7.1 People			
	7.2 Plants			
8. Radionuclides Discharged to Water Body	8.1 People–External Contact			
	8.2 People–Ingestion			
	8.3 Primary Consumers			
	8.4 Fish			
9. Radionuclides Discharged to Ambient Air	9.1 People–External Contact			
	9.2 People–Ingestion			
	9.3 Plants and Animals			
10. Radionuclide Contamination of Ground Water	10.1 People			
	10.2 Plants and Animals			
11. Fogging and Icing	11.1 Ground Transportation			
	11.2 Air Transportation			
	11.3 Water Transportation			
	11.4 Plants			
12. Raising/Lowering of Ground Water Levels	12.1 People			
	12.2 Plants			
13. Ambient Noise	13.1 People			
14. Aesthetics	14.1 Appearance			
15. Permanent Residuals of Construction Activity	15.1 Accessibility of Historical Sites			
	15.2 Accessibility of Archeological Sites			
	15.3 Setting of Historical Sites			
	15.4 Land Use			
	15.5 Property			
	15.6 Flood Control			
	15.7 Erosion Control			

COMMENTS

[1] Where a row is not relevant to a particular alternative, insert n.a. for not applicable.
[2] See Table 3 for units of measure and methods of computation.

The three types of ionizing radiation that usually are associated with reactor effluents are designated by the Greek letters alpha, beta, and gamma. The biological effects they produce are quite different from one another, but there are also many variations within each general type. Radiation effects also depend on the particular material's radioactive half-life, which is a gauge of how long radioactivity will persist, and the material's chemical properties. The latter indicate how it might affect plants, animals, and man, and how it will travel through the food chain. The table on page 41 gives some idea of how much variety there is.

Reconcentration is another phenomenon that has to be considered. Fish remove certain elements (for example, phosphorus) selectively from the waters around them and from the food they eat. They build up a higher percentage of phosphorus in the compounds of their bodies and body fluids than exists in the surrounding water, so if some phosphorus is radioactive an individual fish will gradually concentrate it along with the stable form of the element. As smaller species become the prey of larger ones, further concentration may result. The same process can involve living plants, and ultimately it could affect man. Reconcentration of any type must be taken into account at each site, just as the presence of other nuclear reactors in an area may cause Federal Government regulators to tighten the limitations on the amounts of certain radionuclides that each generating station may discharge.

Over the years, the AEC devoted more than a billion dollars to research on the biological effects of radiation; and the results of that work are reflected in the current enforcement of radiation protection standards. The limits imposed at each power plant site are related directly to potential effects on people in that particular set of circumstances, rather than being based on a plant as it might be abstracted from its own environment. In addition, of course,

Part of an outline for a cost-benefit analysis shows how multiple factors are considered in connection with alternative designs and plans.

effects on other important organisms are also carefully considered before reactors are licensed.

The amount of radioactivity released from a given source over a period of time is usually expressed in units called curies,* but a comparison of those numbers is not very revealing by itself. It is far more important to consider the impact of a plant's operation in terms of biological effects—considering all the possible variables in the types of radiation, half-life, dilution factors, and the tendency toward reconcentration within the local food chain. These can all be consolidated by using a unit called a rem (*r*oentgen *e*quivalent, *m*an).

The rem represents the amount of any radiation which—if it is absorbed by a man's body, or by a certain part of his body—will produce a biological effect equivalent to an agreed-upon standard (the same theoretical effect as 1 roentgen of X rays or gamma rays). This is not to say that a single rem necessarily represents a damaging effect, but only that it provides a convenient measuring system for scientists and laymen in studying and discussing potential radiation effects on people. Gauging the biological effects quantitatively in terms of rems offers a common denominator in foreseeing possible biological damage (which is precisely what everybody is trying to avoid by means of our complex radiation protection systems). It doesn't matter if the radiation source in question is an alpha emitter or a gamma emitter, if a person is standing right next to a small radiation source or is separated from a larger source by shielding and/or distance, if he absorbs the radiation directly or in a

*A curie is not a measure of either weight or volume. It is the amount—a speck or a bathtubful—of any radioactive material that emits radiation at the rate of 37 billion nuclear emissions per second. That is roughly the decay rate of a gram of radium (the first radioactive material to find widespread use, after it was discovered by Marie and Pierre Curie). Because such small concentrations of radioactivity are involved in power plant discharges, the quantities are often expressed in millicuries, microcuries, nanocuries, or even picocuries. These are thousandths, millionths, billionths, and trillionths of a curie, respectively.

Some of the Radionuclides Which Are Discharged in Minute Amounts as Part of a Power Plant's Liquid Wastes

Name	Type of Radiation Emitted	Half Life	Special Comments
Hydrogen-3 (tritium)	Very low-energy beta (less than 0.02 MeV)	12.26 years	There is no known mechanism by which tritium can concentrate in fish or other food chains.
Cobalt-58	Beta & gamma	71.3 days	
Cobalt-60	Beta & gamma	5.27 years	
Krypton-85	Beta & gamma	10.76 years	Nearly incapable of forming chemical compounds. No evidence that it can concentrate in food chains or that it plays any role in biochemical processes, although it is somewhat soluble in animal fats.
Strontium-89	Beta	50.4 days	Can substitute for calcium in bone.
Strontium-90	Beta	More than 28 years	Released in extremely low concentrations.
Iodine-131	Beta & gamma	8.05 days	Reconcentrates in shellfish and some other aquatic organisms.
Cesium-137	Beta & gamma	30 years	Reconcentrates in some fish.

roundabout way, or if there is a single source or many. Lots of other measuring units are used in conjunction with radiation—roentgen, rep, rad, etc. If you are interested in what they all mean, other booklets in this series cover them in some detail. But the rem is the unit that offers the best way to grasp the environmental significance of a nuclear power plant's operation.

The average annual exposure due to natural background radiation in the U. S. ranges between 100 and 250 mrems* in various states. A significant part of this comes from the sun as cosmic radiation. By comparison, the radiation exposure

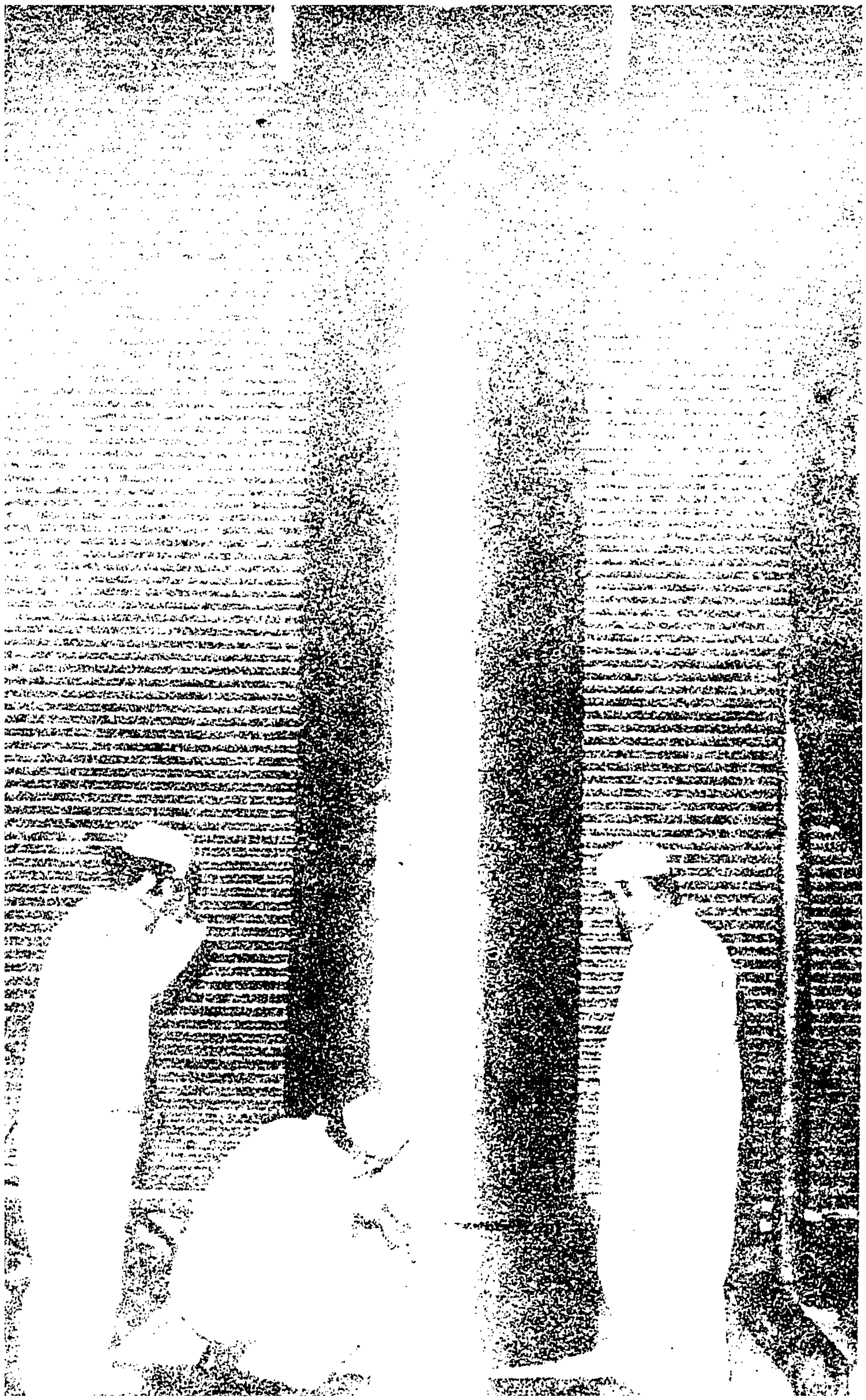
*A millirem (abbreviated mrem) is one-thousandth of a rem.


CONSUMERS POWER COMPANY

added by a nuclear plant that uses known technology and controls seems extremely low. A person who lived along the property line of such a nuclear power plant, drank only water that had passed through its condensers, and subsisted entirely on vegetables grown nearby and fish taken from the plant's discharge canal might expect to absorb no more than a few additional millirems in the course of a year.

There is no direct evidence that the human body shows any ultimate effects from very low levels of radiation. Yet the EPA standards and the NRC's enforcement are based on the assumption that every measurable amount of radiation contributes proportionally to a cumulative effect. The possibility of genetic effects on future generations is also recognized and included in the calculations that underlie standards and operating guides. And actual operation of nuclear power plants is monitored by federal officials (and in many cases by state agencies as well). Federal Government regulators have made it clear that they will order operations suspended at any plant where potential public safety problems exist and where they are not or cannot be corrected promptly.

◀ *A research team from ERDA's Argonne National Laboratory near Chicago places a gill net in Lake Michigan near the Big Rock Point Nuclear Power Plant. Fish are collected for laboratory analysis as part of a study to determine the effect a nuclear generating plant may have on the ecology of the lake.*



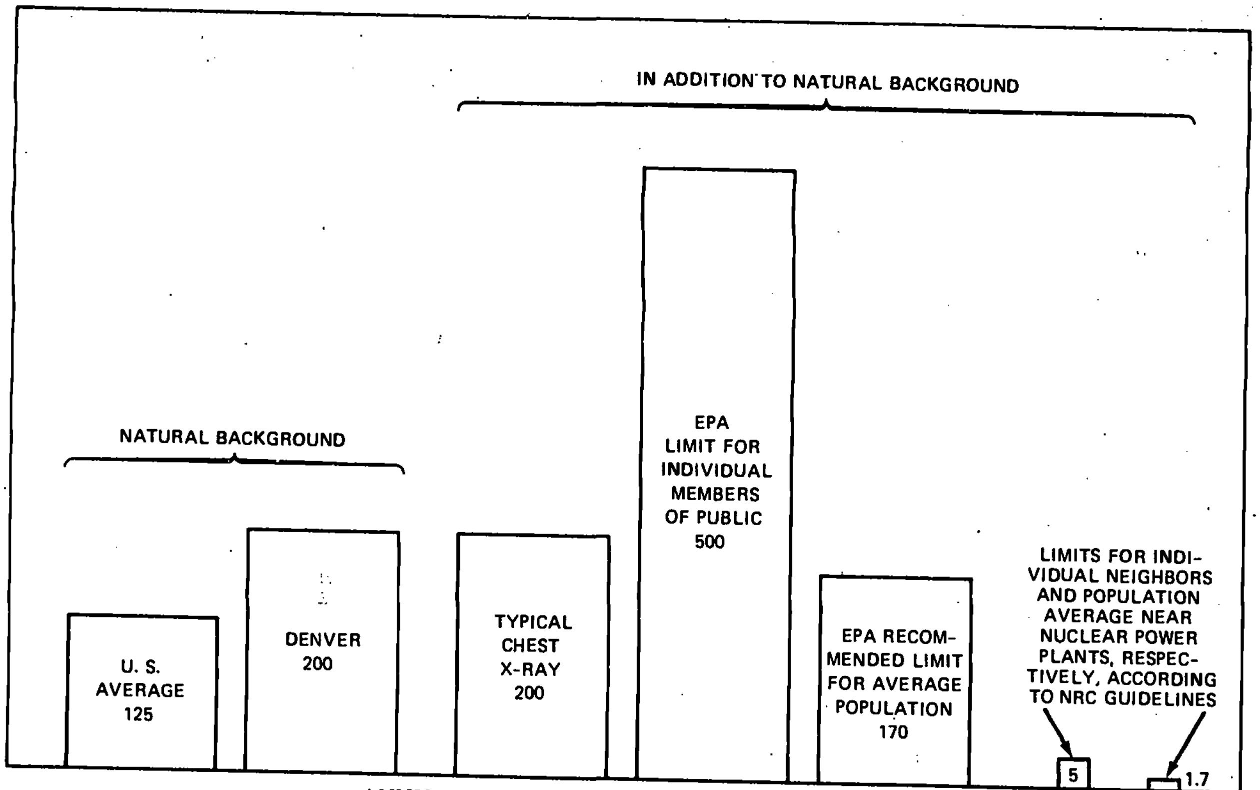
Disposing of the Ashes

The amount of radioactivity that escapes from a power plant during normal operations is quite small. In fact, one of the most difficult aspects of radiation management may be just to distinguish it from a natural background that can easily fluctuate by 10 or 15 millirems per year over a period of time. In the reactor core, however, there is intense radiation. The methods of handling these larger amounts of radioactivity need to be considered separately.

While a power reactor is operating, the men who run it are shielded from the high level of radiation by many layers of material—including steel, concrete, and the reactor coolant itself. When the time comes to replace the bundles of fuel, they are removed by remote control and transferred temporarily to a deep, water-filled, spent-fuel storage pool. Thirty feet or so of water makes a convenient and effective radiation shield. After 3 or 4 months, the radioactivity of the fission products with short half-lives essentially disappears; and the used fuel elements, which are still highly radioactive because of the longer-lived fission products, are ready to be moved to a reprocessing plant.

For several reasons it doesn't make sense to try to "burn up" every bit of uranium fuel in a power plant's core. One intent of reprocessing is to recover the usable fuel that remains after each fuel bundle has helped to supply power for 3 to 4 years. Another purpose is to take out the plutonium, which is an artificial fissionable material that is formed within reactors as they operate. Assuming that NRC approves commercial recycling of plutonium in the future, this material will be used more widely as a reactor fuel itself—probably mixed in many cases with either "virgin" or recycled uranium.

This large shipping cask is used to transfer irradiated fuel assemblies from nuclear reactors to reprocessing plants. It is shown at the reprocessing facility of Nuclear Fuel Services, Inc., at West Valley, New York.



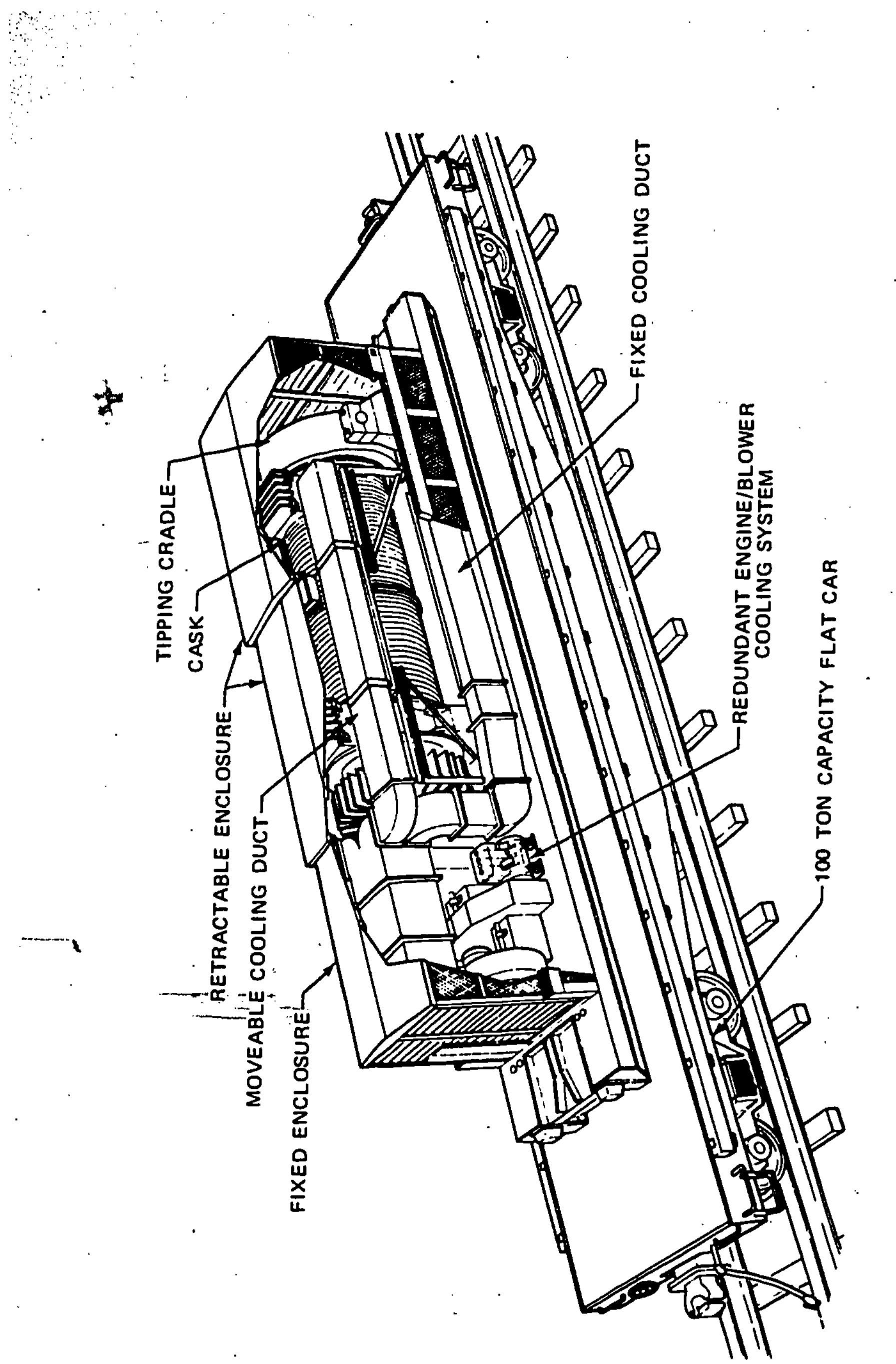
ANNUAL RADIATION EXPOSURE (In Millirems)

Reprocessing has already been demonstrated on a commercial scale to a limited extent, and here is how it works: Spent fuel elements are loaded into their shipping casks under water. These containers are actually portable radiation shields; their heavy walls block all but a minute percentage of the nuclear radiation coming from their cargo. The casks are also built solidly enough to remain intact if they should be dropped or struck or even involved in a fire or explosion.

Mechanical and chemical steps in reprocessing the fuel at its destination are carried out by operators using closed-circuit TV and other remote-handling aids. Fuel cladding is removed, and the fuel material itself (along with the plutonium and fission products that have been formed within it during reactor operation) is dissolved. Like power plants, commercial reprocessing installations are subject to careful scrutiny during the design stage and to monitoring after they begin to operate.

Nuclear fuel reprocessing plants face problems somewhat different from those of power plants, however. For one thing, the reprocessors must deal more directly with radioactive gases. As an example, krypton-85 is a gaseous fission product that stays pretty well locked inside the fuel cladding until the cladding has to be removed at the reprocessing plant. Radioactive iodine, another fission product, changes from solid to gaseous form at a fairly low temperature, which is reached easily during the various reprocessing steps. Activated charcoal is used to soak up both of these gases; and there are also chemical means of removing iodine, even when it is in the form of a vapor.* Krypton offers a special problem because it is one of the noble gases, which does not ordinarily form chemical compounds. This chemical peculiarity is also a safeguard to the environment, however. Krypton shows no tendency to become a part of plant or animal

*For new techniques being developed, see pages 80 and 81.

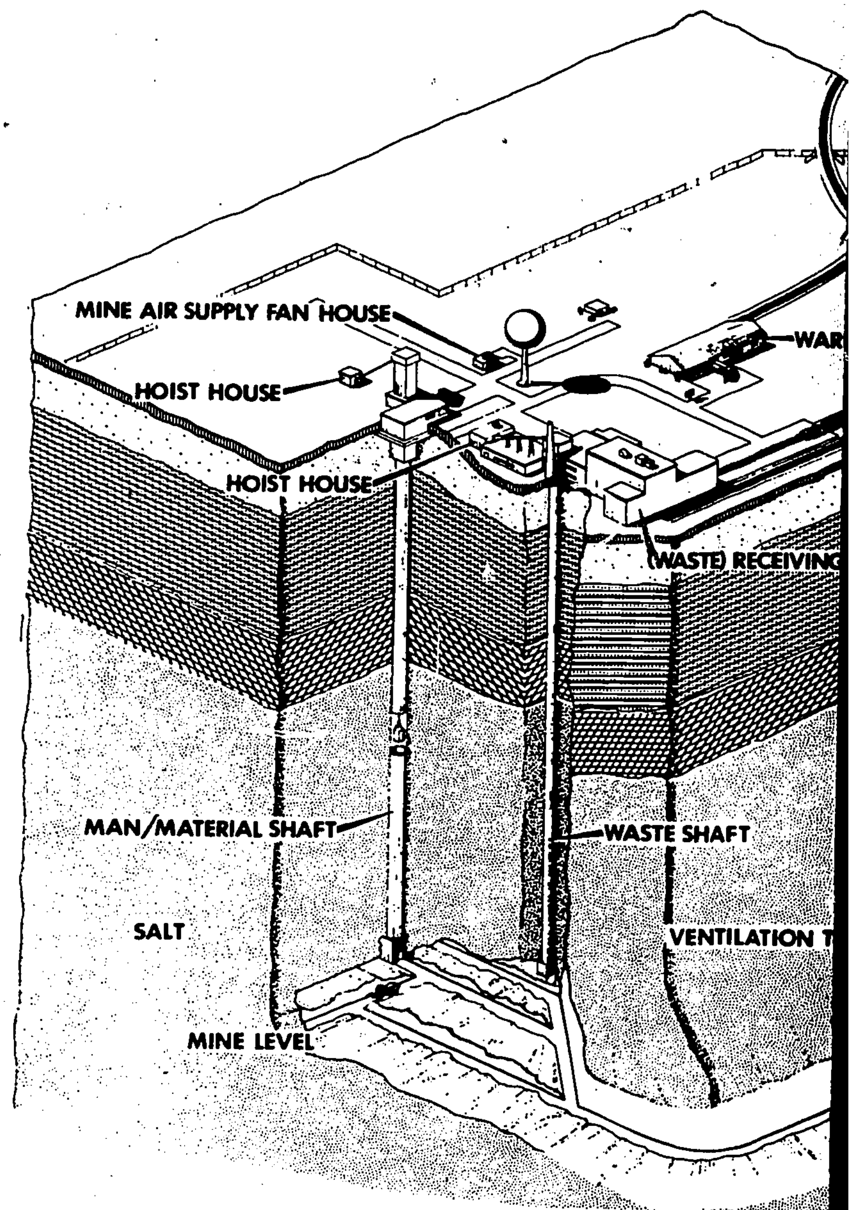

TIPPING CRADLE
CASK
RETRACTABLE ENCLOSURE
MOVEABLE COOLING DUCT
FIXED ENCLOSURE
FIXED COOLING DUCT
REDUNDANT ENGINE/BLOWER
COOLING SYSTEM
100 TON CAPACITY FLAT CAR

tissue, and there is no apparent way for it to reconcentrate. Tritium, on the other hand, poses other problems. It forms compounds readily, because chemically it acts just like nonradioactive hydrogen. Nevertheless, it apparently does not reconcentrate markedly in food chains. The most appropriate way of handling tritium depends on the rate at which it is produced and the degree to which it is concentrated.

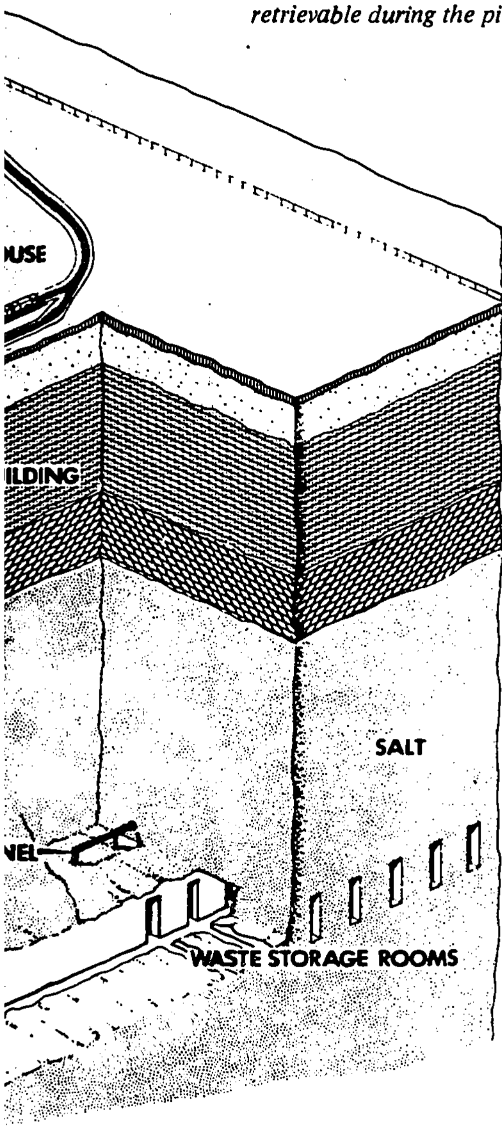
The ideal situation in any industrial process is to recycle or use just about everything—whether it's ordinary garbage or radioactive "ashes" from nuclear reactors. After fuel elements have been reprocessed, only a small residue of highly radioactive fission products and other long-lived radioisotopes remains; but both government and private research groups have devoted many years to finding practical ways of using some of these materials. A large number of applications are described in the companion booklet *Power from Radioisotopes*, but the market for materials like strontium-90, cesium-137, and cerium-144 is still extremely limited. Until technology develops some better ideas, most of the long-lived waste products of nuclear power will have to be isolated from man's everyday environment—either through burial in certain geologic formations (such as salt beds) or by being kept in carefully designed storage facilities at ground level under continuous monitoring and surveillance while geological burial is being developed.

Obviously, this kind of waste burial or storage is a lot more complicated than the sort practiced in municipal trash dumps. The exact technique to be followed depends on the intensity of radiation involved, the physical characteristics of the waste, and the presence of long-lived toxic materials such

The containers used to ship spent fuel are built to withstand even a major accident.


MINE AIR SUPPLY FAN HOUSE
WAR
HOIST HOUSE
HOIST HOUSE
(WASTE) RECEIVING
MAN/MATERIAL SHAFT
WASTE SHAFT
SALT
VENTILATION
MINE LEVEL

This cutaway is an artist's concept of a possible pilot plant to confirm the concept of using underground bedded salt to dispose of solidified high-level radioactive waste. The waste would be placed in salt beds about 1000 to 3000 feet underground and would always be retrievable during the pilot plant operation.



as plutonium.* Radioactive decay generates heat (in fact, that's the basis of the radioisotope power sources that Apollo astronauts left on the moon to operate scientific instruments). To prevent too high a temperature buildup, however, many of the underground storage tanks for high level wastes at ERDA installations have built-in cooling systems.

In time, all high-level liquid wastes from commercial power plants are to be changed to solid forms. This process will reduce the problem of storage and ultimate disposal. It can decrease the volume of liquid wastes by about 90%. Stable solids—either ceramics, glassy substances, or materials in granular form—are also easier and safer to handle. In fact, U. S. Government policy forbids the transportation of high-level liquid wastes from one installation to another, even though storage of liquid wastes is accepted as a necessary interim measure. Such storage at federal sites has been managed for several decades without endangering public health and safety.†

Bedded salt seems to be a natural place for the safe ultimate disposal of high-level solid wastes. Mined cavities in salt formations are free of water. Salt responds to heat by "flowing" around the waste containers and sealing the radionuclides in even more tightly. But studies of alternate disposal approaches are still going on, and until a final decision is reached any high-level waste placed in a geological repository would be stored there in such a way that it could be recovered.

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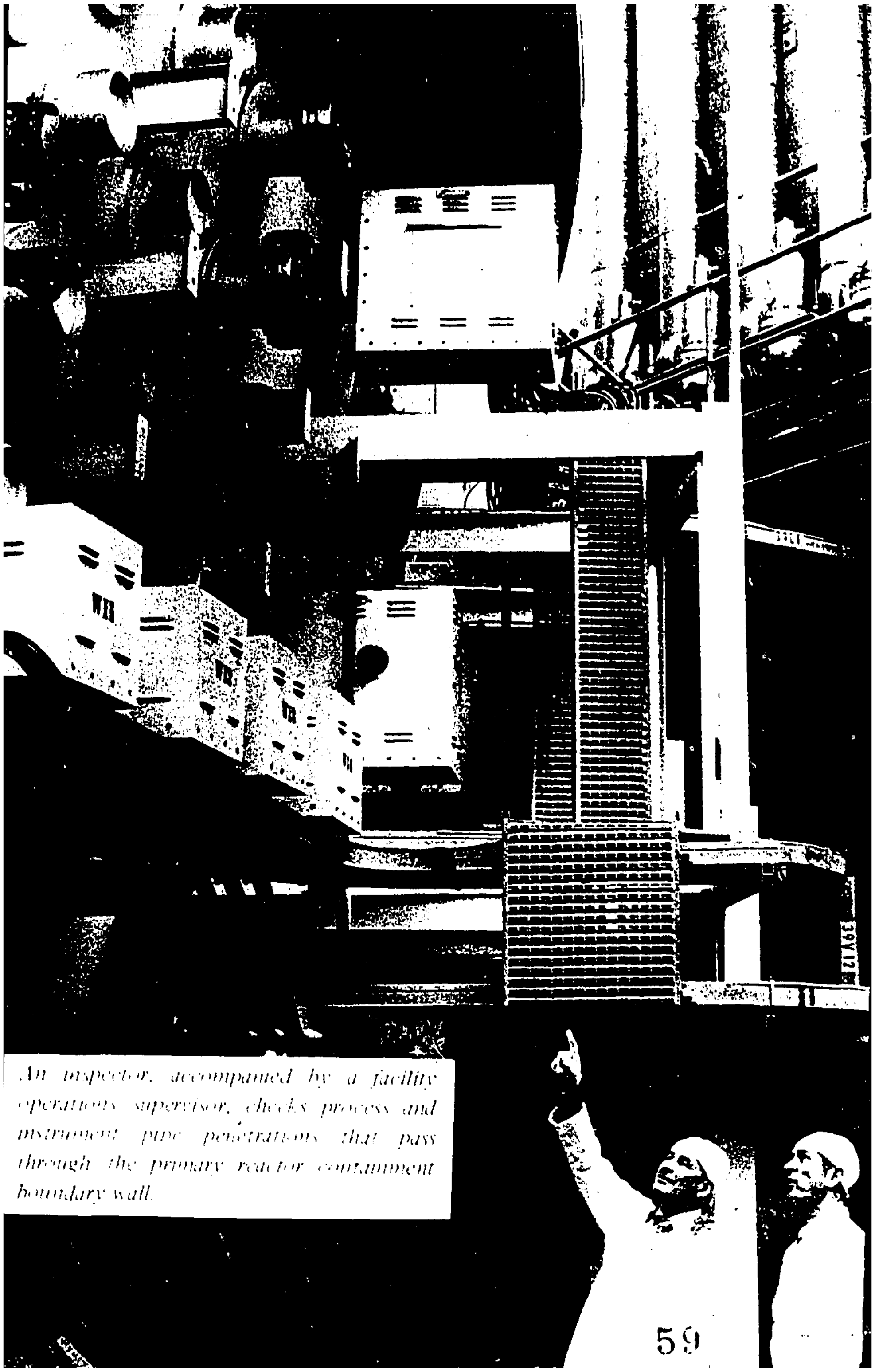
*Nearly all the plutonium formed in the fuel during reactor operations would be removed during reprocessing. In fact, it would be one of the most valuable products of this process; and as much of it as possible would be separated for reuse as fuel. Small traces that couldn't be separated from the wastes by any practical means release a form of radiation (alpha particles) that is blocked easily by shielding, but plutonium-239 has a very long half-life and is highly toxic.

†Leaks have developed in several of the early tanks, but the radioactivity has been held in the soil close to the leaks. No leaks into the soil have occurred with newer double-walled tanks of the type that will be required in future commercial plants.

As might be imagined, there are also some types of radioactive wastes that might be called intermediate. They would include such things as filters used at nuclear plants, as well as old equipment or clothing that has become too contaminated with radioactive material either to clean up or to junk in the usual fashion. Once such wastes have been checked to make sure they don't need any more specialized treatment, they may be buried in trenches at ERDA or state approved sites and simply covered over with earth. Until 1963 this type of burial of intermediate-level wastes was permitted only at installations supervised directly by AEC; but at that time the first state-owned burial sites were established. Now private companies operate them in Nevada, Kentucky, New York, Illinois, South Carolina, and Washington; they are subject to monitoring and regulation by those states. Between 1946 and 1961, some solid low-level wastes were also sealed in concrete and dropped into the oceans, but this practice was discontinued by the U. S. because it was generally much more expensive than land burial.* The technique is still favored by some nations, but its resumption by this country would be in violation of a Council on Environmental Quality policy.

Federal and state regulations prohibit land burial anywhere until the area's geology and hydrology have been studied thoroughly. Possible outlets through underground streams, vents of any sort, or seepage must be explored. Radiation from the various ERDA waste storage sites has never produced a threat to public health and safety, and licensing standards for new sites are aimed at preserving that perfect record. The short-term and long-term environmental implications of nuclear power are kept in mind well beyond the generating process itself.

*Despite occasional reports of waste containers being washed ashore, no such case was ever verified by AEC investigations. Costs of sea burial, however, were sometimes as much as five times as great as land-based techniques, which offer the additional advantage of retrievability.



An inspector, accompanied by a facility operations supervisor, checks process and instrument pipe penetrations that pass through the primary reactor containment boundary wall.

Measuring the Costs

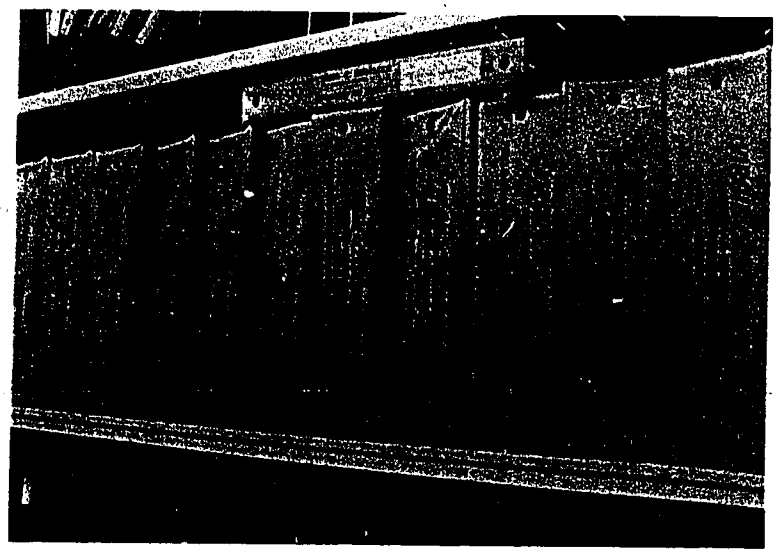
Sometimes actions by nuclear power plant operators that protect the environment also bring them economic benefits. Steps to reduce the likelihood of ruptured fuel elements in a reactor will decrease measurable radiation at a plant site, for example, but they can also save money. Fuel use becomes more efficient, and the total cost of plant maintenance may drop. There are many such instances, and the AEC stressed economic advantages like this in promoting quality assurance programs from the outset. At the very least, a public utility may also hope for the intangible yet important benefit of better relations with its customers and neighbors. Still, there are times when environmental protection measures for both fossil-fuel and nuclear plants simply become an additional cost of doing business within a society that is becoming more alert to the threats of man-made pollution. All the costs and all the benefits should be balanced, financially and ecologically.

Nuclear power is one of our country's energy options. In deciding whether to build a nuclear generating station or one using fossil fuel, utility executives base the choice partly on economics. They know that a nuclear plant will cost more to build, but that in many cases it will be cheaper to operate. However, in order to make a fair comparison, more than the construction and operating costs during a plant's anticipated lifetime must be considered. Keeping money tied up in an expensive plant and a 3-year load of fuel that must be paid for all at once costs money in itself in the form of interest.

NRC license fees must be considered for nuclear plants too. The fees may seem small in relation to a basic investment of several hundred million dollars; but they are not insignificant because the charges are designed to cover the costs of examining plant proposals in great detail and of taking all necessary subsequent steps to enforce continued compliance with regulations. It is not unusual for the licensing fees on a single 1000-MWe plant to exceed a million dollars—not to mention the substantial costs the utility bears internally in preparing studies to support its application.

All in all, the number of nuclear power plants is increasing steadily; utilities all over the U. S. have decided that they make economic sense. Naturally, a utility makes this decision about each new plant requirement as it comes along, based on the particular circumstances.

Delays during construction can be especially costly, because these tie up a company's capital for a longer period without bringing it anything in return. There may be an environmental penalty too. The longer it takes for new "cleaner" generating plants to start up, the longer old fossil-fuel plants must stay in service to help meet a still rising demand for electricity. On the average, it now takes about 6 years for a large new fossil-fuel plant to begin operating after a company decides to build it; but a nuclear plant has often taken 8 years or more. Various ways are being explored to speed up the process without compromising environmental and safety standards.



Some of the early paperwork involved in a construction permit application for one *nuclear power plant is shown on this shelf. It includes nine volumes of the Preliminary Safety Analysis Report, the Environmental Report, and a supplement. Succeeding amendments filed by the applicant also become part of the application.*

An undergraduate student participates in a research program at ERDA's Oak Ridge National Laboratory in Tennessee. The young fish in the tank are exposed to a thermal shock. The student then studies their vulnerability to largemouth bass, their natural predators. These projects introduce students to research and allow them to make significant contributions to current environmental problems.

A number of extra delays for nuclear power plants were unavoidable for a while after a federal court ruled in mid-1971 that the National Environmental Policy Act of 1969 required the AEC to go beyond the scope already contained in Commission regulations regarding environmental review of nuclear power plants. This decision said that the Commission was empowered (and, in fact, directed) by the legislation to go further than it had. The AEC had always considered all radiological matters, but in accepting the "Calvert Cliffs Decision" the Commission agreed thereafter also to consider formally all nonradiological environmental matters (such as thermal effects, the results of dredging, paths of transmission lines, etc.) in granting permits and licenses.

Once the point was clear, the AEC revised its regulations and guidelines. Full environmental reviews were ordered for all commercial nuclear power plants that required licensing action after January 1, 1970—even those for which limited reviews had been completed. In addition, studies were conducted to determine whether construction or operation of more than 50 plants should be interrupted. Most were authorized to continue, but a handful were required to suspend certain construction activities. The whole catching-up process interrupted the normal licensing procedures, but nuclear power delays caused by environmental review (now handled by NRC) should diminish in the future.

It's difficult to compare the environmental costs of fossil-fuel plants with those of nuclear power, because each has assets and each has liabilities when matched against the other. About the best that can be done in general terms is to consider a balance sheet like the table on the facing page. The relative importance of esthetics and land use varies enormously from place to place. Extra care (usually coupled with additional equipment) can eliminate any practical difference in thermal effects, even though this invariably adds to the expense of nuclear plants.

Nor is it a simple matter to balance the goal of environmental protection in any case with practical dollar costs. Zero radiation and zero temperature rise are both unattainable targets for any steam-electric power plant, but how close should a utility try to come? All things considered, is an additional change of 1° in the maximum temperature of a condenser's discharge at a certain site worth a million dollars? Ten million dollars? Fifty million dollars? How about half a degree? Exactly how much research on the possible pathways of radionuclides through the food chain in a particular area is enough?

Electric utilities are spending more money today on research and development than they once did, but this cost still does not seem too burdensome, especially when it can be recovered through electric rates. In 1970 the Federal Power Commission estimated that research and development expenditures in the electric power industry amounted to less

Environmental "Costs" of Nuclear vs. Fossil-Fuel Plants

	Nuclear	Fossil Fuel
Thermal Effects	Water-cooled reactors have thermal efficiency of about 32%. One HTGR has 39%; others may be higher. Breeders should exceed 40%.	Most modern plants are 38 to 40% efficient thermally, but some improvement possible. National average now about 33%.
	Both may require cooling towers or other "artificial" cooling steps in some sites.	
Chemical Pollution of Water	Both may have problems arising from use of chlorine or other biocides to discourage formation of slime in intakes.	
		Strip mining of coal may pollute streams
Air Pollution	Essentially none.	Older plants still give off sooty "black smoke." Fly ash may settle over neighborhood. Some carbon monoxide given off, though small in comparison with that from motor vehicles. Carbon dioxide in atmosphere inevitably increased. Stiffer rules are curbing emissions of sulfur and nitrogen oxides, which may form acid in air, especially in presence of water vapor from cooling towers.
Radiation	Current guidelines keep concentrations to a small fraction of federally allowable and internationally recommended limits, but some is added to both air and water	Small amounts of airborne radiation from naturally radioactive elements in fuel (primarily radium).
Esthetics	Plant itself occupies less room because fuel storage space is unnecessary, but overall area of site is often larger—sometimes allowed to remain in farm use or forest growth.	Rail spur, docking facilities or pipeline always necessary. Fuel storage difficult to make attractive.
	Both have same problems arising from location of transmission lines and cooling towers (when needed).	
Solid Waste	Small volume, but requires special handling	Fairly large volume. Little hope for large-scale byproduct use, but research goes on.
Mineral Resources	See figure on p. 61.	

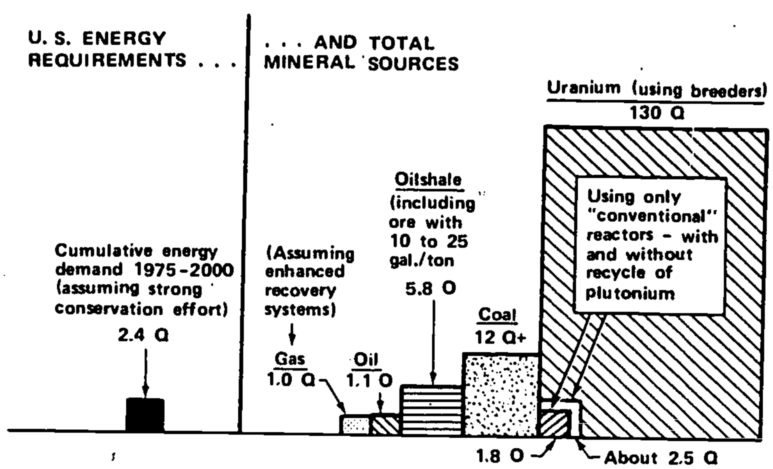
The 15-member Advisory Committee on Reactor Safeguards, shown in session, reviews applications for licenses for nuclear facilities and makes recommendations on the safety of proposed or existing facilities and the adequacy of related safety standards. Committee members are nongovernment scientists and engineers with industrial research and academic backgrounds.

than one quarter of 1% of gross electric operating revenue. In a period of uncertain revenues, it will be up to local regulatory agencies to decide whether utilities can be encouraged to increase their share.

Sometimes, moreover, the balance between costs and benefits in generating electricity must be affected by a factor that is neither financial nor environmental. That factor is public service. Conceivably, an electric utility operating in a relatively warm section of the country might find that its cheapest solution in meeting environmental standards on thermal effects would be to shut down its big power plants for a few days each summer. This solution, of course, would probably be unacceptable to the public for other reasons. Many power companies have undertaken advertising campaigns to discourage frivolous or wasteful uses of electricity (and this is probably a sign of prudence); but it's a fallacy to assume that all the so-called convenience uses could simply be scrapped. Air conditioning, for instance, is a frequent target of environmentalists; yet it plays a definite role in public health. It can't be considered entirely unessential to a safe environment for people. And of course this booklet began by mentioning some uses of electricity that are directed clearly against pollution problems (for example, recycling plants and mass transit).

Longer term environmental effects are hard to balance because prophecy is a tricky game. Nevertheless, it seems clear that nuclear power could help to preserve the earth's shrinking supply of natural resources. This is quite apart from problems this country might face through dependence on foreign supplies. Experts disagree about how long the entire world's store of fossil fuels might last, but this much is certain: Whether their supply is projected for decades or for centuries they cannot come close to uranium as a massive energy source.

Each nuclear fission in a power reactor releases about a million times as much energy as does a single molecule of any chemical fuel when it burns. With potential like that, the earth could have nuclear energy to spare for a long while.



The energy available from various mineral resources in the U. S. compared with one projection of the nation's needs between now and the end of the century. (Q is a term that represents a billion billion British thermal units.)

What's in the Future?

Even though precise predictions are impossible, good planning requires a look at future alternatives. How many of the environmental problems we recognize now in nuclear-based electricity are likely to be affected by breeder reactors? How about fusion power? And that exotically named process, magnetohydrodynamics (MHD)? What else is on the horizon?

Almost from the beginning of this country's nuclear energy program breeders have been envisioned as a means to extend the limited supply of fissionable uranium. Only a small percentage of natural uranium will fission in today's reactors. In a breeder reactor, some types of material that will not fission easily are converted by the capture of neutrons into fissionable fuel. This new fissionable material can be produced in a breeder reactor faster than the fissionable atoms in its original nuclear fuel are used up. Thus, breeding can protect our natural resources by making man's limited fuel supplies go farther and reducing the amount of uranium that must be mined.

Many breeder reactor concepts use cooling fluids other than the water used in the light-water reactors on which the previous discussions of this booklet have been primarily based. Some of the coolants that may be used in breeder reactors are liquid sodium, mixtures of other metals or metal salts, and helium gas. The selection of a particular cooling fluid results in many differences in the design features of the reactor concept.

This nation has assigned its highest priority to the development of the liquid-metal-cooled, fast-breeder reactor,

One of the principal facilities at ERDA's Liquid Metal Engineering Center is this large component test loop for the thermal shock testing of sodium components, small valves, equipment, and instruments for the Liquid Metal Fast Breeder Reactor Program.

or LMFBR as it is often called. This reactor concept uses liquid sodium as a coolant. Sodium is a silvery solid at normal room temperature and it melts at a few hundred degrees Fahrenheit. This breeder concept is expected to be cleaner in its operation, achieve better thermal efficiencies than light-water reactors (thus rejecting less waste heat), and offer other advantages.

After a number of metals and alloys with low melting points had been evaluated, sodium was picked as the coolant for the LMFBR because it offers a favorable combination of characteristics. It does not capture neutrons easily, so more are available for breeding. Sodium transfers heat extremely well. It also has a high boiling point (about 1500°F), so the reactor does not need high-pressure containers to keep the coolant at the temperatures necessary for reactor operation (about 1000°F).

Other design features of the LMFBR offer additional environmental protection. There is an intermediate heat-transfer loop (also containing sodium) between the sodium which circulates through the reactor and the steam that is used to drive the turbines. Also, all components containing sodium are housed in airtight cells filled with nitrogen, a chemically inert gas. Both of these features increase the barriers between the environment and the radioactivity in the reactor.

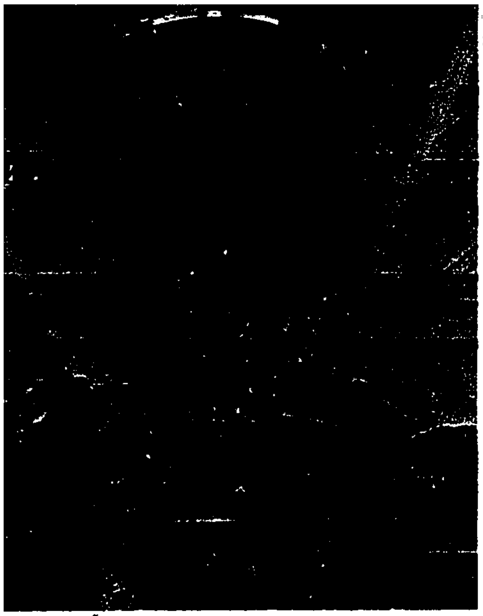
The LMFBR will pose some special problems because of its design and materials. For example, plutonium will intentionally be present in larger concentrations than in commercial power plants thus far, because plutonium will be part of the plant's productive output. Also, molten sodium reacts with most other substances, and corrosion in the reactor coolant systems will have to be inhibited. Sodium itself also becomes radioactive, thus necessitating other precautions. These problem areas are being subjected to a major development effort, drawing on the prior experience of both government and industry. None of these problems is insurmountable because of the long record of safety that already exists in using plutonium and sodium.

An LMFBR demonstration plant on the system of the Tennessee Valley Authority will be ready for operation by the early 1980s. This installation, located near Oak Ridge, Tennessee, will not be an experimental reactor but a demonstration plant that incorporates the results of many years of research and development. Before it gets to the hardware and operational stages, however, this demonstration breeder reactor will have to satisfy all the demanding requirements for environmental protection and safety that have been outlined earlier in this booklet. The demonstration will form an essential part of the national effort to achieve the commercial use of breeder reactors.

ERDA's LMFBR program is geared to a schedule that would enable the use of large commercial LMFBRs on utility systems to start in the 1980s. However, breeder reactors are expected to account for only a small fraction of the U. S. nuclear electric generating capacity before 1990.

Work is continuing on other kinds of breeders, as well as on other reactors that boost thermal efficiency. Two types of breeders designed to change thorium into fissionable uranium are under development. They are the MSBR (molten-salt breeder reactor) and LWBR (light-water breeder reactor).

The high-temperature, gas-cooled reactor (HTGR) has been under active development for a number of years, and the first large commercial power plant of this type will be supplying electricity to utility grids during the 1970s. By using helium as a coolant and operating at temperatures hundreds of degrees above those of water-cooled reactors, the thermally efficient HTGR rejects a smaller fraction of its heat as waste. Thus far there is still only limited operating experience with this type as compared with water-cooled reactors. Nevertheless, the HTGR holds promise as a near-term advanced converter reactor type that seems to produce a minimum of radioactive effluents, as well as smaller thermal effects. In the longer run, gas-cooled reactors may also be turned into breeders to help stretch fuel reserves.



In the upper part of the photograph is the Baseball II superconducting magnet, which is the largest magnet of this type ever built for fusion research. Below the magnet is the vacuum chamber in which the magnet is now sealed at the Lawrence Livermore Laboratory in California.

Fusion power is potentially one of the most environmentally attractive energy sources yet conceived by man. Its primary fuel would be a form of hydrogen, called deuterium. This fuel is abundant in seawater and the total amount available is sufficient to provide fuel for billions of years.

The fusion process is one in which nuclei of light elements collide at high velocity and fuse to form heavier nuclei and release energy. There are a number of such reactions to choose from and thus different fuel cycles are possible for fusion reactors. The simplest and most easily achievable of these reactions appears to be the one in which deuterium fuses with tritium, a radioactive isotope of hydrogen.

The first fusion reaction was studied in the laboratory in 1932. This experiment involved the collision between deuterium nuclei accelerated in one of the first atomic accelerators. The first massive release of fusion energy was demonstrated in 1952 with the first thermonuclear test explosion. About the same time, research on a means of releasing fusion energy in a controlled fashion began independently in the United States, Britain, and the U.S.S.R. Briefly stated, this search was for a means of keeping enough fuseable ions (a gaseous plasma) at a high enough temperature for a long enough time to release more energy via fusion than was needed to produce the plasma in the first place. Since no solid material can exist at the temperature range required for net energy output (on the order of 100,000,000°C) the principal emphasis has been on the use of magnetic fields to confine the plasma. More recently, systems have been studied in which inertial forces generated in solid deuterium pellets by intense laser beams are believed capable of holding the plasma long enough for net energy gain.

The worldwide effort on fusion power has produced a number of recent advances that have markedly improved plasma confinement. These have given scientists clear directions on which to proceed from the previous basic research phase towards large experiments to demonstrate scientific feasibility that is the next step in the program development.

The basic characteristics of a deuterium-tritium fusion reactor are determined by the details of the fusion reaction. Most of the reaction energy (80%) is carried by neutrons as kinetic energy. The neutron energy would then be absorbed in a suitable material with a low atomic number and converted to heat to run conventional turbines. These neutrons would also cause some radioactivity in the reactor structure. (However, this activity can be minimized by an appropriate choice of materials.) The thermal efficiency of the power plant is estimated to be greater than 50%.

Helium, the final reaction product, is inert and thus presents no environmental problem. The only possibility of radioactive release during routine plant operation is from leakage of the fuel, tritium. On the basis of preliminary design considerations and experience with fusion reactors, it appears that tritium leakage can be maintained at very low values, which would be well below all recommended safety limits.

The primary source of radioactive waste from a deuterium-tritium fusion reactor would be activated structural material. Methods of handling and recycling the structural material after allowing time for radioactive decay are being investigated and could virtually eliminate the need for long-term radioactive waste management in a fusion power economy.

Although it's very difficult to predict when fusion power will become available, there are many technical and socio-economic variables that could speed or slow its development. Present estimates indicate that an orderly but aggressive program might provide the first commercial fusion power about the year 2000.

Work on controlling fusion is linked in a way with studies of magnetohydrodynamics (MHD), which is not an energy source at all, but only an especially effective method of converting heat into electricity. It involves passing extremely hot, electrically charged gas through a magnetic field. Once an operating temperature of at least several thousand degrees can be achieved and maintained, as much as 60% of any heat input would be turned into electricity. Like a turbine generator, MHD could be linked to either a nuclear or a nonnuclear heat source in power plants of the future. It would mean a big boost to the thermal efficiency of either one, and a proportional decrease in the problems of wasted heat. Unfortunately, however, no large MHD generator has yet been proved out in a practical working situation. Other forms of direct energy conversion are likewise in their early stages of development.*

The foreseeable future is likely to produce a continuing number of less dramatic victories in the effort to reconcile nuclear power and environmental ideals. Nuclear plants can be designed to be more efficient, while technology also finds ways of further reducing the already minor radiation releases. Later on, the cost-benefit balance may be affected too by multipurpose plants, such as agro-chemical complexes that manufacture fertilizer while generating electricity for rural areas, or nuclear desalination plants that supply both power and pure water.

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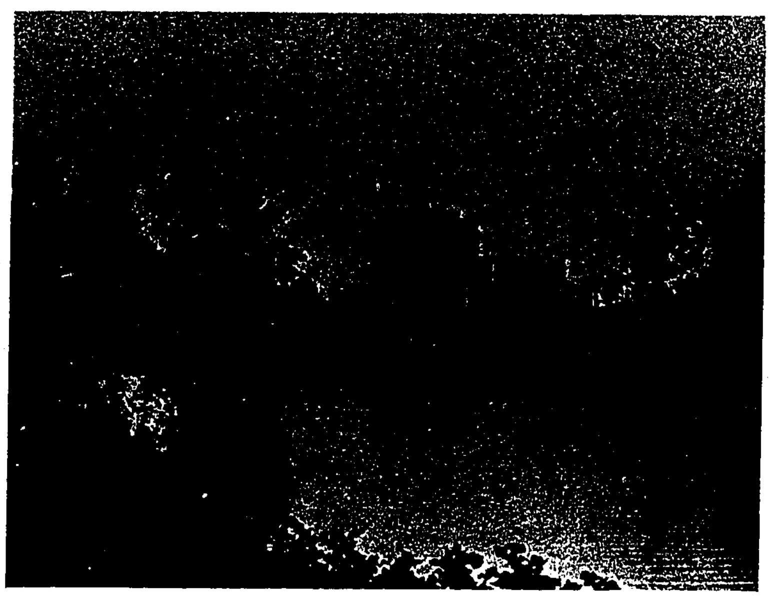
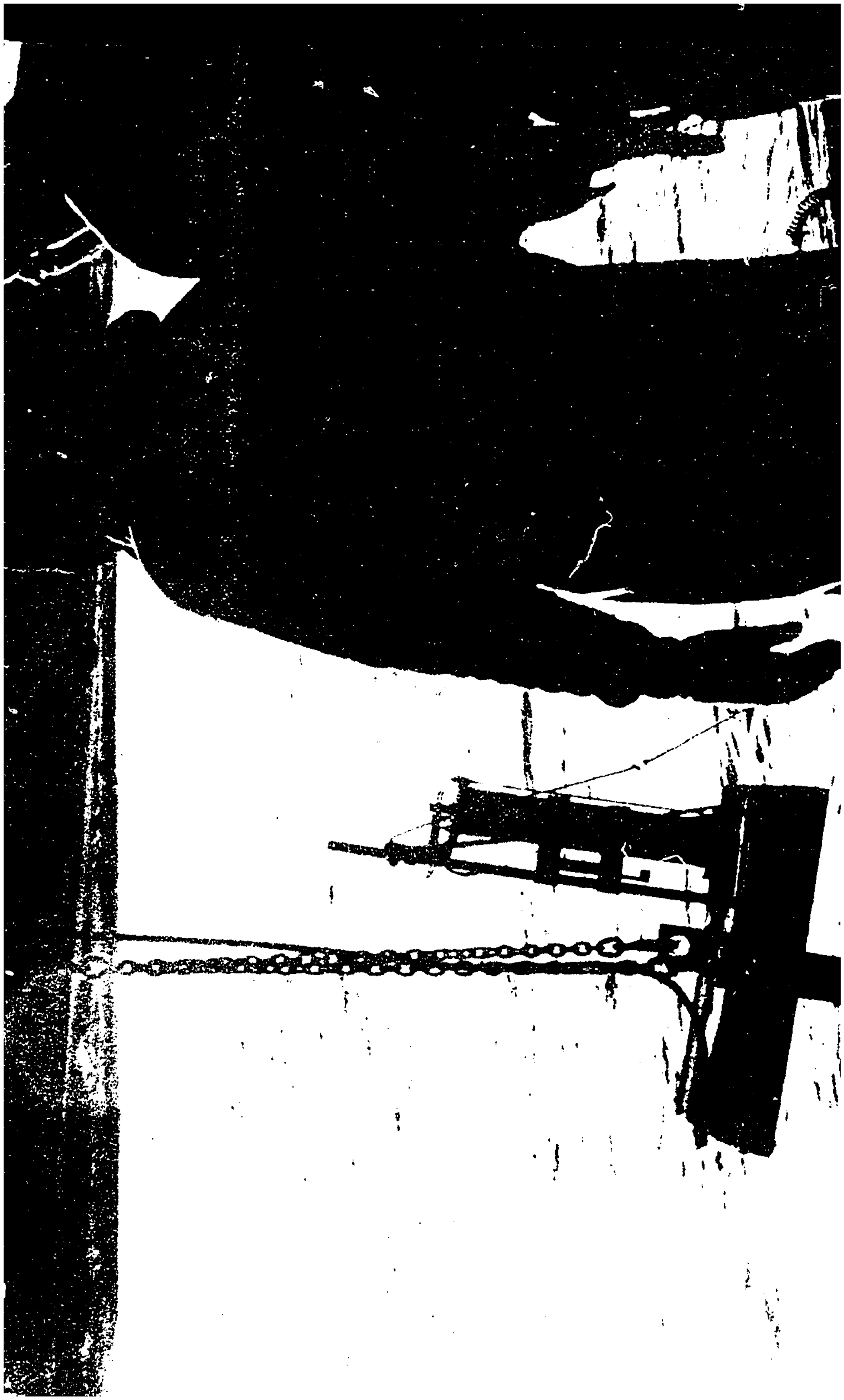
*The booklet entitled *Direct Conversion of Energy* deals with MHD as well as thermionic and thermoelectric converters.

As more generating plants are needed in the most densely populated parts of the U. S., however, it will be harder and harder to find suitable sites. For this reason, a number of utilities and nuclear plant contractors are looking forward to the eventual use of natural or man-made islands offshore. Deep, constantly circulating water around such a location might provide a safe means of dissipating some of the troublesome effluents without any appreciable impact on the environment.

In any event, each new license application will have to be considered on its own merits. Guidelines should become clearer and public policy decisions ought to grow easier as years of research begin to bear fruit. There will be a more precise understanding of how biological cycles, heat, and radiation all fit together.

The thermal efficiency of the high-temperature, gas-cooled reactor at the Fort St. Vrain Nuclear Generating Station in Colorado is rated at better than 39%. Larger versions might reach 43%.





We Must Keep on Learning

The Energy Research and Development Administration, the Environmental Protection Agency, several other federal groups, the electric utility industry, and state and private organizations all sponsor or conduct research on the interrelationship of energy, atoms, and the environment. The Edison Electric Institute reported as early as 1969 that utilities were involved in several hundred studies, just on thermal effects.

Even a quick survey gives some idea of how detailed many of the government and private studies have been, how broad and varied their coverage is, and what they continue to contribute. A sampling of these studies is given below.

Thermal Effects on Various Organisms

The thermal-effect studies begun by the AEC during the 1940s in the Northwest were gradually extended to include other government installations and commercial power plant sites along both coasts, the Great Lakes, and numerous rivers.

Larger fish are sometimes tracked by numbered tags or harmless fluorescent markings or by miniature ultrasonic transmitters that note changes of temperature and pressure. Nonlethal as well as lethal effects are analyzed. One aim is to pinpoint the extent to which an artificial temperature rise stimulates various species of fish to spawn earlier than usual. Eggs and larvae are examined after temperature changes too; and aquatic insects are studied because they provide food for

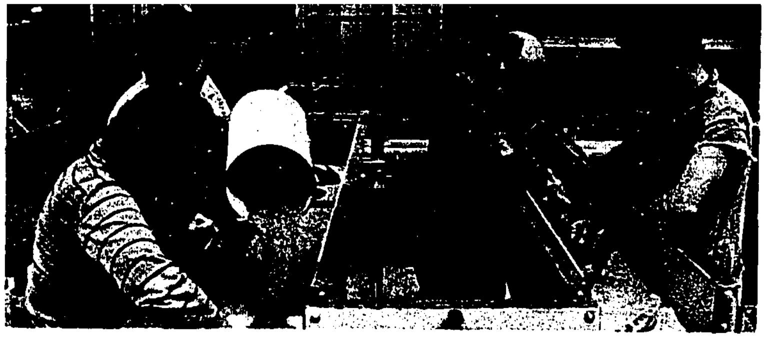
Members of ERDA's Argonne National Laboratory watch as the temperature of Lake Michigan is taken in a thermal effects study near Point Beach Nuclear Power Station.

some fish. Subjects of observation have ranged, literally, from bacteria to alligators. Special attention is also paid to plants rooted along the bottom and to certain varieties of shellfish, which can't move about in order to evade temperature effects that don't agree with them.

Several interesting comparative studies have been made near the sites of old fossil-fuel plants. These have involved both government and private groups. Typically, the aquatic life in the immediate vicinity of the condensers is matched with findings of an undisturbed location nearby. Changes in water chemistry and dissolved oxygen as a result of plant operation have proved to be minimal, and little, if any, damage appears to have been done over the years to the species examined.*

To complement and coordinate the field work, some laboratory programs are devoted largely to thermal biology. At ERDA's Savannah River production facility in South Carolina, for instance, a number of artificial streams have been created in which plant and animal life can be studied under controlled conditions. This makes it possible to calibrate the effect of temperature on selected organisms within any given aquatic food chain. At Oak Ridge National Laboratory, a new aquatic ecology facility, which is perhaps the most advanced one of its type, has a special pumping system that is designed to simulate the thermal discharges of power plants. Short-term effects (for example, those caused by the quick trip that plankton larvae and plant spores may take through the condensers) will be studied together with

*This is not to say that "fish kills" have never taken place in relation to power plant operations. At various times they have been traced to the design and placement of fish screens, to the heavy use of certain chemicals to prevent algae from building up along water intakes, to corrosion particles from condenser tubing, and to water chilling after plant shutdown. *All together, however, an examination of the fish kills reported to the Federal Water Pollution Control Administration throughout one entire year (1968) revealed that more than 98% had nothing at all to do with power plants.* At most (and this is stretching a point), thermal effects from power plants may have accounted for something less than one-tenth of 1% for that year.



In order to examine thermal effects under controlled conditions, scientists at ERDA's Savannah River Laboratory built a laboratory with six man-made streams fed by water from a natural stream nearby. The study will help scientists and engineers to understand and manage thermal effects related to electric power plant operations. Above, rocks, creek bottom sand, and branches are placed in one of the artificial stream beds.

the longer-term adaptations that might come from more or less permanent adjustments in seasonal temperatures.

Analysis of Ecosystems

To understand the impact of either natural or man-made changes in the environment, it's necessary to look at life as an overall pattern from microorganisms to man and beyond. This involves many different scientific specialties, including ecology, animal and plant physiology, meteorology, hydrology, chemistry, and physics. One result of the AEC's (and now ERDA's) coordination has been to put together baseline studies for certain types of regional extremes—arid lands, cold tundra, tropical rain forests, etc. Usually the projects to analyze ecosystems in heterogeneous areas (like the Middle Atlantic region) have been helped by private as well as publicly financed research. Many universities are involved.

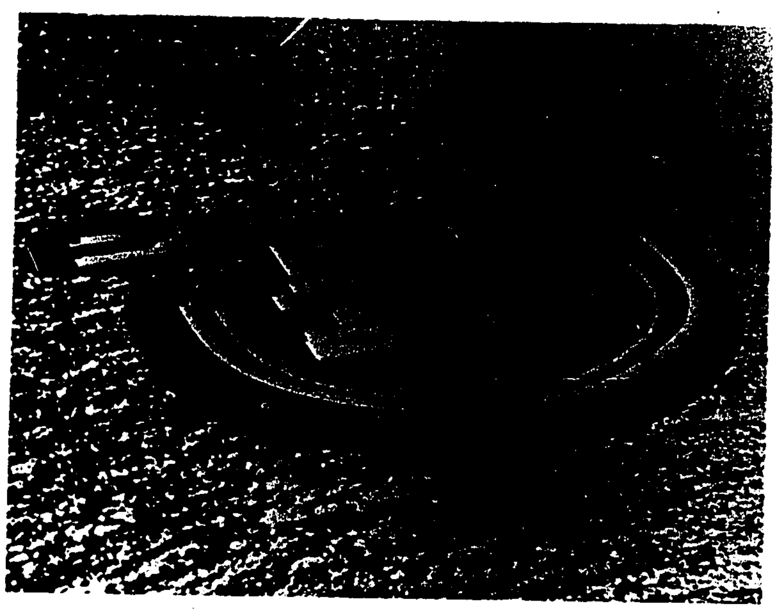
Hundreds of thousands of acres around two ERDA installations have been designated as "Environmental Research Parks" and thus made available as protected outdoor laboratories in which both government and private research teams can study man's effects on his environment. The one near Aiken, South Carolina, includes forests, fields, swamps, and an old town site. The second one is a desert scrub area in Idaho.

The study of a food chain must get to the very bottom of things—the sediments on the bed of a lake or the litter and mosses on the floor of a forest. In some situations, radionuclides that reach them may be passed along to other species, although this is not always the case. The plants and animals that could end up as human food come in for extra study, of course.

ERDA's life sciences laboratory at Hanford includes facilities for studying the metabolism of both large and small animals; and numerous research contracts have been awarded over the past couple of decades to individuals and teams of investigators in related fields.

Beneficial Uses of Waste Heat

There may be an actual improvement when adjacent waters are warmed by a power plant's condensers. In some cold areas like New England and the Northwest, the commercial fishing season could be extended slightly and some desirable species might be encouraged. Experiments in



Model of an off-shore nuclear plant and breakwater.

Smoke is released in one of a series of experiments performed by ERDA's Brookhaven National Laboratory meteorology group in anticipation of placing nuclear power plants at off-shore locations.

England have produced reports of modest success in promoting seafood growth. There is still the problem of thermal shock when such a plant shuts down for maintenance, but research is continuing.

The idea of using heated water to irrigate crops and thus warm the soil has also been explored. Oceanographers have even speculated about using the excess energy from steam power plants to cause massive upwelling of nutrient-rich deep waters. This would enhance the biological productivity of certain sea areas.

The trouble with many of the ideas that have been publicized so far is that they overlook some basic facts: (1) The maximum temperature increase inside a power plant's condensers is really not very great—usually only between 10° and 30°F. (2) This differential is lost very easily if the water has to be transported any appreciable distance. (3) Many of the proposed uses for waste heat are least attractive in tropical areas and during warm periods—in

Maryland Blue Crabs, one of the vital food resources of the Chesapeake Bay, are being studied by University of Maryland scientists as part of a Federal research project to monitor the effects of heated water discharged from the Calvert Cliffs Nuclear Power Plant in Maryland. The project is one of the dozens of thermal effects research tasks being conducted by scientists across the country under Federal Government research contracts. The information gathered by these projects will be useful in designing and operating both nuclear and fossil fuel electric generating plants so that they will have minimal impact on natural bodies of water.

other words, in the very cases that most need a means of dispersing the thermal effects. Research is still going on, and there may be some instances where practical beneficial uses can be developed, but they are not likely to be used very soon.

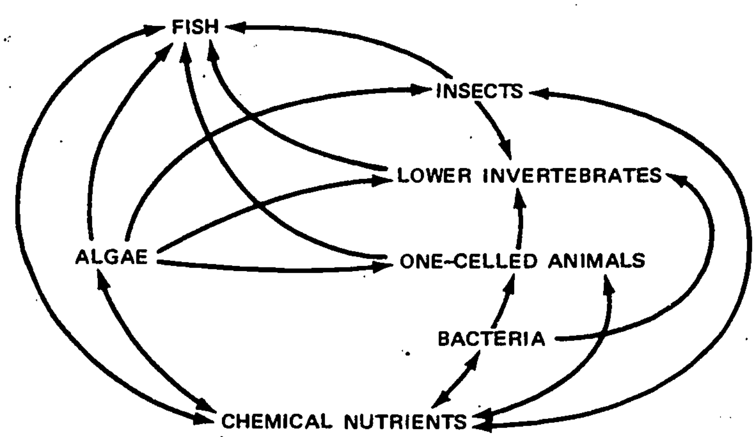
Better Methods of Measurement and Prediction

Sensitive instrumentation keeps power plant operators aware of radiation levels, and it can also warn them instantly if specified limits on discharge temperatures are exceeded. To avoid accidental releases of radioactivity, a special monitoring system was developed at ERDA's Savannah River production plant. It gives warning if abnormally high radiation is detected in water flows, but at the same time it diverts the water automatically into a holding basin. A variety of such systems has long been used inside power plants as part of the safety system.

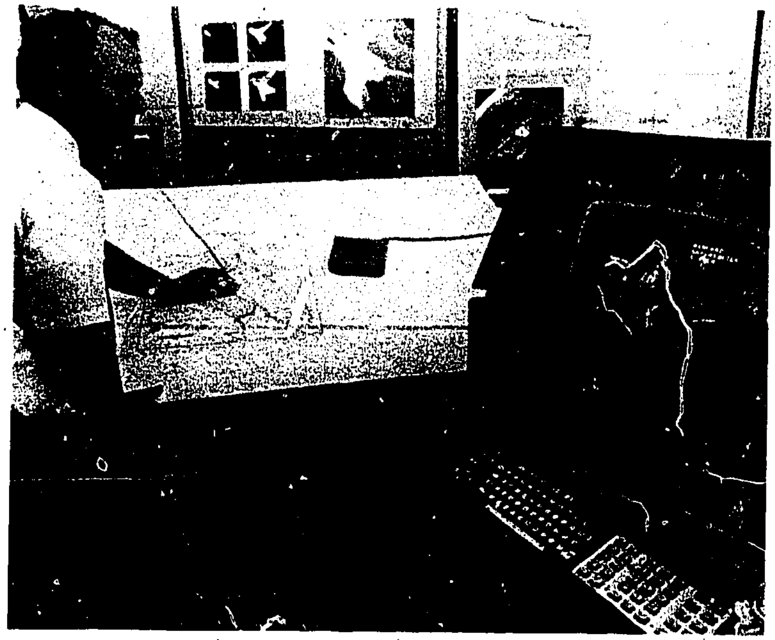
Long before a new power plant is licensed to operate, however, there must be some way of determining what will happen to the liquid effluents that may be released. One predictive technique uses physical models. These can be built to simulate the movements in any particular natural body of water. They match the bottom contours and duplicate the known effects of tides, currents, and tributaries. Experiments on a compressed time scale make it possible to consider many variable factors.*

More and more often, comprehensive mathematical models are also being developed to do a similar job. Computers can be programmed to predict water movements, either on the surface or underground. Early experience at Hanford has led to mathematical models that were useful in evaluating sites along a complex estuary like the Chesapeake Bay or in a large segment of a river system like the upper Mississippi River Basin. By mathematical techniques, the combined impact of any number of sites can be considered. Research of this type has indicated that—without exceeding

*To cite just one case, studies have been carried on at a 200-foot-long model stream at the University of Texas in Austin that can be controlled both hydraulically and biologically. They showed that plant and animal life may store up radionuclides during summer periods of rapid growth, when weeds infest a slow-moving stream. On the other hand, an increase in the amount of sediment suspended in a stream may purge the life forms of radionuclides by shifting the radiochemical balance in an area.



Simplified food web shows how aquatic organisms interact. "Supplies" move in the direction of the arrows.

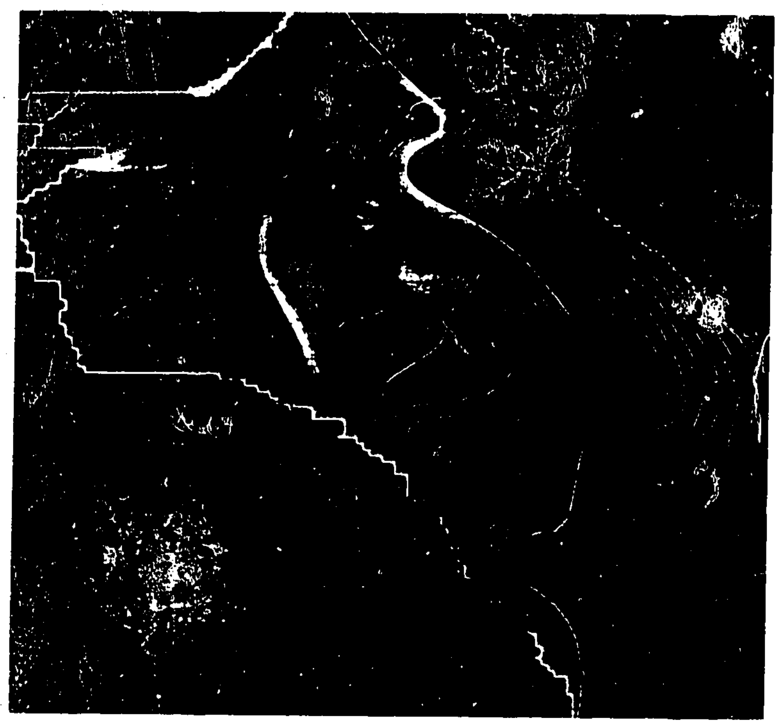


As part of the research and development on safe storage of radioactive wastes, the Pacific Northwest Laboratory has produced a system of mathematical models for simulating groundwater movement. The computer models have enabled scientists to understand and predict groundwater movement at the Hanford reservation.

water quality standards—large streams can usually accept and then dissipate considerably greater quantities of heat than would be suggested by simpler calculation, using only average river flows and plant cooling requirements.

Neither hydraulic models nor computer models are perfect, but either kind can give approximations that should help to make intelligent decisions on design trade-offs. Field checks on their accuracy can prevent any serious errors, and at the same time they should improve the predictive techniques themselves.

Unusual natural events have to be considered too, however. Floods can change the amounts of sediment a stream carries, and they can cause temporary or permanent



Contours of the groundwater table below the surface at the Hanford reservation are shown in this cathode-ray tube display hooked up to a computer. The basic predictive method can be extended to embrace temperature and/or radiation changes as well as water movements.

damage to structures along its banks. Drought might reduce a stream's flow below the point where it could safely dilute and disperse either low-level radioactivity or heat. For this reason, the U. S. Geological Survey undertook several years ago to determine the frequency of such occurrences as well as their maximum and minimum impact.

The Upper Mississippi River Basin was chosen as the first subject for another computer analysis that looks ahead to the year 2000.* This one focuses on radiation effects, and it may

*The Potential Radiological Implications of Nuclear Facilities in the Upper Mississippi River Basin in the Year 2000 (WASH 1209), USAEC Division of Reactor Technology, January 1973.

eventually be extended to additional large geographical areas. The model considers both power plants and fuel reprocessing centers, and it takes into account both the existing types of reactors and the emerging breeder, as well as various systems for treating radioactive effluents before releasing them to the atmosphere. Internally, it can adjust the number and location of all such sources. Its intention is to project radiation dose rates for individuals and population groups according to alternate plans for plant siting and treatment of effluents. The model takes into account various pathways of exposure, and it analyzes the movement of radionuclides through both air and water.

Besides offering clues for early site selection on a regional basis, this project should help to guide future research programs by the various organizations participating in it. They include several divisions of ERDA, the Tennessee Valley Authority, and the National Oceanic and Atmospheric Administration.

Eventually, it may be possible for electronic computers to simulate a complete ecosystem. The National Science Foundation is trying to do this for grassland sites, among others. Translating the interrelationships of living organisms into mathematical terms is certainly a challenging job for researchers, but some scientists believe that this approach holds great promise for wiser resource management. As a matter of fact, with instrumentation getting better and more environmental monitoring stations being set up across the country, computers may offer the only means of analyzing and evaluating all the new ecological data becoming available.

Elimination of Waste Gases

Even though gaseous releases from nuclear power plants are well below the prescribed limits, the quest continues for more effective methods of collecting and containing radioactive gases. As explained above, traditional purification systems can't eliminate long-lived noble gases because these elements are most unlikely to react and they are only present in small concentrations to begin with. Recently, one process has been demonstrated on a pilot plant basis to remove

99.9% of the krypton and xenon from contaminated gas samples. It works on the principle that both rare gases dissolve readily in low-temperature refrigerating liquids. Another product of recent research is a gas-purifying material called "silver zeolite". It appears to be more effective than charcoal for absorbing airborne iodine, especially at high temperature or when moisture is present.

Genetic Effects and Recovery from Radiation Damage

When an excessive amount of nuclear radiation is absorbed in a short time, plant and animal genes are definitely affected. Genetic damage shows up in successive generations. The results are less clear when the radiation comes in very small doses over a long period of time;

Continuous water sampling is conducted on or near ERDA nuclear reservations to assure that no adverse environmental effects are caused by ERDA operations. As shown below, water samples are collected from four river locations and various points on five streams above and below ERDA's Savannah River Plant in South Carolina.

Research at Par Pond, through which reactor cooling water recirculates, showed that plankton photosynthesis increased fivefold between 1965 and 1970. This resulted in a higher population of fish and turtles rather than a harmful algae and plankton bloom.

experiments with fruit flies indicated that the effects always accumulated, but those with mice have suggested the opposite. To take no chances, U. S. radiation limits have always insisted on a pessimistic approach. They assume that all radiation effects on human beings are cumulative, and the strict rules about radiation exposures are framed with this in mind. Nevertheless, work still goes on to clarify the nature and extent of radiobiological effects, including those in the field of genetics.*

Certain ponds in the vicinity of the earliest AEC installations offer some of the best opportunities available for field study. Although the results here are fairly easy to detect, they are not directly comparable to power plant sites.

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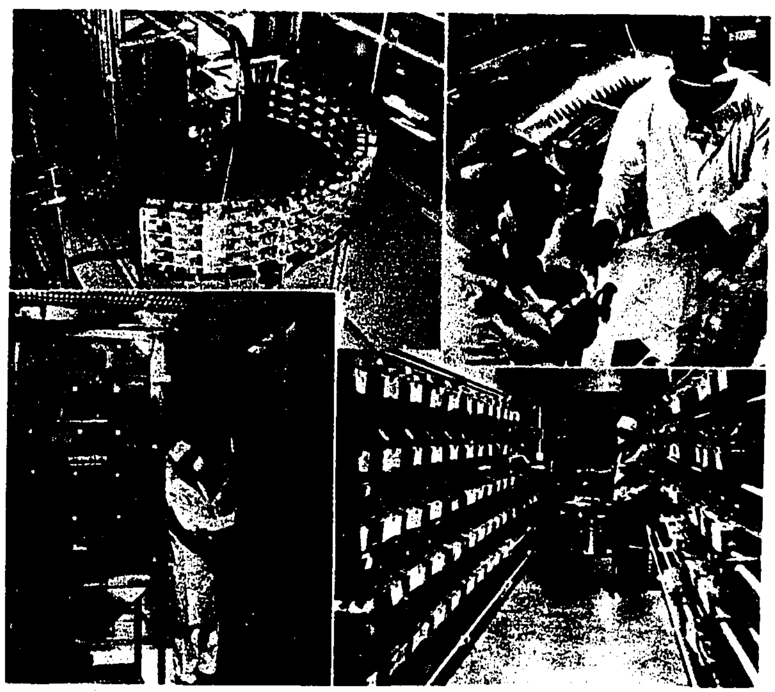
*See *The Genetic Effects of Radiation*, another booklet in this series.

Organisms in these ponds have been exposed to much higher levels of radioactivity than those that occur in connection with commercial power plants, and the exposure has continued for many generations. Access to the study areas is controlled, but results of the investigations are published periodically.

Research during the past 20 years or more has also demonstrated that living cells contain some internal mechanisms for repairing internal radiation damage on their own. Chemical treatments have succeeded in markedly reducing the effects of radiation on tissue samples and various laboratory animals, apparently by stimulating the natural



The animal experimentation facilities at ERDA's Oak Ridge National Laboratory are used to study the genetic and somatic effects of ionizing radiation as well as the effects of environmental pollutants from fossil fuel plants and internal combustion engines.

protection systems. The compounds are hard to administer in effective doses, however, and it is too early to predict any practical applications.

Combined Effects of Radiation and Heat

There are times when radiation and temperature interact in their effect on the environment, but it is difficult to generalize about this. Some fish tend to absorb radioactive metal ions more rapidly as the water warms up. Others show no difference; and in some cases the final effects of radiation might not increase but the effects show up faster.

Minerals that normally occur in water may be a contributing factor too. This is why the AEC and now ERDA have encouraged research in which certain species (for example, the blue crab) are studied under varying combinations of temperature, radiation exposure, and salinity.

Unquestionably, a lot of important findings along these lines will emerge gradually from the comprehensive studies of specific plant sites that are becoming a common part of the licensing process. Utilities stand to gain by ordering competent, fully documented baseline studies of the environment before a plant is installed, and many state as well as federal agencies are intent on keeping track of any changes that might take place later on. As a result, information from scattered sources is combined, and new, unified programs may continue for years. The millions of dollars in private funds being spent to exercise the "nuclear option" will do more than just help to protect the environment. Continuing research should help scientists everywhere understand the environment better.

Reading List

Information about individual power plant and fuel reprocessing projects is normally obtainable from the companies directly involved. Under current NRC regulations, the reports and correspondence relating to license or permit applications are also available to the public at NRC document depositories. The pros and cons of many questions about environmental protection have been debated often in various Congressional hearings, and some of the most significant volumes are included in the list below.

Universities, National Laboratories, and Man's Environment (CONF-690705); (Proceedings of a conference held July 27-29, 1969, at Chicago), National Technical Information Service, U. S. Dept. of Commerce, Springfield, Va. 22151, 167 pp., $3.00

Environmental Aspects of Nuclear Power Stations (Proceedings of a conference organized by the International Atomic Energy Agency at the United Nations in New York, August 10-14, 1970), published by the IAEA, Vienna, Austria, 1971, 970 pp., $25.00.

Nuclear Power and The Environment, an 85-page information booklet prepared by the International Atomic Energy Agency in collaboration with the World Health Organization, Vienna, 1973. Available from UNIPUB, Inc., P.O. Box Y33, N. Y. 10016, $2.00 .

The Calefaction of a River, Daniel Merriman, *Scientific American*, 222:42(May 1970).

Biological Aspects of Thermal Pollution, P. A. Krenkel and F. L. Parker (Eds.), Vanderbilt University Press, 1969, 407 pp., $7.95.

Engineering Aspects of Thermal Pollution, F. L. Parker and P. A. Krenkel (Eds.), Vanderbilt University Press, 1969, 372 pp., $7.95.

Nuclear Power in Maryland, Governor's Task Force on Nuclear Power Plants, Annapolis, Md., December 1969, 49 pp., $3.50.

Nuclear Power and the Environment, proceedings of a conference at the University of Vermont, September 11, 1969. U. S. Government Printing Office, 191 pp., $0.75.

Thermal Effects and U. S. Nuclear Power Stations, USAEC Division of Reactor Development and Technology, August 1971, U. S. Government Printing Office, 40 pp., $0.50.

Disposal of Solid Radioactive Wastes in Bedded Salt Deposits, a report by the Committee on Radioactive Waste Management, National Academy of Sciences–National Research Council, Washington, November 1970, U. S. Government Printing Office, 28 pp., $0.35.

Electric Power and the Environment, Energy Policy Staff, Office of Science and Technology, August 1970, U. S. Government Printing Office, 71 pp., $0.75.

Nuclear Power Plant Siting: A Handbook for the Layman, Dennis L. Meredith, University of Rhode Island Marine Bulletin #6, 32 pp., $1.00.

Thermal Pollution—1968. Hearings before the Subcommittee on Air and Water Pollution of the Committee on Public Works of the U. S. Senate were published (along with associated documents) in four volumes totaling 1,394 pages.. They may be ordered from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C.

Nuclear Power and the Environment: Questions and Answers, American Nuclear Society, Hinsdale, Illinois, 1973, 64 pp., $1.25.

A River and a Nuclear Power Plant, Peter H. Judd, 1970, 30 pp. (Although this booklet was prepared at the expense of Northeast Utilities, it was written by a political scientist interested in conservation and environmental matters—under the express arrangement that he would have full access to information and would be free to write as he chose in describing efforts to integrate a nuclear plant into the environment of the Connecticut River.)

Hearings and Other Publications of the Joint Committee on Atomic Energy:

Selected Materials on Environmental Effects of Producing Electric Power (91st Congress—August 1969), U. S. Government Printing Office, 553 pp., $2.50.

Nuclear Power and Related Energy Problems—1968 through 1970 (92nd Congress—December 1971), U. S. Government Printing Office, 1103 pp., $4.50.

Environmental Effects of Producing Electric Power. These hearings were published in two parts. The first part, covering testimony in October and November 1969, consists of 1108 pages and is available from the GPO for $4.50. Part 2, covering the sessions in January and February 1970, was produced in two volumes. The first (pages 1109 to 1862) is $3.25. The second (pages 1863-2708) is $3.50.

Motion Pictures

The following 16 mm films are available for loan without charge from the ERDA-TIC Film Library, P. O. Box 62, Oak Ridge, Tennessee 37830.

Film Number 0461

No Turning Back, 27½ minutes, 1971. In this film, scientists, who took part in AEC-supported ecology studies, discuss their work. Some of the sites visited are: the ALE (Arid Land Ecology) reserve, a vast desert steppe laboratory in southeastern Washington State; the "Climatron," a tropical forest at the Missouri Botanical Garden; the Savannah River Plant in South Carolina and the Hanford Plant on the Columbia River in Washington State, where extensive research on river ecosystems is conducted; and Lake Michigan, where Argonne National Laboratory scientists study the impact of industry on natural waterways.

Film Number 0447

Nuclear Power and the Environment, 14 minutes, 1969. This film discusses the work involved in studying and controlling the effects of nuclear power plants on the environment; i.e., environmental surveys to predict ecological effects, use of cooling towers and ponds, careful selection of the plant site, waste storage, and plant safety.

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Joseph M. Dukert is an author and consultant who received his B. A. degree in journalism from the University of Notre Dame in 1951 and completed graduate studies in international relations both in this country and in Europe.

As Public Relations Director for the Nuclear Division of the Martin Marietta Corporation and later for that company's Research Institute he developed programs that interpreted both technology and basic research in physics, mathematics, metallurgy, and the biosciences to a diverse group of audiences, including the general public.

He has produced several movies, one of which received a "Cindy" as the best industrial sales film of the year. Another of his films was chosen as the outstanding television newsreel film of the year at the Rome Film Festival.

He is the author of several popular science books, including *Atompower* (Coward-McCann, 1962), *This is Antarctica* (Coward-McCann, 1965 and 1972), *Nuclear Ships of the World* (Coward-McCann, 1973), and numerous booklets, magazine and newspaper articles, and movie and TV scripts.

A word about ERDA . . . .

The mission of the Energy Research & Development Administration (ERDA) is to develop all energy sources, to make the Nation basically self-sufficient in energy, and to protect public health and welfare and the environment. ERDA programs are divided into six major categories:

- CONSERVATION OF ENERGY—More efficient use of both existing and new sources of energy in industry, transportation, heating and cooling of buildings, and the generation of electricity, together with more efficient transmission of energy.
- FOSSIL ENERGY—Expansion of coal production and the development of technologies for converting coal to synthetic gas and liquid fuels, improvement of oil drilling methods, and development of techniques for converting shale deposits to usable oil.
- SOLAR, GEOTHERMAL, AND ADVANCED ENERGY SYSTEMS—Application of solar energy to heat and cool buildings and development of solar-electric power, conversion of underground heat sources for electricity and industrial heat, and development of hydrogen fusion for generating electricity.
- ENVIRONMENT AND SAFETY—Investigation of health, safety, and environmental effects of energy technologies, and research on managing wastes from energy production.
- NUCLEAR ENERGY—Expansion of medical, industrial and research applications; advancement of reactor technologies for generating electricity, especially the breeder concept; and production of nuclear materials for civilian needs.
- NATIONAL SECURITY—Development, production, and testing of nuclear weapons and attention to such related issues as safeguards and international security matters.

ERDA programs are carried out by contract and cooperation with industry, university communities, and other government agencies. For more information, write to USERDA-Technical Information Center, P. O. Box 62, Oak Ridge, Tennessee 37830.

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