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The
PHILIPPINE GEOGRAPHICAL JOURNAL

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THE PROMISE AND PERIL OF NUCLEAR ENERGY[c]

by

KENNETH F. WEAVER

"NUCLEAR ENERGY is dying" — Amory Lovins, Friends of the Earth. "The vigorous development of nuclear power is not a matter of choice, but of necessity" — Hans A. Bethe, Cornell University.

The utter divergence of these points of view has marked the controversy in recent years about energy from fissioning atoms. The man in the street may be forgiven if he is not sure who is right.

The debate has been frequently emotional, sometimes bitter, often confusing. Frightening stories about radiation hazards of nuclear materials vie with worrisome forecasts of energy famine, economic troubles, and even environmental disaster if nuclear energy is abandoned.

Not many years ago prospects for the nuclear industry were booming. Nuclear electricity was heralded as the cleanest, cheapest, and most convenient form of power. It seemed certain to fill much of the vacuum caused by the predicted shortages of oil and gas.

Orders for nuclear plants flooded into General Electric, Westinghouse, and other suppliers. In just three years, 1971 through 1973, the utilities ordered an even hundred reactors. Optimistic predictions foresaw as many as 1,500 reactors in the United States by the end of the century.

Then came the oil embargo of 1973-74, followed by strong national pressures to use less electricity and to conserve fuel. At the same time, the price of electricity was rising sharply. The ever growing demand for electricity slowed. Utilities found themselves over-extended. Abruptly, new reactor orders dropped — only 13 in the four years 1975 through 1978. Dozens of previous orders were canceled or postponed.

Meanwhile, Government policy shifted from enthusiastic promotion to mixed support. Public attitudes, once generally pro-nuclear, wavered. Opponents mounted demonstrations at reactor sites like Seabrook in New

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Hampshire and Diablo Canyon in California. They raised safety questions at public hearings and filed court suits to prevent licensing of further reactors.

Against this background stands one significant fact: Nuclear energy is already providing roughly one-eight of all the electric power generated in this country. More than 70 nuclear power plants in 27 states have received operating licenses. More than 90 others are under construction.

In 1978 nuclear energy produced nearly 300 billion kilowatt-hours, rivaling gasfired and hydroelectric stations. Eighty percent of electricity produced in Vermont comes from nuclear power; in Maine, 65 percent; and in Connecticut and Nebraska, 50 percent or more. All this has come about in just over two decades since the United States' pioneer nuclear plant at Shippingport, Pennsylvania, went into service.

What, then, is the future of nuclear energy? Is it a dead end? Or will it recover from its current troubles and fulfill at least some of the bright promise of a few years ago?

Answers are murky, shrouded in uncertainties. But here are some of the arguments, and essential facts needed to understand them, based on the views of many experts and on tours of nuclear installations in the United States and Europe.*

ATOMS AT WORK AROUND THE WORLD

Across the Energy-Hungry Globe, nuclear power has established a foothold in at least 44 nations. By the middle of 1978, 22 countries had already licensed some 220 reactors, capable of generating more than a hundred million kilowatts of electricity. An additional 320 reactors were under construction or on order.

Large as these figures may seem, increasing opposition in most advanced nations has slowed nuclear power growth. But developing countries continue to seek reactors and other nuclear facilities, in part as symbols of importance.

Such facilities as fuel reprocessing plants produce plutonium that can be used to make nuclear bombs.

This arouses the fear of plutonium pilferage and the consequent spread of nuclear weapons.

* Nuclear power plant completed.
* Nuclear power plant under construction or ordered.
* Civilian nuclear fuel reprocessing plant.
* Major nuclear waste burial site (some closed).
* Major uranium deposit exploitable at current price.

Where two or more sites are close, one symbol is shown. Gray shading marks uranium-bearing areas.

The basis for nuclear power is that certain heavy elements in the earth's crust, such as uranium, have varieties (called isotopes) that can

* Science editor Kenneth F. Weaver initiated the Geographic's coverage of energy in the November 1972 issue with "The Search for Tomorrow's Power." Last November Bryan Hodgson analyzed the natural-gas potential. Consult the *National Geographic Index* for recent articles on oil, coal, wind power, solar power, and geothermal energy.

be made to split, or fission. When the nucleus of such an atom splits, it results in fragments that together weigh slightly less than the original. The loss in mass turn into energy.

The fissioning atom also gives off neutrons, heavy subatomic particles. Under the right conditions these strike other fissionable atoms and cause them to split, thus creating a chain reaction.

A reactor is a remarkable device to stimulate this splitting of nuclei on a grand, but controlled, scale. Resulting energy, as heat, can be harnessed to make steam that drives turbine generators to produce electricity. The scientific principle is simple; putting it into use safely calls for complex, highly sophisticated engineering.

If you could look into the heart of a typical pressurized water reactor — the commonest kind in use — you would see the nuclear core, scores of thick bundles about 12 feet long, made up of slender, shiny tubes. Each tube, or fuel rod, is filled with some 200 pellets of enriched uranium.

The pellets are small — about twice as thick as a pencil and slightly more than half an inch long. But they are mighty: The energy content of each pellet is about the same as a tone of coal or four barrels of crude oil. The cost? Five to ten dollars.

A large reactor operating today holds tens of thousands of fuel rods in which are sealed some eight million uranium pellets weighing about a hundred tons. The capacity of such a reactor is roughly 1.000 megawatts (one million kilowatts) of electricity, enough for a city of 600,000 people. But the life of the core is limited. A third of the fuel must be replaced annually during the expected 30-40-year life of the reactor.

Once reactor operations begin, the core is surrounded and infiltrated with water — thousands of tons — which circulates under high pressure to carry away the intense heat and keep the reactor temperature within limits. The water also moderates, or slows, the flow of neutrons and thus helps control the chain reaction. Core and water are contained in a heavy steel pressure vessel. It, in turn, is shielded by a steel-and-concrete containment structure to prevent radioactivity from escaping into the outside world.

Suppose radioactivity does leak. Why is that a matter of concern? Some kinds of radiation, such as ordinary light, are relatively harmless.

But ionizing radiation, the kind produced by radioactive materials or X-ray machines, is dangerous because — though invisible and unfelt — it can cause serious changes in the cells of the human body. Its intense energy can destroy or distort molecules in cells. It breaks DNA strands in the genes.

The long-range effects may be cancer if the damaged cells go out of control and duplicate themselves wildly. Or there may be birth defects and genetic mutations in future generations if reproductive cells repair themselves incorrectly and produce abnormal arrangements of the DNA strands that govern heredity.

Two kinds of ionizing radiation are actually electrically charged particles: alpha particles, or nuclei of helium atoms, and beta particles, or electrons. Alpha particles travel in air only inches before they are stopped. They cannot penetrate the skin and are not a health hazard as long as they remain outside the body. However, if an alpha emitter, such as plutonium dust, is inhaled, the heavy alpha particles can deposit all their high-energy content directly in very sensitive lung tissues and wreak damage that may eventually result in cancer.

Beta particles travel a few feet in air, and they can penetrate slightly into the body. They especially affect the bones and the thyroid if beta emitters are ingested. The particles can usually be blocked by thin sheets of metal or wood.

Gamma rays, a third type, are shortwave, high-energy electromagnetic radiation, akin to X rays. They penetrate easily into the body. Reactors have a biological shield of thick concrete to reduce their intensity.

Natural Radiation Unavoidable

Clearly, ionizing radiation is something to avoid if possible. And yet, although you may not be aware of it, you are bathed in low-level natural radiation all the time.

RADIATION AND YOU

In nature are found some 60 varieties, or isotopes, of chemical elements that are radioactive. That is, they continuously transform, or decay, into new elements, giving off high-energy radiation in the process. Some two hundred other rad oisotopes are created artificially in nuclear machines, such as reac ors.

When emissions from radioactive substances enter the human body, they injure cells by ionizing (tearing electrons from) atoms. If the damage is slight, or takes place slowly, the body usually makes repairs. But if damages is great, adequate repairs are impossible and the biological consequences can be severe: illness, reduced life expectancy, eventual cancer. Or genetic defects may appear in future generations.

The time it takes a radioactive element to decay is measured by its half-life. After one such period, half the original radioactivity remains; after two half-lives, a fourth; after 20 half-lives, only a millionth.

Some radioactive elements decay swiftly. Iodine 133 has a half-life of only 21 hours. But for Iodine 131 the half-life is 8.1 days, and for iodine 129 it is 17,000,000 years.

Certain parts of the body, such as the gonads, thyroid, and bone marrow, are especially sensitive to radiation. Moreover, some radioisotopes have particular affinities. Strontium 90, for example, is a bone seeker. Iodine becomes concentrated in the thyroid instead of being eliminated.

Iodine 131, cesium 137, and strontium 90 — all produced in nuclear reactors — are especially hazardous to man if they get into the food chain, because of biological concentration.

Most scientists believe it is prudent to assume there is no safe level of ionizing radiation, even though we constantly get some radiation from such natural sources as cosmic rays and granite in buildings.

Cosmic rays from space, for example, subject you to about 40 millirems a year at sea level, even more at higher altitudes. (A millirem is a thousandth of a rem, the standard unit of radiation exposure.)

Also, uranium, radium, and thorium in stone, concrete, and soil, as well as radioactive carbon and potassium in your body and in water and food, combine to provide a radiation background that you cannot escape. From these natural sources the average person receives a whole-body dose of about a hundred millirems a year.

Besides absorbing natural radiation, many people are exposed to man-made ionizing emissions. Medical diagnostic X rays, for example, give the average person 70 millirems a year. TV sets and radium-dial wristwatches add perhaps a millirem over the course of a year.

From these natural and man-made sources, the average person gets close to 200 millirems of radiation annually.

A nuclear reactor, properly operated, adds little to this burden: no more than a few millirems a year for the exposed public. Actually, coal plants emit about the same amount of radioactivity because of radium and uranium in the coal.

How much radiation does it take to hurt you? Radiobiologists regard a single dose to the whole body of 600 rems (600,000 millirems) as lethal to most people; 100 wholebody rems cause radiation sickness; 10 can damage the lymph nodes and spleen and decrease the bone marrow and blood cells, although you do not feel symptoms.

A few millirems or even a few rems seem small by comparison especially, when spread over a period of time. And some scientists believe there is a threshold below which radiation has no permanent effect. But many others insist no radiation level is harmless. Dr. Karl Z. Morgan of the Georgia Institute of Technology, former director of the Health Physics Division of the Oak Ridge National Laboratory, sums up this view:

> "An overwhelming amount of data shows there is no safe level of exposure, and there is no dose of radiation so low that the risk of malignancy is zero. So the question is not: Is there a risk for low-level exposure? Or, what is a safe level of exposure? The question is: How great is this risk? Or, how great a particular radiation risk be before it exceeds the expected benefits, such as those from medical radiography or nuclear power?"

When one visits a nuclear plant, he gets a mixed feeling of the awesome power and the extraordinary precautions to control that power. With Mike Malmros, an inspector for the United States Nuclear Regulatory Commission (NRC), I went to see the Rancho Seco plant in California's

Sacramento Valley, near Lodi. A pressurized water reactor, operating since 1975, Rancho Seco is rated at 913 megawatts.

Our approach from the south brought us through barren hills into vineyard and ranch country, dominated by the Rancho Seco reactor building — a squat silo — and two colossal cooling towers 425 feet high.

"Air and farm products near the reactor are constantly monitored," Mike told me, "to make sure that any radio-activity reaching the outside world does not exceed our very low permissible levels. If the limits are exceeded, the plant is supposed to shut down until the problem has been corrected."

(In practice, critics say, fines are often too small for effective enforcement of safety standards and regulations in some plants.)

A heavy barbed-wire fence surrounds the power station at Rancho Seco. Motion sensors to detect intruders are so sensitive that sometimes jackrabbits set them off.

At the gate, guards put us through detectors to assure we were not bringing in weapons or explosives. Inside we picked up dosimeters and film badges to record any radiation we might receive. We put on special clothing for protection against radioactive particles: coveralls, plastic bootees, cotton gloves under rubber gloves, and hoods that left nothing exposed except our faces.

To reach the containment chamber, we had to go through an airlock tunnel. Signs warned "Radiation Containment Area."

Inside the airlock our ears popped as the massive door locked into position; air pressure was being lowered to that inside the chamber. Because of this lower pressure, if there are leaks, air will always move from outside to inside.

In the cavernous vault we could look directly down on the reactor vessel — a 422-ton steel bottle, 40 feet high, 14-foot inside diameter, with walls eight to ten inches thick. And deep within that cell, under nine feet of water, burns the fire of Prometheus.

But it does not burn unchecked. Cables on the reactor head connect with motors that drive control rods inside, poised above fuel assemblies. If the temperature rises unduly or other serious problems threaten, these rods are designed to drop into the core. By absorbing neutrons necessary for the nuclear chain reaction, they immediately cut it off.

Later, in the control room, we inspected batteries of lights and gauges that monitor the plant's operation. One row of green lights told us that all the control rods were inserted in the core; the reactor had shut down briefly for repairs.

As we toured the plant, Mike explained what he look for in his inspections.

"I come unannounced four to six times a year to see that the reactor is working properly and that our safety requirements are enforced."

He pointed his flashlight down a row of cable trays, looking for dust or debris. "They have to do a lot of housekeeping," he said. "One secret for control of radioactive contamination is to keep things very clean."

He checked pipes for leaks and vibration. He checked valve positions and the readings on radiation monitors in the exhaust stack and at various other positions in the plant.

He also examined records to determine that ultrasonic tests and other methods had been used to assure that pipe welds were holding and that no cracks were forming. This precaution took on added significance in light of recent problems with cracks at other plants.

Mike showed me bins where low-level radioactive wastes, such as contaminated gloves and plastic bootees, are stored before being compacted and shipped to burial.

The most important waste, of course, is in the spent fuel rods. As fissionable uranium 235 in the core splits, it creates a variety of fission products such as cesium 137 and strontium 90. Most are strongly radioactive and produce heat even when the reactor is shut down. Thus when the spent fuel rods in the core are replaced, they must be transferred by remote control to nearby storage pools, where they will sit quietly in underwater racks for months or years as their radioactivity decays.

Our inspection completed to Mike's satisfaction, we underwent radiation checks. We put our hands and shoes in slots in a detector; its slow clicking revealed only background radiation. Finally, we surrendered our dosimeters and film badges, which had recorded no radiation dose.

For those working daily in radiation areas, some exposure is inevitable. Five whole-body rems (5,000 millirems) over an entire year is the normal cumulative dose permitted under Nuclear Regulatory Commission rules. Anyone who reaches this limit is not supposed to work where there is radiation for the rest of the year. In fact, NRC records show, average worker exposure per year runs only 700 to 800 millirems.

For the public, the NRC annual limit on radiation from the Nuclear fuel cycle is 25 millirems. In practice, the actual exposure is a tiny fraction of this permissible limit.

These "acceptable" limits are controversial even though they are seldom reached. Some critics insist they be cut further.

Industry spokesmen note that the public has suffered no known radiation death or injury from the operation of any commercial nuclear power plant in 450 reactor-years of experience. The overall safety record, they say, is good compared to other industries.

ANATOMY OF A NUCLEAR POWER PLANT

One of man's most sophisticated structures, a nuclear power plant for generating electricity operates on the same simple principles as plants powered by fossil fuels: Heated water produces steam; steam drives a turbine that spins a generator; a generator produces electricity.

The heat source for a nuclear plant is the energy released from the fission, or splitting, of the nuclei of fissionable materials, principally uranium 235.

A neutron collides with a U-235 nucleus (A), splitting the nucleus in two (B). Part of the energy that bound the nucleus is released as heat, and other neutrons are ejected (C). Bombarding other U-235 nuclei, the neutrons precipitate a self-sustaining chain reaction.

Energy from the chain reaction of fissioning uranium in the reactor core (1) heats the surrounding water, which is pumped under pressure into the tubes of a steam generator (2) to heat the water already in the generator. This type of reactor, the most common in the U.S. today, is known as a pressurized water reactor.

Heat from the tubes converts water in the generator to steam, whose energy turns the rotors of a high-pressure turbine (3). Lower-energy steam proceeds to low-pressure turbines (4, 5). An electric generator (6) converted the energy from the whirling turbine shaft into power for transmission to consumers through high-voltage lines (7).

Depleted steam from the turbines passes over the cooling coils of a condenser (8) and is converted to water, which return to the steam generator to be heated again.

Critics Wonder, What If . . .

Some people are neither comforted nor satisfied with this record. They point to numerous safety infractions at individual nuclear plants. They note a General Accounting Office study released last fall that criticizes the Nuclear Regulatory Commission for not adequately monitoring the quality of construction in new plants.

And they express considerable concern about certain kinds of accidents. What if there were a "loss-of-coolant accident" in which a major pipe ruptured so that it could not carry cooling water to the core?

Shutting down, or scramming, the reactor does not solve the problem. Although a scram stops the nuclear chain reaction, radioactive fission products in the fuel rods continue to disintegrate and give off heat long after shut-down. Without cooling water, the core would melt within an hour or two, fall to the bottom of the reactor vessel, and burn through the steel and concrete within a day. Buildup of pressure within the containment chamber might rupture the walls and release radioactive gases into the biosphere — the outer world with its living things. Consequences of such a "worst-case accident" could be catastrophic, with heavy loss of life, multitudes of cancer cases and damaged thyroids, and contamination of surface and groundwater and of perhaps a hundred square miles of land for many years. The extent of the disaster would depend on many variables.

Nuclear plant designers have, of course, anticipated such possibilities. They have provided many layers of engineering barriers and emergency systems. Since keeping the reactor core cooled down is of paramount importance, a reactor has four to six backup cooling systems. These can be thrown into use if the main system fails.

So the real question is: How likely is it that the pipe would break, that all the backup systems would then fail, and that the core would melt through all the barriers?

A major effort to calculate such probabilities was carried out by the Reactor Safety Study, published in 1975 by the NRC. It is also known as WASH-1400 and as the Rasmussen Report, for the Chairman of the study group, Professor Norman C. Rasmussen, now head of MIT's Department of Nuclear Engineering.

The study calculated that if there were a hundred reactors operating, a person living within 25 miles of one of them would have one chance out of five billion each year of dying in a reactor accident. (The figure does not include long-term fatalities from cancer.) By contrast, the report contended, there are much greater chances of dying in any year in more ordinary accidents: for example, automobile — one chance in 4,000; fire — one in 25,000; air travel — one in 100,000; lightning — one in 2,000,000.

QUESTIONS AND ANSWERS

• *How do fission and fusion differ?*

Fission involves the splitting of the nucleus of certain heavy atoms such as uranium. Fusion involves joining the nuclei of two very light atoms such as deuterium and tritium, forms of hydrogen. In both cases the nuclear reaction produces significant amounts of energy.

• *How do reactors differ?*

Light water reactors include:

(1) Pressurized water reactors. The most common type, these use ordinary water under pressure to cool the reactor cores. Heat is transferred to a secondary water cycle to produce steam for the power-generating turbines.

(2) Boiling water reactors. These also use ordinary cooling water, but allow it to boil directly into steam for the turbines.

Reactors may use gases or heavy water (which contains heavy hydrogen, or deuterium) for cooling. Breeder reactors generally cool with liquid sodium.

Most U.S reactors use uranium 235 for fuel. Uranium 233 and plutonium 239 are also fissionable and can fuel reactors.

• *Can a nuclear plant explode like a bomb?*

No. The uranium 235 generally used in thermal reactors is not sufficiently enriched to create a nuclear explosion. A nuclear plant could, of course, suffer a steam explosion under certain circumstances.

• *Are we likely to run out of uranium?*

At current prices of about forty dollars a pound for yellowcake (uranium oxide), United States mines can probably produce enough uranium 235 for all the reactors likely to be built in this country for the rest of the century. The breeder reactor, which converts uranium 238 to fissionable plutonium, theoretically could multiply the reactor fuel supply 60-fold.

* *What is reprocessing?*

When spent fuel is taken from a reactor, it contains valuable materials such as unused uranium, as well as plutonium 239 that has been created by the intense bombardment of neutrons during the fission process. Mixed with these useful materials are highly radioactive and very dangerous fission products such as cesium 137 and strontium 90.

Reprocessing plants separate these materials by chemical techniques, concentrating the dangerous materials for storage and making the valuable materials available for use. This is how, for example, the defense establishment gets plutonium for nuclear weapons.

Reprocessing is essential if breeders are to come into use. Only by reprocessing can unused uranium be separated from spent fuel so that it can be irradiated in the breeder to produce additional fuel. Similarly, only by reprocessing can this newly created plutonium be claimed for use in reactors.

* *If a third world country builds a nuclear plant, can it also make nuclear weapons?*

All reactors produce plutonium as a byproduct. With a reprocessing plant, this plutonium can be separated and purified for fuel; it is also highly suitable material for weapons. That is why many people believe the spread of nuclear technology will be followed by the spread of reprocessing, the proliferation of nuclear weapons, and the increased threat of nuclear war.

Indeed, proliferation is regarded by many thoughtful critics as the most serious hazard of nuclear energy. The "nuclear club" — nations possessing nuclear weapons — now numbers five. Two or three other nations are suspected of having them clandestinely. Still others covet nuclear weapons as a matter of national pride or to maintain the balance of power with a hostile neighbor.

* *What about the threat of terrorists hijacking shipments of nuclear materials?*

Terrorists would probably want to steal plutonium for bombs. But they could not likely try to steal plutonium in spent fuel because of the intense radioactivity of fission products, such as cesium 137 and strontium 90, in the fuel rods. However, if the plutonium is separated out by reprocessing, the danger of radioactive contamination would be greatly reduced, and the plutonium would be relatively safe. This, again, is why President Carter and others oppose the reprocessing of fuel from Nuclear power plants.

* *How much energy does the U.S. need?*

Currently, United States consumption of all kinds of energy adds up to about 76 quads (quadrillion British thermal units). While population growth and industrial expansion will tend to increase demand, escalating costs for energy are tending to hold it back. Many estimates see U.S. energy use rising to 100 or 125 quads by the year 2000.

Serious criticism has been leveled at the Rasmussen Report because of some of its assumptions and methods. Also, it does not consider the possibility of sabotage.

The most damaging criticism has come from the recent blue-ribbon Lewis panel, commissioned by NRC. It says that the numbers in WASH-

1400 are not confirmable, that the margins of error and uncertainty are much too narrow, and that the report cannot be used to prove the safeness of nuclear power. NRC has formally endorsed these criticisms.

But, say nuclear supporters, the risks are still smaller than more familiar hazards that society regularly accepts.

As Dr. Jerry Cohen of the Lawrence Livermore Laboratory says, "Somehow there is a feeling that a man killed by a streetcar isn't as dead as a man killed by radiation."

A more immediate problem alarms many nuclear critics — the question of what to do with radioactive nuclear wastes. These may be divided into three groups:

...Low-level waste: bulky, slightly contaminated materials such as clothing, industrial trash, and sweepings, with only weak radioactivity.

...Transuranic waste: higher levels of radiation and more hazardous because of its content of very long-lived alpha-particle emitters such as plutonium.

...And high-level wastes of two kinds: (1) spent fuel, of which the typical large reactor produces about 30 to 40 tons a year, and (2) by-products of the Government weapons program. High-level wastes generate high heat and high penetrating radiation for centuries.

The question of how to handle this extremely dangerous material and isolate it in such a way that it will not harm either present or future generations was neglected for years and only recently has been given serious consideration.

The waste problem cannot all be blamed on nuclear power. The problem began more than thirty years ago when the United States started making plutonium for nuclear bombs and putting nuclear reactors in submarines.

The defense waste is enormous: some 500,000 tons of highly radioactive material and 64 million cubic feet of less radioactive trash. It is stashed temporarily (and not too safely, insist the critics) in tanks and burial pits, mostly on three Government reservations in Washington, South Carolina, and Idaho, awaiting Government action on permanent disposal.

To this huge accumulation, nuclear plants have added something less than 5,000 tons of spent fuel, virtually all of its cooling in pools adjoining the reactors, and 16 million cubic feet of low-level material buried in Government-licensed repositories.

RECYCLING URANIUM

Controversy over nuclear energy in the United States often centers on the fuel cycle — the series of steps from mining and processing of uranium through use as fuel to the eventual disposition of spent fuel from the reactor.

Much valuable material in spent fuel could be salvaged for further use by reprocessing. For example, nearly a third of the original uranium 235 has not been burned up. It could be added to new uranium and further enriched for fuel. Thus the fuel cycle would be closed, having come full circle.

At the same time, the spent fuel contains a substantial amount of plutonium that has been created by neutron bombardment in the reactor. Like U 235 it is fissionable and can be used in fuel pellet. But it is a mixed blessing — plutonium can also be used in bombs.

Many people are deeply concerned about the possibility that plutonium separated from waste might be illegally diverted to terrorists or irresponsible nations. It could then contribute to proliferation of nuclear weapons and handicap efforts to prevent nuclear war.

Thus nuclear critics generally oppose closing the fuel cycle. They want spent fuel to go directly into centuries-long storage.

Yet the fear of radioactivity has focused largely on power plants. And it is true that power-plant waste contains more radioactivity and is increasing more rapidly than defense waste. Critics and proponents alike agree that waste is the political Achilles' heel of the industry, and that a satisfactory solution is necessary if there is to be any future for nuclear power in the United States.

Wanted: A Nuclear-garbage Disposal

The problem is not confined to the United States, of course. Forty-three countries abroad now have some kind of nuclear energy program. Of these, 21 countries have a total of 151 operable power reactors, with a capacity of more than 56,000 megawatts. A like number of reactors are under construction; more are on order.

In each case, waste must be disposed of in some fashion. Moreover, all nations that have nuclear weapons — the Soviet Union, Britain, France, and China, as well as the United States — must worry about waste from weapons production.

Nations have tried a variety of methods for disposing of nuclear waste. The British have been piping low-level effluent into the Irish Sea. The United States Atomic Energy Commission from 1946 to 1970, dumped tens of thousands of canisters of low-level nuclear trash into the Atlantic Ocean 120 miles east of the Maryland-Delaware coast, and into the Pacific 35 miles west of San Francisco.

One ominous sidelight: The manned submersible *Alvin* has located some of these canisters and found them crushed and leaking. Sponges were growing on the drums.

The Soviets, as I learned while touring nuclear facilities in the U.S.S.R., are pumping intermediate-level liquid wastes into sandstone that is as much as 2,000 meters deep beneath impermeable layers of clay.

In West Germany, near Hannover, I visited the world's first salt-mine waste repository. This prototype facility holds special interest because the United States has long considered the possibilities of storage in underground salt beds.

At a depth of about a kilometer, in glistening, low-ceilinged chambers abandoned when the Asse salt mine closed, I saw a stack loader piling yellow steel drums from floor to roof. The 200-liter drums held contaminated clothes and equipment, radioactive ashes, and air filters from nuclear plants. Since 1967 some 100,000 drums of such low-level waste have accumulated.

More dangerous wastes, which must be handled much more cautiously, have been stored at Asse since 1972. Drums of these intermediate-level materials, shielded in special casks, come through the tunnels by truck. Operators using remotely controlled cranes hoist the drums from their shielding casks and lower them through shafts into totally enclosed vaults. On a television monitor I could see the jumbled mass of barrels on the rough cavern floor 15 meters below.

Klaus Kuhn, manager at Asse, told me that the two meters of rock salt between us and the hot wastes served as well as concrete for protection.

"That's fortunate," he added, "since the radiation in that room is 1,000 rems an hour. It would not be a good idea to go in."

German officials hope in the 1980's to establish a permanent waste storage facility in salt beds at Gorleben, near the East German border. That may prove difficult, however; as I left the salt mine, I saw signs demanding "*Kein Atommull in Asse!* — No Atom Waste in Asse!" Anti-nuclear groups who oppose storage at Asse are also fighting against Gorleben. For that matter, they have been vigorously — and successfully — blocking a number of new nuclear plants.

Virtually every country in Western Europe shares to some degree this opposition to nuclear power. For example, in Sweden, which gets nearly a fourth of its electricity from the atom, two governments have fallen partly over nuclear issues. In Austria last fall a national plebiscite by a narrow margin prevented licensing of a completed 600-million-dollar nuclear plant at Zwentendorf — to the great embarrassment of Chancellor-Bruno Kreisky and his government.

In France opposition climaxed in a bloody riot at the site of Super-Phenix, which will be the world's first commercial fast breeder reactor; 5,000 riot police battled some 20,000 demonstrators, leaving one person dead and a hundred wounded.

In the United States nuclear opposition has not reached such violent proportions. But politically the impact has been strong. Thus two states — California and Maine — have prohibited any further nuclear plants until an acceptable solution has been found for waste disposal. Other states have imposed similar restrictions.

To complicate the problem, eight states have banned nuclear waste repositories within their borders, and others are considering such bans. In addition a number of states and communities have banned or severely restricted shipment of radioactive materials through their jurisdictions.

Thus it is not surprising that solution to the waste problem is now high on the priority list of the Department of Energy.

Where to put the waste? How about shooting it into space, into the sun? Fine if it worked, but incredibly costly and out of the question, say most experts, until we develop foolproof rocket launches.

How about the great ice cap of Antarctica or the deep-ocean sediments? Both have been considered, but both involve delicate international considerations. Moreover, both would likely in time expose the wastes to the marine environment, where they could spread to the entire biosphere.

How about copying the alchemists' fabled trick of transmuting lead into gold — that is, bombarding wastes with nuclear particles and converting them from unstable, radioactive elements into stable, innocuous substances? The idea is not ridiculous — after all, radioactive decay itself is a form of transmutation. But, alas, no one knows any practical, economical way of doing it, and the problem will not wait.

Deep Burial Most Likely Solution

Lacking one of these imaginative solutions, most experts both here and abroad believe that dangerous, long-lived forms of radioactive waste would best be concentrated in solid form. Then it should be encased in protective canisters and stored hundreds or thousands of feet deep in suitable geologic formations.

Scientists are currently studying such possibilities as salt beds, granites, basalts, and shales. They seek to learn which are most stable and which would best prevent radioactivity from leaking into the environment.

Much of the technology is now available to put the wastes deep into geologic formations and seal them off, according to several studies, most recently the draft report of the Interagency Review Group (IRG) on Nuclear Waste Management, a task force representing 14 federal organizations.

"A successful isolation of radioactive wastes from the biosphere appears feasible" for a few thousand years, says the report, which adds that assurance of success diminishes beyond that point.

The process of solidifying the waste in glass form is already being tested. At the nuclear center of Marcoule, in France, the government-owned Compagnie Generale des Matieres Nucleaires (Cogema) has since last summer operated the world's first plant for vitrifying nuclear wastes.

In the French process liquid radioactive waste, left over after the reprocessing of spent fuel, is evaporated. The residue is incorporated at high temperature into 1,500-pound blocks of extremely hard glass. These, say the French authorities, may be encased in metal drums and buried safely for centuries.

Many U.S. experts are pessimitic about glass and believe that ceramics, for example, would be less vulnerable to leaching.

Whatever method is used, long storage will be required. The length of time involves the half-life of the most toxic isotopes; that is, the time it takes for half of the radioactivity to disappear. If the half-life is 30 years, for example, half of the atoms disintegrate in 30 years; half of what is left disappears in the next 30 years, and so on. Within 10 half-lives, only one-thousandth of the radioactivity is left; within 20 half-lives, only a millionth.

As it happens, most of the strong gamma emitters in nuclear waste have half-lives of about 30 years or less. Thus in 300 years they will be reasonably safe; within 600 years, nearly harmless. Plutonium 239, however, has a half-life of 24,400 years. A quarter of a million years will pass before most of its alpha radiation is gone.

In all cases the wastes need to be stored in sites where groundwater cannot easily reach them and where quakes and other tectonic activity are highly unlikely. In addition they need to be secure from human mischief.

Some 370 million dollars has been spent researching the waste problem. Yet it is uncertain how soon burial facilities will be available in the United States. The IRG report, which the Carter Administration is expected to use as the basis for a comprehensive waste-disposal policy, warns against undue optimism. It says that 1988 is the earliest that a permanent repository in salt for high-level wastes could be in operation for testing. If the decision goes instead to other kinds of geologic formations, about which we know less, a site would not be ready before 1992 at the earliest.

As a transitional measure meanwhile, the IRG report recommends that the Government set up at least one smaller facility, in which as many as 1,000 spent fuel assemblies could be stored.

One such facility might be excavated deep in salt beds 25 miles east of Carlsbad, New Mexico. For some time the Department of Energy has considered locating the Waste Isolation Pilot Plant there. It would be primarily for transuranic defense waste, with space possibly for storage of spent reactor fuel. But questions have been raised, and the whole idea is unsettled.

Not all nuclear waste comes from power plants and defense uses. In New Mexico, Colorado, and wherever else uranium has been mined and milled, mountain of tailings — pulverized ore from which most of the uranium has been extracted — have been left to be spread by the wind and rain. One such mountain covers a city block four miles from downtown Salt Lake City.

For many years tailings were thought to pose little or no danger. At one time they were even used as foundation material for houses and public buildings in Grand Junction, Colorado, as well as other places.

However, tailings give off a radioactive gas, radon 222, which can seep through wood and concrete. Radon emits damaging alpha particles. In addition its decay products, called daughters of radon, are gamma-emitting solids that adhere to dust and can lodge in the lungs. Over many years they pose a cancer threat. Since radon is itself the decay product of radium 226, which has a half-life of 1,622 years, the problem is long lasting.

In properly operated uranium mines, ventilation carries away much of the radon gas and reduces the dose to the miners. But little has been done to cover or stabilize dumps of tailings. The IRG report calls for the Government to take more vigorous steps to prevent human exposure, and the NRC has begun to draw up regulations for underground disposal.

Waste problems are entwined with two other highly controversial matters: the fast breeder reactor and the reprocessing of nuclear fuel.

The fast breeder is a special kind of reactor that eventually may produce more fuel than it consumes. To understand it, you need to know something about uranium.

As it comes from the ore, uranium consists chiefly of two isotopes. Uranium 235, which is fissionable and thus can be used for fuel, makes up 0.7 percent. Uranium 238, which does not lend itself to fissioning, makes up most of what remains. For fuel pellets in U.S. reactors, the proportion of uranium 235 is enriched to about 3 percent.

After the uranium 235 is largely burned up in the reactor, the huge amount of uranium 238 remains as waste. But if the waste is placed in and around the core of a breeder and irradiated by fast neutrons, some of the uranium atoms absorb neutrons and are converted to plutonium 239. Plutonium 239 is fissionable and can be used in reactors for fuel.

Thus, with breeders, it is theoretically possible to extract sixty times as much energy from uranium as with conventional reactors since the uranium 238 in spent fuel can be used over and over again.

However, the breeder has disadvantages. It is very costly. It is more complicated and in some ways more hazardous than conventional reactors, although its temperature and pressure are lower. And it uses liquid sodium instead of water for cooling.

Sodium is a soft, silvery metal that melts just below the boiling point of water. It will burn on exposure to air and reacts violently with water. And it leaks easily through very tiny openings. Thus extraordinary care must be taken in handling.

Despite such problems the breeder offers apparent attractions for nations that have little fossil fuel and must depend on other countries for uranium for reactor fuel. The breeder can make a little uranium go a long way. For example, the United Kingdom, using breeder reactors and only 5,000 metric tons of uranium, could theoretically unlock energy equivalent to all its estimated recoverable oil and gas in the North Sea.

KEY VOICES . . . PRO AND CON

Reasonable people disagree widely about the merits and dangers of nuclear energy.

Dr. Hans A. Bethe, Nobel laureate and professor emeritus of physics at Cornell University, speaks and writes frequently in favor of nuclear power as a necessary replacement for dwidling oil.

Prof. Norman C. Rasmussen, now head of nuclear engineering at MIT, directed the Government's Reactor Safety Study of 1975. It contended that risks from nuclear reactors are smaller than many commonly accepted risks of life.

Dr. Alvin Weinberg, longtime head of the Oak Ridge National Laboratory, where he stands amid canisters of uranium 238 — is a nuclear advocate. But he has written frequently about the need to improve safety.

Dr. Ted Taylor, nuclear physicist and former bomb designer, warns that nuclear weapons may proliferate without tighter security for fissionable materials.

David Pesonen, a San Francisco lawyer, stands at the site of the proposed Bodega Head nuclear reactor. He led the fight that stopped the plant because of its proximity to California's San Andreas Fault — a landmark defeat of a nuclear project by environmentalists.

Amory Lovins, a consultant physicist with Friends of the Earth, opposes nuclear power as risky and unnecessary, and advocates renewable resources and more efficient use of all energy.

Four nations abroad already are operating such reactors. Japan has a small one. The Soviet Union produces electricity and desalinates water with a 350-megawatt plant at Shevchenko on the Caspian Sea. The United Kingdom feeds electricity into the Scottish grid with a 250-megawatt prototype breeder at Dounreay. France operates the 250-megawatt Phenix, named for the mythical bird reborn from its own ashes. It symbolizes the ability of the breeder to create new fuel as the old is destroyed.

France, together with Italian and West German interests, is also building the 1,200-megawatt SuperPhenix at Cryes-Malville near Lyon. The reactor is scheduled to begin operation in 1983.

The United States has fallen behind Western Europe in breeder construction. There's irony in that fact. In 1951 a small United States breeder produced the first electricity ever generated from nuclear energy — enough to power four light bulbs. Today Experimental Breeder Reactor No. 1, at Idaho Falls, Idaho, is preserved as a national historic landmark.

Whether the United States will ever build large breeders remains uncertain. The Carter Administration opposes the breeder in the U.S. on the grounds that it is unnecessary either for economic reasons or because of uranium shortage. Also, because the breeder recycles plutonium, making it more readily available for nuclear bombs, there is a fear that the breeder will contribute to the proliferation of nuclear weapons among nations that do not already possess them.

For the same reason the administration opposes reprocessing spent reactor fuel — a necessary step if plutonium is to be extracted and recycled.

President Carter hopes that foreign nations follow the U.S. lead in forgoing reprocessing and breeder construction. By way of example, the President has blocked completion of a large reprocessing plant at Barnwell, South Carolina, that has already cost 250 million dollars. It could handle each year all the spent fuel from 50 reactors.

The administration has also attempted to cancel a largely federally financed, 350-megawatt pilot breeder on the Clinch River in Tennessee. Nearly 600 million dollars has been spent, chiefly on design and components for the plant, since the project started in 1973. But, the Department of Energy contends, Clinch River is a poor, obsolete design that has been delayed too long to be of any use.

Congress opposes the President's attempt to scuttle the project and has kept it alive for at least the current fiscal year. Proponents say that with a green light the Clinch River reactor could start producing electricity in late 1986.

Breeder Facility Nears Completion

Despite the fight over Clinch River, breeder research, as this is written, continues in the United States to the tune of almost 600 million dollars a year in federal funds — nearly equal to what all other countries are spending.

In the desolate southeast corner of Washington State, on the 570-square-mile Hanford Reservation, the Department of Energy is completing a huge Fast Flux Test Facility to test breeder fuels and materials, not to generate electricity. This 540-million-dollar reactor will use plutonium and uranium for fuel and will be cooled by a fifth of a million gallons of sodium. The Government expects it to be ready late this year.

A paradox marks the attitude of the rest of the world with regard to the threat of proliferation. President Carter's appeals about the breeder and reprocessing seem to have fallen on deaf ears. Energy officials with whom I have talked in Western Europe say almost with one voice:

"The United States can afford to give up the breeder because it has its own uranium and oil and plenty of coal. We lack those resources, and we must have the breeder and reprocessing to meet our energy needs."

At the same time, these nations — along with the Soviet Union and Japan — have become deeply concerned about proliferation of nuclear weapons. They support the International Atomic Energy Agency (IAEA), headquartered in Vienna, which seeks to promote safeguards against diversion of nuclear fuels.

IAEA inspectors visit nuclear facilities in many countries to determine if supplies of plutonium and other fissionable materials are adequately safeguarded.

But these nuclear watchdogs lack teeth. They do not inspect in the U.S.S.R., or yet in the United States, or in certain smaller countries that have not signed the nuclear Non-Proliferation Treaty. Moreover, the inspectors have no powers of enforcement; they merely try to detect diversion.

Those who fear proliferation and diversion (and they are many) note that the bomb that devastated Nagasaki during World War II contained only ten to fifteen pounds of plutonium.

What if plutonium or uranium, from which bombs can be made, should be stolen by terrorists or by an irresponsible dictator?

A mysterious incident in the 1960's lends color to these fears. The story reads like the scenario for a paperback thriller.

THE PROMISE OF NUCLEAR FUSION

Safe Energy? Clean energy? Energy from an abundant fuel, hydrogen, a component of water. Therein lies the promise of fusion, the same energy process that fuels the sun. But firing the furnace of fusion to stoke man's reactors requires a hellfire of a hundred million degrees Celsius.

At the temperature nuclei of tritium and deuterium (A) fuse into an unstable nucleus (B) that spits out a high-energy neutron (C), leaving a nucleus of helium. In a reactor the neutron would give up its kinetic energy as heat.

Such is the theory, simply stated. Its implementation presents formidable difficulties that will not likely be surmounted until the next century. The two major types of fusion research involve lasers and magnets, a technique being pursued at Princeton University and in the U.S.S.R.

On a wintry November day in 1968 the cargo vessel *Scheersberg A*, flying the flag of Liberia, cleared Antwerp harbor with a brand-new crew. Aboard were 200 tons of yellowcake, uranium oxide, made from ore mined in Zaire. It was bound for Genoa. All papers were in order.

Once in international waters, beyond prying eyes, the drums of yellowcake vanished. The *Scheersberg A* never arrived in Genoa. When she put into a Turkish port 15 days later, the $3,700,000 cargo was missing.

Secret agents tried to trace the shipment. They found nothing but blank walls and blind alleys. The mystery remains unsolved.

Was it a hijacking, masterminded by some sinister private group? Or could it be, as some believe, that the valuable uranium ended up in a secret nuclear laboratory in an Israeli desert? Research reactors can readily produce plutonium.

Radiation, waste, plutonium, proliferation. These are problems plaguing nuclear energy. Two other questions figure in the debate. Does nuclear cost too much? And how will the nation meet its energy needs without increased nuclear power?

Many utilities executives say that current reactors produce cheaper electricity than coal-powered plants. Especially is this true, they say, if coal plants are equipped with all the expensive gear required to protect the environment — devices to filter out particulates, smog-creating nitrous oxides, and lung-destroying sulfur dioxide.

Some economists are not so sure. They note the ultimate cost of waste disposal. They estimate that the price for necessary dismantling or entombing of radioactive plants may be 5 to 30 percent of the original construction costs. Thus nuclear energy could prove to be very expensive.

Even initial costs are getting out of hand. A typical nuclear plant finished several years ago cost about $200 per kilowatt of capacity. Prices in the next couple of years will have tripled, and by the 1990's they could triple again. Of course, costs of coal plants are skyrocketing in similar fashion.

Utilities are shying away from such heavy investments at today's inflated interest rates, with hundreds of millions of dollars tied up unproductively during the dozen years it now takes to go through the prolonged licensing and construction process.

If not nuclear power, what then?

* *Oil?* As domestic energy demand mounts, we are importing more and more oil at high prices. Already we ship in some nine million barrels a day, at a cost of about 45 billion dollars a year. This heavy drain ruins our trade balance, contributes to the fall of the dollar, and spurs inflation. John O'Leary, Deputy Secretary of Energy, estimates that foreign oil could cost a hundred billion dollars a year by 1985 unless we curb imports. Clearly, oil is not the answer.

* *Gas?* Utilities have been ordered to switch to coal because of the threatened shortage. And even if unproved gas resources are far greater than once thought, exploitation on a significant scale will take years.

* *Coal?* Increasingly, coal is seen as a costly threat to the environment with its polluting sulfur oxides, nitrogen oxides, and acid rains. Perhaps worst of all, burning coal pours enormous amounts of carbon dioxide into the atmosphere, where it blocks heat radiation trying to escape from earth.

Many scientists believe that this greenhouse effect, along with other influences, will gradually increase the average global temperature. This increase may in the next century or so lead to a carbon dioxide catastrophe with disastrous changes in global climate.

* *Alternative energy sources?* Increasingly the nation is trying to exploit solar energy, wind power, geothermal energy. Solar energy, especially, offers tremendous possibilities when technology for using it is well developed. Major contribution to electric power production, however, is years away. Even further in the future is the promise of nuclear fusion, power extracted from the fusion of hydrogen atoms — the ultimate power of the sun and the stars.

* *Conservation?* A most worthy objective. Americans waste far more energy per capita than do Europeans. Everyone gives lip service to conservation, and efforts to save (in addition to higher costs) have already slowed the rise in demand for electricity. But whether enough Americans will take the necessary steps to keep electricity use from doubling by early in the 21st century remains a question.

So, is nuclear energy bleeding to death? Some, with hope, say yes. Others, with sadness, agree. Still others see nuclear returning to health *if* uncertainties and licensing problems that now delay construction and increase costs are eased; *if* shortage of capital and high interest rates let up; and, most important, *if* public acceptance can be won for plans to dispose of waste and to safeguard dangerous materials.

It's a murky picture, filled with emotion and uncertainties. Only one sure fact shines through, and it is not comforting: Never again will energy be either cheap or easy.

DENDROTHERMAL PLANTATIONS IN THE PHILIPPINES[1]

by

FRANK H. DENTON[2]

SOLAR ENERGY POTENTIAL

Each hectare of land in the Philippines receives about 2×10^7 kilowatt hours of energy generated per year from the sun. The total electrical energy generated in the Philippines during 1980 was about 18,000 gigawatt-hours. Consequently, the sunlight falling on about 1,000 hectares of land each year is equivalent to the total electricity generation of the nation. That is, there is an enormous potential source of indigenous power from sunlight.

Various means have been discussed to capture that solar energy. They range from the modern and esoteric use of direct sunlight to electricity conversion with photo-voltaic cells to the seemingly prosaic and even archaic photo-synthetic conversion of sunlight to bio-mass followed by the use of bio-mass to fuel thermal-electric generation plants. A recent Mitchell prize paper compared current and near future technology for a range of proposed means of converting solar energy to electrical energy. The author of this paper concluded that the photo-synthetic or bio-mass conversion offered conversion efficiencies comparable to those offered by the other alternatives proposed. (The computed efficiencies were in the range of from 1% to 5%.) Further, the author concluded that the investment required to construct facilities capable of generating a given quantity of electricity from solar energy was many times smaller for a bio-mass based system that would be the case for the alternative examined.

If a conversion efficiency of even one third percent were obtained, enough bio-mass to generate the electricity consumed in the Philippines in 1980 could be produced from about 350,000 hectares.

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[1] Editor's Note: Reprinted with permission from Philippine Development, Vol. VIII, No. 20, March 15, 1981 of NEDA Quezon City Complex, E. de los Santos Ave., Diliman, Quezon City, Philippines.

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Currently, it is estimated that there are some 5,000,000 hectares of cogon land in the Philippines. This land produces very little value to the nation; further, much of this land is entirely suitable for fast growing tree crop production. The dendro-thermal program proposes to exploit this potential for producing electrical power from indigenous resources.

COMPONENTS OF A DENDRO-THERMAL POWER COMPLEX

A dendro-thermal complex involves farming of trees and the use of the harvested wood as a fuel for a steam-electric generator. The components of a complex are:

1. A 1,000 hectare permanent ipil-ipil tree plantation.

2. Ten farmers' associations each with about 10 farmer members which will operate the tree plantation (in one hundred hectare modules).

3. A power plant which will use the wood produced on the tree plantation to produce electricity. The power plant will be of the steam thermal type.

4. A System for transportation of the wood from the tree plantation to the power plant.

The power plant and transportation systems are straight forward and based on established technology. It is the farming of permanent trees as a fuel source which is the novel component of this program. The ipil-ipil tree, which will be used exclusively in the first years of the program, grows very rapidly. First, harvest can be taken from the plantations by the fourth year. The ipil-ipil will coppice (sprout from the stumps of harvested trees) and can be harvested every third year. The tree plantations will, thus, provide virtually permanent forests since the harvesting occurs only every 3 to 4 years and new growth will become significant within 3 to 5 months of harvesting.

PROGRAM OBJECTIVES

Energy production is the basic underlying rationale and the assured market at attractive prices for energy materials is that which makes the economics favorable. But, the program has other important side benefits. The rural areas of the Philippines, in common with most developing countries' rural sectors, are poor and labor surplus. By initiating the product on of a new crop with an assured market, new employment/income opportunities will be directed in the first intance toward those persons in the rural sector without land or steady income sources. The table below shows the projected incomes for participant farmers by stage of the project.

Loans will be made to the farmers' associations to cover cost of land preparation and tree planting. These loans will provide the monthly

Years	*Stage*	*Estimated Annual Income Per Farm Family*
1 - 4	Before 1st harvest	P 6,000 - P 8,000
5 -10	After 1st harvest, before loan repaid	P14,000 - P16,000
11-onward	After loan repaid	P18,000 - P22,000

subsistence income for the farmer participants during the first four years, until harvesting of the tree commences. Each plantation associated with a 3MW power plant will provide a permanent source of income for about 100 farm families. The power plant and transport systems will provide jobs for about another 55 families. Jobs are very scarce in the rural Philippines and these income opportunities are quite attractive.

In addition to the social objectives above there is the deep environmental concern over the accelerated deforestation occuring in the Philippines. Currently, the national is losing thousands of hectares of forests each year. This loss in forest area arises at least in part from two factors:

1) the apparent difficulty of getting a permanent stand of trees from replanting efforts; and

2) the continued depredation of established forests from slash-and-burn farmers.

This energy program will in the limited areas covered address these two factors. First, it is hoped to get the slash-and-burn farmers to become permanent tree farmers as members of the associations and to thereby reduce the amount of forests being cut. Second, as noted above, the plantations when established will be permanent, cultivated stands of trees. Cutting one-fourth of the area will occur each year but the stumps will coppice (sprout); so that in effect there will always be the benefits of flood protection and increased recharge of ground water supplies even from the recently harvested trees.

PROGRAM TARGETS

The planning factors currently in use are for 3 MW power plants and associated tree plantations (about 1,000 hectares). Through 1987 the following targets have been established.

As of December 1980 some 30 farmers' associations have been formed and approximately 6,000 has. of ipil-ipil trees planted. The farmers in the associations are those most disadvantaged persons in their respective areas. Generally speaking, as of the time this report was prepared there was both good cooperation and enthusiasm from

	Cumulative Hectares of Trees Planted	*Cumulative Installed Capacity (MW)*
1981	30,000	12
1982	50,000	30
1983	68,000	54
1984		81
1985		114
1986		153
1987		200

the farmer participants. Tree planting and care (weeding; pest control, etc.) has progressed well. The oldest trees, about 7 months of age, are some 4 meters tall and germination per hill is 85 to 90%. About 2 to 3 weedings appear sufficient at which point the ipil-ipil is of a height and thickness to prevent further weeds from getting started. It has been demonstrated that transplanting is not required sinve excellent results are being obtained with direct seeding.

Although the experience is still limited it appears clear that establishment of the tree plantation is quite feasible. That is both the agronomic characteristics and the organizational requirements are well enough understood to be confident that the plantation can be established. These initial results from the farmers' associations are quite encouraging. Nonetheless, it is well to remember this is a complex program involving concepts and approaches which are still being tested and refined.

SYSTEM ECONOMICS

In contrast to most power programs in which the majority of operating costs are associated with capital construction or with imported fuels the dendro-thermal power plant's generating cost involves a large component from locally supplied fuel and labor which means the money expended by consumers for dendro-generated electricity will feed back to the community rather than flowing out to Manila or out of the country. Thus, the dendro-thermal plant is economically quite attractive in terms of local growth and development.

However, because the power plants are relatively small considerable economics of scale are foregone. For this reason the actual cost of generating power is not as low as, for example, is the case with a large hydro-electric power plant. The dendro-thermal approach is consequently not now appropriate in Mindanao where the electricity from the Maria Cristina generating facilities is relatively inexpensive. However, in the Visayas where there is a considerable reliance on diesel engines for electricity generation and on Luzon where the majority of electric power comes from oil-fired thermal plants the dendro supplied electricity can be competitive, our estimates indicate that generation costs will be competitive. Currently, our estimates indicate that generation will be in the vicinity of ₱0.40 per KWH. This is directly comparable to current costs from large oil-fired plants and well below the generation costs from diesel plants. One important energy benefit is that each 3 MW dendro plant will reduce oil import needs by about 26,000 barrels per year.

SUMMARY

The dendro-thermal power plant can generate electricity at rates competitive with plants using oil as a fuel. Construction of such power plants will, in addition to supplying electricity from local resources, generate local employment and contribute to reforestation of denuded land. Although the program sketched here will involve only a modest part of the area of denuded land of the Philippines. The practicality of the tree plantation is, of course, dependent on a ready market for the power produced. Consequently, the extent of plantings is limited by the rural demand for electricity which will remain modest for some years to come.

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PROGRAM FOR SOLAR ENERGY UTILIZATION IN THE PHILIPPINES

by

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INTRODUCTION

The sources of energy in the world may be classified into two, namely: depletable and continuous. Under depletable sources are coal, petroleum, gas, and nuclear. Included in continuous sources are solar and non-solar. Generally included under solar source are fuel wood, agricultural waste, hydro, wind, photovoltaic, photothermal, and photosynthesis. Non-Solar energy sources are tidal and geothermal. There have been surveys conducted on these energy sources (excluding breeder nuclear plants which are still not perfected, accepted and adopted), which show that the yearly supply of energy from the sun is more than ten times the yearly supply from the depletable sources. The sun, therefore, appears to be an inexhaustible source of energy. Why then have there been little effort exerted in the past to harness the energy of the sun? The answer to this question is obvious. The estimated high capital cost of harnessing solar energy was a limiting factor. Also in the past, competing with fossil fuel was not attractive. There has been no demand for energy that fossil fuel could not meet. However in the light of the energy crisis confronting the world, there are renewed efforts to harness energy from the so called continuous sources. This paper attempts to present the prospects of utilizing solar energy in the Philippines.

In considering any program towards the utilization of solar energy, one has to face a number of questions, namely, (1) is it theoretically possible to harness the sun's energy? (2) does one have the necessary technical know-how to do so? (3) is it economically feasible? All these questions are not answered in this paper. However, the author will try to present some program to serve as channel towards the answers to these questions.

SOLAR ENERGY

Solar energy is inexhaustible. The theoretically available supply dwarfs the demand. It has no critical mass, it is not a health hazard, it is clean with no waste products to worry about and above all, free. On

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the northern hemisphere (within 30°N Lat.) at the height of summer the maximum incident direct solar radiation on the surface of the earth is estimated to be 300 Btu/hr. ft². Ninety percent of the solar radiation lies within the range of wavelength 0 to 4 microns, with the greater portion within the visible region (.4 to .8 u). On the average the solar radiation on the surface of the earth is about 90 Btu/hr. ft².

In 1970 the Philippines consumed at least 50 million barrels of petroleum fuels (representing over 90% of all energy consumption of the country). Assuming only 10% of the available or 9 Btu/hr. ft² solar energy is harnessed, it is estimated that the required area to furnish the equivalent energy content of the petroleum fuel is about 300 sq. km or 17.5 km by 17.5 km area. These rough calculations show that theoretically, all the energy needs of the country could have been supplied from solar source. The reason that there is at present no direct utilization of solar energy is technical in nature. The energy from the sun generally is collected in the form of low-temperature heat. This energy is difficult to store, difficult to transport and difficult to transform into work. The technology, therefore, needed to overcome these difficulties will have to be developed. It is often said that problems on economics are solved with technological break-through.

SOLAR DEVICES

Presently there are a number of devices which have been developed to harness the energy of the sun. These devices are essentially for heating, cooling, distillation and for mechanical power. They are still considered under the development phase. There is need to expand the development phase to include large scale experimentation and research and construction of pilot plants to gain more information which will add to the technical knowledge and economics of utilizing solar energy. The long range program towards the development of devices for utilizing this energy lies probably in the area of photovoltaic and photochemical devices.

Solar Stills. — Theoretically 5×10^9 calories per day incident an area of 100 sq. m. can generate heat to vaporize about 1000 kg. of water. Actually the efficiency would be low and the production of fresh water will correspondingly be less than the above mentioned figure. Solar-distilled water cannot compete in areas where water comes from the present standard sources (underground and above ground). In regions where there is meager underground water source, solar-distilled water appears attractive.

Refrigeration and Airconditioning. — One of the most attractive prospects in utilizing solar energy is for household refrigeration and airconditioning. The potential market for refrigerators and house cooling is tremendous.

The standard absorption type refrigeration system, which is probably simpler and more efficient than the conventional vapor compression mechanical system, is adaptable to the use of solar energy. Research on absorption and desorption of gases in various media should be encouraged.

Storage of Energy. — The intermittent nature of solar energy necessitates development work on devices for storage of energy. Various media for storing solar energy should be investigated. The conventional method is to store energy in insulated hot water tanks. Other media such as fused materials, and salts should be researched on.

Other potential storage systems such as electrolysis of water and subsequent storage of the hydrogen and oxygen in underground bottles should be considered seriously. The gases may be recombined to operate a gas turbine, or to operate a "hydrogen-oxygen" fuel cell.

Solar Engines. — Higher temperature than what is needed for, say solar stills and household refrigeration systems is needed for solar engines. This higher temperature may be achieved using solar concentrating devices. The principle involved in the use of solar concentrating devices is well estbalished. The problem again is economics — how to build low cost reflectors. This energy may be used to operate a steam engine or a hot air engine. Solar-operated hot air engine should be studied because of its simplicity of operation and relatively low cost of construction.

Photochemistry and Photovoltaic. — Any long range program on the utilization of solar energy is to direct attention on research in photochemistry to find a suitable process (photochemical) which allows absorption of solar energy and to reverse this process in the dark accompanied by a release of the absorbed energy. The problem is admittedly a very difficult one.

Perhaps one of the most hopeful prospects in the long-range program of finding devices for the utilization of solar energy is in the area of photo electricity — solar battery. The emphasis of the investigation in this area should be to find less expensive substitute to the very expensive single crystals of silicon which form the battery.

There were initial economic studies on the possibilities of photosynthesis. Based on just .7% solar energy conversion, studies have shown that use of forest for energy is five times less than photo-thermal systems using directly solar-energy. This merits very serious thinking. The idea is simple. A thermal plant is located within a forest.

One area of the tract of land is being cleared and the wood harvested is used for fuel (this cleared tract is subsequently replanted). This is carried out sequentially so that the thermal plant will practically not run out of fuel. It is claimed that about 370 square miles can sustain a 1000 MW generating station.

PROGRAM OF ACTIVITY

There are very encouraging indications that research activities are now starting to surface from its dormant state in so far as solar energy utilization is concerned. Attempts are now being undertaken to coordinate those activities. The NSDB has formed an Ad-Hoc Committee (there is a proposal to make it a standing committee) to prepare research proposals on solar energy. There is now this NRCP sponsored symposium on energy resources of the Philippines (December 6-7, 1973) and next week there is scheduled a workshop/conference on "Energy in the Philippines: Problems, Prospects and Proposals" sponsored by the Department of Public Informaiton and the Development Academy of the Philippines.

These indicate the grave concern for energy. One must, however, pause first and try to systematically plan some program of activity. The program may be divided into two: a short ranged and a long ranged program.

Short Range Program. — The author would like to classify activities that need to be initiated soon and can be accomplished within a relatively short period. During the several meetings of the Ad-Hoc Committee of the NSDB (where the author was a member), several areas were identified where immediate attention should be focused. These are: (1) Refrigeration and air conditioning, (2) use of solar energy for mechanical power, (3) solar heating devices (cookers, heaters, stills and dryers), (4) storage systems. Activities on these areas should be supported with basic data such as solar radiation measurements in the various regions of the Philippines taken over different sky conditions. There have been initial efforts taken along this line (See Table 1).

Long-ranged Program. — Any long-ranged program should be geared towards the utilization of solar energy for power generation on a public utility scale. While short-ranged programs should be started soon, long-ranged programs must also be considered and thought of as soon as possible.

RECOMMENDATION

Recognizing the enormity of the task that lies ahead, it is recommended, in the interest of economy, efficiency, coordination and expediency in the undertaking of these activities, that a center for solar energy research be established. The center will undertake all research and development work including short and long range programs mentioned earlier in the area of solar energy and allied areas.

While such center is still non existent, it is proposed that speedy action be taken on those short ranged programs proposed by the Ad-Hoc Committee of the NSDB on Solar energy utilization.

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TABLE I
(WITH PERMISSION FROM C. R. ALETA)

WORLD SUPPLY OF ENERGY*

Depletable ($\times 10^{15}$ Btu)		Continuous or Renewable (Yearly) ($\times 10^{15}$ Btu)	
Coal	20,100 - 30,000	Solar	837,200**
Petroleum	3,000 - 6,000	fuel wood	90
Gas	2,100 - 5,100	farm waste	60
Total	25,200 - 41,100	photosynthesis fuel	240
Nuclear		hydropower	90
(light water)	— 9,000	wind power	3
(breeders)	— 9,000,000	direct conversion	—
		Non-Solar	
		space heating	18
		tidal	3
		geothermal	2
		Total	837,715

Cumulative demand (1960 to 2000) 10,500 - 21,000

* Based on p. 43, C. Starr, "Energy and Power", Sc. American, Vol. 225, No. 3, Sept. 1971.

** Represents the 20% of the solar radiation falling on land areas only.

TABLE 2

DISTRIBUTION OF TOTAL SOLAR ENERGY*
(WITH PERMISSION FROM C. R. ALETA)

Cause	Amount $\times 10^{18}$ Btu
Absorption in atmosphere, and surface and ocean, and converted directly into heat at ambient surface temperature	2430
Reflection and scattering into space as short-wave length radiation	1560
Utilization in evaporation, convection precipitation and surface runoff of water in hydrologic cycle	1200
Driving force of atmospheric and oceanic convections and circulations and ocean waves eventually dissipated into head by friction	11
Captured by chlorophyll of plant leaves and becomes the energy supply of the photosynthetic process, and eventually of the plant and animal kingdoms	1

* Based on M. K. Hubert, Scientific American, Vol. 225, No. 3, Sept. 1971, p. 63.

TABLE 3

LAND AREAS OF SOME OF THE LARGEST ISLANDS
(WITH PERMISSION FROM C. R. ALETA)

Islands	Area	
	Square Miles	Square Kilometers*
Luzon	40,420	103,000
Mindanao**	36,537	93,800
Samar	5,050	12,850
Negros	4,906	12,600
Palawan	4,550	11,650
Panay	4,446	11,350
Mindoro	3,759	9,650
Leyte	2,786	7,100
Cebu	1,707	4,390
Bohol	1,492	3,820
Masbate	1,262	3,230
Total	106,865	275,500
Total land area of the Philippines	115,820	297,000

* Rounded figures

** Excludes small minerally important Surigao group off its northwestern coast

TABLE 4

MEAN ANNUAL CLOUDINESS AND NUMBER OF RAINY DAYS AT DIFFERENT LOCATIONS (WITH PERMISSION FROM C. R. ALETA)

Station	Mean Annual Cloudiness[1]	No. of Rainy Days[2]
Cotabato, Cotabato	7.3	89 + 12.5
Vigan, Ilocos Sur	4.4	102 + 10
Dipolog, Zamboanga del Norte	7.6	131 + 11
Iba, Zambales	5.9	137 + 11
Cabanatuan City	5.9	133 + 12
Coron, Palawan	5.9	135 + 15
Puerto Princesa, Palawan	7.1	129 + 12
M.I.A., WBFC	6.7	137 + 12
Zamboanga City	7.5	138 + 12
Manila Central Office	6.7	144 + 13
Ambulong	6.0	146 + 13
Cuyo, Palawan	8.1	145 + 11
Cagayan de Oro City	7.5	156 + 14
Iloilo City	7.1	157 + 13
Jolo, Jolo	7.9	165 + 13
Calayan, Cagayan	7.2	172 + 14
Cebu City	8.2	173 + 14
Tayabas, Quezon	7.0	173 + 15
Baguio City	7.4	173 + 12
Romblon, Romblon	6.5	184 + 14
Calapan, Or. Mindoro	7.8	188 + 15
Davao City	7.9	202 + 15
Casiguran, Quezon	6.1	205 + 15
Basco, Batanes	7.9	208 + 15
Baler, Quezon	6.9	214 + 14
Virac, Catanduanes	7.2	219 + 14
Malaybalay, Bukidnon	7.7	222 + 14
Legaspi City	8.0	225 + 14
Daet, Camarines Norte	6.9	228 + 12
Surigao, Surigao	8.0	230 + 12.5
Tacloban City	6.9	211 + 12
Gen. Santos City	6.8	243 + 13
Infanta, Quezon	8.3	243 + 14
Borongan, Samar	7.6	245 + 12

[1] Mean annual cloudiness is a measure of the cloud cover over a particular station.
[2] Yearly means of 1951 to 1970 data.

THE GEOGRAPHY OF GEOTHERMAL ENERGY IN THE PHILIPPINES

by

MANUEL J. NAVARRO*

INTRODUCTION

The energy crisis led many countries to realize that shortages of energy supplies may not be the consequence of resource depletion, but may be due to the lack of their development. The last twenty five years saw the rise of petrofuels as the major source of energy because of its lower costs compared to coal, and because of the manipulation of the market by the so called "Seven Sisters." So that major countries and regions of the world became heavily dependent on imported petrofuels for their vital energy needs, and neglected the development of other potential energy sources.[1]

In economic theory, the concept of energy or mineral reserves is an elastic one, depending partly on the state of technology, which affects the cost of production. Hence, resources may not be developed if the cost of production exceeds the price of the estimated reserves. Since there was then a surplus of oil, little effort was made to look for more possible energy sources.

The whole picture, however, changed with the crisis in 1973. Almost all oil importing countries started frantic searches for new sources of energy.

The Philippine reaction to the energy crisis was to formulate an energy development policy in the context of total national development. The policy was directed towards a two-fold objective, namely; to develop and utilize indigenous sources of energy, and reduce overdependence on costly imported petroleum. The first oil discovery in 1976 prompted the government to launch a more comprehensive energy resources development program. The new program called for the exploration and development of the country's other indigenous resources such as coal, geothermal and nuclear fuels; as well as research and development activities on other less conventional forms of recoverable energy, such as direct solar, wind and biomass.[2]

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[1] Michael Tanzer, *The Energy Crisis: World Struggle for Power and Wealth.* (New York: Monthly Review Press, 1974), pp. 14-20.

[2] Bureau of Energy Development, *Energy Resources Development in the Philippines: A Report of Activities During 1977-1978.*

Purpose and Plan of the Paper. — This paper is focused on the geothermal resources of the Philippines. It presents an overview on the aspects such as the history, development, potentials and economics of geothermal energy.

This paper is not an exhaustive one, as it only presents some of the discussions of earlier and recent studies on this area. However, it is hoped that this paper will contribute to the understanding of this relatively new but abundant resource in the archipelago.

NATURE OF GEOTHERMAL ENERGY

Geothermal is a coined word from "geo" meaning earth, and "thermal" which means heat. Geothermal energy is the natural heat contained within the earth.[3]

Exploitable geothermal resources are likely to exist in those parts of the world with volcanic centers, decadent or active, though they may exist in other areas also. Known geothermal areas include the circum-Pacific "circle of fire" or "ring of fire," which is a region of active earthquakes and volcanoes. These areas are usually observed by surface manifestations in the form of hot springs, fumaroles, mud poles, clear boiling pools, geysers and thermally altered grounds.[4]

The energy in a geothermal reservoir consists of heat, largely stored in rocks and, to a lesser extent, in liquid water and steam-filling pores and fractures. The water and steam provide the means by which heat form deep sources is transferred by convection to depths shallow enough to be tapped by drilling. Water and steam also serve as agents by which geothermal heat escapes at the surface and through which geothermal heat can be tapped commercially by wells.

The fluid in most geothermal reservoirs is liquid water that is held at temperatures above surface boiling by the confining pressure. Decrease in pressure upon withdrawal of the liquid water causes steam to form by boiling, and a mixture of steam and water is produced at the surface. A few reservoirs contain primarily steam, and the wells produce dry or super-heated steam with no water.[5]

These sources of heat are unequally distributed with respect to their thermal gradient and depth. There are consequently two types of reservoir; low temperature and high temperature. In low temperature reservoirs, located mainly in sedimentary basins, hot water is found at a depth of 1,500-2,000 meters and at temperatures ranging from approxi-

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[3] *Scientific Encyclopedia*, 5th Edition, 1976.
[4] *Energy for Rural Development*, National Academy of Sciences, 1976.
[5] *Geothermal Overviews of the Western United States*, Geothermal Resources Council, 1972.

mately 60°C to 120°C. The high temperature reservoirs, of about 200°C to 350°C, are located in continental areas of relatively recent volcanic and tectonic activity and are found at depths ranging from a few hundred to several thousand meters. Here, depending on different conditions of temperature and pressure, heat can be found in the form of dry steam or hot brines. At these depths energy can also be found in the form of heat derived from hot rocks.[6]

History of Geothermal Development. — Geothermal resources have been known since ancient times when they were widely utilized to support establishments for therapeutic hot bathing. For hundred of years this was their only use, particularly in Europe, where cities grew up as spas based upon therapeutic use of hot springs. At the beginning of the 20th century, a new application of geothermal energy was found at Larderello, in Italy, where geothermal steam was used for the generation of electricity.

Even the early pagan people recognized the powers of geothermal potential. Some regarded volcanoes and violent hot water pools with reverence and awe and recognized them as instruments of their gods with which to chastise them in their days of wickedness. In Polynesian mythology, Pele, their goddess of volcanoes extended her influence from Hawaii down to New Zealand and even as far as the Carribean where a volcano in Martinique was named Pele after her.[7]

Exploration and Development. — Geothermal exploration makes use of advanced technology; geothermal drilling requires the use of equipment and techniques similar to those in use in the oil and gas industry, though it requires the use of drilling personnel with geothermal experience. It follows that there is a minimum scale of activity and investment of risk capital that is required if geothermal exploration is to be carried out with good prospects for success. Exploration that is economically and technically justified, normally, must be undertaken where there is a requirement for electricity production of several megawatts or several tens of megawatts. When the requirement for electricity is in the kilowatt range, as in the case of rural application, geothermal resources will not be economically viable unless the cost of steam production is shared by several communities.[8]

The objective of geothermal exploration is to locate reservoirs of sufficient thermal energy capacity to warrant economic development. To minimize the risk of unproductive drilling, exploration and pros-

[6] OECD, *Energy Research and Development*, (Paris, 1975).

[7] Cresencio Quiambao, "Geothermal: A New Source of Energy," *PSME Journal*, Vol. 1, 1978.

[8] *Energy for Rural Development*, National Academy of Sciences, p. 196.

pecting must first be carried out. Exploration is likely to take place in at least two phases; an initial phase of reconnaissance, and a second phase of more detailed investigations and possibly exploratory drilling.

Surveys commonly undertaken as part of the reconnaissance phase include: a) airborne infra-red surveys; b) regional studies of the hydrochemistry of known hot springs and associated cold-water springs; and c) studies of regional geology. Main indicators for further exploration are tectonic features, evidence of faulting, recent volcanism, and hydrothermal manifestations such as hot springs, geysers, and fumaroles. Geochemical and geophysical methods are used to define promising areas for exploratory drilling. Geochemical evaluation prior to drilling involves analysis of surface waters and gases from hot springs and fumaroles. Major geophysical techniques include heat flow and thermal gradient measurement and electrical resistivity, seismic, gravimetric, and magnetic surveys.

The final phase of geothermal exploration is the drilling of exploratory holes. At this stage, reservoir models are used to estimate the reservoir characteristics, including depth, extent, temperature, heat content, and hydrothermal properties. Drilling takes the major part of exploration costs. The exploratory holes should be used to verify the proposed reservoir model with data from cores, downhole measurements of temperature and results of production tests.[9]

The costs of geothermal reconnaissance surveys range between several dollars per square kilometer; the actual costs depend on whether airborne infra-red, hydrochemical, and reconnaissance geological surveys are all carried out and whether the survey covers all potentially productive areas. Costs can be minimized in the case of rural projects if financial considerations require that some limit be set to the distance over which any electricity developed may be transmitted.

Detailed geophysical and geochemical surveys each may cost up to \$1,000-\$2,000 per day. PNOC-EDC estimates is around ₱2,050 per day. Typical expenditures for detailed investigations of a prospect several tens of square kilometers in area may amount to \$100,000.[10] However, costs may vary between different fields because of variations in overall physical and chemical features which may necessitate skipping of some exploration steps.

Development of geothermal energy involves drilling technology, reservoir engineering of hydrothermal systems, development of other types of resources, and reservoir stimulation techniques.

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[9] J. Combs and L. J. P. Muffler, "Exploration for Geothermal Resources," in Kruger and Otte, *Geothermal Energy*, 1973. For a more detailed treatment of exploratory techniques, see *Proceedings; 2nd UN Symposium on the Development and Use of Geothermal Resources*, 1976.

[10] *Energy for Rural Development*, p. 197.

Drilling is generally accomplished by the types of rotary drilling used for oil wells, with either mud or air used as the drilling fluid. Technical improvements are, however, still necessary for economic drilling into deep hot-water and dry hard-rock formations. Alternative drilling methods such as turbine drilling, melting drilling, and erosion drilling are still not available commercially.[11]

Evaluation of reservoirs for deliverability, reserves and longevity are required for optimum field development and production. Methods to evaluate formation characteristics include borehole measurements, production testing, and theoretical models. In some cases, economic justification for power plant construction may require production for desalinated water, commercial minerals, and process heat as by-products, or stimulation methods to increase well productviity.

The physical characteristics of the produced fluid, handling and steam-water separation facilities, turbine and generator equipment, the cooling cycle, well productivity and spacing, environmental impacts, and condensate disposal methods must be considerations in the planning and development of geothermal fields.[12]

The potential of a new field can be predicted only after the producing characteristics of the reservoir have been determined. Each geothermal field can be expected to have its own reservoir matrix and fluid properties and, thus its own producing characteristics.

The key data required in reservoir engineering analysis involve the formation process, temperature, depth, thickness, permeability, porosity, thermal conductivity, fluid and rock density, viscosity, compressibility, and other physical parameters. The estimated parameters include the magnitude of in-place geofluids, the pressure-time history of fluid withdrawal, and the fluid-heat balance of the reservoir. Models for fluid withdrawal from a hydrothermal reservoir are described by experts in the proceedings of the second UN symposium on geothermal resources.

Increasing well productivity can be achieved by artificial stimulation. Investment in geothermal development requires justification by proofs that there are sufficient reserves. Stimulation techniques make the decision to invest easier.

Stimulation may be done by explosives or by chemicals, both appear technically feasible. Several other methods of production are possible to optimize the recovery of heat stored in the geothermal aquifer. Research is needed not only to study these methods, but also to develop a

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[11] Kruger, "Geothermal Energy", in *Annual Review of Energy*, vol. 1, 1976.
[12] *Ibid.*, p. 166.

method for evaluating the changing potential resources across the fluid production lifespan needed to depreciate capital investment.[13]

While development of geothermal energy resources appears attractive from a thermodynamic and economic standpoint, the utilization of nuclear explosives to stimulate latent geothermal sites must be examined further. Geothermal stimulation using small or big nuclear devices has potential environmental impact of radioactive contamination and possible induced seismic fault movement because of the relationship to tectonic-plate boundaries of the geologic formations.[14]

Uses of Geothermal Energy. — The most common use of geothermal resources is the generation of electric power by low-pressure steam turbines. Geothermal energy can be utilized for space heating, water heating, air conditioning, refrigeration, and process steam. Some chemical products may also be associated with geothermal energy utilization, such as the production of dry ice from geothermal carbon dioxide, production of calcium chloride from geothermal brines, and production of borax from geothermal steam. Agriculture also uses heat from geothermal sources for soil conditioning.[15]

A detailed listing of the industrial and other applications of geothermal energy is given by Lindal (see Appendix B).

PHILIPPINE GEOTHERMAL RESOURCES

Historical Development. — Being located in the earthquake zone as well as on a high heat flow region, the Philippines in apparently endowed with the potentials of geothermal energy.

There are at least 71 known surface manifestations in the country associated with decadent volcanism. They occur on the surface as hot spouts, mudpools, clear boiling pools, geysers and hot or warm altered grounds. They are identified with 25 volcanic centers located in the entire archipelago. The potential of these areas have been estimated to be in the neighborhood of 2×10^6 megawatt-centuries (Mwcen), or about 200,000 megawatts generating capacity for a millennium.[16]

The geothermal activities in the Philippines were initiated in 1962 by the Commission on Volcanology. Five years later, on April 12, 1967, for the first time in the country, an electric bulb was lighter by a 1,500-watt turbine generator driven by geothermal energy at Barrio Cole, Tiwi,

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[13] Henry J. Ramsey, et al., "Explosive Stimulation of Hydrothermal Reservoirs," in Kruger and Otte, p. 248.

[14] G. Sandquist and G. Whan, "Environmental Aspects of Nuclear Stimulation," also in Kruger and Otte, p. 311.

[15] *Energy for Rural Development*, p. 194.

[16] Alcaraz, et al., "Geothermal Energy: The Philippines, Today and Tomorrow," Paper read at the International Conference on Human Survival, 1976.

Albay. By 1970, the government, recognizing the magnitude of the untapped potentials and economic benefits from this energy source, commissioned the National Power Corporation to undertake the task of commercial exploration for geothermal energy. Since then, geothermal exploration and drilling activities have been on in full swing in the Tiwi area and in other equally potential fields in the country.

*Status of Geothermal Projects.** — As of June, 1978, three geothermal fields are in various stages of development, and four others are in the exploration stages. A total of 57 development wells have been drilled, 51 of which are productive.

Geothermal fields currently under development are those in Tiwi area, Makiling-Banahaw field, and Tongonan field. Those still under exploration are: Palimpinon-Dauin in Southern Negros, Manat-Masara in Davao, Manito in Albay, and Mambucal-Mandalagan in Northern Negros (see Table I, Summary of Acitvities). A total of ₱5.28 Billion have been estimated as investment requirement for geothermal development.[17]

Tiwi geothermal field is being developed into a power-producing field by the National Power Corporation while drilling of production wells is being undertaken by Philippine Geothermal, Inc. To date, 27 wells have been drilled, with 24 steam-producing. Power generation with an initial capacity of 110 MW is expected to start by December this year (1978).

The Makiling-Banahaw project in the province of Laguna is also at a stage where production wells are being drilled. The area is also being developed by the National Power Corporation with the PGI carrying out the deep well drilling operations. Power generation with an initial capacity of 110 MW is expected to start in the middle of 1979. A total of 22 wells have been drilled, with 19 wells productive.

In the Tongonan project, exploration and development is being undertaken by PNOC-Energy Development Corporation with the National Power Corporation in the power generation aspects. The project is being undertaken in cooperation with the New Zealand government represented by Kingston, Reynolds, Thom and Allardice, Ltd., and the Department of Scientific and Industrial Research.

A total of 8 wells (deep exploration-production) have been drilled, 7 of which are steam producers. Geo-scientific studies are only 95% complete. The first steam producing well was hooked up to a 3-MW portable type, non-condensing turbo-generator unit, which was made operational in early July of last year (1977). The power generated

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* As reported by the Bureau of Energy Development.

17 NEDA, 5-Year Philippine Development Plan, 1978-82, Profile of Selected Development Projects.

TABLE I. SUMMARY OF PHILIPPINE GEOTHERMAL ACTIVITIES
I EXPLORATION AND DEVELOPMENT

STAGE OF ACTIVITY	GEOTHERMAL AREA	ENTITY ENVOLVED	NUMBER OF WELLS DRILLED	TOTAL DEPTH (Meters)	EST. TOTAL CAPACITY (MW)	EXPECTED DATE OF COMPLETION OF ACTIVITY	% COMPLETION		TARGET POWER PRODUCTION
							DRILLING	GEO-SCIENTIFIC	
DEVELOPMENT	TIWI (Albay Province - Luzon Island)	PGI	27	52,961	125 (24 Wells)	4th quarter of 1978	100 %	100 %	110
	MAKILING-BANAHAW (Laguna Province-Luzon Island)	- do -	22	39,530	107 (19 Wells)	2nd quarter of 1979	97 %	100%	110
	TONGONAN (Leyte Island - Eastern Visayas	PNOC-EDC and KRTA	8	15,562	42	Last quarter of 1980	40%	95%	105
EXPLORATION	PALIMPINON-DAUIN (Southern Negros Island-Central Visayas	- do -	5	5,330	- - -	Middle of 1979	55 %	90 %	Purely exploratory hole
	MANAT North Davao, Mindanao	PNOC-EDC	1	920	- - -	Ist quarter of 1979	14 %	70 %	Purely exploratory hole
	MANITO (Albay Province - Luzon Island	- do -	- - -	- - -	- - -	2nd quarter of 1978	- - -	60 %	Purely geo-scientific work
	MAMBUCAL - MANDALAGAN (Northern Negros - Central Visayas	- do -	- - -	- - -	- - -	Last quarter of 1979	- - -	50 %	- do -

Source: Bureau of Energy Development.

TABLE II. — NATIONWIDE ASSESSMENT OF RESOURCES

GEOTHERMAL AREA (LOCATION)	ENTITY INVOLVED	EVALUATION	POWER MARKET	REMARKS
BATONG-BUHAY (Kalinga-Apayao-Luzon Island)	BED-ELC	Very promising based on geological and geochemical Investigations	50 MW foreseen for mining operation of Batong-Buhay copper project	Detailed geological and geochemical work is currently being undertaken by BER-ELC
MAINIT (Sadanga, Mountain Province-Luzon Island)	— do —	Promising area	Fair power market	Needs further detailed investigation.
ACUPAN (Benguet-Luzon Island)	— do —	— do —	70 MW needed in mining development plus private users.	— do —
ASIN (Benguet-Luzon Island)	— do —	— do —	Can be connected to national grid	— do —
CAGUA (Cagayan-Luzon Island)	— do —	Favourable geologic environment	Fair for agricultural and fishing industry	— do —
MARIVELES (Bataan-Luzon Island)	— do —	Heat source seems promising based on geochemistry of spring water	Fast developing market	— do —
BULUSAN (Sorsogon-Luzon Island)	— do —	Favourable geologic condition	Can be connected to national grid	— do —
MONTELAGO (Mindoro Oriental-Luzon Island)	— do —	Promising heat source and geologic environment	Fair market for mining development and local consumption	— do —

PGI — PHILIPPINE GEOTHERMAL, INC. (UNION OIL, U.S.A.)
PNOC-EDC — PHILIPPINE NATIONAL OIL COMPANY — EXPLORATION DEVELOPMENT CORPORATION
KRTA — KINGSTON REYNOLDS THOM and ALLARDICE, NEW ZEALAND
BED — BUREAU OF ENERGY DEVELOPMENT
ELC — ELECTROCONSULT

Source: **Bureau of Energy Development.**

from this small plant supplies the electrical requirements of this project and the nearby city of Ormoc. Expected operation of large-scale power generation will be in 1981.

Other Potential Areas for Development. — Under the Philippine-Italian Technical Cooperation Program, the country's geothermal resources are undergoing assessment in order to come up with priority areas for further exploration and development. Defined geothermal areas can be availed of by both local and foreign private companies through a service contract system with the Ministry of Energy.

Selection of priority areas for exploration and development are determined largely on the strength of surface thermal manifestations, chemistry of spring water, geological condition and georesistivity of the areas. The appraisal of the area in terms of geothermal potential and the decision for a follow-up work are based on social and economic factors.[18]

As reported by the Bureau of Energy Development, out of fifteen areas visited, eight are considered promising for geothermal potentials (as of June, 1978). A description of the areas and a preliminary evaluation of their potentials are shown in Table II.

Institutional Arrangements. — Republic Act No. 5092, known as "Geothermal Law," provides for the conditions for exploration and development activities of the country's geothermal resources. Another law involving such activities came out last June 11 of this year — PD 1442.

As provided by the decree, geothermal firms may avail themselves of tax exemptions similar to those enjoyed by oil exploration companies as in the importation of capital equipment. A service contract scheme is introduced and to be implemented by the Bureau of Energy Development. In effect, only the government, in partnership with the private sector can engage in geothermal resources development. Present holders of valid and subsisting gothermal exploration permits and leases granted by the government prior to January 17, 1973, are required to enter into service contracts within six months from the date of effectivity of the said decree.

Under the decree, the government may undertake exploration and development under service contracts awarded through public bidding or through negotiation with a foreign or domestic contractor who must be technically and financially capable. In cases, however, where the contractor can furnish the necessary services, the service contractor may be paid a fee not exceeding 40% of the balance of the gross value of the geothermal operations after deducting the necessary expenses incurred in the operations.

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[18] Bureau of Energy Development, *Energy Resources Development in the Philippines: A Report of Activities During 1977-1978.*

ECONOMIC ASPECTS OF GEOTHERMAL ENERGY

Economic factors that affect all forms of energy supply are total capital costs per installed power unit and operational costs per unit of energy produced. For geothermal energy, the two factors are dependent on the specific characteristics of individual reservoirs and the size of installed power units. Capital costs include the investments for exploration, drilling and completion wells, gathering lines, and waste handling systems for all utilizations. For thermal energy applications, they also include the distribution system, and for electric power production, they include the power plants and transmission networks. The production costs are influenced by the growing interest rate, operations and maintenance, and plant utilization factor.[19] To these, must also be added the element of financial risk, since it cannot be guaranteed that an adequate quantity and quality for electricity generation can be found after all the costs for exploration and drilling have been incurred.

The characteristics of geothermal fluid found in the Philippines favors its use for generating electric power. The economics of geothermoelectric production is controlled by the dimension of the generation facilities, which depend on two basic factors, namely; (1) the range of available resources, and (2) the power market of the area where the field is located. The geographic characteristics of the country suggest the use of two types of power plants — large power plants of 50-100 MW capacity, and small non-condensing unit with 1-10 MW capacity.

Power demands of big islands could be supplied by installing geothermoelectric units of 55 MW. Such units have a net output of 50 MW. If supported by the availability of geothermal resources, 2 units can be installed in one power house, making the total generating capacity to 110 MW.[20]

As applied to local conditions, experts involved in geothermal development has calculated the production cost for steam to be about 9 US mills/kwh or ₱.0675 and the total generating cost for geothermoelectric energy is 17 US mills/kwh or ₱.1275.[21] As compared by Meidav, oil-based electricity would have a fuel component of about 18 US mills/kwh in 1973 prices. It follows that generation cost would be much higher, considering that the given estimate is only for fuel consumption. Meidav goes further by comparing generation costs of geothermal energy with other conventional types such as diesel based power plant, nuclear plant, coal and liquified natural gas. Nuclear power costs have increased from $150/kw in 1968 to $600/kw in 1974, not to mention the environmental

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[19] Kruger, "Geothermal Energy," *Annual Review of Energy*.
[20] Alcaraz, et al.
[21] *Ibid.*, see computations.

hazards of nuclear plant operation, which, in fact is a big implicit cost component.[22]

The foregoing analysis asserts that the cost of geothermal energy development is low compared to other alternatives. While other energy sources face higher production costs, it should also be mentioned that geothermal exploration requires fairly high capital investment. Discovery of deeper and hidden resources will require the sophistication of geophysics and geochemistry. Deeper drilling or a higher failure rate in the future will further increase the costs of delivered energy. Special corrosion-resistant casing, descaling techniques necessary for minimizing silica and scale disposition, will raise the price tag for geothermal steam further, and would make the prediction of the economics of power generation inaccurate. Maintenance of generation efficiency also requires replacement of wells after some period of time.[23]

Aside from large power plants, small geothermoelectric units of 1-10 MW capacity could be used mostly in the early stage of the development of a field. These units are compact and easy to remove and reinstall in other places. These units are also suitable for installation in minor islands, where, even if the geothermal resources are existing in a large scale, the power demand is limited. In this case, they can represent a viable alternative to more costly generation system such as a diesel plant.

Computations by Filipino experts, show that generation costs for a 3 MW geothermoelectric portable unit (permanent installation) ranges from 10 US¢/kwh at load factor of 20% to 2.23 US¢/kwh at 90% load factor. A diesel unit of the ame capacity cost at 6.75 US¢/kwh at 20% load factor to 3.84 US¢ per kilowatt-hour, at 90% load factor. A geothermal unit of this capacity is therefore competitive.[24]

In an evaluation made by Capistrano, et. al, the Tiwi geothermal power plant was compared to a thermal plant of the same capacity to find out which of the two alternatives would warrant further development. The usual benefit-cost analysis and cost-effectiveness analysis patterned after that of Goldman's System Comparison Study were used in the evaluation.

It was found out that both plants are not economically feasible, hence, resulting in losses to the government. Both plants required high generation costs per kilowatt-hour. To cover the costs, the government can either increase the price of electricity, or retain the prevailing rates and choose on which plant to establish. Increasing the price of electricity

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[22] Tsvi Meidav, "Geothermal Opportunities Bear Closer Look," Oil and Gas Journal, 1975.

[23] *Materials Problems Associated with the Development of Geothermal Energy Systems*, Geothermal Resources Council.

[24] Alcaraz, et al.

requires due consideration because of its possible repercussions on the economy. At going rates of inflation, the government should determine whether the economy can shoulder the price increase. With a high rate of unemployment, coupled with low real wages, an increase in price of electricity, which has become a basic necessity, might aggravate the already serious inflationary situation of the economy.

However, decision to establish more geothermal power plants may be justified since, (1) it is more cost-effective and involves lower losses compared to a thermal plant, (2) it would lessen dependence on imported oil, the supply of which is uncertain because of the feud between OPEC and the Western countries, (3) foreign exchange savings, and (4) it is less polluting.[25] The last justification merits further attention.

ENVIRONMENTAL CONSIDERATIONS

Geothermal energy is considered to be one of the least polluting of the many forms of energy available. However, some environmental problems exist which should be defined and evaluated in order to plan for suitable actions to ensure an environmentally acceptable development of geothermal resources.[26]

The chief impact from the use of geothermal power occurs during the period of development of the field and construction of the steam-gathering lines and power plants. The impact, however, is only limited to the area of the field and poses nothing like the disruptions of the landscape as in thermal power plants.[27]

Basically, the possible causes of detrimental impact on the environment due to geothermal development come from the extraction of fluid from the subsurface, disposal of effluent, and discharge of the gases to the atmosphere. The corresponding effects would be ground subsidence and induced seismic activity, chemical pollution, and thermal pollution.[28]

Ground subsidence may occur in exploiting liquid dominated geothermal systems without corresponding reinjection of water. Continuous withdrawal of geofluids and reinjection of condensates may alter existing tectonic stresses and the normal patterns of earthquake activity.[29] It is argued, however, by eminent seismologists and scientists, that induced seismic activities may be potential tools in preventing destructive earthquakes from occurng by relieving the accumulating strain in the rocks through small releases of energy.[30]

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[25] Manuel Capistrano, et al., *An Evaluation of the Tiwi Geothermal Power Plant,* (Undergraduate thesis, UP School of Economics, 1976).

[26] Alcaraz, et al., also in Kruger, in *Annual Review of Energy,* vol. 1, 1976.

[27] R. G. Bowen, "Environmental Impact of Geothermal Development," in Kruger and Otte, 1973.

[28] Alcaraz, et al.

[29] Kruger, p. 174.

[30] Alcaraz, et al.

Chemical and thermal pollution due to the saline content and temperature of disposed hot water can be controlled by treatment or by reinjection. Disposing it to the sea would alter water temperature and could cause death to marine life. Use of a retaining tank as in Otake Geothermal Power Plant in Kyushu, Japan could check such kind of pollution.[31]

Atmospheric pollution is caused by the emission of non-condensible gases contained in geothermal fluid to the air. Local climate would be affected if the volume of such emissions will be strong enough to cause alterations in atmospheric balance. However, these gases, mostly carbon dioxide, nitrogen, hydrogen, methane, and hydrogen sulfide are minor. In cases where hydrogen sulfide occur in high concentrations, there are methods to reduce the discharges to tolerable limits.[32]

Artificial stimulation (see Chapter 2), may induce seismic activity and radioactive contamination due to mass flow from the reservoir.

CONCLUSIONS AND RECOMMENDATIONS

The foregoing analyses lead to the conclusion that prospects for geothermal energy in this country are bright. With an increasing rate of energy consumption, the development and exploitation of this energy source and other promising ones, merits attention.

While it may be argued that geothermal power generation is capital intensive, other factors, mainly socio-economic must also be considered to make the decision fair. Since the government has pronounced its desire to reduce dependence on imported oil, it follows that local sources must be developed and exploited. However, caution must be exercised in policy making, as some energy sources may be uneconomical for exploitation, as in the case of offshore oil drilling which requires fairly higher investment costs. Nuclear power plants may be very hazardous, as there is always the possibility of radioactive leakage.

Geothermal energy is also unique in the sense that it no longer requires conversion processes before it could be utilized. Aside from electrical power generation, it has a wide range of industrial and agricultural uses.

Since the nature of geothermal electric generation necessitates the putting up of power plants in the vicinity of the geothermal reservoir, it could support the industrial dispersion program by bringing electricity to the rural areas and stimulating local employment. This could help solve urban congestion by encouraging growth of population near geothermal areas with the creation of new job opportunities.

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[31] Jovito Manuel, "Hot Water Disposal From Geothermal Steam Production Wells," *NSDB Technology Journal*, October December, 1976.

[32] Kruger, p. 174.

In terms of its environmental impact, geothermal power generation appears to be the least damaging, as compared to other energy sources, especially that with nuclear plants.

In view of the above considerations, the Philippine National Oil Company, through the Energy Development Corporation, has set the following recommendations:

1. The infusion of more development funds,
2. The grant of some incentives for the private sector to participate more in geothermal development, especially in the field of drilling operations,
3. Continue and expand present efforts to build a pool of technologists and solid-earth scientists by attracting more young people to take up these disciplines,
4. Step-up researches in the non-electrical uses of geothermal energy with particular attention to Philippine needs.
5. Promote further cooperation and technological exchanges among countries involved in geothermal energy development through seminars, conferences, work-shops, and training fellowships.[33]

APPENDICES

APPENDIX B

Industrial and other Applications of Geothermal Energy:

— desalination
— district heating
— textiles
— paper manufacture from wood pulp
— timber seasoning
— sugar processing in conjunction with the manufacture of paper from bagasse
— dried milk
— fruit or juice canning or bottling
— manufacture of fish meal or fish drying
— cattle meal from bermuda grass
— pre-cooking of rice
— other food processing, canning or crop drying
— manufacture of plastics
— salt production
— air conditioning (cooling) in summer, combined with space heating in winter
— total gasification of coal (Turgi process)
— heavy water production
— refrigeration of fish and other foods
— curving of hides
— preliminary drying in birch manufacture
— recovery and processing of certain minerals
— balneology

[33] Alcaraz, A., et al.

APPENDIX C

TABLE I — POSSIBLE POWER GENERATION BY GEOTHERMAL ENERGY 1976-1985 (in megawatts)

GEOTHERMAL FIELD	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	ESTIMATED CAPABILITY OF FIELD* (in Mw)
TIWI, ALBAY			110		55	55		55	55		560
MAKILING-BANAHAW (Los Baños)			55	55		55	55		55	55	720
TONGONAN, LEYTE					55	55		55	55		Resistivity survey still in progress
SOUTHERN NEGROS (Palimpinon-Dauin)						55	55		55	55	425
NORTHERN NEGROS (Mambucal)					Initial investigation of area underway						
DAVAO (Manat-Masara)						55	55		55	55	500
TOTAL ANNUAL			165	55	110	275	165	110	275	165	
CUMULATIVE			165	220	440	660	880	1045	1210	1320	

* Based on Resistivity Survey.
Source: Bureau of Energy Development.

— extraction of valuable minerals from the geothermal fluids
— raising of winter crops of flowers and vegetables under glass
— mining and upgrading of minerals
— greenhouse and soil warming
— use for animal husbandry such as for hatching of eggs and raising poultry
— use to help bio-degradation of waste from pigsties
— washing and drying of wool
— heating pools, mineral baths, steam baths, and mud baths for recreational and recuperative purposes

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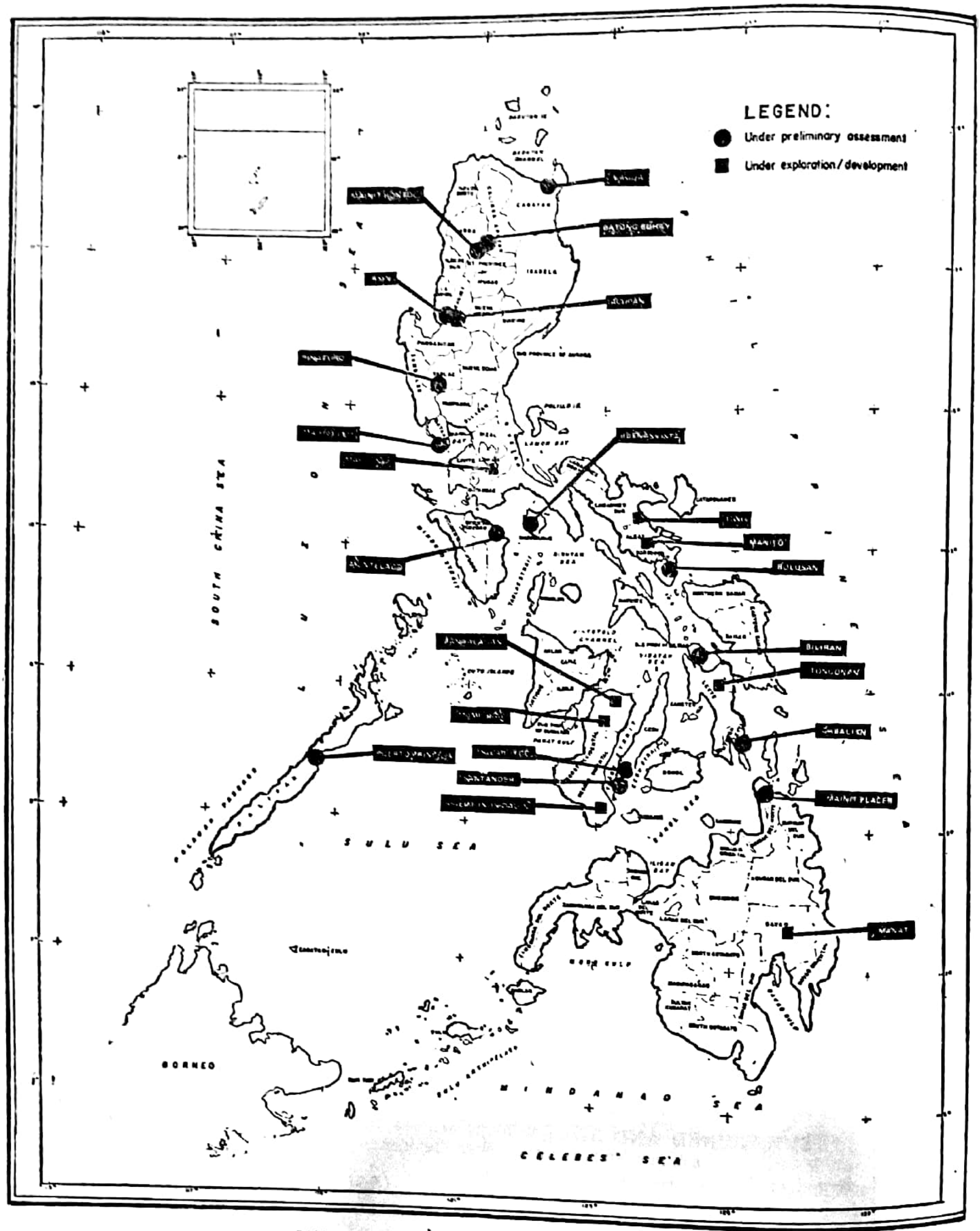

PHILIPPINE GEOTHERMAL OPERATIONS MAP

SCALE 1:4,500,000

100 50 0 100 200 300 km.

BOOK REVIEW

INTRODUCTION TO RURAL SETTLEMENTS. By R. B. Mandal. New Delhi: Concept Publishing Company, 1979. 312 pp. illustrated, maps, tables, references and index. Hard cover. Rs. 90, $18.00.

To a layman, especially one who is city-oriented and travelling in the countryside, rural settlements may appear drub and uninteresting. But to a trained geographer like the author, R. B. Mandal, human settlements found in farming areas spell excitement, romance and unending challenges for scrutiny, analysis and deep involvement in order to arrive at a semblance of possible explanation of a complex phenomenon.

For as we look into the nature of *rural settlement geography*, we may note that *rural settlement* and *urban settlement* are two distinct areas of *settlement geography* discipline which in turn is a new branch of Human Geography. The author defines settlement geography as the study of the form of the cultural landscape. "It is a science of systematic inquiry of occupancy features distributed over space with differentiation in relation to man. The minutest detail of the distribution of population manifests itself in the form of grouping of houses scattered at places and agglomerated at others."

"Rural settlement, as man's living and functional space, dots the countryside since prehistoric times and forms an integral part of the human life. A rural settlement, as the point of origin and primary residence of human society, is the linking thread and life blood of all geographical studies. Therefore, the consideration of settlement runs like a thread through almost the whole fabric of geographic thought."

Further, "rural settlement means the totality of human community in rural areas with all the social, material, organizational, spiritual and cultural elements that sustain a community. These elements may be spelt out in terms of physical requirements for housing work, energy supply, transport, communication, water availability and sanitation; services for education, health protection and welfare; systems of territorial organization, government, law and economic management; and cultural facilities for art, recreation leisure, etc. With factors like the growing population, increasing migration from rural to urban areas, demand of habitations for rehabilitation of displaced persons, etc., the problems of rural settlement is further widened in scope and requires an integral approach for its solution."

The site for this rural settlement study is the Bihar Plain, Bihar State, India. The Plain covers an area of 91,599 square kilometers of rural countryside with 38.76 million people living in 38,520 villages as of 1971. The rural population density at the time was 423 persons per square kilometer.

Being a specialists in rural settlement geography, the author presented vividly and in easy reading fashion the various topics (17 chapters) in his book. He has done this by starting from the fundamentals of rural settlement geography, including principles and approaches, to landscape models of farm villages and their development. With the increase of rural population along with corresponding livelihood activities and the improvement of local/regional communication or transportation facilities, residential houses increase in the old or existing villages, or new groups of houses may start new villages in previously unsettled areas. Considering that Bihar Plain is now densely populated and its settlement beginnings were of prehistoric vintage, one would expect many types of rural settlements and village patterns to exist and are thus existing. The author proceeded to go in detail of describing rural dwellings and house types but also considered development trends of rural settlements.

It may be mentioned that two sets of variables affect rural settlement types, namely, the agglomerating and deglomerating factors. Both of these are in turn influenced by the physical and the cultural environments prevailing. The tendency of the settlement to become compact (agglomerated) or dispersed (deglomerated) depends on the relative strengths of the centripetal and the centrifugal forces at hand.

Since geography is a discipline in distance, the author, also a recognized statistician, quantitatively analyzed settlement spacing, dispersion, or agglomerations in rural regions. Thus, settlement types and patterns can be measured quantitatively, rather than merely descriptive.

Some settlements, because of their strategic, geographical, industrial or service location/function, become centers for these services or functions. As time goes on and population continues to increase in these centers, they move up to the categories as towns or cities. But along this movement are also the attendant myriad problems that confront towns and cities, such as congestion, housing, transport, communication, infrastructure, water supply, education, crime, and environmental decay.

Ram Bahadur Mandal is a specialist in rural settlement geography, being a holder of Ph.D. and D. Litt degrees in geography from Patna University. A prolific writer, Dr. Mandal is the author and editor of several books on geography in addition to his teaching activities.

This is a good source book for students, geographers, rural scientists and technicians, town and regional planners and administrators.

F. M. LAPID

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Cost of One Kilowatt-Hour of Electricity*

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2. Geothermal .... 27.85 centavos
3. Coal .... 32.05 centavos
4. Nuclear Generation .... 36.63 centavos
5. Fuel Oil .... 53.28 centavos
6. Diesel Oil .... 54.21 centavos

* Manila Daily Bulletin, October 22, 1981, page 1.