SCOMM

#44:2

(b) To the extent practicable, the state shall require its lessees or sublessees to provide separate smoking areas. (§ 1 ch 125 SLA 1975)

Sec. 18.35.330. Display of smoking prohibited signs. Every owner, manager, proprietor or other person who has control of a place or vehicle set out in § 300(1) — (5) of this chapter shall conspicuously display in the place or vehicle a sign reading "Smoking Prohibited by Law". (§ 1 ch 125 SLA 1975)

Sec. 18.35.340. Penalties. (a) A person who wilfully violates the provisions of § 300 of this chapter is punishable by a civil fine of not less than $5 nor more than $25 for each offense.

(b) A person who wilfully violates § 330 of this chapter is punishable by a civil fine of not less than $10 nor more than $100 for each offense.

(c) Punishment under this section shall be initiated only by civil complaint or citation. The court may establish procedures for payment of fines by mail. (§ 1 ch 125 SLA 1975)

Chapter 45. Atomic Energy.

Article 1. Atomic Energy Development.

Section
10. [Repealed]
25. Facilities siting permit required
30. Conduct of studies concerning changes in laws and regulations with a view to atomic industrial development

Section
40—50. [Repealed]
60. Injunction proceedings

Cross reference. — As to radiation protection, see AS 18.60.475 et seq.

Sec. 18.45.010. Declaration of intent.
Repealed by § 12 ch 172 SLA 1978.

Editor's note. — The repealed section derived from § 1, ch. 119, SLA 1959.

Section 10, ch. 172, SLA 1978, provides: "Regulations adopted under authority of statutes repealed or amended by this Act shall remain in effect until repealed by the Department of Environmental Conservation in consultation within the Department of Health and Social Services."

Sec. 18.45.025. Facilities siting permit required. No person may construct a nuclear fuel production facility, utilization facility, reprocessing facility, or nuclear waste disposal facility in the state unless he has first obtained a permit from the Department of Environmental Conservation. The Department of Environmental Conservation shall adopt regulations governing the issuance of these permits; however, no permit may be issued until

(1) the legislature has approved the regulations by a concurrent resolution concurred in by a majority of the members of each house;

(2) the local government with jurisdiction over the proposed facility site has approved the permit;

(3) the legislature has approved the permit by a concurrent resolution concurred in by a majority of the members of each house; and

(4) the governor has approved the permit. (§ 8 ch 172 SLA 1978)

Cross reference. — As to radiation protection, see AS 18.60.475.

Sec. 18.45.030. Conduct of studies concerning changes in laws and regulations with a view to atomic industrial development. The following departments and agencies of the state are directed to initiate and to pursue continuing studies as to the need for changes in the laws and regulations administered by it that would arise from the presence within the state of special nuclear, by-product, and radioactive materials, from the operation of production or utilization facilities, and from the generation of radiation, and, on the basis of these studies, to make the recommendations for the enactment of laws or amendments to law administered by it, and the proposals for amendments to the regulations issued by it which it considers necessary:

(6) the Department of Commerce and Economic Development particularly as to the insurance of persons and property from hazards to life and property resulting from atomic development;
(am § 77 ch 218 SLA 1976)

Effect of amendment. The 1976 amendment substituted "Department of Commerce and Economic Development" for "Department of Commerce" in paragraph (6).

As the rest of the section was not affected by the amendment, it is not set out.

Secs. 18.45.040 — 18.45.050.
Repealed by § 12 ch 172 SLA 1978.

Editor's note. — The repealed sections derived from § 5(1)—(4), ch. 119, SLA 1959.

Section 10, ch. 172, SLA 1978, provides: "Regulations adopted under authority of statutes repealed or amended by this Act shall remain in effect until repealed by the Department of Environmental Conservation in consultation with the Department of Health and Social Services."

Sec. 18.45.060. Injunction proceedings. When, in the opinion of the governor, a person is violating or is about to violate § 20 or 25 of this chapter, he shall direct the attorney general to apply to the appropriate court for an order enjoining the person from engaging or continuing to engage in the activity and upon a showing that the person has engaged, or is about to engage in the activity, the court may grant a permanent or temporary injunction, restraining order, or other order. (§ 6 ch 119 SLA 1959; am § 9 ch 172 SLA 1978)

Effect of amendment. — The 1978 amendment substituted "§ 20 or 25 of this chapter, he shall" for "§ 20 of this chapter, he may."

Editor's note. — Section 10, ch. 172, SLA 1978, provides: "Regulations adopted under authority of statutes repealed or amended by this Act shall remain in effect until repealed by the Department of Environmental Conservation in consultation with the Department of Health and Social Services."

Chapter 50. Vital Statistics Act.

Article 4. Records.

Section
310. Disclosure of records

Sec. 18.50.310. Disclosure of records.

(e) The department may by regulation provide for the release of information to authorized representatives of organizations or foundations that counsel the next of kin of victims of infant sudden death syndrome.
(am § 1 ch 132 SLA 1978)

Effect of amendment. — The 1978 amendment added subsection (e).

As the rest of this section was not affected by the amendment, it is not set out.

Chapter 55. Housing, Urban Renewal, and Planning Assistance.

Article
5. Regional Native Housing Authorities (§§ 18.55.995 — 18.55.997)

Article 1. Alaska State Housing Authority Act.

Section
100. Powers of authority
190. [Repealed]
210. Right of obligee of authority to bring injunction
255. Procedure for sale of land

Editor's note. — As to class actions brought by owners and occupants of housing constructed from certain proceeds alleging defects in the design and construction of the housing units, see §§ 12-15, ch. 167, SLA 1978, effective July 18, 1978, in the 1978 Temporary and Special Acts and Resolutions in Binder 9.

As to loans to the Alaska State Housing Authority for the purpose of providing housing for persons of lower income in the capital city area, see editor's note to AS 44.63, art. 5 of AS 29.18, AS 18.56.094, or AS 44.58.270.

ALASKANS FOR CLEAN ENERGY

Whereas enough evidence exists to question the plans of nuclear power companies to do intensive construction of nuclear power plants by the year 1990

Whereas an in depth report by Senator Mike Gravel, entered into the Congressional Record on May 15, 1979, documented at length the poor record of nuclear power plant safety as well as inadequate nuclear waste disposal plans (A portion of the report is attached.)

Whereas the nuclear power companies were not interested in extensive construction of nuclear power plants until the Federal Government (your tax dollars) created the Price-Anderson Act to place the government as an insurer of damages up to 560 million dollars

Further, whereas legislation in other states has banned the construction of nuclear power plants and still other states are considering such legislation

Be it resolved that we the undersigned promote legislation that will ban the construction of nuclear power plants in the state of Alaska, and we ask that this legislation be initiated this legislative session

Be it further resolved that we the undersigned promote legislation that will prohibit the use of Alaskan lands and or waters for the disposal of nuclear wastes, and we ask that this legislation be initiated this legislative session

Be it further resolved that we the undersigned promote legislation that encourages the development of environmentally sound alternate energy sources within the state, and we ask that this legislation be initiated this legislative session

	SIGNATURE	NAME PRINTED	DATE	ADDRESS
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From:
ALASKANS FOR CLEAN ENERGY
1012 Dunton Street
Ketchikan, Alaska 99901

February 21, 1980
Thursday

To:
The Honorable Hugh Malone ,

Please find enclosed a petition and attached information portraying our concern about nuclear energy in Alaska. This effort is from no special interest group. It has arisen from a grass roots concern for environmentally sound alternate energy programs.

Signed petions from Ketchikan, where this effort originates, will be sent to our representatives Freeman and Gardiner and our senator Ziegler. We ask for your support as well.

Sincerely,

Ron Weishahn
LoAnn Jackson

Coordinators

ALASKANS FOR CLEAN ENERGY

Thank you.
I, and most of the present Alaska legislators agree with your concerns about nuclear energy. The greatest danger facing the State of Alaska with nuclear power will come from the federal gov't. Our state power authority has no authorization to develop nuclear power. Alaska Statutes place severe restrictions on a nuclear power. I also refer you to HB ___ (attached) which relates to hazardous wastes and is worthy of your support.
I also support legislation which promotes the development of alternative energy and cosponsored HB 851 & 687 (attached) towards that end.

MIKE GRAVEL
ALASKA

United States Senate
WASHINGTON, D.C. 20510

Dear Friend:

Our government and the electric power industry hope to commit the United States to nuclear-generated electricity within the next decade. But there are profound and inherent hazards connected with nuclear power -- hazards so far-reaching that we must carefully contemplate the consequences of a nuclear power future.

Here are a few facts you should know:

ABOUT RADIOACTIVE WASTES

-- Nuclear power reactors produce deadly radioactive wastes like fallout. Each year, a large reactor accumulates the radioactive poisons of 1,000 Hiroshima bombs. These poisonous wastes must be isolated from the natural environment for centuries. If they are released accidentally into our air or water, they can enter the food chain to be distributed and concentrated uncontrollably.

-- The intense radioactivity of reactor wastes can lead to cancer and genetic damage. With burial grounds of reactor waste, we leave to future generations an unprecedented threat to life and health. In the words of Dr. Hannes Alfven, Nobel laureate in physics, "The fission reactor produces both energy and radioactive waste: We want to use the energy now and leave the radioactive waste for our children and grandchildren to take care of."

-- In a fully-developed nuclear economy, overwhelming amounts of radioactive waste would be generated. The release of as little as a fraction of a per cent of these wastes would threaten human health. And yet, even though the U.S. is proceeding with nuclear plant construction, we do not have any program for the ultimate safe disposal of the hazardous wastes. And in our nuclear weapons program, 500,000 gallons of high-level wastes have already leaked from storage tanks.

ABOUT REACTOR SAFETY

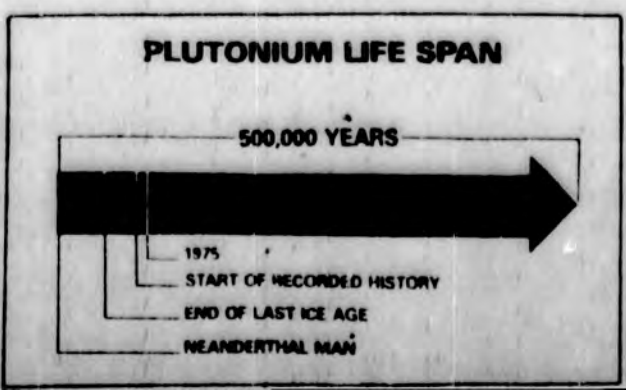
-- A study by the Atomic Energy Commission said the worst accident at a power reactor could kill 45,000 persons and cause more than $17 billion in property damage. An area the size of Pennsylvania could be contaminated.

-- The Emergency Core Cooling System, a device meant to prevent such a catastrophe, has been proven only by computer. The ECCS failed six out of six semi-scale tests, and full-scale testing is several years behind schedule. In a fire at the Browns Ferry reactor in March, 1975, the ECCS failed to operate when called upon.

-- Even though damage could be in the billions of dollars in a nuclear accident, the government protects the nuclear industry from claims beyond only $560 million. Federal insurance even covers some of this, because private insurers refuse to provide the full $560 million. Furthermore, damage from nuclear accidents is explicitly excluded in homeowners' insurance policies. If nuclear power is "safe", why does the nuclear industry put our assets on the line but not its own?

ABOUT PLUTONIUM

-- Plutonium, an element created in the fission reactor, is one of the most poisonous substances known. It is also the material that makes atomic bombs. One pound of plutonium represents the potential for billions of lung cancers. Less than fifteen pounds is needed to construct a nuclear bomb. But by 1985, world production of plutonium may exceed 200,000 pounds per year. Plutonium remains dangerous for hundreds of thousands of years.



-- By spreading nuclear reactors around the world, we are spreading nuclear weapons capability. With a large reactor, even the most unstable country will be able to produce plutonium for a nuclear arsenal.

-- Terrorists with stolen plutonium could threaten huge areas. They might threaten to release the plutonium into the air -- or they could construct a bomb. Atom bomb technology is now public property, and it has been proven that laymen can design a credible weapon from public reference works. The terrorist menace also implies a threat to our civil liberties -- what rights would we not forego to avoid nuclear terrorism?

ABOUT OUR ENERGY PRIORITIES

-- Our nation's first energy priority is currently the Fast Breeder Reactor, which is to produce large quantities of plutonium (to be used as reactor fuel) while it generates electricity. The Breeder will be even more dangerous than today's reactors. Total costs for the Breeder program are now estimated at $10 billion, up from original estimates of less than half that amount. Cost estimates for a Breeder prototype have gone from $700 million to $1.95 billion. A Breeder facility in Washington state now is to cost $933 million, up from $87 million.

-- Proven U.S. reserves of uranium are small, perhaps not enough to fuel the reactors we already have throughout their lifetimes. Thus, if America turns to nuclear electricity, we will become dependent on foreign uranium, and we could find ourselves at the mercy of another energy cartel -- a "UPEC." Nuclear energy would harm the U.S. economy in the long run, because it would produce less energy for each dollar of investment it requires. In other words, if we use reactors to supply the energy we need, this will draw away job-producing capital from other sectors of the economy. We should quickly develop the non-hazardous energy alternatives which are available to us, especially solar energy. These are our best long-term investments.

For many years, nuclear energy has not received sufficient public scrutiny. Today, as the hazards of nuclear power become better known, it is clear that many citizens believe that the risks of this technology outweigh the benefits.

In Montana, voters in 1978 passed a law banning nuclear plants there. In Vermont, state legislative approval is needed before plant construction begins. In a series of town meetings, Vermonters voted overwhelmingly to ban nuclear plants. Bills to prevent construction have been introduced in many state legislatures, and in Congress. In addition, nationwide, about a million voters have signed the Clean Energy Petition, asking government officials to keep nuclear power out of our lives. The petition, which is endorsed by Ralph Nader, is being used to make nuclear and solar energy into major issues at the local, state and federal levels.

Our citizens need to become fully aware of the hazards of nuclear power before we find ourselves irrevocably committed to the nuclear option. My office provides free information about nuclear energy and about the nuclear debate in Congress. Write to me at 3121 Dirksen Senate Office Building, U.S. Senate, Washington, D.C. 20510.

I urge you to examine this issue carefully and critically. Arnold Toynbee, the historian, has pointed out that man's nuclear fire can destroy life on this planet -- both through war and through radioactive waste. The question before us is as important as that -- and we must give our answer soon.

Mike Gravel

Mike Gravel
U.S. Senator from Alaska

NUCLEAR REACTORS IN U.S. 1975

PROPOSED REACTORS YEAR 2000

PROFILES

MASTER OF THE TRADE~III

Hans Albrecht Bethe

THE physicist Hans Albrecht Bethe, who came to this country from Germany in 1935 to teach at Cornell University, has devoted a great deal of his life to looking carefully at numbers. Bethe's memory is prodigious, and he has the ability—unusual even among physicists—to hold in his mind all the strands of the most complicated technical arguments imaginable, and, further, to manipulate them, and to come up with reasonable estimates of the consequences of their development. Thanks to this ability, he has worked successfully on a broader range of technical problems than almost any other modern theoretical physicist. Among other things, Bethe discovered the specific nuclear reactions that produce energy in the sun and other stars—a discovery that brought him the Nobel Prize in Physics in 1967. Enrico Fermi had a similar range, as did Bethe's first great teacher, Arnold Sommerfeld. Since 1974—the year of the Arab oil embargo—Bethe has been devoting nearly all his time to the study of the energy problem. Where do we stand, and where are we going? Where can we go?

The concern and the intensity that Bethe brings to the problem reflect experiences from his childhood. President Carter has declared that this country should regard the energy crisis as "the moral equivalent of war," but the President and most of the rest of us do not have firsthand knowledge of what such a crisis can do to the population of an industrialized society. Bethe has. He was just entering his teens when the First World War ended, and his memories of its aftermath in Germany have never left him. He told me during a recent visit I paid him in Ithaca, where he spends his time when he is not lecturing or serving as a consultant around the country, "One of my important teenage experiences was the great German inflation. It was terrible. In the years just after the war—1919 to 1922—the value of the German mark went down by a factor of about a thousand, and in 1923 this was topped by a further inflation of a factor of a *billion.* My father, who headed the Physiology Department at the University of Frankfurt, got his salary twice a week to keep pace with the continuing devaluation. I was the only person in the family who could at least deal with the numbers and grasp the fact that a million of today's marks were worth only five hundred thousand of yesterday's. So it was my job to collect my father's salary and spend it as quickly as I could. The money was generally paid by the university cashier at ten o'clock in the morning. By one o'clock, the money had to be spent, because the stores closed between one and two. The new dollar value of the mark would be published during this hour, and in the afternoon everything would be twice as expensive as it had been in the morning—or, sometimes, only one and a half times. Fortunately, I didn't have school in the morning—only in the afternoon—so I would go twice a week on my bicycle to get the money and spend it immediately. I had a list of the food items I was to buy, and after I returned home with the food the family had something to eat for the next few days."

After a pause, Bethe continued, "The reason I did not have school in the morning was that there was a scarcity of coal, and the scarcity of coal was due, in turn, to the occupation of the Ruhr district by the French in retaliation for nonpayment of war reparations by the Germans. The Ruhr was the main source of coal, so there was a shortage all over Germany at that time. Schools consolidated. Our school was combined with another school, whose students had their instruction in the morning, while we had ours in the afternoon. I witnessed the complete breakdown of the monetary system and the partial breakdown of coal supplies and food supplies which went with it. The whole period from the end of the war, in 1918, until the beginning of 1924 was a time of tremendous insecurity—insecurity in the industrial base of Germany and in the supply of goods. I am afraid that unless we solve our energy problems something similar may happen here and elsewhere in the future."

Until recently, the energy debate in this country was conducted in an almost surreal atmosphere. We appeared to be awash in oil and gasoline, and most Americans seemed to feel that this state of affairs would continue indefinitely. The crisis in Iran and the rise in the price of oil on the world market may have changed that. For the first time, the American people are apparently beginning to come to grips with what is going to be a fact of life for many years—we are going to be desperately in need of useful energy sources. The purely technical problem of developing new sources is compounded by the fact that we live in an age when few of us truly understand how anything works. Technology has got away from us, and intelligent citizens find it increasingly difficult to make the decisions necessary to safeguard the future of us all. The difficulty is compounded when scientists and engineers disagree among themselves. Furthermore, we *are* dealing in futuristic estimates on which, within certain limits, honest and informed people may disagree. What is essential is to develop a sense of these limits and a general feeling for what is true and what is not.

For these reasons, Bethe's ideas about the energy crisis are particularly

A Bar in the Wrong Neighborhood

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honey," Sal says, touching her arm. "Your Southern's coming back. Hey, where's that artist husband of yours? Isn't he going to want some steak?"

"May be against his religion," Ben says. "I hear tell artists are supposed to starve." He slaps himself on his imposing stomach. "Guess I'll just be a laborer in this life. Your daddy, now, there was an artist who could be a laboring man at the same time."

April peers up into the wind, as hungry for news about her father as she is for the steak now sizzling on the makeshift grill.

"Was he, Uncle Ben?" She hears it in her voice, and she is sure Ben hears it, too—the pleading near whine of a young girl wanting a story before bedtime.

"Come round these parts more often and I'll tell you plenty, April."

April smiles politely. There's a feeling she has, a question she wants to ask, but something catches her eye down the beach, a dark flicker above the water too low to be a leaping fish, too high to be a skimming bird hunting for its holiday brunch. Whatever it is, it's gone.

Ben is speaking, but his words whip away like ashes from the tip of his smoldering cigarette.

Abruptly, April turns to look behind her. Nothing there but the Gulf. She's trembling now. It doesn't please her to be back on this beach—lured by William into marriage, lured down to Mexico to take a job she didn't like, tempted back across the border by the need to feel like family. Marina is the only real choice in her adult life that she can call her own. And Marina was an accident.

Ben has stopped talking. Excusing herself, April walks over to the car. There, in the front seat, she spies grandmother and granddaughter sleeping. Satisfied with the sight, she walks south along the strand.

WITHOUT footprints to guide her—they have been either washed away by the waves or blown away by the warm stiff breeze—April tracks William by instinct, trying to gauge which particular configuration of light, cloud, sea, sand, and grass, bird in flight, or driftwood might appeal to his eye. There's a certain laxity to his vision she recognizes from having posed for him when they first met. He likes to look at things that appear to have been flung down in front of him, attempting in his drawings to catch the world on the edge of motion. That's how he likes me, with my life in disarray, April thinks. But she can't know for sure. William has never found the words to express what he sees. He talks very little. In that respect, he is just the opposite of her father. And yet the hold he has on her reminds April all too much of the dead newsman who used to conduct her along this same beach. It's not just words that can catch you. There are other ways. Mute infants. And dumb shows of love. She has another thought as she's walking, and it startles her. If her father were alive, they'd probably quarrel all the time.

"William?"

As though a hand had flicked the edge of a scarf in her face, the wind slaps her words back at her.

"Will?"

She looks down the beach toward the car, the family now no more than a dark blur on the dunes. To her left are the leaping waters of the Gulf, ahead of her the sunny sky above Mexico. At her right, the dunes rise to the height of her chest. She climbs high enough to survey the leeward side of the island.

Here three men stand in a trough between the waves of sand, two of them poised with rods in their hands, their lines stretching beyond the range of dunes that edge the shore. The third man is William, hands at his sides, staring into the grass.

At first, she thinks the two men have gone mad, casting into the sand rather than into the ocean at their backs. Then she recalls the old custom of baiting hooks with savory bits of meat to attract coyotes, those wild scavengers with a bounty on their heads who made the dunes their home. Once, as a child, she had disobeyed her father and wandered away from the Christmas Day picnic, just as William has now, and watched as a lone angler hauled in a yipping, whimpering patchy-coated coyote, hooked through the jowl.

She doesn't wait to see it happen again. Poor William, she thinks, as she stumbles her way back among the dunes, recalling his empty hands: he had no intention of sketching anything. In her struggle this morning with her family, she hadn't even noticed that he never brought his materials along with him. A high-pitched shriek, but whether of beast or bird or woman or baby she cannot immediately determine, rises suddenly on the wind. Something catches in her throat, and she races along the shifting sand to answer a cry of distress.

—ALAN CHEUSE

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FULLER EXPLANATION DEPT.

[*Printed slip found in the carrying case of a miniature computer*]

THIS BAG IS MADE
OF MAN MADE VINYL

valuable. He has often said that he is a pure pragmatist, with no doctrinaire axe to grind. Since he is able to manipulate all the technical concepts involved, talking with him about energy is rather different from the usual discussions of the subject. One is able to say to him, for example, "So-and-So claims that what you think is x is really $2x$. What do you make of that?" Bethe will then patiently explain the consequences if his number is the correct one and the consequences if the other number is correct, and what the consequences would be if the truth lay somewhere in between. He will also explain all the assumptions that have gone into the computation of the various numbers and point out where any of these assumptions, including his own, might be suspect. It is an education both in the subject of energy and in how to think about it.

BY definition, miracles do not often happen, and it is not likely that the energy problem will be solved by a miracle. The solution, if there is one, will be found in the laws of physics. Physicists identify four basic forces in nature. In order of increasing strength, they are: the force of gravity; the so-called weak force; the electromagnetic force; the so-called strong force. Gravity is the weakest force; its apparent strength in holding us to the surface of the earth is due to the fact that we and the earth are made up of a vast number of gravitating masses, whose effects add up. The weak force is responsible for processes like the radioactive decay of many nuclei, and also for some of the energy-generating processes in stars like the sun. The electromagnetic force produces not only the evident effects of electricity and magnetism but also chemical reactions. The strong force holds the nucleus of an atom together, despite the fact that the protons in a nucleus, which are positively charged particles, tend to repel one another electrically.

The interactions among these forces do not produce energy but, rather, conserve it. In fact, the term "energy production" is a misnomer, for no force or combination of forces produces energy. There are different types of energy, and the interactions among the four basic forces transform one type of energy into another; the total remains constant. Consider the water flowing in a mountain stream. The stream's energy is a result of gravitation; the force of gravity pulls the stream along, and some of the potential energy of gravitation is converted into the energy of motion—kinetic energy. This can be converted into electrical energy if we use the moving water to turn an electrical generator. The water in the stream has been produced by the melting of snow, and the melting has been caused by the snow's absorption of the radiant energy of the sun—absorption that involves the electromagnetic force. And the radiant energy of the sun is a result of nuclear fusion. In the sun, fusion is a two-step process. First, the weak force causes two free hydrogen protons in the sun's interior to fuse, the result being a nucleus of heavy hydrogen, a positron, and a neutrino. These three particles have less mass than the two protons, and the loss of mass is available as kinetic energy, shared among the three particles. Then the electromagnetic force causes the heavy-hydrogen nucleus—known as a deuteron, because it consists of two particles, a neutron and a proton—to fuse with another proton, the result of this fusion being a light isotope of helium and a gamma ray, which is a quantum of electromagnetic energy. The gamma ray diffuses out of the sun's interior, gradually changing its wavelength to that of ordinary light, and this light eventually arrives at the surface of the earth.

In the course of energy transformations, "useful" energy is constantly being depleted. Some of the kinetic energy of the mountain stream gets converted into useless heat. Not all the combustion energy of fossil fuels goes into useful work; the remainder, again, is dissipated in useless heat. There is no way to avoid such losses, which are what the Second Law of Thermodynamics has reference to in stating that in any processes entropy will normally increase. Entropy is, roughly speaking, a measure of the disorder, or randomness, of a system. The chemical energy stored in a fossil fuel is in a highly ordered state, but when it is converted into the thermal energy of steam—a

"Don't you think it's time you put your jacket on?"

vapor made up of chaotically moving water molecules—disorder increases. When we use that steam to drive any sort of engine—an electrical generator or a steam locomotive, say—not all the steam's energy can be converted into the ordered motion of the engine; a lot of it remains in the disordered state, and is therefore not useful. It is in this sense that, even though energy is, strictly speaking, conserved at every stage, our energy sources are constantly being depleted.

One thing is therefore certain: a time will come when all the nonrenewable sources of energy on the earth will be gone. The oil and the natural gas will be gone. The uranium will be gone, and so will the coal. To get some sort of feeling for the depletion times involved, Bethe has put together the most accurate estimates of the existing resources and has weighed those estimates against the ways in which we are now using the resources. He has integrated the estimates of commercial enterprises, like oil companies; government estimates, such as those of the United States Geological Survey; and the estimates of various bodies of independent scientists, like the National Academy of Sciences. Where there are differences, he has taken numbers somewhere in the middle. Bethe and many other experts have concluded that until recently, at least, Americans have been using precious nonrenewable resources just about as irresponsibly as they possibly could.

It is instructive to see where the route of such irresponsible use will take us. The first thing we must understand is that if we simply want to maintain our present standard of living, with no improvements, our energy consumption will have to keep increasing in the near future, because our population is increasing. It is true that the birth rate in the United States appears to have levelled off, but this phenomenon is recent, and so for perhaps another decade more people will enter the work force than will retire. Jobs will have to be provided for them. This will require energy, and so will our current goal of bringing into the work force millions of Americans who are now unemployed. There is no sign in our society that any significant group is willing to accept a decrease in its standard of living, and most Americans feel that it is immoral to condemn either their offspring or large sectors of the existing population to permanent unemployment. So energy production, evidently, must be increased. Bethe, in making his analysis, posits a growth of three per cent a year in our gross national product, which means that by the year 2000 it will nearly double. Three per cent is a meagre growth rate—in Bethe's words, "a starvation diet"—so his figures give a conservative estimate of the situation we will face in the year 2000 or so.

WHITE FIELD

It is like standing beyond
a snowfield with a single
set of footprints across it
and you say, Those prints are mine
because no one else has ever been here.
All day the snow comes down,
all day you tell yourself what you feel,
but you remain in that place
beyond the snowfield.
Is there better proof
of your presence than
this open field, where you stand
now looking back across the white
expanse that is once more new to you?
As snow fills the places
where you must have walked,
you start back to where you began,
that place you again prepare to leave,
alone and warm, again intact, starting out.
—DANIEL HALPERN

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The doubling of the gross national product does not automatically mean that twice as much energy will be consumed in the year 2000. In fact, over the past thirty years fuel consumption per unit of G.N.P. has declined very slightly. If strict conservation methods were adopted—and there is not much indication that they will be—then Bethe would accept as the most optimistic serious estimate of our energy needs a forty-per-cent increase over what we now use. This means that we would have to use about a third less energy for everything we make and do.

But suppose we were able to alter our lives. Suppose we could somehow learn to live so that our energy consumption would not increase at all in the next few decades. How would we be able to supply our energy needs in the year 2000? Essentially, everyone who has studied these matters now agrees that, whatever happens, we would not be able to do it with oil. Oil production in the United States peaked in 1970, and we have produced less oil each year since then. (Alaskan oil will only temporarily halt this decline.) As for the great Arabian oil fields, their production will have peaked by the year 2000 or a little later—depending on the rate at which the remaining oil is used. The Soviet Union, which produces about eleven million seven hundred thousand barrels a day—the Saudis currently produce about nine and a half million barrels a day—is also experiencing a production peak, and expects to import oil in the nineteen-eighties. In this country, we now use about six billion barrels of oil a year. Our reserves of discovered oil, including the Alaskan oil, are about sixty billion barrels. If we had to rely on this oil alone, then, it would run out in ten years. The estimates of our undiscovered oil, Bethe finds, range from fifty billion to a hundred and fifty billion barrels; the United States Geological Survey estimates eighty billion. The total supply could be extended another ten years if the methods of recovering oil from wells could be improved by making the oil less viscous. Attempts at reducing the viscosity have been made, with limited success. It is widely agreed, at any rate, that we will have to continue to import several billion barrels of oil a year.

As the world's reserves of oil diminish, it is becoming clear that some-

time before 2000 we will have either to reduce our standard of living dramatically or to find substitutes for oil. With natural gas, the situation seems to be somewhat better; if our supply is used at the present rate, it may last as long as forty years, provided that an all-out effort is made to find new gas and that the effort is successful.

At present, we have operating in this country something like seventy power-producing nuclear reactors, and there are about ninety new ones in various stages of construction. It takes perhaps ten years to build a nuclear power station, and costs a billion dollars. The working lifetime of a station is usually given as thirty years. The fuel for nuclear power stations is a mixture of two uranium isotopes—ninety-seven per cent of it being the common isotope U-238, and only three per cent the readily fissionable isotope U-235. In the working lifetime of a station, about six thousand tons of uranium ore is used. In order to keep a typical reactor going, fresh fuel must be supplied periodically, and a third of the fuel elements are changed annually. During the three-year period that the fuel normally spends in the reactor, not all the U-235 is fissioned; perhaps a quarter of it is left. Furthermore, in the working cycle of the reactor, plutonium—the fissionable isotope Pu-239—is produced by nuclear reactions in the U-238. In other words, a power reactor regenerates some of its own fuel; something like sixty per cent of the used U-235 has been replaced by usable plutonium. Much of this plutonium is itself fissioned while the fuel is in the reactor, yet there is still a substantial amount of fissionable material left in the fuel elements after they have been removed from the reactor—about a third of the original amount. President Carter has decided that we should not reprocess the spent fuel to recover this material, so it is simply discarded. The Department of Energy estimates that today there is three and a half million tons of minable uranium oxide in the United States. If this is used in the future as it is being used at present, there is enough to power at least five hundred reactors for thirty years. If five hundred reactors were operating in the year 2000, they would supply about half of our electricity, or a quarter of our total energy needs. But although they would clearly contribute to the solution of our energy problem in the year 2000, they would have no effect a few decades thereafter. Other industrial countries, with less uranium, are not following our example in the use of uranium but are planning to use reactor techniques that "breed" new fuel.

Of coal we have a great deal, but by no means an infinite amount. Estimates of the recoverable coal deposits in this country range between two hundred billion and six hundred billion tons. It has been estimated that in the year 2020 we will have to use something like two and a half billion tons of coal. Most of this will go to make electricity; some will go to make gas and oil; and some will go to make petrochemicals, such as fertilizer. Given the figures, it is quite likely that citizens in the year 2020 will look upon coal much the way we look at oil now. They will feel, rightly, that there is a lot of it, and they will also feel, rightly, that it is a precious, finite resource that may begin to run out at the end of *their* century. For these people, the energy problem will present itself somewhat differently. They will be forced to look at renewable energy sources, and at those alone. To them, the problem may appear as a purely technological one: Can the renewable sources be made to yield the necessary energy? Since these renewable sources—the sun, the oceans, the trees, the wind, the streams—are widely shared by the people of the earth, it is possible to imagine that the international political tensions that dominate our present thinking with respect to the nonrenewable energy sources will have vanished, and that some sort of coöperative global effort will appear to be the most logical way of approaching the harnessing of the renewable ones. In that sense, the next century may turn out to be a good time to be alive—a more benign time. The problem that we have is how to get from here to

"I know what I want for Christmas! I want one of those itty-bitty toolboxes that have an eentsy-weentsy screwdriver and an eentsy-weentsy hammer and an eentsy-weentsy pair of pliers and on the lid is the cutest eentsy-weentsy beentsy-teentsy tiny little padlock and key!"

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there without destroying ourselves either by warring over diminishing resources or by polluting our environment beyond repair. None of the choices involved are simple, and none of the paths that we may choose are without risk. What someone like Bethe is able to do is provide an analysis of the various choices and their attendant risks and advantages.

BETHE has remarked that, historically, there has been a time lag of at least twenty years between the invention of a new energy technology and the building of the first prototype. For example, nuclear fission was discovered in 1938, and the first privately financed nuclear power plant in the United States went into operation in Dresden, Illinois, on August 1, 1960. Though some work was done on controlled nuclear fusion in the early fifties, the intense effort to develop it as a power source began only in the late fifties—mostly after the subject was declassified by the United States, on the occasion of the second United Nations International Conference on the Peaceful Uses of Atomic Energy, which took place in Geneva in 1958—and Bethe thinks that the feasibility of fusion power may be proved experimentally in the mid-nineteen-eighties. The reason for such lags is that doing the research and engineering to develop a prototype requires a good deal of time. In addition, building a prototype does not in itself deliver any energy to the consumer, and putting a new technology into extensive use requires a lot of money. The entire Manhattan Project, of which the laboratory at Los Alamos was only one part, cost two billion dollars in the mid-forties, or a present value of about eight billion dollars—eight times the cost of a nuclear power station today. Thus, the nuclear power stations that are being constructed now are costing as much as a dozen Manhattan Projects. And to put sums of money like this together without dangerously bleeding the economy also requires time—usually a lot more time than the research and development. "Sometimes one hears the suggestion that we should have a Manhattan Project for energy—a concentrated research effort to speed things up," Bethe remarked. "I think that this idea misses the point. While it is true that research and engineering can often be done at an accelerated pace, actually making use of the results to supply a large number of consumers presents a problem of a totally different magnitude. If one adds the time required to engineer the prototype to the time required to put together the vast capital sums for constructing power stations and the time required to build them, then it is fair to say, I think, that any technology that is going to produce substantial energy by the year 2000 has already been invented. This does not mean that improvements in the existing technologies—new inventions related to them—will not be adopted. What it does mean is that only developments related to existing technological ideas are likely to have much of an impact in the next twenty years or so." The existing technologies that are relevant to the energy problem involve the wind, the sun, coal, nuclear fusion, and nuclear fission. Oil and natural gas are omitted from this list because it is not clear that any invention can alter the steady depletion of these resources; so is hydroelectric power, because—in the industrial societies, at least—it is already essentially being fully utilized.

The most controversial of these technologies is surely nuclear fission. Although there are many different types of fission reactor, only one system is in general use for producing commercial electric power. Broadly, that system has two basic components—a reactor and steam generators. In a nuclear power plant, the reactor functions as a heat source; it replaces the coal or oil furnace of a conventional power plant. In so-called pressurized-water reactors—the more common type—this heat is converted into steam in units separate from the reactor; in so-called boiling-water reactors, this conversion to steam takes place within the reactor unit, from which the steam is conducted to the turbines. In either case, once the steam has been produced the electricity is made by entirely conventional methods, with turbines of the sort that are always shown in newspaper photographs when there is a power failure.

In a pressurized-water nuclear power plant, both the reactor and the steam generators are placed inside a building—called the containment building—resembling a large silo, two hundred feet high, of which the reactor occupies a relatively small part. The reactor vessel—a steel chamber whose walls are at least eight inches thick—is about sixteen feet in diameter and about fifty feet high, while the floor of the building has a diameter of about a hundred and twenty-five feet. In this system, water at about five hundred and fifty degrees Fahrenheit is constantly fed into the reactor vessel through large pipes, and is there heated to six hundred and twenty degrees. The heated water is kept under high pressure—about twenty-two hundred and fifty pounds per square inch, as opposed to the normal air pressure of about fifteen pounds per square inch—so that it will not boil. This cycle generates the steam needed to run the turbines and also keeps the reactor core—the fuel within the reactor vessel—at a temperature low enough to prevent its melting. All the potentially serious accidents that pressurized-water reactors are subject to can be traced to some interruption in the cooling cycle.

Where does the fuel in these reactors come from? And what does it cost? Uranium is distributed all over the surface of the earth, at an average concentration of three parts per million; in certain ore deposits, the concentration is as high as thirty per cent. In this country, ore with a concentration of a few hundredths of one per cent is considered profitable to mine. About ninety-nine and a quarter per cent of this uranium is in the form of the isotope U-238, whose nucleus is composed of ninety-two protons and a hundred and forty-six neutrons. The isotope U-235, which has three fewer neutrons, occurs in natural uranium in the ratio of about one part in a hundred and forty. Mined uranium currently costs about forty dollars a pound. After it is mined, this uranium is enriched; that is, it is partly separated into its isotopes until the mixture, instead of being less than one per cent U-235, reaches the required three per cent—a process that is costly both in energy and in money. When one speaks of reserves of uranium, one means those reserves that can be mined and enriched at a cost low enough to produce energy at rates comparable to those for other fuels. In the future, it may be worthwhile to exploit shale, although it has a much lower concentration of natural uranium, and even to try to recover uranium from seawater, but today these processes are too expensive.

In a conventional power reactor, whether pressurized or boiling, uranium that is chemically bonded to oxygen—uranium oxide—is used. The uranium-oxide fuel is shaped into pellets about an inch long and half an inch in diameter, and these pellets are fitted into tubes about twelve feet long. These tubes, called fuel rods, are made of a zirconium alloy that is highly resistant to radiation damage and will not melt at the working temperature of the reactor. In a large pressurized-water reactor, there are about forty thousand fuel rods, which are packed into bundles of about two hundred rods each. Ordinary water circulates among the fuel rods to cool them.

How does this arrangement generate energy? Part of the natural background radiation, to which we are all subjected, consists of "thermal," or low-energy, neutrons. These neutrons are produced by, for example, cosmic rays entering the earth's atmosphere and breaking up the nuclei of the air. When a thermal neutron encounters a U-235 nucleus, several competitive processes are possible, one of which is that the neutron simply bounces off the uranium. In many of the collisions, however, the thermal neutron will cause the U-235 to split up—to fission—into two lighter nuclei and a number of neutrons. There are at least thirty different ways in which a U-235 nucleus can fission, and in all of them two lighter nuclei emerge, along with a certain number of neutrons. If one averages the number of released neutrons, the figure comes out to about two and a half per fission. Most of the energy that is produced goes into the motion of the fission fragments—it gives them their so-called kinetic energy. Since these fragments remain in the fuel rods that contain the uranium pellets, their kinetic energy heats the rods. These rods, in turn, heat the water used for cooling, and so produce the steam that generates the electricity.

How much energy is released in a typical fission? Physicists calculate it in terms of an energy unit called an electron volt, which is, roughly, 4.5×10^{-26} kilowatt-hours—a very small amount of energy on a practical scale. In each fission, about two hundred million electron volts of energy is released. A typical neutron or proton is bound to a uranium nucleus with an energy of about seven million six hundred thousand electron volts, but in the fission fragments the typical binding energy per particle is eight and a half million electron volts. When a substance is transformed into one that is more tightly bound, energy is released. The water molecule, for example, is more tightly bound than the molecules of oxygen and hydrogen, so energy is released when hydrogen burns to form water. Similarly, in a fission the difference in binding energy is released—nearly a million electron volts per nuclear particle—and becomes the kinetic energy of the two fission fragments. Since there are about two hundred nuclear particles in the uranium nucleus, the total energy release per fission is about two hundred million electron volts. The average American uses electric power at a rate of about a thousand watts. A watt is an amount of energy per unit of time; it is an energy rate. It corresponds to 238.9 calories a second. Since there are about nine thousand hours in a year, the average American uses nearly nine thousand kilowatt-hours of electrical energy in a year. The rest of the world averages about one-fifth of that. If one gram of U-235 could be fissioned completely, it would provide a year's supply of electric power for one American. Even though natural uranium is expensive per pound and separated U-235 is even more so, by the early nineteen-seventies the fuel cost of uranium per kilowatt-hour was already less than that of any of the fossil fuels, and projections for 1981 suggest that uranium will cost about one-seventh of what oil will cost and about half as much as coal. Bethe is fond of saying, "Coal is wonderful stuff, but uranium is even better."

In a reactor, the neutrons released

"If it isn't Dial-A-Joke, it's Sports Phone. If it isn't Sports Phone, it's Dial Dr. Brothers or the Big Apple Report. And now, if it isn't any of those, it's Dial Santa."

by the U-235 fission are fairly energetic—too energetic to fission more U-235 effectively. The water used for cooling in the reactor emerges in another role—that of "moderator." Collisions with the protons in the water molecules slow the energetic neutrons, and these newly slowed neutrons can, in their turn, fission the U-235. (They can also transform some of the U-238 into Pu-239.) That is to say, a chain reaction occurs. Some of the neutrons simply get lost in this process, either by being absorbed into one of the U-238 nuclei or into the oxygen or possible impurities in the water, or by escaping from the reactor altogether by absorption into the steel walls surrounding it. In practice, a reactor must be designed to keep enough neutrons constantly available for further fissions, and if a reactor uses natural uranium—not enriched with U-235—no chain reaction will take place in it unless the moderator is either graphite or heavy water; ordinary water will not work. Because most of the power reactors in use today do use ordinary water for cooling and moderating, they are referred to as light-water reactors.

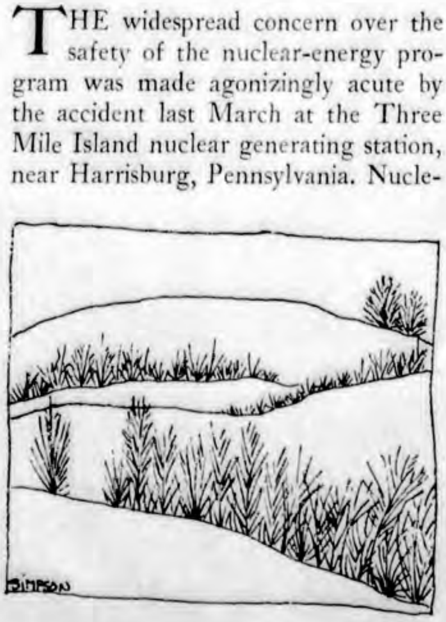
In the normal working cycle of a light-water power reactor, fission fragments are created each time a U-235 or Pu-239 nucleus undergoes fission. These fission fragments, which are generally unstable nuclei in the middle of the periodic table of elements, collect in the fuel pellets or as gas in the spaces within the fuel rods. Because these fission fragments can capture neutrons, they make the fuel elements unusable by extracting neutrons from the fission chain. Sooner or later, then, the fuel rods have to be removed, and since the present practice is to remove one-third of them annually, if President Carter's program is continued these fuel rods will simply be stored, with no separation of the still usable uranium and plutonium from the fission fragments. (In volume, something like two cubic metres of waste is present in the removed rods.) Many of the fission fragments have a relatively short half-life, so after a few months or a year of storage much of their radioactivity will have abated. During this time, the rods are put in a pool of water forty feet deep, where they cool off both in temperature and in radioactivity. Nonetheless, because they also contain long-lived radioactive isotopes, provision must be made for storing them over long periods. The long-lived isotopes are of two types: fission fragments such as strontium and cesium, and the so-called actinides, or transuranic elements—the elements into which uranium decays, among them plutonium. Strontium and cesium have isotopes with half-lives of about thirty years, and both have biologically unpleasant features, since they are readily absorbed by the human body. Strontium can replace calcium in the bones, and any radioactivity in the bones can lead to cancer. Cesium concentrates in the reproductive system and can cause mutations. These isotopes must be stored in isolation for something like six hundred years—until their radioactivity is reduced to a negligible level. And if the fuel rods are not reprocessed, they will also contain Pu-239, which has a half-life of twenty-four thousand years and must be stored for something like two hundred and fifty thousand years before its radioactivity reaches an acceptable level. Storing radioactive wastes remains one of the main concerns of the nuclear-energy program.

The present proposed method of long-term storage calls for the fusing of a number of fuel rods with a ceramic to make a solid package about a foot in diameter. These packages are then to be put in steel cylinders about fifteen feet long, which are to be permanently stored two thousand feet underground. The preferred storage medium is bedded salt. An underground bedded-salt deposit has three advantages. First, it is in a region that is free of underground water (if water had been present, it would have dissolved the salt), and water transport is the only important way in which underground deposits can be brought back to the surface of the earth. Second, bedded-salt deposits are in geologically quiet regions—regions that have not had seismic activity in many millions of years, and are thought unlikely to be disturbed by seismic activity in the future. Finally, salt flows plastically under pressure, so any cracks that might be opened up in the salt by mechanical or thermal stress will anneal themselves. (Salt is not the only possible disposal medium; experts agree that granite might be equally good, or possibly even better.) What is proposed is that a mine two thousand feet deep be dug into a salt bed and that tunnels, each just large enough to hold a single cylinder, be dug in the walls of the mine. One such bed has been proposed on federal land in southeastern New Mexico, but the Department of Energy has not given the go-ahead to begin using it, so the matter of waste disposal is now in a sort of political limbo.

This situation is typical of the crisis of confidence that has troubled the nuclear-technology program. A large segment of our population has lost faith in technology and technological estimates. Each day of our lives, we do accept hundreds of technological assumptions—that bridges will not collapse when we go over them, that the wheels of our automobiles will not fall off when we drive, that airplanes are safe enough for us to fly in. Most of us are in no position to verify the details of such technologies. We must at some point take the word of experts that these things will really work the way they are supposed to. But so much emotion has been engendered in the debate over nuclear energy that many people have lost confidence in any sort of technical expertise in the matter. The fact that the best scientists available have studied the problem does not inspire confidence; rather, it often generates further skepticism. On the positive side, this skeptical attitude has made many of the studies much better and more careful, but skepticism could also bring the nuclear program to an end. Though this might be a source of satisfaction to some, it would have serious consequences. Unless we can come up with realistic alternatives to the known methods of energy production, we will simply have less energy and a drastically lower standard of living—and this, in turn, could have dire social and political consequences.

With respect to waste disposal, it may not seem reasonable to have confidence that a disposal site will remain geologically undisturbed for thousands of centuries, but Bethe points out that nature has provided us with a site where this has already happened. A few years ago, the remains of a "natural" nuclear reactor were discovered in Gabon, in an area that has rich uranium ore, with concentrations of between twenty and thirty per cent. Both U-238 and U-235 are radioactive, but U-238 has a longer half-life—which is why it is now so much more abundant than U-235. A billion eight hundred million years ago, however, uranium ore was about three per cent U-235. In addition, the ore contained water, which acted as a moderator. This configuration was analogous to the basic design of a light-water reactor, and, indeed, it functioned that way. The effect of this "reactor" activity was to leave in the ground an anomalously low concentration of U-235, along with the fission fragments. By analyzing samples of the soil, French radiochemists have found that most of the fission fragments have scarcely moved in the nearly two billion years since they were formed. (The position of the short-lived fragments can be determined by identifying their decay products.) This is also true of the plutonium that the "reactor" generated. It moved less than one millimetre from the time of its formation. Thus, this natural reactor, so long quiescent, provides a model for a disposal site. Meanwhile, until the government sees fit to act, the nuclear power plants operating in this country are disposing of their partly spent fuel by putting the fuel rods in the water pools, which were intended to hold them only temporarily. Since the pools were designed with the idea that there would be a continual turnover in spent fuel rods, which were to be sent elsewhere for reprocessing within a year, their capacity is limited, and the utilities that operate the nuclear plants will soon find themselves in the position of having to construct new pools, which may turn out to be useless if the government's policy changes.

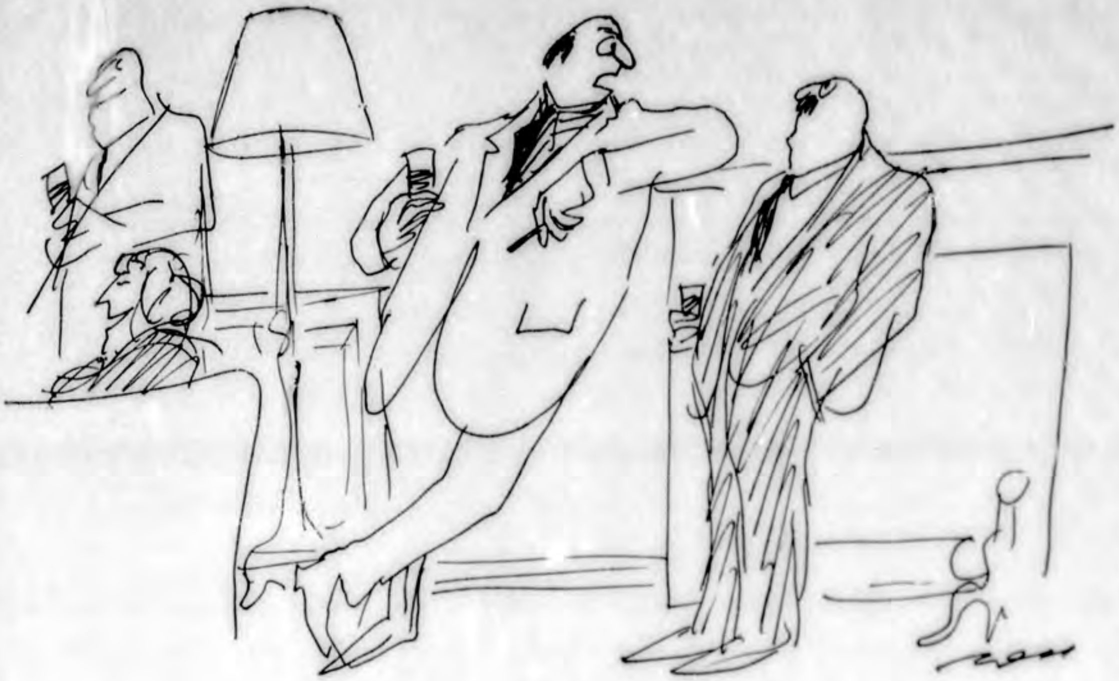
THE widespread concern over the safety of the nuclear-energy program was made agonizingly acute by the accident last March at the Three Mile Island nuclear generating station, near Harrisburg, Pennsylvania. Nuclear power plants at present generate about fifty thousand megawatts of electric power in the United States—almost fourteen per cent of the total. Their operation represents over five hundred reactor-years of experience. Whether one considers this a large or a small amount of experience with commercial power-generating reactors depends on one's estimate of the likelihood that something will go seriously wrong. It is Bethe's view that "one cannot make a reactor safe without having reactors and gaining experience from them." He says, "One can put in many sorts of safety measures, and this has been done, but then one must find out what happens in the real world. There one has to expect some incidents, some anomalous occurrences, and, indeed, some accidents. There are hundreds of occurrences every year. All of them have to be reported to the Nuclear Regulatory Commission. The overwhelming majority of them do not endanger the integrity of the reactor, but they all have to be learned about, because one has to find out what not to do."



The sort of accident that everybody agrees must be avoided at all costs is the one that disrupts the cooling system—the system that keeps the reactor core at a safe temperature. In the light-water power reactors being used today, the cooling system keeps water circulating around the fuel rods. If the flow of water is interrupted and nothing replaces it, the core will melt, and in certain circumstances the melting could lead to a release of radioactivity from the containment building.

All reactors are designed with safeguards. Suspended above the core when the reactor is in operation is a cluster of control rods—thirty-foot-long rods made of neutron-absorbing materials, like boron. When the control rods are lowered into the core, they absorb neutrons and bring the chain-reaction cycle to a halt. In an emergency, the control rods are driven into the core automatically and very rapidly—a procedure known as a scram. This is the first line of defense. But if the scram fails to operate, the reactor will tend to shut itself off anyway, because when excess heating occurs the reactor core (like any material) will expand, becoming less dense. As it becomes less dense, neutrons will escape more easily into the structural material, and so will be removed from the chain-reaction cycle.

In addition, the reactor must be safeguarded against any accident that could cause any loss of the water in the core. For example, in case one of the pipes that carry this water ruptures, there must be some mechanism for replacing



"Momentum is very important. You got momentum?"

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water in the core of the reactor. In general, these methods are referred to as the emergency core-cooling system. In a typical pressurized-water reactor, there are three systems, which should be independently operable. The main system, known as the accumulator, consists of water under high pressure. When the pressure of the water circulating in the core drops because of a break in one of the pipes, water from the accumulator is automatically injected into the reactor vessel. There is also a second emergency system of water under high pressure—water that can be injected into the primary water system in case of a slow depressurization or a small leak. And there is a low-pressure water-injection system, which is designed to replace the usual cooling loop once the temperature of the core has been reduced. This third system is designed to operate for as long as ninety days. For many years, doubts were raised about the effectiveness of the emergency core-cooling system. In 1978 and 1979, however, two exacting tests of it were made at a test facility in Idaho. In those tests, the system performed just as had been expected—in fact, better, because the core became less hot than had been predicted. The Idaho test reactor is a scaled-down model of a real power reactor—about one-sixth the size—but the water-flow systems are an exact replica. Before the tests were carried out, computer calculations were made at Idaho and at Los Alamos to predict what would happen. In particular, the precise time at which the water flow would be restored to the reactor was predicted, and the prediction was confirmed. This gives one considerable confidence that in an emergency the core-cooling system will work as it should. At Three Mile Island, the difficulties were not in the operation of the system but in the actions of the human operators who interfered with it.

Indeed, when one looks at these arrangements in the planning diagrams in, say, a typical nuclear-engineering text, it appears that the reactor designers have thought of everything that could go wrong. Yet obviously no one could have predicted the exact sequence of events that led to either of the two most serious accidents that have occurred in nuclear power plants—the Three Mile Island accident, and the accident at Browns Ferry, which preceded it by four years. The Browns Ferry Nuclear Power Plant, which is on the Tennessee River near Decatur, Alabama, is one of the largest electricity-generating facilities in the world. At present, it consists of three reactors that, combined, generate six per cent of the electricity produced by nuclear power in the United States. The Tennessee Valley Authority began building it in 1966, and on August 1, 1974, it went into commercial operation with one reactor. A second reactor began operating early the following March, and the third in March of 1977. Shortly after noon on March 22, 1975, an electrician, Larry Hargett, was testing for air leaks in the cable room—a room beneath the plant's control room, which adjoined the containment buildings housing the reactors and their steam generators. The air pressure in a containment building is kept at less than normal atmospheric pressure, so that if a malfunction causes the fuel rods to leak radioactive material, this material will not spread outside the containment facility. There are holes in a containment building through which pipes and electrical cables pass in to the reactor and the steam generators. There had been a recent modification in the cable room, and a hole through which cables ran had just been stuffed by Hargett and an associate with strips of polyurethane foam, which is flammable. After stuffing the hole, Hargett wanted to see if he had made it airtight, and he used what was then the standard procedure to test for leaks—a lighted candle, whose flame would be drawn by any leak into the low-pressure containment building. When he held his candle close to the hole, he found that it had not been completely sealed, for the flame was sucked horizontally into the hole. Then the insulation on the electrical cables caught fire. Hargett and his associate tried to douse the fire with fire extinguishers, but after about fifteen minutes they realized that they could not bring it under control, and they reported the fire to a guard. When firemen arrived, the plant operators instructed them not to use water on the spreading fire, because electrical equipment was involved; instead, they tried various types of chemical extinguishers. The fire burned out of control for seven and a half hours and damaged sixteen hundred electrical cables, of which six hundred and eighteen were related to the plant's safety systems.

Meanwhile, engineers in the control room were engaged in a desperate struggle to keep the reactors under control and then cool them down as the control room itself began filling up with smoke. It took about sixteen hours after the fire had started to bring both reactors to a normal shutdown. The engineers accomplished this by bringing into play one of three auxiliary water supplies, which, while not part of the original emergency safety plan for the reactors, were adapted to that use. In the end, the fire caused many millions of dollars' worth of damage, and the power facility was restored only after eighteen months. Still, there were no serious injuries; there was no meltdown of the cores; and there was no release of radioactivity.

Clearly, no one ever wants a repetition of the Browns Ferry accident. But, just as clearly, it was as instructive an accident in terms of reactor safety as one could imagine. The material now used for cable insulation is unquestionably nonflammable, and it is a rule that all power reactors must have two different systems to supply electricity to the reactor safety equipment. And no one will ever again use an open flame to test for air leaks in a reactor plant.

The Browns Ferry accident is an illustration of the ability of human operators to prevent what might have been an extremely serious, possibly catastrophic incident. The Three Mile Island accident appears to be an illustration of nearly the opposite. If human operators had not intervened, this grave incident would probably have been a relatively minor one. In the normal operation of a pressurized-water power reactor, the primary cooling water flows into the reactor core through stainless-steel pipes. The same water is pumped continuously through the system, absorbing heat in the reactor and giving it up again in the steam generators. This water becomes slightly radioactive, because the neutrons passing through it will react with the oxygen or any possible impurities in the water. The water in the secondary loops—which enters the generators, turns to steam to drive the electric turbines, and condenses—does not come in contact with either the reactor core or the radioactive water. The two systems flow alongside each other in the steam generators, and the cooler secondary water absorbs the heat of the primary water, which is transferred through the pipes. No radioactive water is turned to steam. To maintain the required degree of coolness in the reactor core, the secondary loops must constantly draw the heat away; otherwise, the primary water would get constantly hotter and would eventually evaporate, leaving the core exposed.

At 4 A.M. on Wednesday, March 28th, a series of pumps that were circulating water in the secondary system at Unit 2 of the Three Mile Island nuclear power station—one of the plant's two reactor units—broke down. This meant that the unit's two steam generators dried out and the primary water rapidly heated up. After about two minutes, both steam generators were completely dry. In such a case, they were supposed to have been supplied with water by emergency backup systems, but these systems were closed—a fact that was not discovered until eight minutes into the accident. Meanwhile, the increasing temperature of the primary water had caused the pressure in that system to build up. Actually, the buildup had taken place in a few seconds, and a relief valve in a pressurizer tank had opened automatically, reducing the pressure in the primary water system to its normal level by releasing some of the radioactive water into a drain tank on the floor of the containment building. The valve should then have closed, but it did not. Consequently, water—mostly in the form of steam—was continuing to flow out through it, and the pressure within the system was continuing to drop. The drop in pressure automatically activated the emergency core-cooling system, which began pumping water into the primary system to replace the water being lost. It was at that point that the reactor operators made a serious error. They shut off the emergency water. Their reason for doing so seems to have been a misinterpretation of various confusing signals from the reactor. There was an indicator that showed the water level rising in the pressurizer tank. The operators assumed that the rise in the water level meant that the emergency water had overfilled the primary system and thus that the core was safely under water. In reality, the relief valve was still open, and the water from the emergency core-cooling system was escaping through it. When the system was turned off, the water pressure dropped again. After five and a half minutes, what was circulating in the primary system was a mixture of water and steam, and the core was on the way to becoming uncovered.

The water that escaped through the relief valve overflowed the drain tank on the floor of the containment building. The core became so hot that the fuel rods cracked and fission fragments escaped, and so this water contained considerably more radioactivity than normal. The radioactive overflow was pumped into tanks in an auxiliary building which were not designed to hold high pressures, and some of the radioactive steam from this water was released into the atmosphere through the building's ventilation system. Most of the radioactivity that escaped from the Three Mile Island reactor did so in this fashion. At 6:22 A.M., the operators, having finally realized that the relief valve on the pressurizer tank might be stuck open, closed a backup valve to seal the primary coolant system. At 7:45 A.M., the Nuclear Regulatory Commission was notified that something was wrong at Three Mile Island. By about 9 A.M., the President had been informed, and the first news of the incident had reached the public.

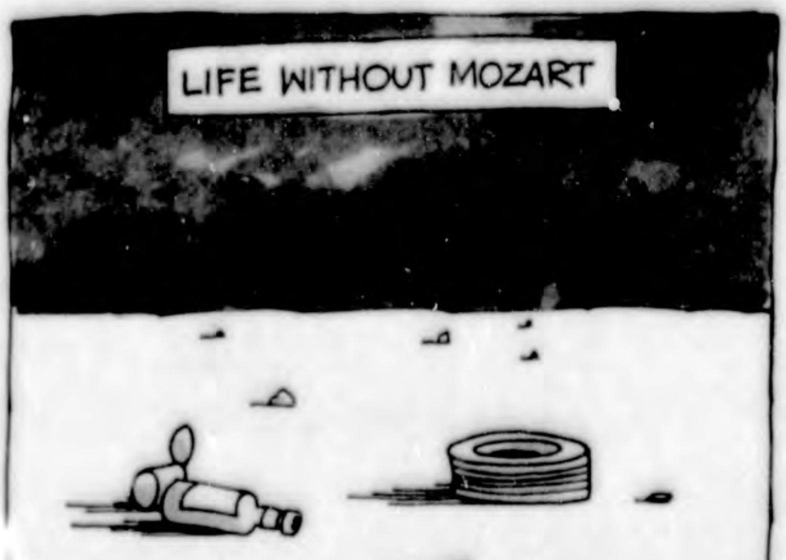
In the meantime, a chemical reaction was taking place within the reactor. The top part of the reactor core, which was no longer covered with water, reached a temperature perhaps as high as four thousand degrees Fahrenheit, and the zirconium in which the fuel rods were encased reacted with water to produce zirconium oxide and free hydrogen. The hydrogen began to accumulate as a bubble at the top of the reactor vessel. On Friday afternoon, the Nuclear Regulatory Commission dispatched a dozen technical experts to Three Mile Island, and these people realized that, for two reasons, the expanding hydrogen bubble was a potential cause of alarm. In the first place, the bubble, as it expanded, could force down the level of the water cooling the core, and thus expose the core to even more extreme temperatures. (Even though the chain reaction in the reactor had been stopped by the control rods almost at once, the fission products continued to generate heat.) In the second place, hydrogen and oxygen are an explosive mixture when the oxygen reaches a certain concentration. (Hydrogen and oxygen, in combining to form water molecules, release a great deal of energy.) It was assumed—wrongly—that because oxygen might be accumulating from the breakup of water molecules, such a mixture might be building up in the reactor vessel, and there was concern that it might explode and possibly rip open the containment building, with a huge release of radioactivity. On Friday evening, Harold Denton, director of the N.R.C.'s Office of Nuclear Reactor Regulation, briefed Richard Thornburgh, the governor of Pennsylvania, about the gas bubble. Governor Thornburgh had already issued an advisory that pregnant women and young children keep more than five miles away from the plant. It was recognized that in the atmosphere of crisis so many conflicting theories had been generated that making coherent plans was all but impossible. Indeed, the chairman of the Nuclear Regulatory Commission, Joseph M. Hendrie, said at the time that he and the Governor were being forced to operate "almost totally in the blind," and added, "His information is ambiguous, mine is nonexistent, and—I don't know, it's like a couple of blind men staggering around making decisions." In retrospect, it is clear that there was never any real danger of a chemical explosion—and this is something that the Nuclear Regulatory Commission must have realized by the following Sunday, at the latest. Zirconium is known for an exceptional readiness to combine with free oxygen. Thus, any oxygen generated by the reaction with water was aborted by the zirconium, and so the bubble never contained any significant amount of oxygen. This fact was never explained to the public, and until the next week, at least, the general feeling was that we were all living on the edge of catastrophe. Only on Tuesday, April 10th, in testimony before a congressional subcommittee, did Hendrie state that an explosion could not have taken place, since "little, if any, oxygen" was present in the bubble.

Before discussing the implications of this accident for the future of nuclear power, I asked Bethe what the worst possible case at Three Mile Island might have been.

"People are always fascinated by the worst possible case, without clearly understanding that these worst cases are wildly improbable," Bethe said. "This emphasis on the worst possible case can do positive harm. In fact, the President's Commission investigating the Three Mile Island accident pointed out forcibly that the Nuclear Regulatory Commission has devoted far too much effort to examining major potential accidents such as large breaks in pipes carrying the coolant, and that it should, rather, have instructed the utilities how to prevent and deal with lesser accidents, such as the series of mishaps that led to the situation at Three Mile Island. The member of the President's Commission living closest to Three Mile Island, Anne D. Trunk, noted in a supplemental view to the commission's report that during the accident the news coverage—especially the evening national-news reports by the major networks—emphasized too much the 'what if' rather than the 'what is,' and said, 'As a result, the public was pulled into a state of terror, of psychological stress.' Three Mile Island did not even come close to a meltdown, and even a meltdown would not necessarily mean a major hazard to the public. Let us suppose that in a future accident, in spite of all safety devices, a meltdown actually takes place. Then the fission products that are normally contained within the fuel rods can escape, and can move around freely inside the reactor vessel. It will take somewhere between a half hour and an hour for the molten fuel to melt the steel wall of the reactor vessel itself. During this time, many of the fission products decay. There is much less radioactivity at the end of that time than there was at the beginning. So this time lapse is very important.

"Once the steel has melted, the fission products—a molten pool—would spread over the floor of the containment building. Inside the containment building, there are auxiliary safety systems. In particular, there is a spray system that is designed to cool the atmosphere in the building. Activating the spray system will reduce the pressure in the building, and at the same time it will condense some of the fission products that have been released as gases. Fission products run throughout the periodic table, and some of them can be condensed by cooling the atmosphere and some cannot. Xenon and krypton cannot be condensed, but if they are released into the atmosphere they are relatively harmless, because they just pass over as a cloud, and don't make fallout. Iodine does not condense easily at high temperatures, but if it is released into the colder outside air it can produce fallout, and this would constitute the main hazard. Most of the strontium would be condensed within the containment building, and as for the plutonium, only a minute fraction of it will evaporate in the first place. The radioactive gases that do not condense are confined within the containment building. In fact, because the containment building is designed to withstand very high pressures, in the vast majority of these hypothetical accidents the radioactivity will be confined within the containment building itself. There is, of course, the China syndrome—that is, the molten fuel melting the floor of the reactor building and passing into the earth underneath. But there it will be well confined, and will not get into the atmosphere. A difficult but feasible mining operation could probably remove it."

Bethe paused, and then said, "Danger to the public comes only when, after a meltdown, a break occurs in the containment building. It is clear that many unfortunate events have to occur in succession before this happens, and so it must be a rare event. If it ever does happen, then the radioactive materials that are still gases will be released into the atmosphere. Even then, however, the effects on the public will not really be as catastrophic as they are pictured in many popular accounts. It is just impossible that an area the size of Pennsylvania—some forty-five thousand square miles—will be made uninhabitable. In a really bad accident, the area that might become unusable is on the order of twenty to two hun-



dred square miles. Perhaps an area ten times as large will have to be decontaminated by removing radioactive cesium and strontium from houses, streets, and so on. It has been predicted that unless the accident occurs at a time of unusually bad weather, no member of the public will die of radiation sickness within weeks. However, the radioactive fallout may cause delayed cancers. In estimating the number of such cancers that may be expected, one commonly uses the method put forth in the early seventies by the Committee on Biological Effects of Ionizing Radiation of the National Academy of Sciences—the so-called linear hypothesis, according to which a given amount of radiation causes the same number of cancers whether it is distributed over a thousand or a million people. With this hypothesis, it has been estimated that the delayed cancers caused by a bad accident in average weather conditions may be about a thousand in the course of thirty years. More recent detailed biological evidence indicates that small doses of gamma rays are considerably less dangerous in causing cancers than the linear hypothesis predicts, so the estimate is probably too high. In any case, since in the population affected by the fallout there will develop over the same thirty years about three hundred thousand cancers from other causes, it will be nearly impossible to tell whether the fallout has increased the cancer incidence, even statistically.

"But much more important than speculating on the worst possible case is to see what we can learn from the Three Mile Island accident. One of my friends said, 'After this accident, reactors will be much safer than they were before.' He is right. Regrettable as Three Mile Island was, it has taught us a lot about how to improve reactor safety. Probably the most important change will be to display much clearer signals to the operators concerning the condition of the reactor. For instance, it would be easy to have a signal indicating that the water cooling the reactor will begin to boil unless the pressure is increased—which can be done through the emergency core-cooling system. There should also be a signal indicating that the relief valve on the pressurizer tank is open when it should be closed. At present, it seems, the operators get too many signals, so the important ones do not stand out. Edward Teller has suggested going further. Many data are constantly measured in the reactor, but it is difficult for an operator to put them together and draw the right conclusion quickly enough, so Teller suggests that this be done by a computer. The operator could ask the computer 'What is going to happen if I turn Valve No. 13?' and the computer would give the answer. The judgment would be left to the operator, but the time-consuming analysis of the state of the reactor would be done by the computer.

"The sequence of events that led to the Three Mile Island accident was listed as one of about seventy sequences in the 1975 Rasmussen report on reactor safety. That list should be used in the training of all operators; they should be trained to respond quickly to any sequence. Since Three Mile Island, better instructions have already been given to operators. Generally, not only should the training of operators be improved but it should be recognized that operators have a great responsibility, similar to that of airplane pilots. The dignity of the profession should be raised, and the pay made commensurate with the responsibility. Technical help was apparently made available to Three Mile Island quickly, but the provision of such help could be planned ahead of time. An important requirement is to have the best technical competence available in the Nuclear Regulatory Commission."

Bethe made this analysis before the President's Commission on the Accident at Three Mile Island, headed by John G. Kemeny, the president of Dartmouth, issued its report. The technical analysis of the accident given in the report is essentially the same as Bethe's. The commission emphasized the need for better training of reactor operators as well as for improvement in the way signals are displayed on the control panels. Concerning the severity of the accident itself, the report notes:

> Based on our investigation of the health effects of the accident, we conclude that in spite of serious damage to the plant, most of the radiation was contained and the actual release will have a negligible effect on the physical health of individuals. The major health effect of the accident was found to be mental stress.

It then goes on:

> Our calculations show that even if a meltdown occurred, there is a high probability that the containment building and the hard rock on which the TMI-2 containment building is built would have been able to prevent the escape of a large amount of radioactivity. These results derive from very careful calculations, which hold only insofar as our assumptions are valid. We cannot be absolutely certain of these results.

The commission was also highly critical of the N.R.C., especially of its licensing procedures and of its approach to reactor safety. It called for a complete revision of the N.R.C.'s procedures and attitudes, and even of its basic structure. The report emphasized that the licensing of nuclear reactors should be contingent on "the competency of the prospective operating licensee to manage the plant and the adequacy of its training program for operating personnel." In addition, licensing should be contingent upon "review and approval of the state and local emergency plans." As the commission emphasized, if nuclear power is to have a future in this country it must become clear to the public that the Three Mile Island accident has provoked a real change—and not a cosmetic one—in attitude toward nuclear safety on the part of all concerned.

When I discussed the Kemeny report with Bethe, he said that he agreed with its recommendations. He added that it was essential to have procedures that would guarantee that the people making decisions in the event of an accident had accurate information—which was not the case at Three Mile Island. An accident does not necessarily constitute an emergency, and even in an emergency the response, in the words of the Kemeny report, "may range from evacuation of an area near the plant, to the distribution of potassium iodide to protect the thyroid gland from radioactive iodine, to a simple instruction to people several miles from the plant to stay indoors for a specified period of time."

What effect has the Three Mile Island accident had on the nuclear power programs of other countries? So far, it appears to have had very little. France and the Soviet Union are continuing the development of nuclear power as rapidly as possible. The French have little choice if they are to maintain their present standard of living, for France has essentially nothing in the way of alternative energy sources. Still, like the Soviet Union, it does have a large pool of technological skills to draw on. Whatever other lessons Three Mile Island teaches, it has shown that having such technology available is an absolute necessity in any emergency situation. Though the local power company that operated the Three Mile Island plant—Metropolitan Edison—simply did not have the personnel to deal with the crisis it found itself in, people who could deal with it were available elsewhere in the country, and could be brought in to help control a rapidly deteriorating and extremely dangerous situation.

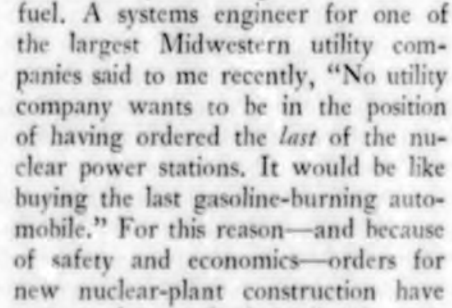
But what about Third World countries? In a recently published article in *Nature*, Anil Agarwal concludes:

> From all present indications, it seems that the incident of Three Mile Island has scarcely sent a ripple through those Third World countries which are keen to buy and build as many nuclear reactors as they can. Part of the reason for this behavior is that nuclear programs have come to be associated by developing countries with enormous political prestige. The efforts of Western governments to control the spread of nuclear technologies are seen by many Third World governments as a crude attempt to monopolize a technology that is of considerable importance to the world. These discriminatory Western pressures have helped to make nuclear power, as a senior IAEA [International Atomic Energy Agency] official recently put it, "an immensely patriotic issue" in many developing countries and even in some developed ones like Japan. Under these circumstances, nuclear authorities in Third World countries will move very cautiously to accept safety-related arguments against nuclear power.

Beyond the matter of national prestige, there is enormous economic pressure in these countries to keep power reactors running, even when they do not meet proper safety standards. The closing of a reactor could mean the loss of a significant percentage of the country's electric power. Agarwal gives an example. Much of the electric power for the city of Bombay is supplied by the Tarapur Atomic Power Station, known as TAPS. It was built in 1969 by General Electric, and was the first nuclear power station to go into operation in the Third World. It now appears that it has for some time been using defective fuel bundles, with the result that the amount of radioactivity in the plant during normal operation is well above acceptable safety levels. Agarwal quotes from the journal *Business India:* "TAPS is so heavily contaminated . . . that it is impossible for maintenance jobs to be performed without the maintenance personnel exceeding the fortnightly dose of 400 millirem in a matter of minutes. Thus the maintenance worker—who is often not an employee of TAPS—holding a spanner in one hand and a pencil dosimeter in the other, turning a nut two, three rotations and rushing out of the work area is a common phenomenon in TAPS." When a TAPS engineer was asked why the plant was not shut down for decontamination, he replied, Agarwal says, "Ideally, that should have been done in 1974 or earlier, but there is such great pressure from the Department of Atomic Energy on us to produce power that we cannot shut down." Even so, India at least has a large pool of trained nuclear engineers, whereas many of the other Third World countries have neither trained personnel nor a body that, like the Nuclear Regulatory Commission, has the authority to oversee the safety of nuclear plants. The I.A.E.A. is planning to organize an emergency-assistance program to fly experts from one country to another in case of an accident. But the accidents at Browns Ferry and Three Mile Island illustrate how vital it is to be able to take effective action in a matter of minutes. What is needed if Third World plants are going to be kept running at an acceptable level of safety is internationally recognized standards, and also clearly defined and accepted guidelines for the number of operators and the level of their training. Similar international standards seem to be accepted by the aviation industry, and surely they are as urgently needed in the nuclear power industry.

Without a supply of uranium that is guaranteed to last for some time, no utility company will invest in a billion-dollar plant designed to use that fuel. A systems engineer for one of the largest Midwestern utility companies said to me recently, "No utility company wants to be in the position of having ordered the *last* of the nuclear power stations. It would be like buying the last gasoline-burning automobile." For this reason—and because of safety and economics—orders for new nuclear-plant construction have come to almost a dead stop in this country, and the technicians who work on the plants are beginning to be laid off.

IN addition to apprehensions about the safety and the environmental impact of nuclear power, there is deep concern over the possibility that the proliferation of nuclear reactors will lead to a proliferation of nuclear weapons—some of which, it is feared, may fall into the hands of irresponsible governments or of terrorist groups. This fear certainly appears to be a significant factor in the policies of the Carter Administration toward nuclear energy—policies that, intentionally or not, may bring our development of nuclear power to an end. The heart of the matter is whether and in what way the development of large numbers of nuclear power stations can increase the availability of plutonium and whether this plutonium can be obtained by governments or individuals who should not have it. As we have seen, nuclear fuel does not initially contain plutonium but consists of a nonexplosive mixture of U-235 and U-238; plutonium does not occur naturally but is made in a reactor. For making a bomb, the necessary isotope of plutonium is Pu-239. In a power reactor, Pu-239 is produced in three stages. First, a neutron is captured by a U-238 nucleus to produce U-239. This is an unstable isotope, and it decays, by the emission of an electron, into an isotope of neptunium, Np-239, which, in turn, decays by electron emission into Pu-239. Another isotope of plutonium, Pu-240, is also produced. Pu-240 is not suitable for making a bomb, because it emits neutrons spontaneously and copiously, and these may ignite the bomb material prematurely and produce a greatly reduced explosion—a fizzle. The plutonium that is produced in a power reactor is therefore not ideal for making nuclear weapons. Indeed, when India made its nuclear device, what the scientists used for making plutonium was not a power reactor but a specially designed research reactor, which made sizable quantities of Pu-239 and very little Pu-240.



Nonetheless, in a year a power reactor produces about a hundred and thirty kilograms of Pu-239, which remains in the fuel rods. The "reprocessing" of nuclear waste involves the separation of this isotope of plutonium from the fission fragments and the uranium also remaining in the rods. When the rods are removed from a working reactor, they still contain about a third as much fissionable material as they did when they went into the reactor. Since this is valuable, no power company simply wants to throw it away by burying it in a hole two thousand feet deep. In any event, no such hole currently exists, so—temporarily, at least—the rods are sitting at the bottom of the specially designed pools of water. Anyone who tried to steal either the stored rods or the rods in a working reactor would be mad—suicidal. The rods are

so hot, in both their actual temperature and their radioactivity, that to steal one would mean certain and rapid death.

The serious problem is the availability of plutonium if the partly spent fuel elements are reprocessed. The idea is to split the fuel elements by chemical means. The fission fragments are separated from the uranium and plutonium, and these two elements are then separated from each other. The fission fragments are considered waste, and are safely disposed of accordingly. The uranium may be returned to an isotope-separation plant to be re-enriched, or it may be used in making new fuel elements. The plutonium could be either added to the fuel for the present generation of reactors or saved for future use in breeders. The concern is that if this scheme were followed, the plutonium might be stolen and used for the illicit manufacture of atomic bombs, and very careful measures would have to be taken to prevent such thefts. This is, in Bethe's view, a valid reason for the Carter Administration to have been adamant about not selling reprocessing plants abroad. But in addition President Carter has stopped the development of reprocessing plants here. In this way, he hoped to set a moral example for the other nuclear nations. In the main, however, this has not been very successful. It has had some benefit, in that it has discouraged, at least temporarily, the Germans and the French from selling reprocessing plants abroad. But many of the nuclear countries (including the Soviet Union) are either reprocessing now or tooling up to do it. Their uranium economy just will not function otherwise. So these countries are not making the slightest effort to follow our "example," and probably consider it merely confirmation of their notion that our energy policy borders on the irrational.

IF our nuclear-fission program were in fact now coming to an end, what would that mean? This is a question that I explored in detail with Bethe. One can suppose, for argument's sake, that our energy consumption will remain fixed at its present level. If one allows for growth, the numbers will look a lot worse; if one assumes that we will conserve radically, the numbers will look somewhat better. But suppose that we want to live exactly as we do today—to use the same number of kilowatt-hours from year to year. Physicists distinguish between two types of kilowatts—thermal kilowatts, which indicate the rate at which fuel energy is released by burning; and electrical kilowatts, which are what we use when we turn on a light switch. In burning fuel to make electricity, there is an inevitable loss of energy, owing to the Second Law of Thermodynamics. The Second Law puts a powerful constraint on the efficiency with which thermal energy can be turned into electrical energy. Though engineers have been working hard to cut this loss to a minimum, it is unlikely that it can be reduced below a half. With the present machinery for going from thermal kilowatts to electrical kilowatts, there is a loss of about two-thirds; that is to say, one-third of the thermal energy is converted into electrical energy.

If we express all our energy needs in terms of electrical units, whether or not the energy is used as electricity or in other forms, the United States uses about seven and a half trillion kilowatt-hours each year. Of this energy, natural gas gives us two trillion two hundred billion kilowatt-hours. Domestic oil, foreign oil, and coal give about one and a half trillion kilowatt-hours each. An additional amount of about six hundred billion kilowatt-hours of electrical energy is supplied by hydroelectric and nuclear power. Hydroelectric power, which, as has been noted, we are already using to essentially the fullest extent possible, is highly efficient: nearly all the kinetic energy of the water can be converted into electricity. A nuclear power plant, as plants are now designed, has only about a thirty-three-per-cent efficiency.

According to the best estimates, our known domestic supply of natural gas will be used up in about a decade. If the unproved reserves are as large as some estimates suggest, the supply might be prolonged until perhaps the year 2020. By that time, our known reserves of domestic oil will also have run out. This means that just to maintain our present total energy consumption we will have to find another source to produce more than three and a half trillion kilowatt-hours of energy. In the absence of nuclear energy, the only real alternative is coal. This means that in the year 2020 we will have to mine at least four times as much coal as we are mining now; in other words, we will have to mine some two and a half billion tons of coal a year. Most of the new coal will have to come from strip mining in the Western states; Eastern coal mines are, in general, old mines, and most of the coal that it is practical to mine in the East is being mined. This means that the coal will have to be shipped, on the average, something like a thousand miles to where it is to be used. The present total railroad capacity of the United States is about a trillion ton-miles a year. But if we have to rely on coal, our railroad capacity will have to be about two trillion four hundred billion ton-miles in the year 2020 just to ship coal; that is, even if we want to ship only coal, and nothing else, on the railroads we must at least double their capacity in the next forty years. Yet at present our railroad system is in a state of decay. Moreover, the environmental impact of quadrupling coal production and burning so much coal must be considered, and so must the consequences of having our entire energy production in the hands of one industry—the coal industry.

Even if we do manage to replace our depleted domestic oil and natural-gas supplies with coal, we will still be running short of energy raw material. We cannot assume that we will be able to continue to import foreign oil in the present quantities, since that oil is also running out. So a large part of this gap will also have to be filled with coal. It has frequently been suggested that we should fill some of the gap by using biomass—animal and human wastes and such agricultural waste as cornstalks. This material burns only about half as efficiently as coal. It is also widely dispersed, so its collection would require a great deal of transportation—which would require more energy. If all the biomass produced in the United States in one year were burned, it would be the equivalent of a billion tons of coal, or about half of our projected needs in forty years. This could make a dent in the energy problem, but the cost of transportation and of construction of the facilities needed to convert biomass into fuel has to be taken into account, as does the additional energy needed for the transportation, construction, and conversion.

Of course, some of the energy that must be replaced could come from nuclear sources. But unless there is a change in attitude toward nuclear energy in this country, that will soon cease to be an option. In 1978, the American utilities industry cancelled the construction of ten nuclear power stations, for reasons having to do with the present complicated licensing procedures, the failure of the federal government to provide a long-term waste-disposal site, and the uncertainty of the uranium supplies, as well as with the public view of the safety and environmental problems presented by nuclear plants. Another important reason is that the growth in demand for electricity has slowed since 1973. In the very near future, our country must make a clear-cut decision about nuclear power. The present unsettled situation simply delays the decision to the point where events will decide things for us. The rest of the technologically developed world has already made its decision, and—on a governmental level, at least—has proceeded with nuclear technology, to the point where American technology has fallen behind. And this gap continues to widen.

In other industrialized countries, the research and development of nuclear technology are focussed on the preservation and manufacture of nuclear fuel. In any such schemes, reprocessing of the fuel elements plays a crucial role. The United States may shortly be the only nuclear country that does not reprocess. (The British government has just approved the construction of the largest reprocessing facility in the world, at Windscale, in northwest England.) We are at present using uranium in our nuclear power program in about the most wasteful way imaginable.

Most of the nuclear power stations under construction here are gigawatt stations, one gigawatt being a million kilowatts. It would take about four hundred gigawatt stations to produce the electricity now being produced by fossil fuels, and using such stations would free the fossil fuels for things that other energy sources cannot be used for—transportation and petrochemicals among them.

But a gigawatt light-water reactor consumes about a ton of U-235 in a year. It returns about two hundred and fifty kilograms of plutonium. At any given time, it contains about ninety tons of U-238, which cannot be used as fuel in such reactors, because thermal neutrons will not fission U-238. In other words, these reactors extract about six-tenths of one per cent of the potential energy content of the uranium. Yet we can extend our uranium supply by about forty per cent even if we continue to use light-water reactors simply by reprocessing the partly spent fuel elements. Beyond that, we can

make enormously impressive qualitative changes in the fuel situation by upgrading reactor technology. These are not futuristic ideas; prototype models are now in active use abroad.

Light water is not an especially good moderator. The reason is an interesting bit of nuclear physics. A water molecule consists of two protons and an oxygen nucleus, along with a cloud of electrons that don't play any role in the nuclear physics, since they are far away from the nucleus. When a fast neutron is produced in a fission, it escapes from the fuel element and enters the moderator—in this case, water. It now begins to collide with the protons and the oxygen nuclei in the water molecules. Some of the collisions are elastic; that is, the neutron simply bounces off one of these particles. After about twenty such collisions, the neutron is slowed down enough—has lost enough energy—so that it can cause further fissions of the U-235 or the Pu-239. Elastic collisions are not the only thing that can happen to the neutron, however. It can be absorbed by the water. Or it can be captured by the uranium without fission—another source of neutron loss. A neutron and a proton can collide and combine to form a nucleus of heavy hydrogen—a deuteron, which consists of one neutron and one proton. When that happens, the fission neutron is removed from the fuel cycle. It turns out that the neutron capture by protons is a fairly likely process. This is the reason a light-water reactor will work only with fuel that has been enriched with U-235 or Pu-239; in a light-water reactor using natural uranium, too many neutrons are absorbed by the moderator and by the U-238.

If instead of using ordinary water as the moderator, however, one uses heavy water, the situation changes. The molecule of heavy water consists of two deuterons and an oxygen nucleus, and neutron capture by a deuteron is only about five ten-thousandths as likely as capture by the proton alone, the reason being the neutron in the deuteron nucleus. Since an oxygen nucleus captures very few neutrons, heavy water is such a good moderator that heavy-water reactors can be fuelled by natural uranium, with no enriching admixture of U-235. This is a great economy factor, because isotope separation is a difficult and costly business. Heavy-water power reactors are now in use in Ontario and Quebec, and these, which are known as CANDU (Canadian Deuterium Uranium) reactors, have been exported to Pakistan, India, Korea, and Argentina. Bethe called the CANDU a "technical wonder," and told me, "Not only is it very conservative in fuel but it works with a regularity and reliability that are absolutely fantastic. The reactor seems to be practically always available. Our reactors, because of the need to replace spent fuel rods and to do other maintenance work, are available only seventy to eighty per cent of the time, but the CANDU, because it can refuel without shutting down, is available ninety per cent of the time." The drawback is the price. It is expensive to separate heavy water from ordinary water, and, besides, additional plumbing must be designed to insure that none of the water gets lost in the working cycle of the reactor. This and other design features add about twenty-five per cent to the cost of building such a power station, but the countries that have invested in reactors of the CANDU type have decided that this extra cost is compensated for by the economies that such a reactor makes possible.

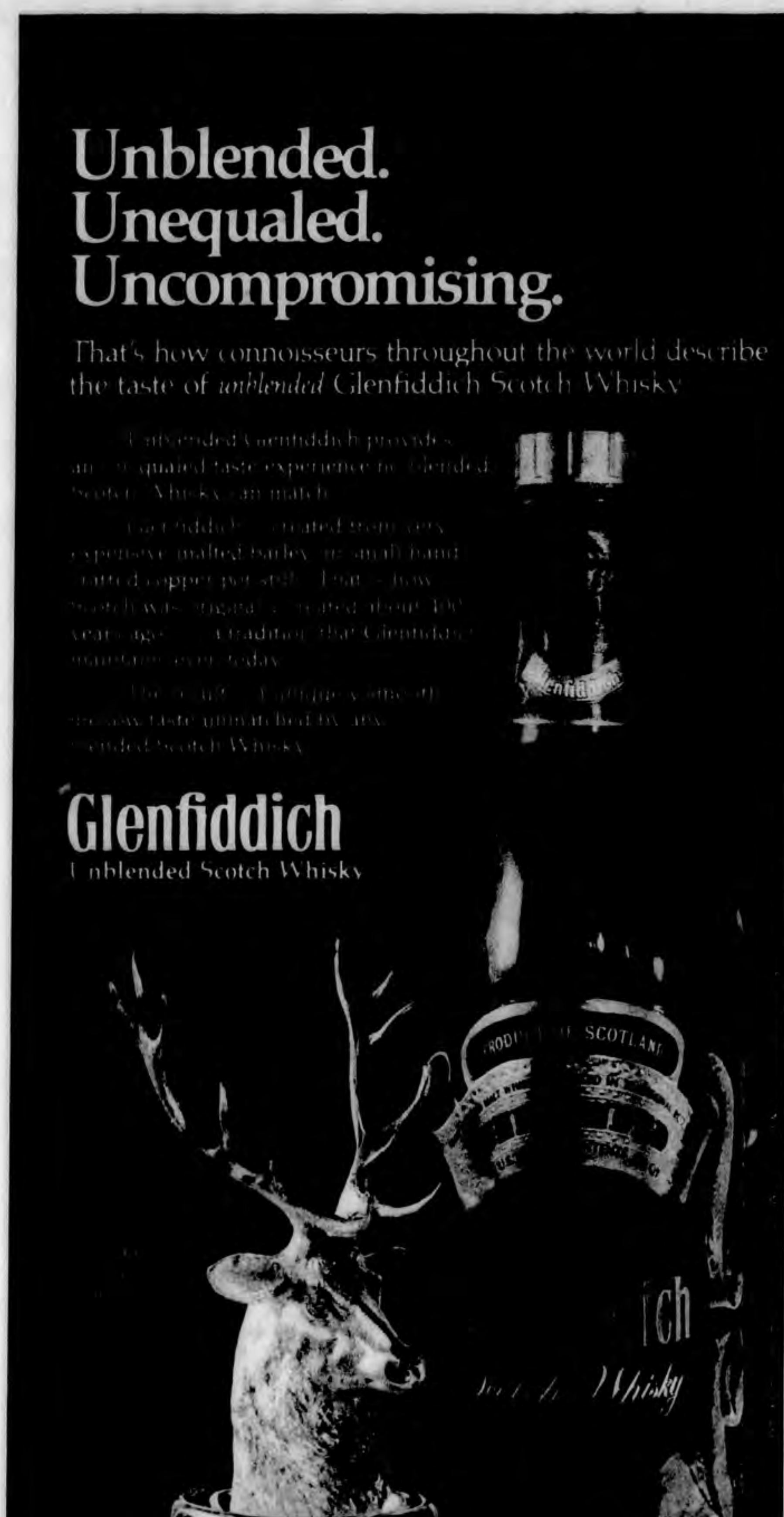
With the help of reprocessing and the use of slightly enriched fuel, Bethe pointed out to me, the CANDU would be able to do so well in preserving nuclear fuel that it would look at first sight as if it did not use up any fuel at all. To understand this, one must trace the route of the fission neutrons in this type of reactor. When the U-235 fissions, something over two neutrons—on the average—are released. One of these neutrons goes on to make the next fission, which sustains the chain reaction. In a light-water reactor, the other neutron tends to get absorbed by the structure of the reactor itself, by the fission fragments, or, most frequently, by the water moderator. In the heavy-water reactor, this last source of absorption is essentially eliminated, so the extra neutrons reënter the uranium fuel—mostly U-238—often enough to cause a conversion of a U-238 nucleus

into plutonium, which is as good as the original U-235 for the chain reaction. Thus, ideally, in a heavy-water reactor there is for each U-235 nucleus split a Pu-239 nucleus created, and no loss of fuel. However, neutrons do still get absorbed by fission fragments and the reactor structure, so the conversion is not complete. To increase the efficiency even of a heavy-water reactor, fission fragments must be separated from the uranium every two or three years—and that once again raises the issue of reprocessing.

Bethe told me that an even better arrangement for a CANDU type of reactor would be to use U-235 mixed with thorium—an element more plentiful than uranium. If thorium is used, the extra neutrons will convert the thorium not into plutonium but into U-233, a lighter isotope of uranium, which is extremely rare in concentrations of natural uranium. As a fissionable material, U-233 is more efficient than either plutonium or U-235, and by using it one could reproduce, with reprocessing, well over ninety per cent of the fissionable material that was originally put into such a reactor. One would have to supply only the remainder.

There is a reactor now being developed abroad that produces more fuel than it consumes. This is the so-called breeder. The notion of making a reactor that produces more fuel than it consumes goes back to the beginning of reactor technology. Bethe recalled a lecture that Fermi gave at Los Alamos just after the Second World War in which he said, perhaps overoptimistically, that the country that learned to build a breeder reactor would have solved its energy problems forever. (Bethe himself began working on the breeder concept, with emphasis on its safety aspects, in the late nineteen-forties.) In fact, the first reactor ever to produce electricity was a breeder—a so-called fast breeder—designed by Fermi with the physicist Walter Zinn; it was built in Idaho by the Argonne National Laboratory, and went into operation in 1951. It is likely that similar fast breeders will serve as the prototypes for the next generation of power reactors. However, because the Carter Administration has indicated opposition to the development of breeder reactors the field has been taken over by other countries—most notably France and the Soviet Union.

The essential feature of these reactors is that the neutrons in them are moderated as little as possible. The neutrons from a given fission remain



"fast." Since fast neutrons fission even the common isotopes of uranium and thorium, these can now act in part as fuels. The main working fuel, however, is plutonium, which has particularly favorable properties when it is used with fast neutrons. In fact, breeder reactors, when they are developed, may provide an excellent way of "burning" excess plutonium and so reducing the amount of it available for potential use in nuclear weapons; the breeder can be made to consume rather than produce plutonium. Today, however, in the Phénix reactor, which went into operation in Marcoule, France, in 1973, the fuel consists of about eighty per cent U-238 and about twenty per cent plutonium. Its mixed-fuel rods form the interior of the core, and there is also a blanket of uranium rods surrounding the core. The breeding is done in this uranium blanket. It comes about because when fast neutrons fission Pu-239 about three neutrons are released. If none of the three are absorbed elsewhere, one is available for the next fission to keep the chain reaction going, and the two others can convert U-238 nuclei into plutonium. Ideally, then, two plutonium nuclei are created for each one that is split. In practice, there is parasitic neutron absorption, but, even so, the breeder will produce more plutonium than it consumes. (There has also been research on so-called slow breeders, which would use slow neutrons to convert thorium into U-233, but this technology has not advanced to the prototype stage.) The entire core is immersed in a pool of liquefied sodium, which serves to cool it. Water is not used because it slows down the neutrons. One advantage of these reactors is that the sodium coolant is at atmospheric pressure within the reactor, and this arrangement eliminates some of the problems associated with those reactors whose coolants have to be kept under high pressure.

The Phénix is basically a prototype and does not really breed significant amounts of plutonium, but now France, in collaboration with West Germany, Italy, Belgium, the Netherlands, and Britain, is constructing a Super-Phénix, at Creys-Malville, about thirty miles east of Lyons, which is designed to produce over a gigawatt of power and which will breed. In such a breeder, about two hundred and fifty kilograms of excess plutonium will be produced in a year, and it appears to be this fact—not only the safety aspects of the reactor—that caused the Carter Administration's reluctance to develop a breeder. The basic argument in favor of the breeder is that any country with a breeder reactor has nuclear independence. Any country that relies on a light-water reactor and does not have its own supplies of enriched uranium is forced to call upon a supplier country when it runs out of fuel, so the supplier can exert some control over how the consumer country uses the plutonium it manufactures in its reactors. If the consumer country is diverting plutonium to make weapons, the supplier country can simply withhold new fuel supplies—as we recently withheld them from India for a time. To this extent, Bethe agrees with President Carter's policy of not exporting either breeders or reprocessing facilities to nonnuclear nations, but he strongly disagrees with the corollary that President Carter appears to have decided on; namely, that in order to set an example for the other nuclear nations we should not have a breeder, either. It is partly for this reason that the Administration has requested the cancellation of funds for our large breeder prototype on the Clinch River, in Tennessee. Bethe feels that we should develop a prototype—not necessarily of the Clinch River design—in case we want to use breeders someday, especially since, whatever we may do, the other nuclear nations are building breeders, for the simple reason that they recognize their resources of coal and oil and uranium to be limited.

THE reactors now in use produce energy by nuclear fission. It is also possible to build a reactor that produces power by nuclear fusion, but a working prototype of a fusion power plant does not currently exist anywhere in the world. The nearest place to find one is the sun. Indeed, the whole idea of fusion is to reproduce some of the characteristics of the sun's interior. The controlled-fusion research enterprise is nearly thirty years old, and at present the mood of the scientists engaged in it is generally hopeful. Bethe, for one, thinks that some form of crude power-producing fusion reactor may be realized in the mid-nineteen-eighties, and that in the next century fusion may be one of the common ways of achieving power production.

The interior temperature of the sun is estimated to be fourteen million degrees Celsius. Matter at such temperatures is in the form of a plasma gas that consists of free nuclei—mostly protons and helium—and the electrons that have been stripped from the corresponding atoms. This gas would simply fly apart under its own pressure if it were not that there is so much of it that the gravitational forces keep the sun's mass in equilibrium against this pressure. If any significant number of fusions are to be produced on earth, there must be a plasma kept at a working temperature of many millions of degrees, and some force must keep the plasma from flying apart. In a laboratory, the latter objective is achieved by the use of high magnetic fields. A charged particle in a magnetic field will tend to move along the lines of that field, executing spirals around them. In fusion research, therefore, a magnetic field is designed in such a way as to confine the plasma within a limited space. Such a magnetic-field configuration is often referred to as a magnetic bottle. At each end of the bottle, the field lines converge, so that, ideally, a charged particle will spiral to the end and reverse itself, and continue to spiral back and forth indefinitely. In reality, the plasma, for various reasons, tends to develop instabilities, and these instabilities cause kinks—sharp bends—in the field lines, which make the bottle leak. For years, workers in the field of plasma physics were plagued by discoveries of new and unexpected ways in which instabilities developed, and it began to look as if no practical way would ever be found to confine a plasma magnetically. In the mid-nineteen-sixties, however, a group of Russian physicists hit upon a design that they called a TOKAMAK—an acronym for the Russian words meaning "toroidal magnetic chamber." It appears to offer great promise. In the area of magnetic-field confinement, most of the present fusion research, both here and abroad, is done on TOKAMAKs, and several experimental models have been built.

The TOKAMAK looks like a large, fat metal doughnut—a torus—made of stainless steel. One of the largest such reactors in the world is now under construction at the Princeton Plasma Physics Laboratory. The outer circumference of the torus is seventy-five feet; the doughnut itself is six feet thick. A high vacuum is maintained inside a TOKAMAK. Electrical wire is wrapped around the outside, and this produces magnetic fields to guide the charged plasma particles introduced into the vessel. Some of the wire is wrapped the long way around the doughnut, and some is wrapped in loops around the

short way. By adjusting the strength of the magnetic fields produced by these separate windings, one can force a charged particle to move in orbits inside the torus. Experimental results showing that there is a reasonably stable confinement of the plasma in such machines have led to the present optimism over the future of the program. Moreover, the "confinement times" have increased from only 10^{-5} seconds in the magnetic bottles designed in 1955 to as much as a tenth of a second in the modern TOKAMAKS.

To make a TOKAMAK like the one being built at Princeton produce power, a mixture of deuterium and tritium will be injected into the vacuum vessel. (Tritium is another isotope of hydrogen—one whose mass is three times that of ordinary hydrogen.) This mixture will be heated electrically to a temperature of a hundred million degrees Celsius—a process that, of course, consumes energy. But as the mixture is heated and the electrons are stripped off by collisions, the nuclei, being confined by the magnetic fields to a region where they encounter one another, and not the walls of the torus, themselves will begin to collide. Energy is produced when a deuteron (consisting of a proton and a neutron) and a triton (consisting of two neutrons and a proton) collide, and fuse into a helium nucleus (consisting of two protons and two neutrons), with the release of an energetic neutron. (This reaction releases seventeen and a half million electron volts of energy, most of which is taken off by the released neutron. A fission reaction releases about two hundred million electron volts of energy, so fission is a much more energy-productive process.) In a future TOKAMAK power reactor, the vacuum vessel containing the plasma will be surrounded by a blanket of materials that absorb the neutrons, which emerge from the plasma at high speed. The kinetic energy of the neutrons will heat the blanket; the blanket is to be provided with pipes containing a cooling fluid to carry the heat away; and this heat will generate the steam to produce electricity.

One thing that is surprising about these machines is how little matter there actually is in the working plasma—the heated gas. Typically, there are about 10^{14} particles per cubic centimetre of the plasma, whereas in a solid the density is a billion times as great. This helps to explain why a fusion machine cannot explode like a hydrogen bomb, which also works by fusing deuterons and tritons. In a hydrogen bomb, the mixture is contained in a lithium-hydride solid and is

heated in a few billionths of a second by the explosion of an atomic bomb. All the fusion energy is released in another few billionths of a second, and the mixture explodes. In a fusion machine, the energy release is, relatively speaking, very slow—so slow that no explosion can take place. The plasma is heated fairly slowly by electric power, and then it must be held together for at least a second by the magnetic fields so that the fusion energy will compensate for the energy that has gone into heating the plasma. In the sun, gravity holds the plasma together for billions of years, and therefore weak processes like the fusion of two protons to make a deuteron, a positron, and a neutrino produce energy, but these processes are too slow to be of any use in producing energy in an apparatus like a TOKAMAK.

The deuteron-triton plasma that future fusion power reactors will require as fuel poses a problem. The triton is unstable, having a half-life of twelve and a half years. Thus, it occurs as a natural isotope only in very minute quantities, and must be manufactured. The manufacturing will be done by bombarding lithium with neutrons, to produce a triton and a helium nucleus. If part of the blanket in a future TOKAMAK power reactor is made of lithium, tritons will be manufactured as the machine operates; like a breeder, it will produce fuel as it goes along. It would therefore be much better to use pure deuterium as the fuel, for deuterium can be extracted from seawater; it is not radioactive and so is simpler to handle; and there is enough in the sea to supply our needs for the next ten billion years. The trouble is that this pure-deuteron plasma does not "ignite" until it reaches a temperature of about three hundred million degrees, compared to a hundred million for the deuteron-triton mixture, so it may be that it will come into use only after scientists have learned to make a fusion machine that produces power with the deuteron-triton mixture. While fusion does take place in the present generation of experimental machines, all of them consume much more power than they produce. It is hoped that the next generation of machines will begin to break even in power, and that fusion power will eventually become a practical possibility. With all the ancillary equipment, the new experimental machines now cost hundreds of millions of dollars, but that investment will pay off handsomely if we can learn to make electrical power from seawater. It may also be possible to use these machines to breed new fissionable material by surrounding them with blankets of thorium, which the escaping energetic neutrons can convert into U-233. Hopeful as some people may be about the prospects for fusion, however, it cannot be counted on to make a contribution to our energy problem within the next few decades.

A NUMBER of people who have pondered the energy question feel that solar energy may help solve our energy problem in the near future. In Bethe's view, solar energy may help to some extent by the year 2000, but even then its contribution will be relatively small. Wishful thinking about solar energy, he feels, should not be allowed to dominate our consideration of the energy problem to the extent that we fail to develop those sources of energy which *can* make a decisive contribution. "The best way to use sunlight is the way that mankind has used it for ten thousand years; namely, to grow grains and forests, and to use the grains to feed ourselves and our animals, and to use the forests for building, paper, and the rest," Bethe told me. "But that is not what people have in mind when they talk about solar energy. They have in mind two things. One is its use for heating houses and for heating water, and the other is its use in the production of electricity. I have looked into both of them quite closely, and I am sorry but I am quite negative about them. I like the sun—after all, I found out how the sun works. But after looking at the available evidence I do not believe that the sun will solve our problems—certainly not in the twentieth century. Maybe in the twenty-first. That I just don't know."

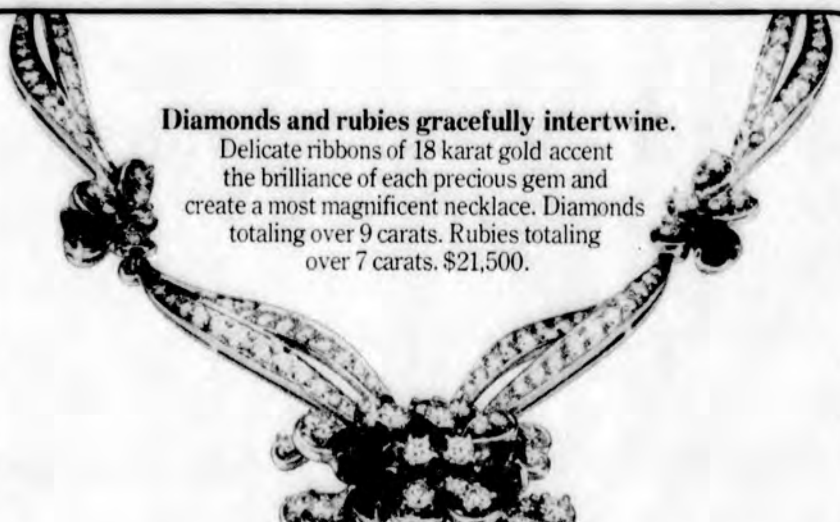
Bethe paused for a few moments, and then said, "The heating of water by solar radiation *is* a perfectly feasible procedure. It would be economical in many parts of this country, and it is practiced in many places in Europe. The reason that heating water is more important than heating space is that one needs hot water all year; one can make use of solar heat in the summer, when there is lots of sunlight everywhere. Space heating by sunlight is economical today only under certain circumstances and in certain parts of the country. The first question is, how expensive are the solar panels? Currently, they cost something like fifteen dollars a square foot. It is possible that with mass production the cost could be brought down to something like seven dollars a square foot, but what really costs a lot of money is the rest of the system—the pipes going through the house, and the hot-water-storage facility one needs because the amount of sunlight is variable. Today may be a sunny day, but tomorrow may be terrible. In fact, the storage of heat is the main problem with the use of solar energy. If one wants to go completely solar, then the heat must be stored for a long time. Otherwise, the solar installation has to be supplemented by a conventional source, such as gas. Most solar-heating systems have a two-day or three-day storage capacity, and after that one has to fall back on the gas company. Generally, the solar people agree that a reasonable strategy would be to get half the heat from the sun and half from natural gas or some similar source. If one does this, and if one can get the panels and the ancillary equipment down to about seven dollars a square foot, then in some parts of this country solar heating will be dollar competitive with the *future* price of gas, natural or synthetic. Almost nowhere is it competitive with the present average price of natural gas, which costs the consumer three to four dollars per thousand cubic feet. This price probably won't last very long, and if we have to use synthetic gas—made from coal—rather than natural gas, it is likely to double, at least. If it does, there will be some parts of the country where solar heating will be economically advantageous. These are not the places one might expect. They are the Rocky Mountain area from New Mexico to Montana, and the coast of California. The reason is that these places get a lot of sunshine in the winter, when homes have to be heated. If one goes to Texas or Florida, one also has lots of sunshine in the winter, but one's home hardly ever needs heating. It should also be realized that the energy consumed in the manufacturing of solar installations is considerable, because all of them are rather bulky."

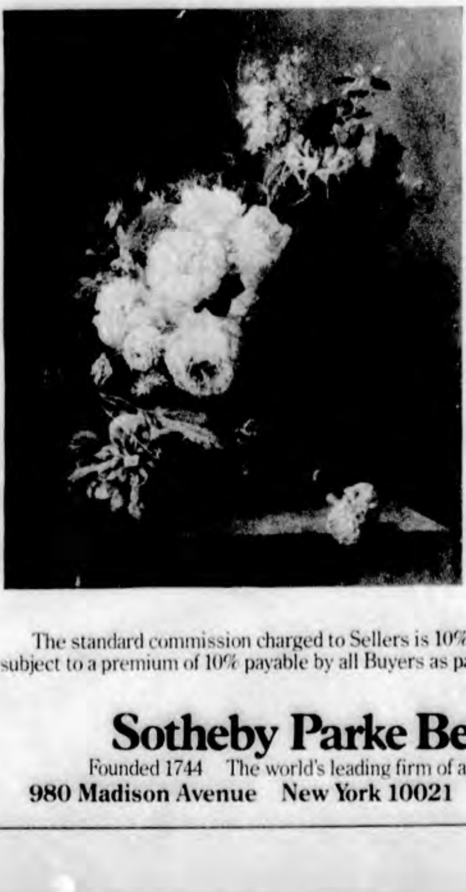
After another pause, Bethe said, "I have made a little calculation of what a private individual might do about solar heating. Others have made similar calculations, but mine may be somewhat simpler. A private individual has something else to worry about, and that is inflation. A private individual has no good way to protect himself against inflation, and in my calculation I take this fact into account. It turns out that if a person in one of the regions of the country that are favorable for solar heating buys one of the cheaper solar-heating units and it lasts for twenty years, he will be better off than if he puts the same amount of money in a savings account and then uses the interest to pay his heating-gas bill in the future. In making this calculation, I have assumed that the price of gas will increase at ten per cent a year in real dollars until it reaches an average of seven dollars a thousand cubic feet. On this assumption, solar heating is a good investment. I do not think that the same thing applies to apartment houses or office buildings, because in these one does not have a large enough surface area to trap the required solar heat. But one must always keep in mind that at present only about ten per cent of our energy consumption goes into the heating of private homes. Even if all the new houses that are going to be built between now and the year 2000 were equipped with solar heating, it would account for only about two per cent of our energy consumption in that year. Still, a two-per-cent saving of energy is worthwhile, because it is two per cent of an enormous number. Though it will not solve our energy problem, it can contribute to a solution, and I am glad that so many people are working on it."

Bethe went on, "By the way, Theodore Taylor, the Princeton physicist, has come up with a nice idea that might, in the future, help quite a lot in solar heating. This has to do with heating not individual houses but a complex of, say, a hundred houses. His notion is to take advantage of seasonal heat storage. He would construct enormous pools of water, about a hundred metres on a side and ten metres deep—pools that are exposed to the sun's heat during the summer. One would cover these pools with plastic, so that the stored heat would not be lost by either evaporation or radiation. In the winter, one could use this heat by piping the water into the complex of houses. The idea appeals to me, and I hope it works. But one must keep in mind that it is at present untested and that it would apply, in its present form, only to places where the population density is rather small. One must set aside an area about the size of a small park just for a pool. It would take some time to install these facilities, but if enough space is avail-

able one might be able to make communal solar-heating facilities at prices competitive with the present price of natural gas.

"This is about the best idea I have heard of for using solar energy on a large scale. When it comes to the prospects for making electricity from solar heat—either for a small community or for a large central power station—things look a great deal worse. The development that I have studied is the one that is now going on in Barstow, California. Four teams are participating. Each team consists of a big industrial firm, an architect-engineering firm, a research group, and a utility. They are constructing what is known as a power tower. This is the cheapest way that has so far been proposed to produce electricity from solar radiation. It consists of one tower—perhaps a hundred metres high—surrounded by a field of about eighteen hundred heliostats, or movable mirrors. Each mirror is a square six and a half metres on a side. The mirrors are individually directed by a computer during the day so that they continuously reflect the maximum solar radiation on the central tower. This heats water in the tower, and the boiling water is fed into a standard electricity generator. It is estimated that with the current technology the power tower can produce electricity at a price of about fifteen hundred dollars per installed kilowatt—about twice the present price of nuclear power. In this price estimate, all the savings on mass production of the mirrors have been figured in. Moreover, the kilowatts are available only in the daytime and possibly a few hours afterward—with suitable heat storage—while nuclear power is available twenty-four hours a day. A system like that is practical only in a desert, because the areas involved are very large—about eight square miles to produce as much power (one gigawatt) as the standard nuclear or coal-fired plant—and one would not want to divert such areas from agricultural production. If one wanted to supply all our electrical power this way, one would need about eighty million mirrors, covering an area of almost five thousand square miles. Such an array could be accommodated in our Western deserts and also in many tropical countries, but it would be difficult to find similar areas in Europe or Japan, even if reliable sunshine were available there. The environmental effects have not yet been assessed. At the estimated mass-production prices, five thousand square miles of mirrors and their gen-

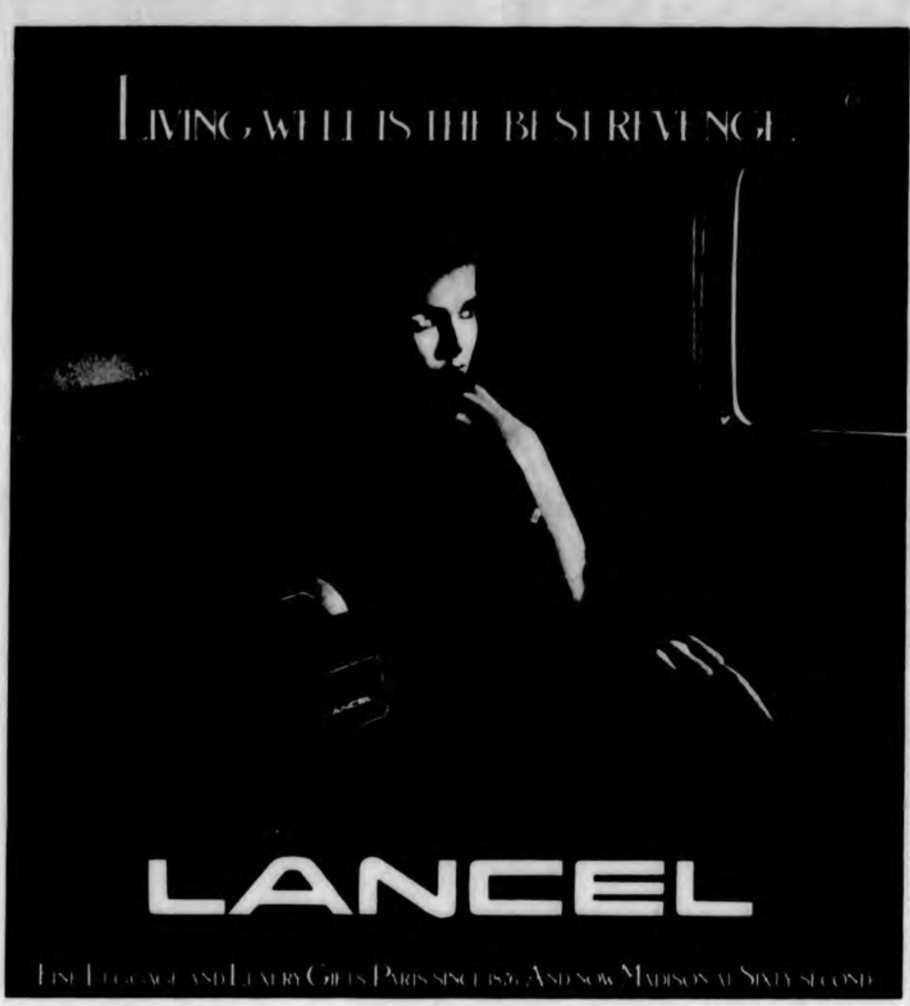




erating stations would represent an investment of nine hundred billion dollars. Our present rate of investment in power stations is about twenty billion dollars a year, and at that rate it would take forty years to install enough solar power stations to supply even our present needs—and, of course, the first station would have broken down before the last one was built."

Much of the interest in the use of solar energy is centered on what are known as photovoltaic devices, or solar cells. These have been used to provide electric power for spacecraft. In the space program, economics was not a consideration, whereas economics is the primary consideration in large-scale terrestrial applications. First, how do these devices work? When light of sufficient energy illuminates a material like silicon or germanium, the electrons that are always present in the material can be promoted, energetically, into what is known as the conduction band. These electrons can then flow, and the resulting current is available for useful work. It turns out that only a relatively narrow part of the solar spectrum is useful for exciting the electrons. When the sunlight is below a minimum energy, the electrons cannot be induced to flow, and above a certain energy a significant portion of the light energy is dissipated in useless heat. This limits the theoretical efficiency of the cells. A silicon cell has a maximum theoretical efficiency of about twenty-nine per cent, while a gallium arsenide cell has about a thirty-six-per-cent efficiency. A recent study on solar-photovoltaic energy by the American Physical Society notes that ingenious combinations of materials might produce a maximal efficiency greater than fifty per cent; but the more complex the arrangement, the more it will cost to make. In practice, the limitations on the working efficiency of the cells are considerably below the theoretical maximum, because of imperfections in the cells. Present-day cells convert sunlight into electricity with an over-all efficiency of about ten per cent.

What, then, would the cost of photovoltaic electricity have to be in order to be competitive with, say, coal-generated electricity in the year 2000? The American Physical Society study concluded that, so far as cost was concerned, it did not matter significantly whether the cells were used in a central power station or whether they were deployed residentially. In either case, to be competitive their price would have to be between ten and forty cents (in 1975 dollars) per generated watt. (The analysis is done for peak watt-



age—when the sun is shining at its brightest. Evidently, the cells will generate no electricity when the sun is not shining.) In other words, the price would have to come down by a factor of about twenty. In a discussion of the study, published in *Physics Today*, Henry Ehrenreich, the study group's chairman, and his colleague John Martin note, "This requirement is sufficiently stringent as to require major technical advances, if not breakthroughs, before extensive deployment can become a reasonable course of action." They worry that "a premature entry into large-scale U.S. deployment before the technology has reached fruition might lock us into an overly costly technology. Indeed, the national interest may well be served optimally by an emphasis on research and development accompanied by measured and technologically appropriate progress in government-assisted commercialization." They conclude that it will be "some thirty years or more" before photovoltaics can make a real dent in our energy problems.

When I discussed this with Bethe recently, he commented, "Photovoltaic devices, which convert solar radiation directly into electric current, have become much cheaper in the last few years, and a lot of research is going on in this field, but they are still at least three times the price of the power tower. Perhaps their price will come down in the future, but we cannot count on that. The use of satellites for collecting solar energy and beaming it down by microwaves to earth is, as far as I can see, far more expensive still, because of the cost of transporting all the materials up into space. Windmills have been proposed as an indirect way of harnessing the sun's energy; they may have their uses in certain regions, where winds are strong and steady, especially if the regions are also very remote—such as the Aleutian Islands, where it is costly to bring in conventional energy sources. But on the whole wind-generated power is high-cost power compared to conventional sources, and, in any case, it is not very reliable."

Bethe went on, "As you can see, I have been rather negative about solar energy in this discussion. That does not mean that I am against using solar energy—on the contrary. Wherever it is economically reasonable, it is a very good thing to use. The trouble that I have with proposals to use solar energy is that so many people promise that it will by itself solve our energy problem. It won't—or, at least, there is nothing now in sight to indicate that it will. It will contribute here and there to the heating of water, to the heating of houses, possibly to some industrial heating. But our need for energy is much too great to be satisfied this way, and the production of solar electricity on a large scale is as yet nowhere in sight. Therefore, what I am troubled about with solar energy is that people use it as an excuse, a reason for not developing other sources of energy—primarily nuclear and coal—which we know how to use, and which, in combination, could satisfy our energy needs. To postpone and slow down the use of these important sources of energy because of some distant future in which solar energy may become very important seems to me a dangerous thing for our country and for the world. I am not against solar energy. Let us do all the research we can on it. Let us use it in every way that is economically feasible. But let us not use it as an argument against taking energy measures that are more immediate and necessary."

IN the light of Bethe's over-all analysis, I asked him what he felt the country should be doing to deal with the energy problem. What specific steps should we be taking now?

"First of all, the country has to realize that the energy problem is terribly serious and is likely to be permanent," he answered. "Next, it must recognize that there are really two problems: one is to provide enough *total* energy, and the other is to provide fluid fuels of all types—mainly oil and gas. But for the next twenty years, at least, I believe that the mainstays will have to be coal and nuclear power—that we will need more of both of them. Much more. We should make every effort to get more coal, not only from our Eastern mines but also from our Western mines. I do not think that this is a time when we should favor one kind of mine over the other. We will need them all, and we will need to open Western mines, in particular, rather quickly. We will have to rebuild our railroads so that in the future we can transport coal from our Western mines. We should replace oil with coal in the production of electric power as soon as possible. The use of so much coal will require us to adopt a more flexible attitude toward the pollution problems that coal produces. For example, Western coal is largely free of sulphur, so power plants that use it should not need the elaborate scrubbers required for plants that use Eastern

coal. These scrubbers, which remove the sulphur from the smoke, add about a hundred million dollars to the cost of a coal-burning power plant. There will have to be some give-and-take between the obvious need to prevent air pollution and the equally obvious need to conserve oil. Coal should be substituted for oil wherever possible in electric power plants and in industrial heating. Coal can also serve as a raw material for solving the second problem, that of providing fluid fuels—synthetic gas and oil. It is believed that synthetic gas can be made for about five dollars per thousand cubic feet—a price that is equivalent in heating value to a price of about thirty dollars for a barrel of oil, which is not very far from the present world-market oil price. Synthetic oil from coal would be more expensive. Luckily, for this purpose we have an alternative—shale oil, which can be distilled from certain rocks. We have a great deal of oil shale, especially in Colorado and Utah, and we should begin to exploit these deposits.

"The prospects for synthetic gas and oil look rather hopeful. Both the President and Congress want to sponsor an effort to develop synthetic-fuel plants, both from coal and from oil shale. The plan is similar to one that was proposed in 1975 by Vice-President Nelson Rockefeller; namely, to set up a special energy fund for lending money for such investments. We have lost four precious years, but now that the urgency is more obvious I hope this plan will materialize quickly. The oil will be needed to replace natural petroleum for running cars, trucks, diesel locomotives, and airplanes, and both oil and gas are essential for making the petrochemicals that are basic for so many of our industrial products.

"We clearly need to improve the safety of our nuclear reactors. One of the lessons that Three Mile Island taught us was that the signals on the control panel of a reactor must be improved so as to give the operators a clear picture of the state of the reactor at all times. Reactor operators must be better trained and better paid, and the weaknesses in some of the specific reactor designs must be corrected. The accident also appears to have convinced the nuclear industry to take some strong new steps to improve reactor safety. It is not just a matter of improving the industry's public image. The financial losses in an accident like that at Three Mile Island, even when there is no substantial effect on the health of individuals, are enormous. In every way, the industry simply cannot afford to have accidents like that. There are three major new programs—the Nuclear Safety Analysis Center, the Institute for Nuclear Power Operations, and a mutual-insurance program to help individual electric utilities in case there is an accident. In my view, the most important of the new entities is the Institute for Nuclear Power Operations. In addition to setting educational and training requirements for nuclear-power-plant operators, it will also conduct independent evaluations to assist utilities in meeting the standards it sets. Very likely, participation in this program will be a condition for inclusion in the mutual-insurance program. So there will be strong incentives for individual utilities to meet high standards of safety and excellence in reactor operation. I feel sure that through the joint efforts of industry and government nuclear safety in the future will be much greater than it has been and that the probability of a major accident can be reduced to a very low level indeed—much lower still than the estimates in the Rasmussen report."

Summing up, Bethe said, "Aside from improving nuclear safety, we must also start serious efforts toward the disposal of nuclear wastes. In particular, we must make a systematic geological study of places that might be suitable for waste disposal. Large amounts of nuclear waste exist now, and it will not go away by wishful thinking. We must also understand that uranium, like oil, is a vanishing resource. Hence, we should develop reactors like the CANDU, which use less uranium for the generation of a given amount of power than our present power plants do. I think that—for the next few decades, at least—nuclear power is essential for our energy needs. But it is not enough to solve our energy problems. We need a determined conservation effort, especially in transportation and in the insulation of houses. We must start to conserve now. We need a vigorous program to make synthetic fuels, and it now seems that the government will inaugurate such a program. Research and development of solar energy should be encouraged, although I do not believe it will make a substantial impact in the next twenty years or so. No one of these programs by itself will solve our energy problems, but all of them together have a good chance of succeeding."

—JEREMY BERNSTEIN

(This is the last part of a three-part Profile.)

THE THEATRE

Surviving

TO be overly ambitious is a good failing in a young and gifted playwright, and I am quick to forgive Martin Sherman for most of the flaws in "Bent" (at the New Apollo), a play that is well worth our serious attention. Mr. Sherman has tried to tell two or three stories at once, and sometimes the working out of their plots leads not to enlightenment but to collision, and yet what passionate, blood-drenched theatre he offers us along the way! Beaumont and Fletcher in Heaven must be gnashing their teeth with envy. "Bent" 's curtain rises on a flaw: in what comes close to being a mere prank, the playwright seeks to conceal from us that the opening scene—a homosexual household on the morning after a night of drunken partygoing—though it appears at first to be laid in the present, in a flat that might well be in Greenwich Village, is in fact laid in Berlin in the early nineteen-thirties. The play's hero, Max, is stumbling about in the grip of a prodigious hangover, while his lover, Rudy, solicitously feeds him breakfast. Soon it turns out that Max has brought home a conquest, who emerges from a sleeping alcove Adam-naked, and a few minutes later is unceremoniously done to death by uniformed thugs—Storm Troopers purging their ranks of homosexuals. No doubt Sherman hoped that this introductory juggling with place and time would serve to indicate the universality and duration of the homosexual "problem," but it gets the play off to a false start; looking back, we feel an irritated sense of having been gratuitously trifled with.

"Bent" has two main themes: homosexual love and the nature of survival. Max is an incessant flirt, who finds himself incapable of love and who affects to believe that love is beyond all homosexuals; he fails, in the celebrated phrase of E. M. Forster, to connect. Fearing for their lives, he and Rudy escape from Berlin, but are tracked down, arrested, and put on a train that is to carry them to the Nazi concentration camp at Dachau, where Hitler is engaged in providing a final solution for homosexuals as well as for Jews. To his horror, Max finds himself being made to act as the not altogether unwilling instrument of Rudy's death; subsequently, hoping to be imprisoned as a Jew rather than as a homosexual, he convinces his captors of his masculinity by performing (mercifully for us, offstage) a grotesque act of sexual intercourse. Nothing matters to him so much as the brute need to survive. In the grim isolation of Dachau, he chooses a new lover, Horst, whose amorous advances he then for a while rejects. Both men suffer horrifying fates as the play ends, but the message of the play isn't a despairing one: Max finally elects not to survive, because he perceives that he has become capable of love. His death is a form of connection.

After the bustling, highly colored melodrama of the first act of "Bent," we are confronted in the second act with a gray aridity of word and gesture that puts us in mind of Beckett. The disparity is less troubling than one might fear, thanks to a first-rate cast and the bold chance-taking of the director, Robert Allan Ackerman. Richard Gere, David Dukes, and David Marshall Grant play, respectively, Max, Horst, and Rudy; they are all very fine indeed, as are George Hall, in a small role as an aging "fluff," and Michael Gross, as a heterosexual female impersonator. The settings are by Santo Loquasto, the lighting is by Arden Fingerhut, and the costumes are by Robert Wojewodski.

"BETTE! DIVINE MADNESS" is the silly title of the musical show that Bette Midler has brought to the Majestic, but Miss Midler is far from being a silly woman. What she lacks in talent she makes up for with courage and energy; she will do *anything* to please an audience, whether it be telling dirty jokes and displaying a bosom that, in the words of T. S. Eliot, gives "promise of pneumatic bliss" or simply and bizarrely crawling about the stage on her hands and knees. She sings in a voice that has been amplified over sixteen speakers and is as deafening and unmusical as Victoria Falls; in lieu of dancing, she struts, and from first to last she takes care to smile, smile, smile, smile, smile. I am always mindless and happy in her presence. Miss Midler is accompanied by three female singers (Franny Eisenberg, Linda Hart, and Paulette McWilliams) and a male dancer who calls himself Shabba-Doo, and who, being tall, slender, black, graceful, and highly skilled, makes an admirable foil for her. The musical direction of the show is by Tony Berg and Randy Kerber, the choreography is by Marla Blakey, and the lighting is by Chipmonck.

"THE ART OF DINING," by Tina Howe, closed at the Public Theatre on Sunday after a brief run (and will be turning up soon at the Kennedy Center, in Washington). It's a delightful little comedy, about a couple of young people who have just opened

Joan -- see if Hugh likes this --

Dear Mr. xxxxMxxx Weisxhahn and Ms. Jackson (for Alaskans for Clean Energy)

Thank you for your letter and information. I ~~support~~ agree with your position on nuclear energy, and supported the effort of ~~worked with~~ Representative Gruening during the 1978 to enact legislation which forbids the siting of <u>any</u> type of nuclear facilitywithout the direct approval of the legislature, the governor and the local community. I have enclosed a copy of the legislation for your benefit. In addition, the Alaska POwer Authority is specifically prohibited from developing nuclear power facilities.

xxxxxxxxxxxxxxxxxx I encourage you to support legislation pending this session which encourages the development of alternative sources of energy. This includes HB 851, establishing a state energy conservation policy, and HB 687. establishing the Alaska Energy Center.

S/

(I mentioned Clark's name since they enclosed information from Gravel)

Senate Resources 3/7

Gov. Egan