Nuclear salvation or nuclear folly?
By Ralph E. Lapp
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The odds against a serious atomic power-plant accident will be 10,000 to 1

Nuclear salvation or nuclear folly?

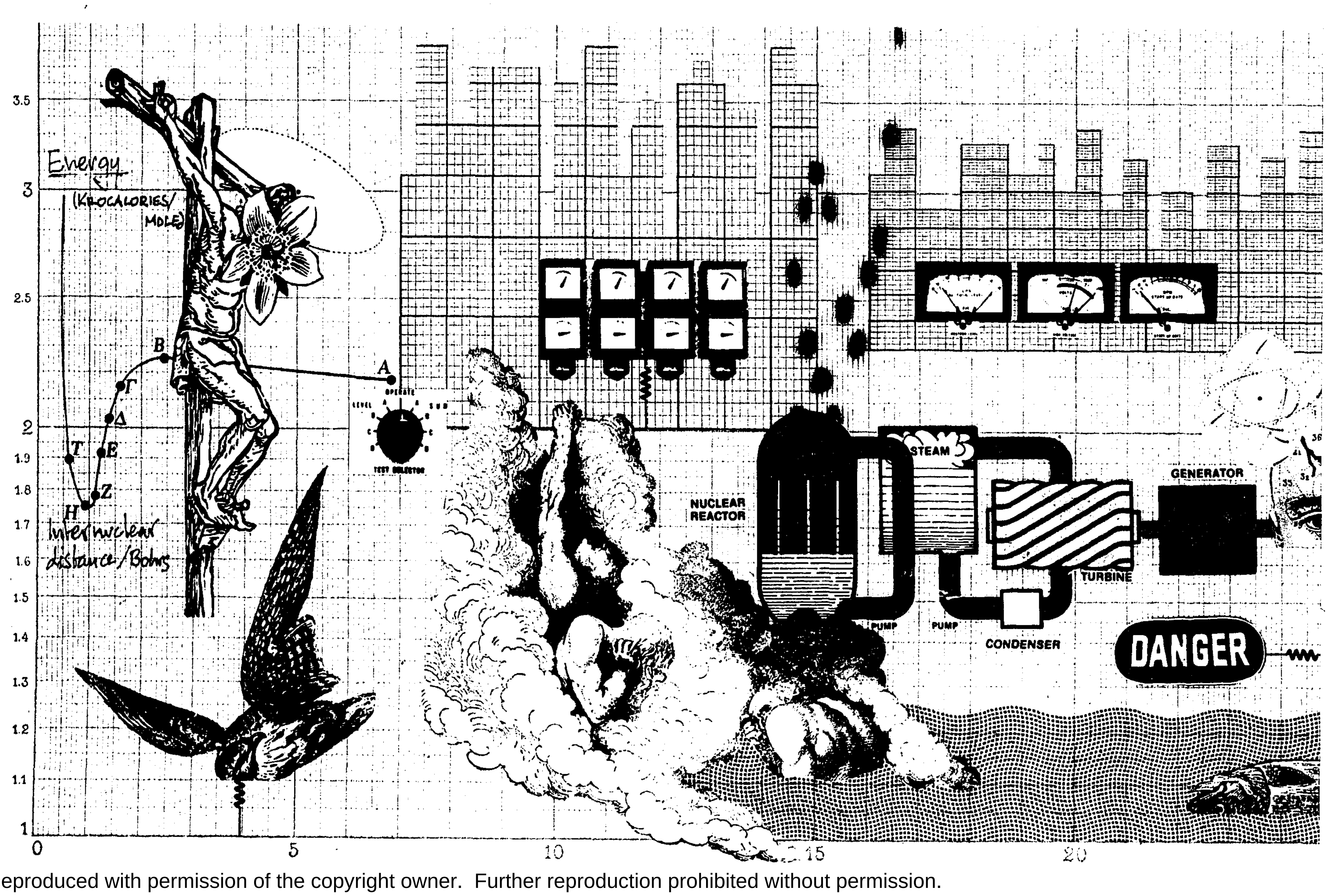
By Ralph E. Lapp

Nuclear power is a reality—some 40 plants are turning out badly needed electricity today—but the argument about the safety of this new power source has continued to smolder, and as Senator John O. Pastore, chairman of the Joint Committee on Atomic Energy, put it recently: "The public is absolutely confused."

Lately, two figures have dominated the debate. The Atomic Energy Commission, the Federal agency so hated by critics of nuclear power, a year ago gained a new and colorful chairman, Dr. Dixy Lee Ray. The agency's sagging credibility improved considerably with the appointment of Dr. Ray, an environmentally conscious marine biologist.

At the same time, Ralph Nader, the consumer advocate, has begun to exploit the nuclear safety issue. Although he finds nuclear power too hazardous from the moment uranium is dug from the ground until its radioactive ashes are earth-interred, he emphasizes: "The underlying point is that no society should rest its energy future in a fragile nuclear-fission basket when the risks of accident and sabotage are at a point of catastrophic consequence unparalleled in the history of mankind."

Nader's attacks have not always been temperate. "The problem with Dixy Lee Ray" he told a press conference in San Francisco last November, "is that she is suffering from professional insanity. She is locked into a bureaucratic momentum that has so distorted her capacity for reason that she is leading the Atomic Energy Commission into this drive for technological suicide, through nuclear fission." Madam Chairman Ray (she dislikes the word "chairwoman") responded to that tirade with



softer language, saying that Nader was wrong and had based his case on "innuendo and inaccuracies."

So the stage is set for a protracted debate on the safety of nuclear power at the very time when new plants will be "coming on stream," as utility executives put it, at the rate of one a month. By 1980, if the nuclear program proceeds at full speed, one-fifth of all U.S. electricity will be generated from uranium. Some parts of the country are already quite dependent on nuclear power. In Illinois, for example, where Commonwealth Edison dominates the energy picture, the company's executive vice president, James J. O'Connor, estimates: "Our seven operating nuclear power plants will provide more than a third of our electric power in 1974. Uranium fuel will substitute for 12 million tons of coal, or 41 million barrels of residual oil, this year."

Yet Nader argues: "If the public knew what the facts were and if they had to choose between nuclear reactors and candles, they would choose candles."

Just what are the facts? And whose interpretation of them is more valid, Nader's or the A.E.C.'s? This article is an attempt to dig into the substance of the issue, and to place the problem in perspective.

It is essential to describe the anatomy of a nuclear power plant if we are to understand how accidents might happen and how designers have provided mechanisms to prevent them and to lessen their consequences. In conventional electric plants, fired by coal, oil or natural gas, the fossil fuel is burned in the firebox and the flaming heat serves to generate steam in a boiler. This steam—the historic propellant of the Industrial Age—roars into a huge turbogenerator at high pressure, sometimes reaching 5,000 pounds per square inch, and at a searing temperature of up to 1,050 degrees. The steam spins the huge turbine, whose shaft is coupled to a mammoth generator which produces electricity. The new steam-electric plants generate more than 1 million kilowatts of power. Their fossil-fuel appetite is prodigious; a coal-burner requires more than 400 tons each hour.

A nuclear plant "burns" a flameless fuel, uranium; heat is released as atoms split in a controlled chain reaction. Since there is no combustion, there is no exhaust gas and, of course, no sulphurous pollution. The nuclear firebox consists of a compact core smaller than a living room. It contains a year's supply of nuclear fuel—about 100 tons or so of uranium-oxide pellets of thimble size. About 10 million of these tiny pellets are neatly arranged in 12-foot tubes or fuel rods sheathed to prevent leakage of radioactivity.

The nuclear fuel used in modern power plants is a very dilute form of the weapon-grade material, and there is no danger that a reactor will explode like a bomb. However, it's still potent stuff—a single half-ounce pellet releases the same energy as 160 gallons of oil. The energy is released during a chain reaction—a self-sustaining sequence of atom splittings in which particles released when one atom splits collide with other atoms, causing them to split. To start a chain reaction, all you need to do is to put together in a core enough fuel and enough of a light substance such as water. When a uranium atom splits, it releases two or three nuclear particles called neutrons; these particles are speedy when first born, but oddly enough, they are more effective at splitting other uranium atoms when they are slowed down by bumping into atoms of other elements. Water is added to a reactor core to slow down the neutrons and thus promote the chain reaction.

Certain elements, like boron, tend to swallow up neutrons, and their presence in the core opposes a chain reaction; they may be said to act as poisons. Reactor designers are careful to make sure that poison-loaded rods are positioned in the reactor core before it is filled with water. With programed withdrawal of these control rods, the chain reaction develops, the quiescent reactor "goes critical"; further movement of the rods increases the power output of the machine. At the control panel of a reactor there are two red buttons marked SCRAM, which an operator can push in the event of a need to shut down the machine in a hurry. Actually, the reactor system is carefully monitored by instruments and any abnormal behavior triggers automatic scrams. To scram the reactor, control rods are thrust back into the core, terminating the chain reaction.

Water in the core serves two purposes—it acts to promote the chain reaction and also to remove heat from the uranium fuel. The whole core structure fits inside a huge pressure vessel made of steel—a great pot with a domed head that is bolted down and opened up only once a year for replacement of fuel.

The six-inch-walled vessel is fitted with huge pipes that serve one of two purposes, depending on the reactor's design. In one case, they convey water heated by the reactor core, but pressurized to prevent its turning to steam, to a heat exchanger, where it transfers its heat to another vessel of unpressurized water that boils and provides steam to power a turbine. In the other, water in the core is permitted to boil, and *(Continued on Page 64)*

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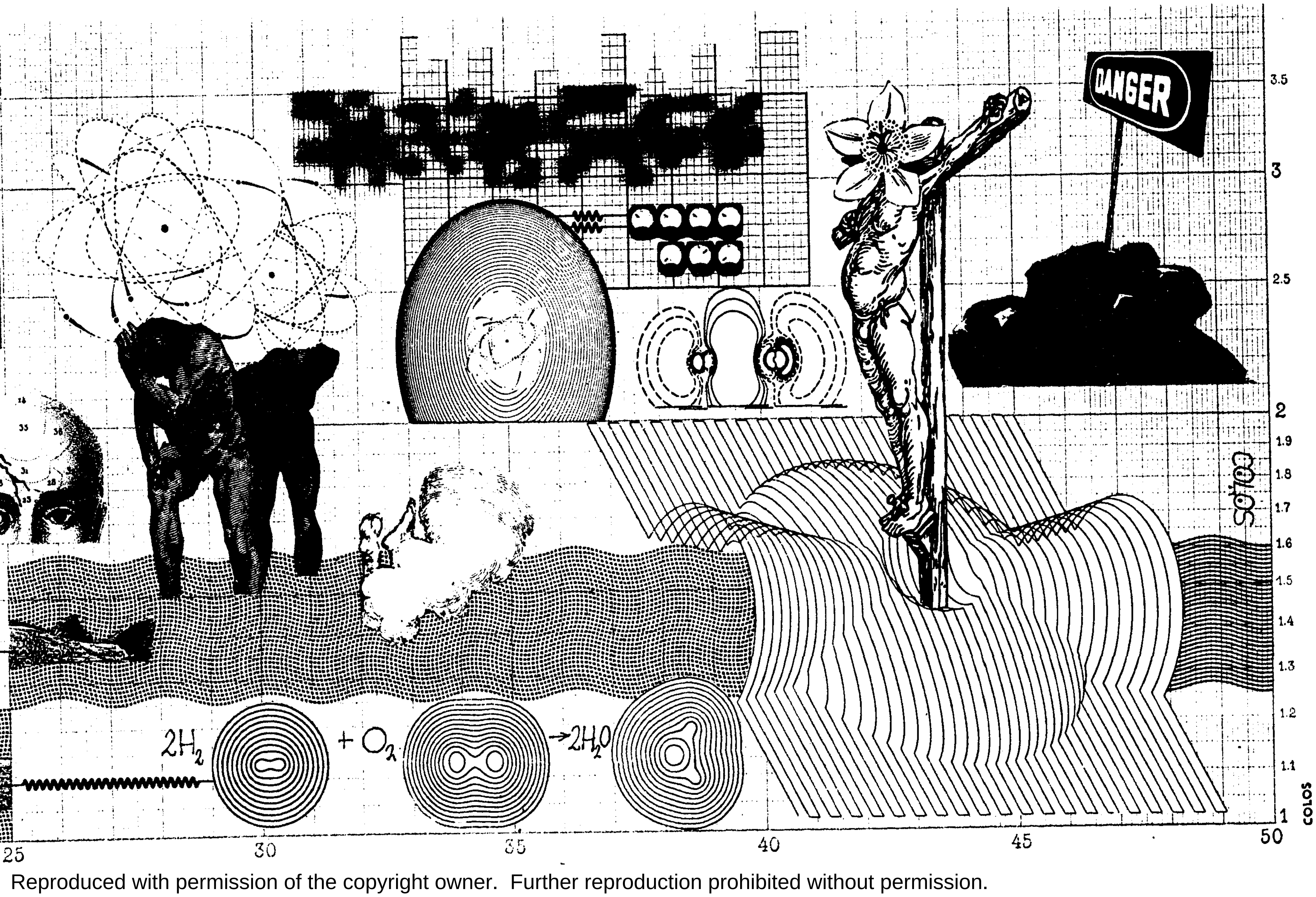

Nuclear power

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the pipes convey steam directly to a turbine.

Inevitably, the water surrounding the core becomes somewhat radioactive. This occurs because as uranium breaks down during a chain reaction, other radioactive elements are created. The sheathing of the fuel rods is intended to prevent these radioactive elements from passing into the water, but a small amount always escapes through tiny flaws in the sheathing. Fears about the safety of nuclear power begin with the fact that these radioactive elements are continually being generated at the heart of the reactor. Under the most catastrophic circumstances, they could be released to the environment in large amounts.

Dr. Henry W. Kendall, a high-energy physicist at the Massachusetts Institute of Technology, who is probably Nader's most astute adviser, expresses the radiation hazard of a nuclear power plant (reactor) as follows:

"The radioactive accumulation in a large power reactor is equivalent to the fallout from thousands of Hiroshima-size nuclear weapons. . . . Consider, for example, that 20 per cent of a reactor's radioactive material is gaseous in normal circumstances and, if released to the environment in one way or another, could be swept along by the winds for many tens of miles to expose people outside the reactor site boundaries to what could be lethal amounts of radioactivity. The lethal distance may approach 100 miles."

And yet this view obviously is not shared by the Atomic Energy Commission. The commission approved the siting of three powerful nuclear reactors just 26 miles north of New York City at Indian Point, south of Peekskill. If Dr. Kendall's estimate of the situation is anywhere near accurate, such a siting would have to be viewed as an act of Federal and corporate recklessness. So what is the actual risk, and why is there such a difference of opinion about it?

The reactor accident most commonly visualized by nuclear engineers is known as the loss-of-coolant accident, or LOCA; it would begin with a break in one of the heavy pipes that carry water and steam to and from the nuclear core. Such a break might occur because of faulty construction and maintenance, sabotage, or natural disaster. (The A.E.C. requires utilities to design reactor installations strong enough to withstand the assaults of earthquakes, hurricanes, tornadoes and even giant sea waves, or tsunamis.)

The first consequence of such a break would be a reservoir of water, condensing of a mixture of water and steam that would carry with it any radioactivity that had leaked through the protective fuel-rod sheath. Reactors are designed with containment systems to prevent this primary expulsion of radioactivity from reaching the atmosphere. In one design, the escaping water/steam is conducted through large-diameter pipes to a huge metal doughnut-shaped container, where the steam exits into a reservoir of water, condensing and reducing the pressure and temperature within the containment. In another design, the kind built at Indian Point for Con Edison, the primary containment takes the form of a tremendous silo made of reinforced concrete, which is designed to be big enough and strong enough to absorb the pressures and temperatures created by a severe blowdown.

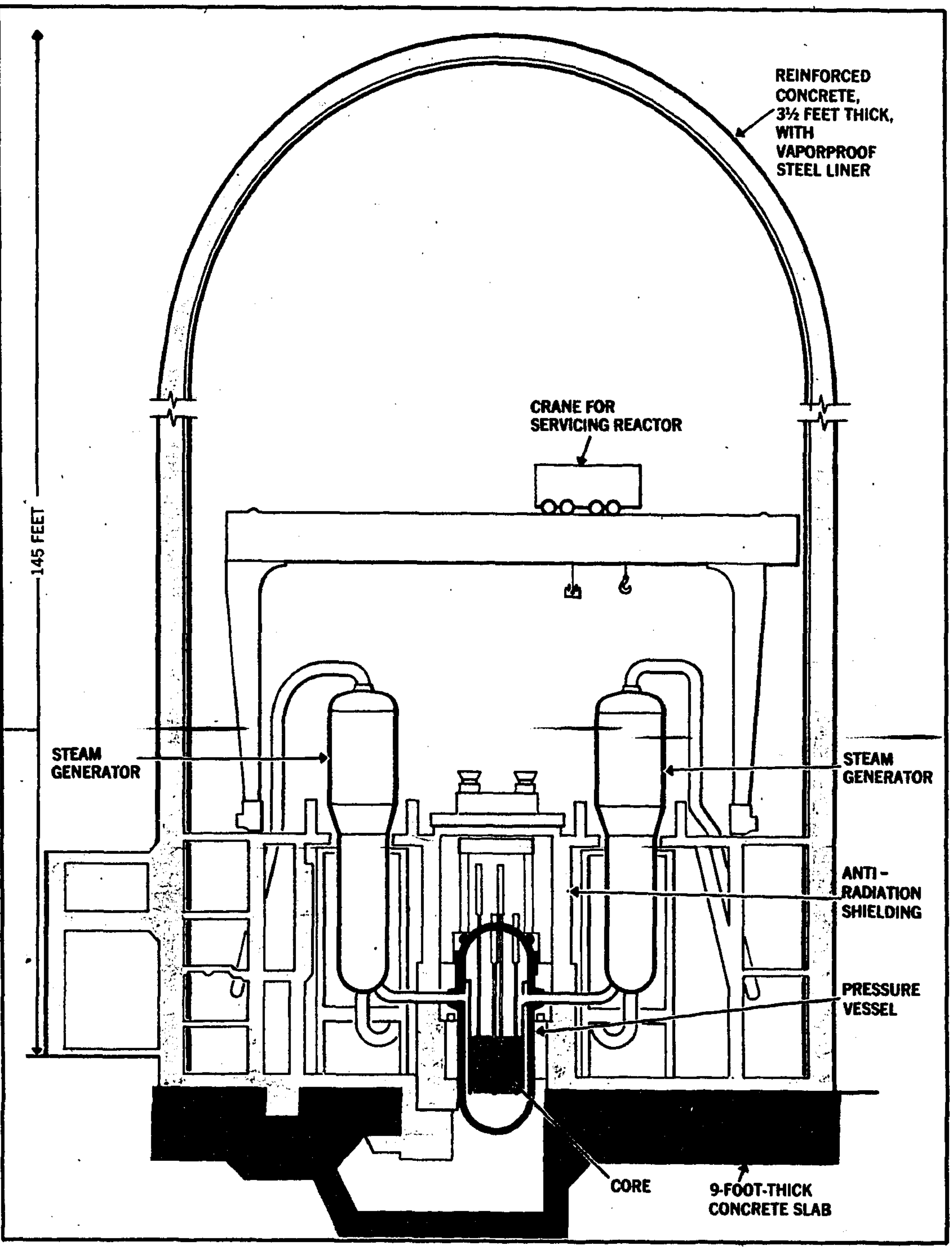
But handling the violent release of high-pressure, high-temperature steam in the event of a pipe break is not the only problem, for a reactor core deprived of its coolant might melt. At this point we must explain a strange quality of the nuclear core. Unlike an automobile engine, which stops generating heat when the pistons cease moving and no gasoline is burned, a nuclear reactor core cannot be turned off completely—it keeps giving off heat when it is fully scrammed and there is no vestige of a chain reaction. This afterheat is produced by the radioactive disintegration of the split atoms which accumulate within the fuel rods. Reactor engineers have to handle it whenever a plant is shut down, whether routinely or accidentally.

When the chain reaction is terminated, a reactor still generates about 7 per cent of the power it had been producing just prior to shutdown. Normally it is dissipated as water in the reactor cools off the core. Now, if water is blown out of the core by an accident, the afterheat of fuel pellets will build up within the fuel rods and, in the absence of further cooling, the rod sheaths may deteriorate. If this happens, then continued fuel melting could cause the pellets in the core to form a molten mass which could eat its way through the bottom of the thick steel vessel. Such a melt-through could spill hundreds of thousands of pounds of superhot radioactive debris into the primary containment vessel. Since the vessel would be no match for the viscous "dropped core," it might melt itself, permitting a glowing mass to penetrate into the earth, perhaps reaching a spherical diameter of 100 feet. Where would it stop? It would depend upon the nature of the substratum underlying the site, but experts have coined the phrase "the China syndrome" to describe the fate of the dropped core. It would take many years to cool off.

Experienced reactor experts admit that this sequence of events could happen, but contend that it's dependent on a series of highly improbable events. For example, unless the molten material concentrates first at the bottom of the reactor vessel and then at one point in the concrete base, there would be no melt-through. Further, as we shall see shortly, engineers contend that safeguards will prevent fuel from melting in the first place.

A melt-through is a nightmare for reactor designers, but it is not the China syndrome that worries the experts as much as the breakout of radioactive gases and particulates that would occur within the first hour or two. A great puff of radioactivity released through the fractured containment would be at the mercy of the winds and the weather. This is the severe sort of accident that forms the basis of Nader's concern that nuclear power is too risky an energy source for man.

This kind of hazard was on the minds of physicists even before the first chain reaction was achieved on Dec. 2, 1942. Moreover, it was of great concern to utilities in the mid-nineteen-fifties as they contemplated building nuclear power plants to generate electricity. Utilities prefer to site power plants close to metropolitan centers, yet such sit-



Safe enough? One type of reactor is covered by a domed 145-foot concrete silo lined with steel; it rests on a heavy concrete slab. The structure, experts claim, can contain the "blowdown" of radioactive steam and water in the event of a pipe break.

ing might involve great liability in the event of an accident. Accordingly, the Atomic Energy Commission set out to provide some estimate of the hazard, and in March, 1957, it published a 105-page report called WASH-740 and titled "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants." Its findings included the following two paragraphs:

"For the three types of assumed accidents, the theoretical estimates indicated that personal damage might range from a lower limit of none injured or killed to an upper limit, in the worst case, of almost 3,400 killed and about 43,000 injured.

"Under adverse combination of the conditions considered, it was estimated that people could be killed at distances up to 15 miles, and injured at distances of about 45 miles. Land contamination could extend for greater distances."

Here it should be noted that the power plants assumed in the WASH-740 analysis were seven times less powerful than the modern machines being ordered by utilities. In addition, today's reactors are being sited closer to large populations than assumed in the 1957 report. Taking such differences into account, it would seem that Dr. Kendall's estimate of a 100-mile lethal distance is not off the mark.

"That 1957 report doesn't apply today," asserts Dr. Dixy Lee Ray. "For one thing, reactors today feature a whole panoply of safeguards built into the basic design so as to prevent accidents and to mitigate their consequences should one occur. But even more importantly, the WASH-740 study assumed conditions that were so extreme that they would be virtually impossible to accomplish even if there was some unimaginable reason to try to do so. Such an an accident would require instantaneous meltdown of a reactor core with no safeguards operable and a breach of the containment system."

In order to understand the basic reason for Dr. Ray's confidence we need to look at a safeguard which is the primary mechanism for preventing fuel melting in a reactor core. It is known as the emergency core-cooling system (ECCS), and it is a set of mechanisms for flooding a reactor core with water in the event of an accident, such as a big pipe break. For example, one emergency cooling system consists of pumps and water supply to inject water at high pressure back into the core; another operates at low pressure to flood the core. These systems are powered by independent sources of electricity run by sets of diesel generators that start up automatically if a situation requires ECCS action.

Nuclear engineers maintain that these emergency systems will work to reflood the water-starved core in the event of an accident, while critics argue that such assurance is based on models and computer codes and not on actual testing under real accident conditions. The A.E.C. as developer of power reactor designs has an elaborate nuclear safety research program that has already cost over half a billion dollars. One safety program is called LOFT, for loss of fluid test; it is a nuclear reactor built at the A.E.C. Idaho reactor test site, and it's designed to be wrecked deliberately. Sometime next year the LOFT reactor will be subjected to a planned pipe break or LOCA, and the whole sequence of events following the accident will be examined in a systematic manner.

Critics of LOFT take a skeptical view, saying that it is "too little, too late." The wreckable reactor, they say, is small compared to today's giants, which are 70 times more powerful. Therefore, any results from the LOFT experiment will have to be scaled up and may not apply to the actual power units in operation. Antinuclear spokesmen also call attention to the fact that some 60 nuclear plants will be in operation by the time LOFT experiments are analyzed. This, they assert, means that the A.E.C is conducting a *post factum* safety research program.

It was a small scale experiment in the LOFT program that served to precipitate the argument over emergency core-cooling. This experiment took place in Idaho late in 1970 and yielded initial results that were interpreted by some as meaning that a water-deprived core would not be reflooded; thus doubt was cast upon the models and computer codes that the industry was using for predicting the performance of their emergency safeguards. Dr. Kendall, spearheading the efforts of a tiny group known as the Union of Concerned Scientists, challenged the

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A.E.C. criteria for emergency core-cooling, and in January, 1972, the A.E.C. began public hearings that dragged on through the summer of 1973. Some 22,200 transcript pages of testimony were taken down—some of it could as well be Sanskrit even to many physicists. Here, for example, is one of many assumptions spelled out in the testimony of an expert: "The time to DNB is computed using the W-3 critical heat flux correlation in both the CRAFT and THETA 1-B codes, except that the B&W-2 correlation is used in THETA 1-B for the non-vent valve plants." That's enough to cross a lawyer's eyes—and lawyers abounded in the protracted A.E.C. hearing on emergency core-cooling.

On Dec. 28, the A.E.C. concluded its review of the emergency core-cooling issue and put forth a 29-page acceptance criteria backed up by a 140-page exposition of technical factors involved in core-cooling. Basically, the commission judges nuclear power plants to be safe, but will require utilities to re-examine the margin of safety in their operation; in the event it is judged inadequate, the power level of the plant involved would be reduced. Although the A.E.C.'s decision on nuclear safety embraced objections of Dr. Kendall and constituted a minor victory for him, he was joined by Ralph Nader in an instant response that the decision "represents a continuation of the A.E.C. cover-up of critical safety problems."

When Dr. James Schlesinger, now Secretary of Defense, took over command of the A.E.C. in the summer of 1971, he recognized that the agency's failure to revise its 1957 report on theoretical accidents in nuclear plants allowed critics to scale up the hazard estimate of that 1957 analysis to correspond to large modern reactors, intensifying fears of a nuclear accident. He set up a task force of technical experts to assess the probability of a serious accident in a large modern reactor and to define its consequences. Dr. Norman Rasmussen, an M.I.T.-trained nuclear expert, was picked to head up this group, and it is understood that he will avoid the "worst case" approach of the 1957 report; instead, speculations will be based on "best engineering judgment."

Dr. Rasmussen sums up his philosophy of accident analysis this way:

"Uncertainties are treated by developing realistic probability values of all possible outcomes rather than choosing the worst possible values. This approach will lead to a prediction of the most likely consequence and the probability of smaller or larger consequences. This should provide a more complete and accurate view of nuclear accident risks than previous studies that computed only 'worst case' values."

To illustrate what is called the probabilistic approach, let's assume, as do many con-

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Beyond the technical complexities of reactor operation and design, the layman must face an even more bewildering problem: How safe is safe enough?

servative experts, that, in a given year, the chance of a major pipe break in a reactor leading to a loss of water from the core is 1 in 1,000. The Rasmussen task force then goes on to analyze the other links in the accident chain and, in particular, the probability that the emergency core-cooling will fail to function. Nuclear experts in industry claim that there is only one chance in a thousand of its failing.

The combination of these two probabilities — that the core will dry out under accident conditions and that safeguard systems will fail to reflood the core — is the product of the two individual probabilities, or 1 in 1 million. Projecting ahead to 1980, when over 100 reactors are scheduled to be in operation, this should mean that the chance of *any* nuclear accident would be 1 in 10,000 for a single year. And from the viewpoint of a single community near a reactor this chance would be only 1 in 1 million.

Presumably, this is the kind of conclusion that the Rasmussen analysis will reach when the final report is published this summer. The report is going to be backed up by many technical appendices documenting the task force findings, but it may take a nuclear Rosetta stone to translate the prose into something understandable to the man in the street.

For their part, critics charge that the nuclear industry's record does not instill high confidence that a nuclear accident of serious magnitude can be avoided, whatever the probabilities calculated by experts. They point to the A.E.C.'s own extensive tabulation of "abnormal occurrences" in reactor construction and operation as evidence that quality control in this new industry is inadequate. For example, Con Ed's Indian Point 2 plant has been plagued with incidents, the latest of which was a pipe break in the steam system that affected the reactor building, but not the core area, and may have caused damage to the steel surface of the huge containment structure.

The A.E.C. admits that there have been numerous abnormalities in plant construction and operation, but maintains that their detection is in fact proof that quality control is being exercised. Far from covering up such incidents, the A.E.C. maintains, the record is made public in various publications, such as an annual compilation titled "Safety-Related Occurrences in Nuclear Facilities." Each utility is required by the A.E.C. to submit timely reports on all unusual occurrences at nuclear plants, and the commission's regulatory staff studies these reports and issues analyses of them.

Quite apart from the difficulty of comprehending the complex technical niceties of this debate, the layman must also face the bewildering question: How safe is safe enough?

No group of experts can pass judgment on the acceptability of a public risk. The A.E.C.'s accident-consequences report will only put the risks in better perspective.

Modern life confronts people with a multitude of risks; some of these are obvious—like the risk of accident in an automobile collision or an airplane crash—others are subtle, remote and not immediate in ill effects.

For example, the risk of being bitten by a rattlesnake in Times Square is low, but not zero. The chance of being hit by a car is fairly high. People accept the risk of death involved in traveling on a common carrier, such as an airline —that risk is about one in a million, for each flight.

But calculations of the odds are not always the last word. Suppose you go out to Shea Stadium to watch a ball game. How safe is that in light of the chance that an airplane might crash into the stadium? The probability of that happening has been calculated as very low, yet strange things can and do happen: One night not long ago an airplane was circling to land at LaGuardia Airport. The weather was soupy and the pilot mistook the lights of Shea Stadium for those of the airport. He nosed his 727 down to land and only at the last minute did he realize his error. Fortunately he was able to zoom the 727 upwards and the event was recorded as a "near miss."

We tend to react to this problem of risk by making choices based on the magnitude of risk as we perceive it and the benefits to be gained from accepting the risk. The public apparently judges the convenience of commercial air travel to be worth the risk that results in 200 fatalities per year; the convenience of driving an automobile is considered worth much higher levels of risk. Sometimes the public judgments are not especially rational. About 49 million Americans continue to smoke cigarettes despite the clear warning of risk to their health printed on each package.

If we assume, as we have to, that public demand for electric power will continue to increase, then we must consider the question of nuclear safety in this risk-benefit context.

Furthermore, we have to realize that we do not have a great many options. Environmentalists argue that the problems of current power-producing technology might be avoided by developing alternatives such as solar power, geothermal energy or fusion energy. But a utility burning 9,000 tons of coal per day would need a collection area of 18 million square yards of level ground to absorb the necessary solar heat —that's almost 6 square miles! If one assumes that the heat can be trapped and converted to electric power at 30 per cent efficiency, this would mean paving over 20 square miles with solar catchers. That's not an option for Con Ed even if the technology for solar conversion to electric power were available at rea-

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sonable cost. Geothermal energy is available in limited amounts at relatively few geographic sites, unless one wishes to exploit "hot rock" beneath the earth's crust—a still unproved technology. As for fusion power, the hoped-for generation of energy by fusing atoms of hydrogen in a controlled reactor, $1-billion in research and development has not yet realized the first practical laboratory demonstration of this scientific principle. And even if scientists succeed in the laboratory it will take another two decades to engineer massive energy conversion equipment so that it constitutes a significant contribution to energy production.

This means that for our future electric-power needs, we will have to rely either on nuclear power or else on fossil fuels—and as it looks now, the main fossil fuel will be coal. Right now utilities depend on fossil fuels for four-fifths of their energy; coal makes up more than half of this total, natural gas about a quarter and oil about a fifth. Gas and oil are in short supply and can be expected to remain so.

Recognizing these facts permits us to restate the problem of "nuclear safety" in more sophisticated terms: In the years to come, how will the balance of risks and benefits of nuclear power generation compare to the risks and benefits of heavily increased reliance on coal?

The benefit of nuclear power is that it is based on a new fuel that does not need to be mined in disruptive quantities, and whose flameless "fire" does not pollute the air. The risks involve the chance of catastrophic reactor accidents as discussed above, plus the additional problem of waste disposal. Many fear that the radioactive ashes left over when nuclear fuel is spent cannot be disposed of safely and will build up the level of radioactivity in the environment to intolerable levels. (Dr. Ray of the A.E.C. disputes this, however, contending that technology exists to store the wastes safely.)

The benefit of coal is that it is abundant in America and that it does not pose the risk of catastrophic accident or residue that emanates dangerous radiation. But it does pose other risks. Most obviously, it contributes in a big way to air pollution. Except in certain locations, coal is a deeply buried resource, and the mining of it is one of the most dangerous occupations in the country. In this century, more than 100,000 miners have lost their lives digging coal out of the ground. Millions more have been injured or afflicted with "black-lung" disease. Where coal beds come close to the earth's surface, it may be extracted by strip-mining, but that practice so grossly lacerates the earth's surface that it has caused widespread popular reaction. Yet it is only through strip-mining, particularly in the rich Fort Union Formation of the Upper Missouri basin, that the coal industry can increase production enough to meet the growing demands of utilities.

So is nuclear power too risky? I believe that nuclear power plants can be operated safely if their designs are carefully checked out, if high quality control is exercised in their construction, and if their operation is subject to vigilant regulation at all times. I also believe that a further margin of safety could be gained by siting plants so that in the improbable event of an accident, the radiation risk to the population nearby is minimized. Standardization of plant design can help in assuring that the licensing time can be shortened and quality control in construction can be increased. And the plants can be clustered at "nuclear parks" where greater nuclear security can be achieved.

When opponents of nuclear power argue that it should be stopped dead in its tracks unless, as Nader testified before the Joint Committee on Atomic Energy Jan. 29, reactors "are safe beyond any question of doubt and superior to other energy alternatives," they jeopardize the whole environmental movement, because their short-term alternatives—usually solar power and geothermal energy—are not real options for an energy-hungry society. And when Nader suggests that coal replace uranium, he seems to have no concept that the amount of coal required for such replacement, at least two billion tons annually by the end of the century, involves immense environmental assault as well as exorbitant social costs for the nation.

Given the alternatives, given their availability and their risks, I see nuclear power not only as an acceptable risk for the United States, but also as the only practicable energy source in sight adequate to sustain our way of life and to promote our economy. ■