DOCUMENT RESUME

ED 132 025 | SE 021 547

TITLE	The Environmental Impact of Electrical Power Generation: Nuclear and Fossil.
INSTITUTION	Pennsylvania State Dept. of Education, Harrisburg.
SPONS AGENCY	Energy Research and Development Administration, Washington, D.C.
REPORT NO	ERDA-69
PUB DATE	75
CONTRACT	AT-40-2-4167
NOTE	233p.; For related Teacher's Guide, see SE 021 548; Contains occasional marginal legibility in Tables and Figures
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 ($3.05)
EDRS PRICE	MF-$0.83 HC-$12.71 Plus Postage.
DESCRIPTORS	Adult Education; *College Science; Curriculum; *Electrical Systems; *Energy; Energy Conservation; *Environment; Fuels; Higher Education; Instructional Materials; Science Education; *Textbooks; Utilities

ABSTRACT

This text was written to accompany a course concerning the need, environmental costs, and benefits of electrical power generation. It was compiled and written by a committee drawn from educators, health physicists, members of industry and conservation groups, and environmental scientists. Topics include: the increasing need for electrical power, and current and proposed methods for meeting this need; nuclear power and fossil-fueled plants, their wastes, and health effects; considerations for choosing the site for a new power plant; energy conservation; and environmental effects of power generation. The appendices include a glossary of terms, a bibliography for further study, a decision-making model to help the reader analyze the information received, and a brief outline of the procedure that must be followed by a utility in order to construct and operate a nuclear power plant. (MH)

ERDA-69

The Environmental Impact of Electrical Power Generation: Nuclear and Fossil

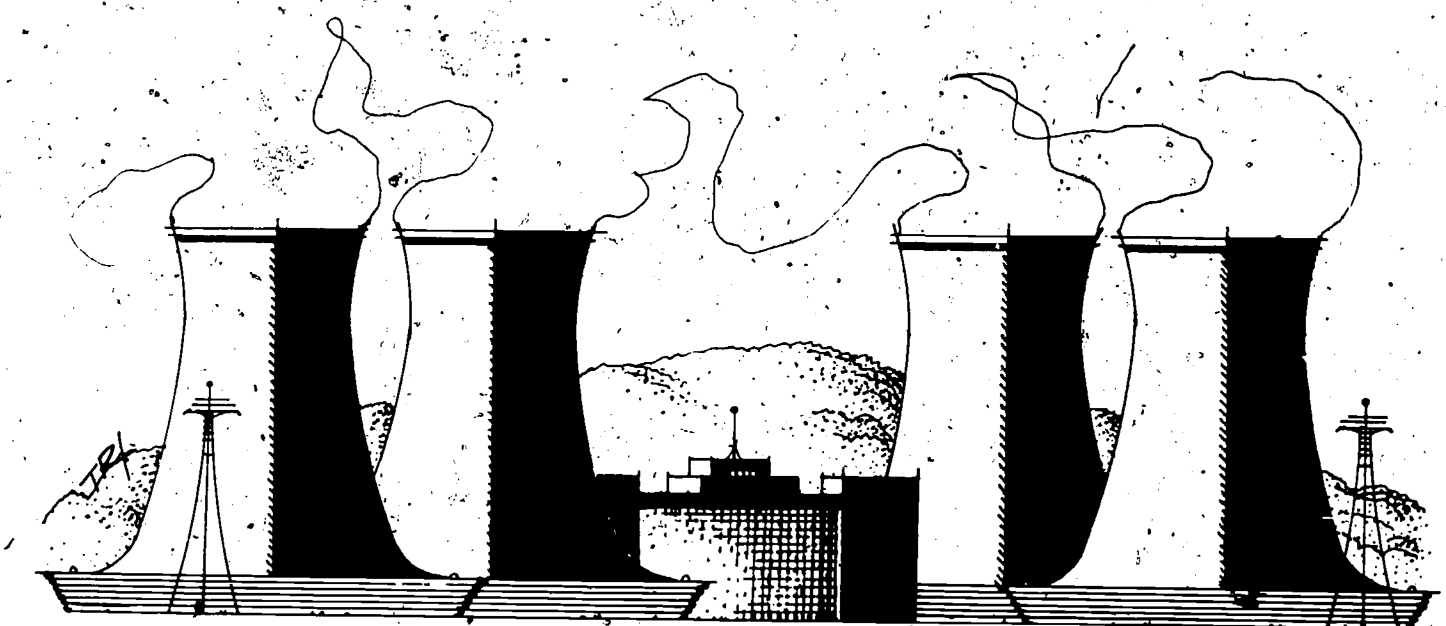
Prepared under contract AT (40-2)-4167
U.S ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
by
PENNSYLVANIA DEPARTMENT OF EDUCATION
1975

NOTICE

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

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price $3.05

ERDA-69
UC-2, UC-13



The Environmental Impact of Electrical Power Generation: Nuclear and Fossil

Prepared under contract AT (40-2)-4167
U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
by
PENNSYLVANIA DEPARTMENT OF EDUCATION
©1975

Commonwealth of Pennsylvania
Milton J. Shapp, *Governor*

Department of Education
John C. Pittenger, *Secretary*

Office of Basic Education
Frank S. Manchester, *Commissioner*
Harry K. Gerlach, *Deputy Commissioner*

Bureau of Curriculum Services
Michael Flanagan, *Acting Director*

Division of Science and Technology
Irvin T. Edgar, *Chief*
John J. McDermott
Senior Program Adviser, Science

Pennsylvania Department of Education
Box 911
Harrisburg, Pa. 17126

TABLE OF CONTENTS

6

PURPOSE OF COURSE

In an era when the requirement for additional sources of power is growing at an ever-increasing rate and when concern for the protection of our environment is rightfully coming to the fore, it is imperative that an unbiased, straightforward view of the advantages and disadvantages of the various methods of generation of electrical power be made available to our schools.

This course is an effort to describe the need, environmental costs and benefits of electrical power generation.

The development of this minicourse by the Pennsylvania Department of Education was suggested by the U.S. Atomic Energy Commission, with the continued sponsorship of the Energy Research and Development Administration. It was written and compiled by a committee drawn from educators, engineers, health physicists, members of industry and conservation groups, and environmental scientists.

The Committee

John J. McDermott, Project Director	Pennsylvania Department of Education
Janet Fay Jester, Technical Writer	
Charles Beehler	Rose Tree Media School District
William H. Bolles	Pennsylvania Department of Education
Robert H. Carroll	Pennsylvania Department of Education
Irvin T. Edgar	Pennsylvania Department of Education
Alan H. Geyer	Pennsylvania Topographic and Geologic Survey
George L. Jackson	Harrisburg Hospital Division of Nuclear Medicine
Willard T. Johns	Pennsylvania Fish Commission
William A. Jester	The Pennsylvania State University
Richard Lane	U.S. Environmental Protection Agency
James McQueer	Titusville Area School District
Frank B. Pilling	Sierra Club
Marget A. Reilly	Pennsylvania Office of Radiological Health
Robert S. Schwille	Pennsylvania Department of Education
Michael Szabo	The Pennsylvania State University
John D. Voytko	Westinghouse Environmental Systems
Daniel Welker	North Schuylkill School District
Warren F. Witzig	The Pennsylvania State University
Harold H. Young	Energy Research and Development Administration
William Steigelman	Franklin Institute
Lawrence Aikers	Oak Ridge Associated Universitites
Douglas A. James	Energy Research and Development Administration

INTRODUCTION

Chapters 1 and 2 of this text present the increasing need for electrical power, and current and proposed methods for meeting this need. Expansion of electrical generating capacity in the immediate future will be limited to nuclear power plants or fossil-fueled plants. These plants are discussed in Chapters 3 and 4. Basic ecology is the subject of Chapter 5. Wastes from nuclear and fossil-fueled plants are discussed in Chapter 6, while health effects are discussed in Chapter 7. Chapter 8 presents some of the factors that must be taken into consideration when choosing the site for a new power plant. In addition to increasing electrical power generating capacity, we must begin to conserve the energy sources we have. Thus energy conservation is the subject of Chapter 9. Finally, a summary of environmental effects is given in Chapter 10.

Appendix I is a glossary of useful terms, many of which are used in the text. Appendix II is an extensive bibliography containing many useful references for further study. Appendix III is a decision-making model to help the reader analyze the information received. Appendix IV is a brief outline of the procedure which must be followed by a utility in order to construct and operate a nuclear power plant.

Papers from scientific journals and other supplementary information are included in the colored pages at the end of each chapter. These are for course enrichment, and may be used or omitted at the discretion of the teacher.

8

CHAPTER 1

THE DEMAND FOR ENERGY

1. World Energy Consumption

Energy, the ability to do work, is the basic building block of civilization. People's use of energy once came only from their own muscles. Later humans learned to use fire to keep warm and cook food. Then they learned to use the energy of the wind in sailboats and windmills, the energy of falling water in waterwheels, and the energy of animals to work for them. Today we use a great variety of energy resources, and in doing so, we are able to control many of the events which affect our lives, and thus raise our standard of living.

Figure 1 shows that a country's standard of living is directly related to its use of energy. The right side of the chart shows per capita energy consumption for many countries in 1968. The per capita energy consumption for a country is the total energy consumption of that country divided by its population, and is thus the average amount of energy used by each person in the country. The left side of the chart shows per capita income - the average income for each person in the country - for the year. It can easily be seen that countries with a high standard of living, are those with high energy consumption. The United States leads the world in both energy consumption and standard of living. In fact, with only about 6 per cent of the world's population, the United States accounts for about one third of the world's energy consumption. Other industrialized countries of the world follow the U.S. in energy consumption, while the developing countries show the smallest energy consumption, corresponding to lower standards of living.

Thus, it appears that in order for the developing countries of the world to raise their standard of living through increased food production, improved sanitary conditions and increased availability of manufactured products, they must increase their per capita energy consumption. It also appears that a continued high per capita consumption of energy will be necessary to maintain the high standard of living that the United States and other countries enjoy. This increasing demand for energy by the world's population is one of the reasons for the current energy shortage and the increasing cost of energy.

In addition to an increasing per capita consumption of energy, we must consider the world's increasing population. Figure 2 shows world population estimates for the past and future. At the beginning of the Christian era, there were 200 million to 300 million people in the world. It took about 1,600 years for the population to double to 500 million. The population doubled again to one billion by 1825, in the next 225 years; during this time the first industrial revolution, based on steam power, started, allowing the world to support a larger population. By 1930, world population had doubled again to two billion in only 105 years. During this time, the second industrial revolution, based primarily upon the development and use of electrical power, took place.

In the 45 years since 1930, the population has doubled again to four billion. During this period, medical advances have increased life spans, causing even greater population increases. Some forecasters predict that the world population may well double again before the year 2000.

Figure 2 shows that most of this gain will take place in the underdeveloped regions of the world. Thus, these countries have an especially hard task. Since they will have so many more people, they must increase their energy consumption by a tremendous amount to increase per capita consumption.

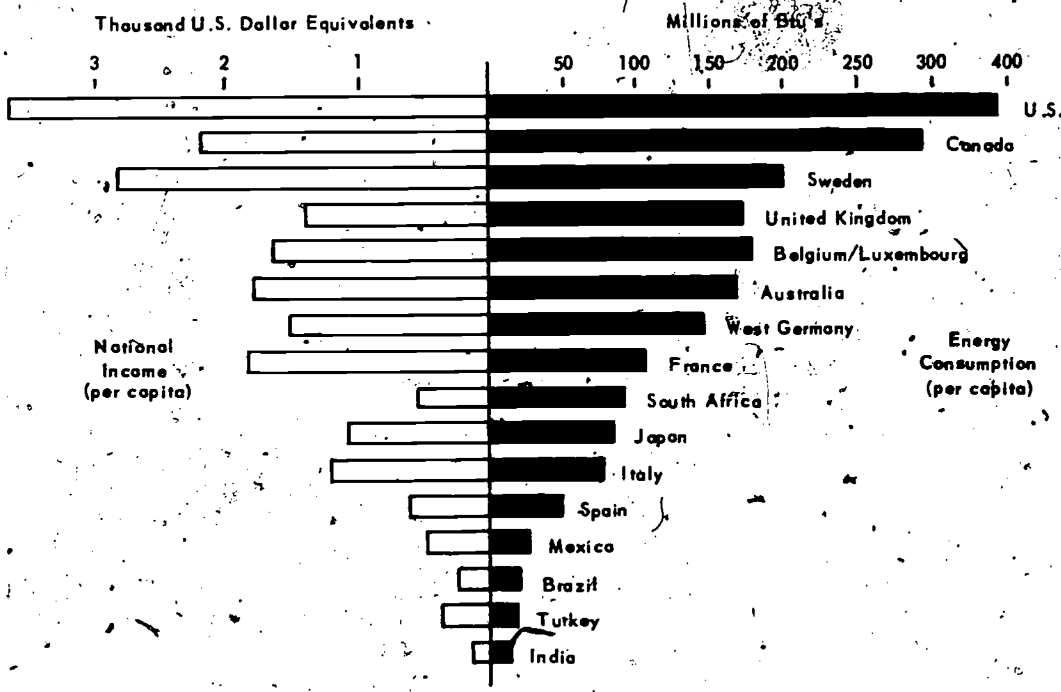
The effect of growing per capita consumption and rapidly expanding population has been a great increase in world energy consumption. This is shown in Figure 3, which illustrates the rise in energy demands, including some predictions for the future. Note that the demand rises so fast that it goes off the top of the graph by the year 2000. Figure 3 introduces "Q" as a measure of large amounts of energy. A standard measure of energy is the British Thermal Unit (BTU), which you have probably heard in descriptions of the capacity of heaters or air conditioners. A Q is a billion billion BTU's of energy - that is, a one followed by 18 zeroes. It can also be written 10^{18} BTU. One Q is an astonishingly large amount of energy. To put it into perspective, the total world consumption of energy in 1970 was $0.2Q$, while the U.S. consumption was $0.07Q$.

Figure 3 also shows the amount of energy obtained from the three major fossil fuels: coal, oil and natural gas. These materials, deposited on the earth hundreds of millions of years ago, represent the fossile remains of ancient forests and peat swamps. Note in Figure 3 how the use of fossil fuels increased rapidly, starting with coal about 800 years ago, followed by oil and gas at the beginning of this century. For the last hundred years or so, fossil fuels have accounted for most of the world's energy consumption. Coal, oil and natural gas will be supplemented in the future by petroleum products from sources such as oil shale and tar sands. But note that the fossil fuel use curve is leveling off, and within a hundred years, fossil fuel use is expected to begin a rapid decrease. This decrease will be caused by the fact that the world's fossil fuel supply, which is not replaceable, is being used up rapidly. Other energy sources must be found to fill in the gap between world energy needs and dwindling fossil fuel supplies.

Prior to 1850, most of the world's energy was supplied by the three W's - wind, wood and water.

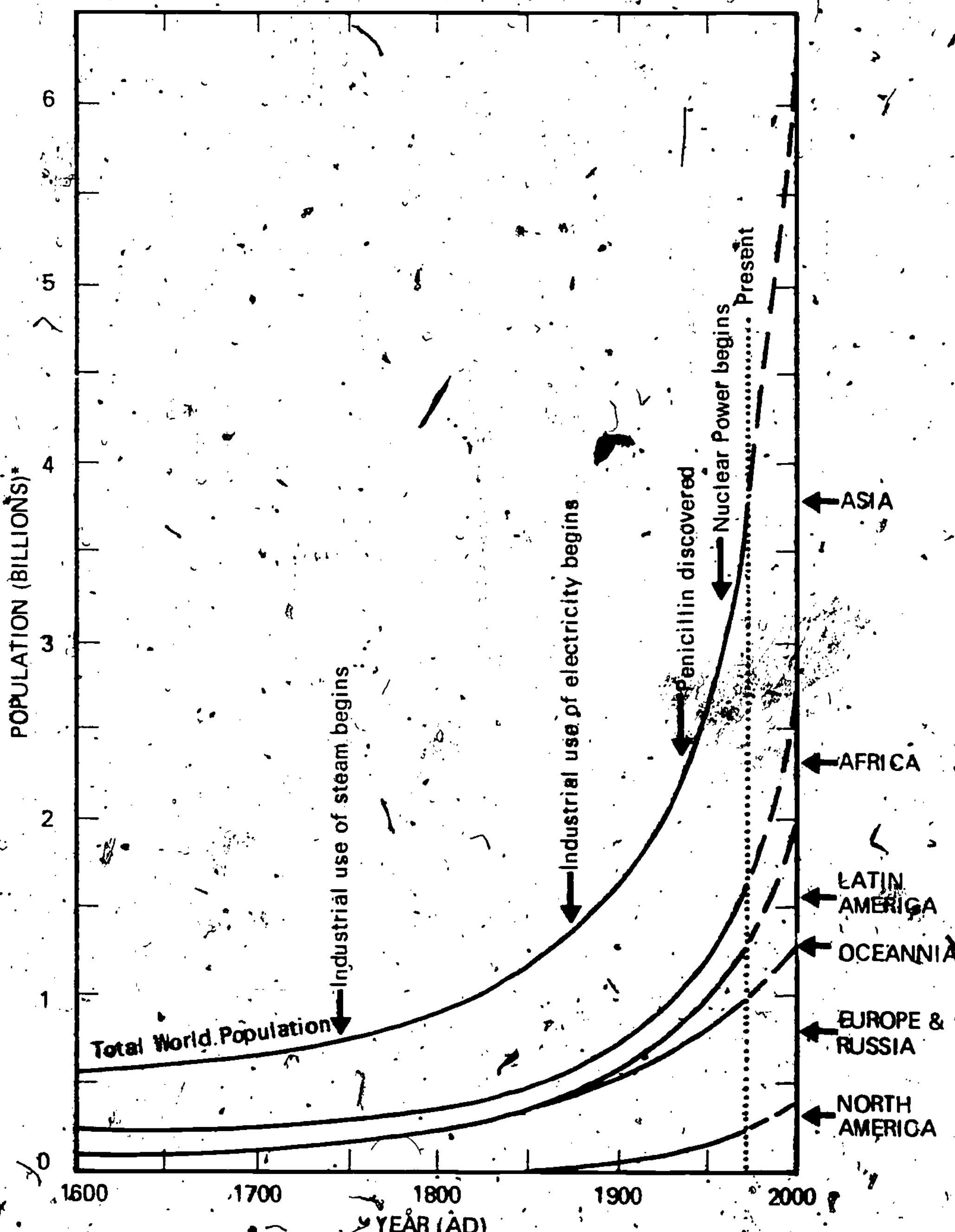
Figure 1

Per Capita Income and Energy Consumption, 1968



Source: U.S. Department of the Interior, 1972. United States Energy—A Summary Review, Washington, D.C.: U.S. Department of the Interior, p. 2.

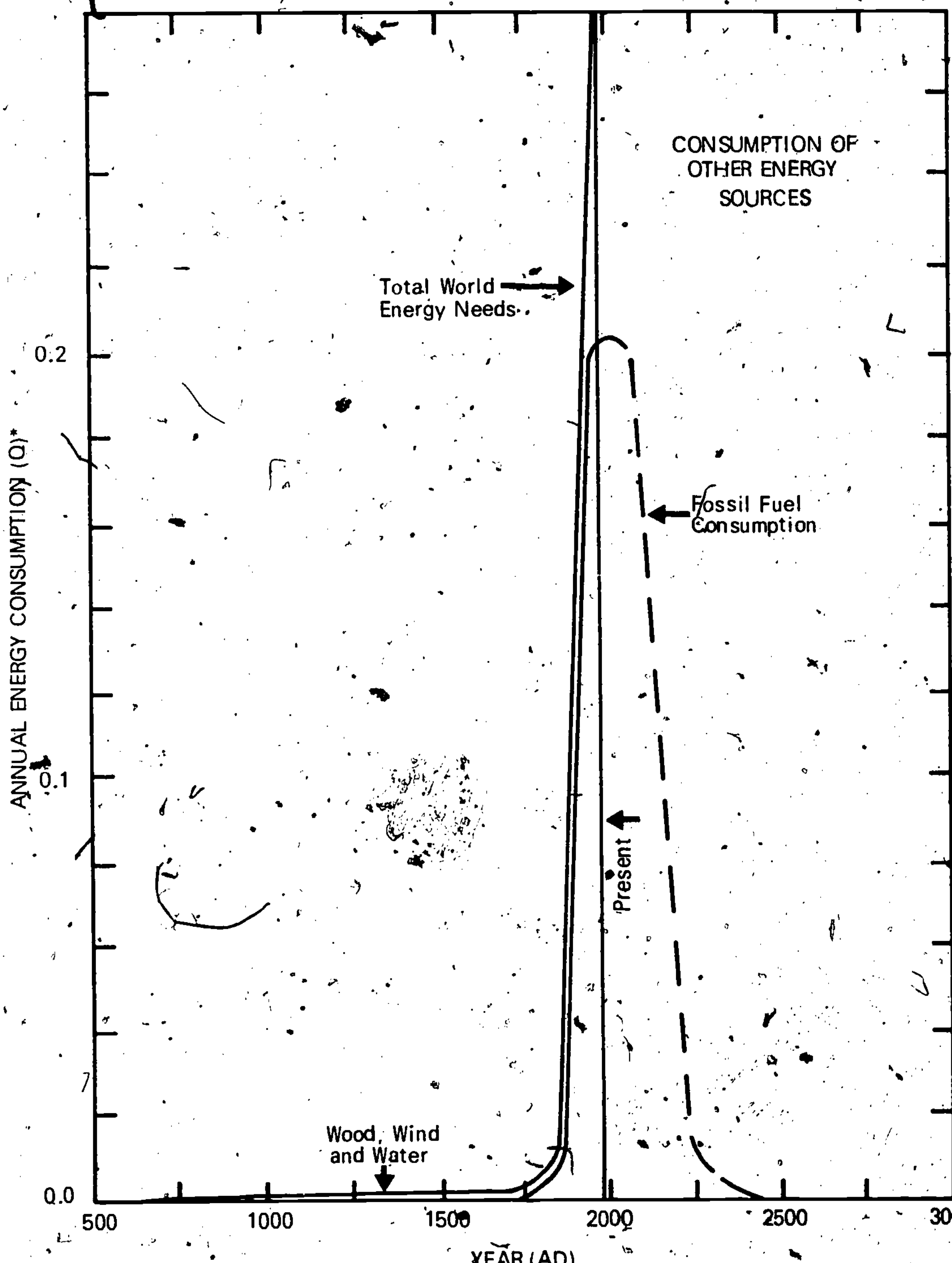
Figure 2
WORLD POPULATION ESTIMATES
Past and Future



* 1 Billion = 10^{12} People

11

Figure 3
WORLD ENERGY CONSUMPTION
Past and Future



*1Q = 10^{18} BTU

These are still used today, but even expanding their use could not make up the difference between worldwide needs and the available supply of fossil fuel. This is the reason for the increased emphasis on research into other energy sources.

2. Energy Consumption in the United States

Figure 4, covering 400 years for the United States, gives a more detailed breakdown of the various energy sources consumed in the past 175 years, along with a possible future breakdown. This figure shows that oil and gas from both domestic and foreign sources will probably be consumed by the middle of the next century. The large resources from tar sands and oil shale, which are just becoming economical to use, will probably be consumed by the end of the next century.

Coal is the one fossil fuel which will last us for several centuries. Fortunately, this country has much of the world's known coal reserves. The area labeled *"coal"* on Figure 4 also represents the increasing use of coal to produce gas and oil. That part of the figure representing wood, wind and water in the past is expanded to include the predicted future use of tidal and geothermal power and the combustion of agricultural waste and other refuse as energy sources. This figure shows the recent introduction of uranium-235 in nuclear reactors for the production of electricity. Note that this source of energy cannot be used indefinitely - the economical supply of uranium-235 will eventually run out. In the future will come the use of uranium-238 and thorium-232 in breeder reactors, which produce more fuel that they consume. These breeder reactors, along with solar energy and fusion reactors, will probably be our major energy sources in future centuries. There may even be some completely new energy source, undreamed of today.

The need for energy sources will, of course, depend on how fast the demand for energy grows. Figure 4 shows the demands that three possible growth rates would make. Energy consumption has increased an average of 3.4 per cent each year between 1950 and 1970. The steepest line on Figure 4 represents a continuation of this growth rate. All possible energy sources would have to be developed as rapidly as possible to environmental consequences. The horizontal line projects the reaching of zero energy growth by the year 2000. Since the population will still be increasing, this approach would probably result in a gradual lowering of the average standard of living. Even this level of energy use cannot be long maintained by our traditional energy resources. More efficient consumption of the energy being produced would help stretch our previous energy resources. The possibility of energy use increasing at its present rate, but with more efficient use, is represented by the 1.7 per cent growth rate line.

3. Economic Impact of the Energy Shortage

Abundant energy at a reasonable cost is basic to an industrialized country like the United States. When this energy is not available, or when its cost rises greatly, the impact is felt by all of us. For example, the petroleum shortages of 1973 and 1974 had effects far beyond the long lines at the gas pumps. Oil shortages have also helped to slow our economic growth and have been a major factor in the continuing inflation.

The energy pinch is felt in many ways. For example, the price of electricity has increased significantly for the first time in years, and people are buying smaller cars as fuel economy becomes increasingly important.

The shortage of energy sources, coupled with concern over evironmental pollution, has caused severe problems for electrical generating plants and other industries. They are forced to search for energy substitutes and to pay greatly increased prices for fuel.

Petroleum products are the basic ingredient in many man-made products, such as fertilizer, synthetic fibers, plastics, synthetic rubber, detergents and paints. In the future, food will probably join the list. With such products in short supply, we should perhaps consider whether such manufacturing uses rate a higher priority than simply burning the petroleum products as fuel.

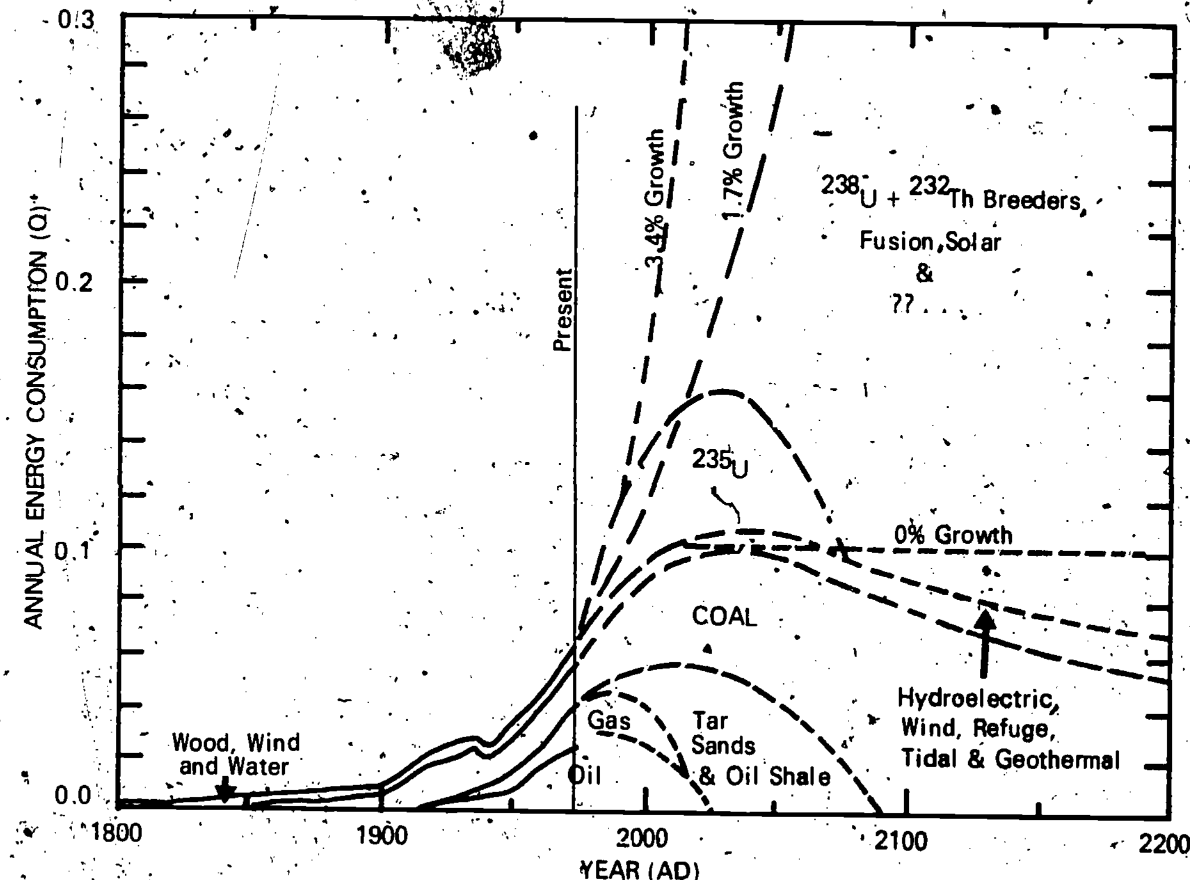
In the short term, considerable energy savings can be realized through conservation and careful energy management. However, in the long run we must develop new energy resources and restructure our energy demands, since the availability and cost of energy have a dramatic impact on our lives.

4. The Demand for Electrical Energy

Perhaps you have some feeling now for the complex energy problems facing us today. We will now narrow our discussion to only one important aspect of the energy picture: electrical power generation and its environmental impact. The reason for our concentraction in this area is that electrical power generation is predicted to be the fastest growing area of energy use. In 1947, about 13 per cent of the fuel used in this country was used to produce electricity. By 1970, this figure had increased to 25 per cent. By the year 2000, it is predicted that between 40 and 50 per cent of the fuel used will be consumed in the production of electricity. In the next century, most of the energy we consume will probably be in the form of electricity.

A number of factors contribute to the increased use of electricity over other agency forms. First, shortages and increased costs of gas and oil will lead

Figure 4
U.S. ENERGY CONSUMPTION AND FUEL RESOURCES
Past and Future



*1Q = 10^{18} BTU

to more use of coal and uranium-235. These two fuels are most suited to the production of electricity. Secondly, the burning of fuel to produce electricity at a few large installations should make for better pollution control. Pollution control is extremely difficult when millions of homes, factories and cars consume gas and oil for heat, cooling or power. These two factors will lead to the increasing use of electricity, probably including the widespread use of electric automobiles and public transportation.

Electrical consumption is also growing because of new consumer products and industrial processes demanded by the American public to maintain an ever-increasing standard of living. Do members of your family own more electrical appliances than they did five years ago? Chances are good that they do, and this use of electricity in the home represents only part of an individual's per capita consumption of electricity. Much more electricity is expended to manufacture the goods and services required to maintain the desired standard of living. Most of the items which Americans take for granted, such as plastics, aluminum and glass, require the use of electrical energy in their manufacture. In fact, the nation has become so dependent on electrical power and other forms of mechanical energy that human muscle now accounts for less than one per cent of the work done in factories.

In addition to these increasing demands for electricity, significant amounts will soon be required for cleaning up the environment by such uses as recycling of wastes and sewage treatment.

Table 1 shows how the electricity consumed in the United States is divided among various segments of the economy.

Table 1

Consumption of Electricity in the United States

Use	Percentage (U.S. Average)
Residential	32%
Commercial	22%
Industrial	42%
Other Uses	4%

SUPPLEMENTARY
MATERIALS
FOR
CHAPTER 1

TABLES OF ENERGY SOURCES AND USE

From "Background Info," Public Affairs and Information Program, Atomic Industrial Forum, Inc.

Nuclear power will be of considerable significance in helping to solve the U.S. energy problems, specifically in providing greater amounts of electricity. This can be illustrated by projecting alternative power sources and their uses over the next few decades. These projections indicate that electricity will become increasingly important in the years ahead, and that nuclear power (along with coal) will be vitally needed as a major source of large-scale electric power supply. Today electricity represents 25 per cent of all energy used in the United States; by the year 2000 it will represent almost 50 per cent.

For the most part the projections in this paper are in terms of the British Thermal Unit (Btu*). For comparison purposes some Btu equivalents follow:

TABLE 1

	Common measure	Btus
Oil	Barrel**	5,800,000
Natural Gas	Cubic feet	1,032
Coal	Short ton	24,000,000 to 28,000,000
Nuclear fuel (such as Uranium-235)	Pound	360,000,000

Sources: National Petroleum Council and Atomic Energy Commission

** 1 barrel of oil equals 42 gallons of oil.

U.S. Energy Sources

This table was put together before the 1973 Arab boycott with the ensuing shortages and spiralling costs of oil and gas. Though the boycott is officially over, it is widely believed that shortages will continue perhaps indefinitely. Therefore the oil and gas figures, particularly those for 1985 and 2000, could be considered optimistic. *It is uncertain that we can import enough fossil fuels to meet our needs or produce enough to attain self-sufficiency. Today about 75% of our energy comes from oil and gas. By the end of the century their proportion will decline, and coal and nuclear use must increase.*

* One Btu is the standard unit for measuring the amount of heat energy and is equal to the amount of heat energy necessary to raise the temperature of one pound of water one degree Fahrenheit.

TABLE 2

Where Our Energy Comes From (Trillions of Btus)

Energy Source	1971	1975	1980	1985	2000
Coal	12,560 (18.0%)	13,825 (17%)	16,140 (17%)	21,470 (18%)	31,360 (16%)
Oil	30,492 (44.0%)	35,090 (44%)	42,190 (44%)	50,700 (43%)	71,380 (37%)
Natural gas	22,734 (33.0%)	25,220 (31%)	26,980 (28%)	28,390 (24%)	33,980 (18%)
Nuclear	405 (0.6%)	2,560 (3%)	6,720 (7%)	11,750 (10%)	49,230 (26%)
Hydropower	2,789 (4.4%)	3,570 (5%)	3,990 (4%)	4,320 (5%)	5,950 (3%)
Total	68,989	80,265	96,020	116,630	191,900

Sources: U.S. Department of the Interior, December 1972

Energy Use

This table was also prepared before the boycott. As a result, the figures for *"Electrical generation"* for the years 1985 and 2000 may be low. In the future more energy from coal and nuclear may be needed to generate even more electricity than this chart indicates to replace our dependency on oil and gas.

TABLE 3

Where Our Energy Goes (Trillions of Btus)

	1971	1975	1980	1985	2000
Household and commercial	14,281 (21%)	15,935 (20%)	17,500 (18%)	18,960 (16%)	21,920 (11%)
Industrial	20,294 (29%)	22,850 (28%)	24,840 (26%)	27,520 (24%)	39,300 (21%)
Transportation	16,971 (25%)	19,070 (24%)	22,840 (24%)	27,090 (23%)	42,610 (22%)
Electrical Generation	17,443 (25%)	22,410 (28%)	29,970 (31%)	40,390 (35%)	80,380 (42%)
Synthetic gas			870 (1%)	2,670 (2%)	7,690 (4%)
Total	68,989	80,265	96,020	116,630	191,900

Source: U.S. Department of the Interior, December 1972

Electrical Energy Sources

Even with coal more than doubling its current contribution, nuclear will have to increase fifty-fold to meet the inevitable increase in electricity demand that is resulting from uncertainties over oil and gas.

TABLE 4

Where Our Electricity Comes From (Billions of Kwh)

	1972	1980	1990
Hydro	273 (15.6%)	317 (10.2%)	381 (6.4%)
Coal	771 (44.2%)	1,211 (38.9%)	1,651 (27.8%)
Oil	272 (15.6%)	421 (13.2%)	512 (8.7%)
Gas	375 (21.4%)	410 (13.2%)	445 (7.5%)
Nuclear	54 (3.1%)	750 (24.1%)	2,913 (49.3%)
Other	2 (0.1%)	4 (0.1%)	20 (0.3%)
Total	1,747	3,113	5,922

Source: Speech by John N. Nassikas, Chairman, Federal Power Commission, at the Annual Symposium of the New England Conference of Public Utilities Commissioners, July 9, 1973.

While the latest AEC predictions of installed nuclear capacity are less than previous figures, mainly because of power plant delays, nuclear is still expected to account for more than half the total electrical generating capacity by the year 2000.

TABLE 5

United States Nuclear Electrical Generating Capacity*

	1973	1980	1990	2000
Megawatts	25,000	102,000	475,000	1,090,000
Total Electric in U.S.	429,456	630,000	1,150,000	2,000,000
Nuclear's Per cent of total	5.5	16	41	55

Source: Office of Planning and Analysis, Atomic Energy Commission, April 24, 1974.

*These forecasts are part of a range of projections with the above table viewed as the most realistic.

Uses of Electricity

The make-up of electricity usage is not expected to change appreciably in the years ahead, but each category will expand significantly.

TABLE 6

Where Electricity Goes (Billions of Kwh)

	1973	1980	1985	1990
Residential	555.0 (32%)	930.2 (33%)	1,310.8 (34%)	1,749.3 (34%)
Industrial	706.1 (41%)	1,108.7 (39%)	1,470.1 (38%)	1,942.8 (38%)
Commercial	390.8 (23%)	634.0 (23%)	876.0 (23%)	1,141.6 (23%)
Other	68.0 (4%)	122.4 (5%)	169.0 (5%)	234.0 (5%)
Total	1,719.9	2,795.2	3,825.9	5,067.7

Source: *Electrical World,* **September 1973**

Estimated Uranium Reserves

Based on favorable geologic indications, it is expected that the United States has reserves to meet requirements up to 1990. Since the uranium industry usually develops an eight-year forward reserve, continuing exploration at a high level is indicated in order to meet requirements after 1990. Based on favorable geologic characteristics of areas contiguous to known producing areas and elsewhere in the U.S., it is believed that there is sufficient uranium in the ground to satisfy this requirement.

TABLE 7

AEC Forecast of Domestic Uranium Requirements (0.3% U-235 Tails)
(Short Tons U_3O_8)

Year of Delivery	Annual	Cumulative
1973	10,000	10,000
1975	18,200	42,100
1980	38,400	189,700
1985	71,500	474,100
1990	117,900	968,500

TABLE 8

Domestic Sources of Uranium (Short Tons of U_3O_8*)

Maximum forward cost per lb. of U_3O_8	Reasonably assured reserves	Estimated additional resources	Total
$ 8	277,000	450,000	727,000
10	340,000	700,000	1,040,000
15	520,000	1,000,000	1,520,000

Source: AEC January, 1974

***A refined form of uranium called *yellow cake* that is enriched for use as nuclear fuel in U.S. reactors. A large nuclear power plant typically contains from 100 to 150 tons of uranium of low enrichment.**

NEWS RELEASE - Bureau of Public Affairs
Department of State
Office of Media Services

LECTURE: INTERNATIONAL REALITIES OF THE ENERGY CRISIS

Following is the text of a lecture given by Dr. Chauncey Starr at the U.S. Department of State in Washington, D.C. Dr. Starr, founder ~~of the American~~ Nuclear Society, is Vice President of the National Academy of Engineering, a member of the President's Task Force on Science Policy and a member of the Office of Science and Technology's Energy Panel.

Also participating in the presentation was a panel of three other distinguished scientists: Dr. Robert A. Bell, Dr. Ralph E. Lapp and Dr. Gordon J. F. MacDonald.

The presentation was one in a series of science lectures sponsored by the State Department.

International Realities of the Energy Crisis

"Between now and 2001, just 30 years away, the U.S. will consume more energy than it has in its entire history. By 2001 the annual U.S. demand for energy in all forms is expected to double, and the annual worldwide demand will probably triple. These projected increases will tax man's ability to discover, extract and refine fuels in the huge volumes necessary, to ship them safely, to find suitable locations for several hundred new electric-power stations in the U.S. (thousands worldwide) and to dispose of effluents and waste products with minimum harm to himself and his environment. When one considers how difficult it is at present to extract coal without jeopardizing lives or scarring the surface of the earth, to ship oil without spillage, to find acceptable sites for power plants and to control the effluents of our present fuel-burning machines, the energy projections for 2001 indicate the need for thorough assessment of the available options and careful planning of our future course. We shall have to examine with both objectivity and humanity the necessity for the projected increase in energy demand, its relation to our quality of life, the practical options technology provides for meeting our needs and the environmental and social consequences of these options."

The above quotation is taken from a paper I prepared more than a year ago. It describes the nature of the continuing problems we face - and which have recently reached public attention in the form of the *"energy crisis."* The term *"energy crisis"* has served as a convenient layman's umbrella for encompassing a wide variety of society's concerns with the energy situation. Because these do not have a common solution, it is important to examine them separately and to clarify the several issues we face.

The *"crisis"* designation tends to be misleading, because it implies that quick-fix emergency steps should be taken to cure situations which have developed over many years. In fact, there are no quick fixes. Further, the practical realities of the situation have not yet required an immediate national *"crisis"* response by applying true emergency measures - such as energy rationing and cessation of energy consuming activities.

The fact that pressing localized issues have arisen should give us concern, both as indicators of widespread inadequacies and as they may portend more serious things to come. To use a medical analogy, the patient may have aches and pains, but can still do a day's work and live normally - the situation doesn't justify hospitalization now, but could get worse if remedial treatment is neglected.

In like manner, the most pressing energy need is for a coherent and long-range program to plan and manage our national and international energy systems. It takes 10 to 20 years to significantly alter the trends of these huge systems. Waiting until the situation becomes intolerable must now be recognized as intentionally planned neglect - a societal irresponsibility difficult to condone.

Our national and international energy systems consist of a complex of interlocked activities, including fuel resources (most notably the fossil fuels - coal, oil and gas), the distribution of these fuels either by pipeline, truck or tanker, the distribution of electricity generated from these fuels, and finally the many end uses of energy.

Energy is consumed for residential purposes, for transportation, by the manufacturing industry, and in sundry other ways. All activities of any energy system have some environmental impact. For example, the development of fuel resources gives rise to land use and esthetic issues. The distribution of these fuels involves transportation risks both to the public and to our ecology.

The conversion of these fuels into either electricity or into their end functions - such as automobile transportation, industrial operations, and the like - creates air polluting effluents and waste heat. In addition to these more obvious environmental impacts, there are secondary by-products from energy systems that are not as directly visible to the public, but which are also important societal costs - such as fires, explosions and accidents.

The current public focus on the energy crisis arises primarily from a few immediately visible near-term events. First, because of the occasional shortages and malfunctions of the electricity delivery system, which cause dramatic blackouts and brownouts in spot areas, the public affected has a discomforting anxiety about the reliability of supply. The *"crisis"* nature of this issue tends to be very localized in place and time. The great majority of our population have no difficulty with getting electricity on demand.

The second near-term issue is that related to urban air pollution. However, air pollution arises from a great variety of sources, many of an industrial nature not directly related to the energy systems. The contribution to air pollution which arises from the generation of electricity is significant, but usually only a modest part of the total. Most notably the use of petroleum products for private and public motor vehicles is a major source. These two items, the continuous delivery of electricity and urban air pollution are generally the stimuli for the public attention to energy issues.

The continuous delivery of electricity to meet demands, without the penalties of brownouts or blackouts or other failures, has always been the traditional objective of the electric utility industry. In order to accomplish this, the industry has anticipated a decade ahead the growth in demand for electricity, so as to schedule the construction of power generation and distribution facilities to meet such foreseen needs.

Electric utilities have also tried to maintain a sufficient surplus of generation capacity to provide a reserve for unexpected breakdowns of equipment, maintenance and other causes of disruption. In the past several years the normal anticipatory planning of the electrical industry has gone askew because of conditions not anticipated at the time when the original commitments for future plants and equipment were made. These unanticipated issues have arisen from many sources, but perhaps the two most important are the first recently restricted availability of suitable fuel and second the new environmental criteria for power plant performance.

The traditional fuel for power plants has been the fossil fuels - coal, oil and gas. Coal, while an abundant mineral in the United States, unfortunately produces the largest overall environmental impact. The mining operations, underground and strip mining, involve social costs associated with safety and land use which are quite substantial and require very large remedial investments. In addition, coal contains a large number of foreign elements, including sulphur compounds, which are environmental pollutants.

The result has been that while the demand for coal has continuously increased for power production purposes, its use creates problems which have yet to be solved satisfactorily. In particular, the ability to remove the sulphur contamination from the coal, either prior to its use or after its discharge as a gas in the power plant stacks, requires the commercial development of new technologies only now undergoing pilot plant trials.

The available indigenous oil in the U.S. has not been sufficient to meet our needs. Because of the slow development of both our onshore and offshore oil reserves, we have become one of the great importers of oil. Oil, like coal, contains sulphur which generally requires either removal prior to combustion or in the power plant stack gas. Naturally low sulphur oil is available in relatively small amounts.

The recent environmental restrictions on oil drilling on the continental shelf (because of the possible leakages into the marine environment), and the concern with the ecological impact of oil pipelines all have tended to slow down or inhibit the full exploration and development of oil resources.

Natural gas is the least contaminated form of fossil fuel and is therefore in great demand for power plant use. It is also in great demand for industrial and domestic use, because of the ease with which it can be transmitted and distributed and the simplicity of combustion equipment. For complicated reasons, including pricing policies, natural gas has been mostly a byproduct of oil development. At the present time there appears to be an insufficient reserve of natural gas in the United States to permit continued expansion of its use. Thus, this most environmentally acceptable of all the fossil fuels is also the most limited for the future.

For all these reasons the utility industry recognized some years ago that the unique *"clean air"* characteristics of nuclear power would make it a very desirable addition to the available technical options for the generation of electricity. For almost two decades the utility industry has actively supported nuclear power development, and underwritten the higher costs of the first stages of commercializing nuclear power.

The rate at which nuclear power has entered into the production of electricity is, however, disappointingly less than that which was expected by the utilities. The initial delays were associated with establishing the reliability needed for commercial operations. More recently these plants have been delayed by the intervention of various public groups fearful of their potential environmental impact.

These interventions are primarily serving as a means of public education and communication concerning the relative safety of nuclear power. Unfortunately, the associated delays, sometimes extending for several years, have had a serious impact on reducing the planned expansion of nuclear power availability.

Thus, as a result of the combined effects of an inadequate supply of environmentally suitable fossil fuels to meet expanding requirements, the time needed for technical development of anti-pollution devices to permit use of available coal and oil, and delays in the authorization for nuclear power plants, we face a near-term situation where the generating capacity of our national electricity system does not contain everywhere an adequate reserve for meeting unique peak demands and providing protection against unexpected power plant failures.

There are many regions of the country where these issues have not been pressing. Unfortunately, there are many urban areas that have had a large expansion of electricity demand, and in these the margin of reliability has been so reduced that even minor malfunctions or unusual weather conditions can create electricity shortages with considerable public discomfort and, in some cases, public hazards.

Such problems can only be avoided by administrative removal of unproductive delays and interferences, and by the most efficient use of the available resources of fuel and power generation facilities. Because it takes a decade or more to bring new technical developments or new fuel systems into operation in our energy system, it is not likely that these near term pressures will be rapidly removed by technologies still in the process of development.

The availability of energy has always been of basic concern because of the intimate relationship of energy to our societal development. It has become a major public issue only in the past several years, and will probably always remain with us as a primary consideration in the future. Basically, our society cannot function without energy in various forms. We utilize it for elemental physical comfort by heating and cooling, we utilize it to run our industries, and we use it for recreational purposes.

All these uses have always had some impact on the environment. As our per capita use has grown in the past several generations, and as our population has grown and also concentrated in large urban areas, these environmental impacts have become sufficiently severe that we now must begin to develop either better energy technology or some limitations on energy use, or both. It must be recognized that there is no form of energy which may be used without some environmental impact.

The issue is not one of *"good or bad"* but one of balancing the beneficial aspects of energy use against its undesirable environmental effects. As a nation we are presently engaged in developing a socially acceptable balance between these two issues through public debate, technical and scientific research, and through empirical trial and error. This development of a sound social philosophy for the use and control of energy, so as to maximize the public good, may be one of the most important national issues of this decade.

Long-range planning of our national and world-wide energy systems must start with some estimate of future energy demands. A conception of the future may come from a simple extension of historical trends, or may be developed from a more sophisticated analysis of changing life styles and their impact on end-use needs.

Since 1900, the average per capita energy consumption in the world and the U.S. has doubled every 50 years, with some short term perturbations. There appears to be small likelihood that this long-term trend of increasing per capita use will change in the next several decades.

In spite of increased public concern with the impacts of such a growth, there is actually very little that can be done pragmatically to limit it - other than direct scarcity or rationing - because of the intimate connection between the life styles of peoples, their aspirations, and their energy supply.

The future need for energy in societal development is of two broad types, one characteristic of the highly developed sections of the world and one typical of the underdeveloped portions. During the past two centuries the industrialized nations of the world significantly increased their energy use in order to sustain their population growth and to improve the condition of their people.

It is likely that in the next century the per capita energy consumption in these advanced countries will approach an equilibrium level, first because the quality of life for the majority of the population will be less dependent on increased energy use, and second because environmental constraints will make energy more costly and thus encourage increased efficiency of its end use. The hoped for population equilibrium in advanced nations will also lead to an eventual leveling-off of total energy need for these countries.

While it is possible that the future creation of socially desirable high-technology energy consuming devices may maintain a continuously growing energy demand, nevertheless, the realities of resource economics will probably create a trade-off ceiling on

energy demand. Only the development of new energy resources (such as fusion) which are both low cost and extensive can lift such a ceiling. Even so, the availability of investment capital - a manmade resource - may limit such growth.

For the underdeveloped part of the world, which contains most of the world's population, the situation is quite different. These peoples are still primarily engaged in maintaining a minimum level of subsistence. They have not as yet had available the power resources necessary for the transition to a literate, industrial, urban, and agriculturally advanced society. Historically such transitions have always involved both an increase in population and an increase in per capita energy consumption. We are seeing this now in most of the underdeveloped countries. So, the inevitable population growth, combined with an increased per capita energy use, could result in an enormous worldwide energy demand.

A capsule example of what can occur is provided by Puerto Rico. It is being shifted to an industrial economy from an agrarian sugar economy by the planned investment of foreign capital. In 1940 the annual electricity consumption was about 100 kwhrs per capita, comparable to India's present usage. By 1950 this had been more than doubled to 220 kwhrs per capita. By 1968 this had increased to 1800 kwhrs per capita. This is an average doubling time of about 7 years. (By comparison, the U.S. consumption in 1968 was about 7200 kwhrs per capita with a present per capita doubling time of about 12 years. Now, in 1972, the U.S. level is about 8800 kwhrs per capita.) Puerto Rico is, of course, a unique case of accelerated economic development; but the 20-fold increase in per capita electricity comsumption is nevertheless startling.

At present the U.S. consumes about 35 percent of the world's energy. By the year 2000 the U.S. share will probably drop to around 25 percent, due chiefly to the relative population increase of the rest of the world. The per capita increase in energy consumption in the U.S. is now about 1 percent per year. Starting from a much lower base, the average per capita energy consumption throughout the world is increasing at a rate of 1.3 percent per year.

It is evident that it may be another century before the world average even approaches the current U.S. level. At that time the energy gap between the U.S. and the underdeveloped world will still be large. With unaltered trends it would take 300 years to close the gap. By 2000 the world's average per capita energy consumption will have moved only from the present one-fifth of the U.S. average to about one-third of the present U.S. average. Of grave concern is the nearly static and very low per capita energy consumption of areas such as India, a country whose population growth largely negates its increased total production of energy.

If the underdeveloped parts of the world were conceivably able to reach by the year 2000 the standard of living of Americans today, the world-wide level of energy consumption would be roughly 10 times the present figure. Even though this is a highly unrealistic target for 30 years hence, one must assume that world energy consumption will move in that direction as rapidly as political, economic and technical factors will allow. The problems implied by this prospect are awesome.

Increasing per capita income is an essential for increasing the quality of life in underdeveloped countries, and this requires energy. It has often been suggested that because of its environmental impacts, energy use be arbitrarily limited everywhere. This requires the same type of societal decision that would be associated with arbitrarily limiting water supply or food production.

Given the objective of providing the people of the world as good a life as man's ingenuity can develop, the essential role of energy availability must be recognized. With the same motivation that causes the agronomists to seek an increased yield per acre, it is the function of technology to make energy available in sufficient amount to meet all essential needs, and with sufficiently small environmental impact as to ensure that the benefits outweigh all the costs.

Because even in the industrial societies the per capita use of energy in large amounts is only a century old, and in most of the world it has not even started, we have both a growing need and an opportunity to develop long-range plans for optimally supplying this essential aid to world-wide social development.

One can better appreciate the energy problem the world faces if one simply compares the cumulative energy demand to the year 2000 - when the annual rate of energy consumption will be only three times the present rate - with estimates of the economically recoverable fossil fuels.

The estimated fossil fuel reserves are greater than the estimated cumulative demand by only a factor of two. If the only energy resource were fossil fuel, the prospect would be bleak indeed. The outlook is completely altered, however, if one includes the energy available from nuclear power. As has often been stated, nuclear fission provides another major resource - with the present light water reactors about equal to the fossil fuels, and with the breeder reactors almost 100 times as much.

There is no question that nuclear power is a saving technical development for the energy prospects for mankind. Promising but as yet technically unsolved is the development of a continuous supply of energy from solar sources. The enormous magnitude of the solar radiation that reaches the land surfaces of the earth is so much greater than any of the foreseeable needs that it represents an inviting technical target.

Unfortunately, there appears to be no economically feasible concept yet available for substantially tapping that continuous supply of energy. This somewhat pessimistic estimate of today's ability to use solar radiation should not discourage a technological effort to harness it more effectively. If only a few percent of the land area of the U.S. could be used to absorb solar radiation effectively (at, say, a little better than 10 percent efficiency), we would meet most of our energy needs in the year 2000. Even a partial achievement of this goal could make a tremendous contribution.

The land area required for the commercially significant collection of solar radiation is so large, however, that a high capital investment must be anticipated. This, coupled with the cost of the necessary energy-conversion systems and storage facilities, makes solar power economically uninteresting today. Nevertheless, the direct conversion of solar energy is the only significant long-range alternative to nuclear power.

The possibility of obtaining power from thermonuclear fusion has not been included in the listing of energy resources because of the great uncertainty about its feasibility. The term *"thermonuclear fusion,"* the process of the hydrogen bomb, describes the interaction of very light atomic nuclei to create highly energetic new nuclei, particles and radiation. Control of the fusion process involves many scientific phenomena that are not yet understood, and its engineering feasibility has not yet been seriously studied. Depending on the process used, controlled fusion might open up not only an important added energy resource but also a virtually unlimited one. The fusion process remains a possibility with a highly uncertain outcome.

It has been proposed that tapping the heat in the rocks of the earth's crust is feasible, and if it is, this could be important. At present, the initial probing of this source has not yet been tried - so its pragmatic availability is yet uncertain.

It is clear from all such studies, that for the next century mankind is unlikely to run out of available energy. Instead, the important issue is whether the increasing cost of energy (including environmental costs) will become a major handicap to world-wide societal improvement. Just as an increasing cost of water with increasing usage might limit the development of an area, the same could apply to the use of energy in various parts of the world.

Within nature's limitations man has tremendous scope for planning energy utilization. Some of the controlling factors that enter into energy policy depend on the voluntary decisions of the individual as well as on government actions that may restrict individual freedom. The questions of feasibility, both economic and technical, depend for their solution on the priority and magnitude of the effort applied.

The time scale and costs for implementing decisions, or resolving issues, in all areas of energy management have both short-term and long-term consequences. There are so many variables that their arrangement into a *"scenario"* for the future becomes a matter of individual choice and a fascinating planning game. The intellectual complexity of the possible arrangements for the future can, however, be reduced to a limited number of basic policy questions that are more sociological than technical in nature.

Dr. Starr referred to a table, not reproduced here, showing a partial list of the controlling factors which enter into energy planning. He continued:

As shown, the only parameters under our control which can alter the nature and trends of near-term energy systems are a limited number of individual and governmental choices - life style and value oriented rather than technological in nature. An individual choice of energy device (home heating, for example) can be made and implemented with a time constant of about a year. A choice by a societal unit (location of a power station, and effluent regulation, for example) takes about a decade to make and implement. Thus, the full effect of such societal decisions often doesn't develop until more than a decade has passed.

In the technological domain of new economically acceptable energy devices, we are really working for the next generations, rather than our own. Even nuclear power, which was certainly supported by government as enthusiastically as any technology in history, has taken 25 years to establish a commercial base - and still hasn't made a real impact on our energy supply.

Of all the energy needs projected for the year 2000, nonelectric uses represent about two-thirds. These uses cover such major categories as transportation, space heating and industrial processes.

The largest energy user at that time will be the manufacturing industry, with transportation using about half as much. Transportation is illustrative of the possibilities in societal planning. The automobile is responsible for almost half of the world's oil consumption - and a corresponding part of its air pollution. Except for the airplane, the private automobile is the most inefficient mode of using energy for travel.

For passenger travel, railroads are 2 1/2 times as efficient as autos and 5 1/2 times as efficient as airplanes. Buses are 4 times as efficient as autos. For freight, railroads are 3 1/2 times as efficient as trucks and 55 times as efficient as airplanes. Clearly, to reduce energy consumption an extensive nationwide network of railroads, with local bus service, is far superior to an automobile road network. Unfortunately, the world-wide trends have been diametrically opposite, and the human preference for personal mobility have reinforced such trends.

Finally, contrary to much public comment, the development of new speculative energy resources are investments for the future, not a means of remedying the problems of today. Unfortunately, many of these as yet uncertain and undeveloped sources of energy are often misleadingly cited publicly as having a great promise for solving our present difficulties. In addition to their technical uncertainties, many of these speculative sources are likely to be limited in their contribution, even if successful.

Unfortunately, the attraction of *"jam tomorrow"* may persuade us to neglect the need for *"bread and butter"* today. Because of the very long time required for any new energy device to become part of the technological structure of our society, these speculative sources could not play a major role before the year 2000. The quality of life of the peoples of the world depends upon the availability in the near future of large amounts of low cost energy in useful form. This being the case, we must plan an orderly development and efficient use of the resources available to us now, and these are primarily fossil fuels and nuclear fission.

Given this situation, what are the possible impacts on U.S. relations with foreign countries? Because of our present limitations on the use of high sulphur coal, and the present unavailability of more natural gas, a rapid shift to oil is now underway, because oil can be found with low sulphur or can be desulphurized.

There is no emergency remedy except rationing. Because roughly half our oil goes to transportation, this is the likely area to be controlled, not electricity. U.S. oil production can be increased only fractionally even if all internal controls are removed.

If the politically distasteful course of rationing is not taken, our 1970 foreign oil purchase of \$5 billion will become \$10 billion in 1975, and \$15 billion by 1980, at which time half our oil consumed will be foreign. For perspective, these dollar outflows may be compared with the total U.S. annual capital investments of less than \$100 billion. I will not dwell on the international monetary consequences.

It should also be remembered that increased fuel cost means increased cost of goods, reduced foreign sales, and worsened trade balance. The foreign relations issue is, of course, aggravated by the increasing dependency of the U.S. on the oil-producing nations without a balancing dependency on their part. The international tensions so produced can lead to consequences of the most serious nature - a variety of scenarios can be imagined.

A parallel situation exists in Western Europe, and both France and Germany have embarked on the construction of oil storage facilities to provide at least three months reserve. (The U.S. now has a 2-3 week stored supply.) The recent North Sea discoveries will help but not solve this problem. These countries are also developing pipeline connections to the USSR and Eastern European oil fields. Western Europe and the U.S. may end up in conflict for limited world resources.

For the U.S., the Canadian supplies are attractive, but both trade barriers and lack of incentives have made this a slowly developing course. Perhaps we should offer the D_20 (heavy water) for their oil. The Canadians have no reason to be concerned with our problem and may be viewing it with some skepticism, as do many foreigners.

After all, the environmental issues that have engendered our situation have a very dubious rationality. The public health causality relations which are the reputed origin of our pollution standards are not, in fact, based on demonstrable or credible risk-benefit analyses. They are instead judgmental levels set primarily for esthetic or comfort purposes, with health benefit marginal at best. This is not likely to create international sympathy.

Although the near-term U.S. situation has no quick fix, the intermediate term (post 1980) has several optional aids. Offshore drilling, for example. This is much less polluting than tanker imports, and given time could probably meet much of our needs. Of course, we must resolve the issue of the *"law of the sea"* if we wish to exploit the resources beyond the three mile limit. Another option is to ease the environmental and esthetic constraints and reactivate coal mining, and this may occur when the public realizes the situation. Another is speed up coal desulphurization, gasification and liquefaction, and

the recovery from oil shales and tar sands. These take both the development of commercial technology and much capital.

In the very long term (post 2000) we have the "clean air" option of nuclear power. The abundance of uranium and the fast breeder gives us potentially ample energy. Obviously, the rate at which nuclear power comes on the scene is dependent in the U.S. on public acceptance. It should be pointed out that this issue does not exist in most foreign countries. As a consequence, we may be buying foreign reactors eventually.

We must recognize and resolve the several very basic trade-offs between environment, life styles, personal freedoms, amenities, international tensions, high energy cost and high cost of goods, public health, personal income, and allocation of national resources - and perhaps others. The issue may be as basic as national security vs. social costs.

For example, based on my perceptions of the alternates, I would very much rather accept the minimal risks of large scale nuclear power than the already evident risks of international tensions from foreign oil. These issues are so important, and the energy systems so ponderous and slow to change, that our national planning must be based on a comprehensively developed long-range insight rather than a fickle public emotion and short-term political expediency. Let us hope it is.

Student Activity: How much electricity do you use?

1. Make a list of the electrical appliances in your home. Do not forget such items as electric furnace fans, light bulbs, air conditioners, kitchen appliances, hair driers, etc.

2. From the table below, write the annual *kilowatt-hour* (KWH) consumption beside each entry on your list.

3. Add these for the total annual kilowatt hour consumption for your family.

4. Divide this total by the number of persons in your family to arrive at your per capita annual kilowatt hour consumption.

Electrical Consumption for Some Common Home Appliances

Appliance	Estimated Annual KWH Consumption
Air Conditioner, Window	940
Bed blanket	147
Broiler	100
Carving Knife	8
Clock	17
Clothes Dryer	993
Coffee Maker	106
Deep Fat Fryer	83
Dehumidifier	377
Drill, Electric	65
Dishwasher	363
Fan, Attic	291
Fan, circulating	43
Fan, furnace	450
Fan, window	170
Floor polisher	15
Food blender	15
Food freezer (15 cu.ft.)	1,195
Food freezer, frostless (15 cu.ft.)	1,761
Food mixer	13
Food waste disposer	30
Frying Pan	186
Grill, sandwich	33
Hair dryer	13
Heat lamp	13
Heat pump	13
Heater, radiant	176
Heating Pad	10
Hot Plate	90
Humidifier	163
Iron (hand)	144
Iron (mangle)	158
Light Bulbs	25
Oil burner or stoker	410
Radio	86
Radio-phonograph	109
Range	1,175
Refrigerator (13 cu.ft.)	728
Refrigerator (12 cu.ft. frostless)	1,217
Refrigerator-freezer (24 cu.ft. frostless)	1,828
Roaster	205
Saw	65
Sewing Machine	205
Shaver	18
Sun Lamp	16
Television (B & W)	362
Television (Color)	502
Toaster	39
Tooth brush	5
Vacuum Cleaner	46
Waffle Iron	22
Washing machine, automatic	103
Washing machine, non-automatic	76
Water Heater, standard	4,219
Water Pump	231

If you know the amperage rating of any appliance, you can estimate the kilowatt hour consumption by using the formula

$$KWH = \frac{\text{Amps} \times \text{volts}^{*} \times \text{hours of use}}{1000}$$

*Use 110 or 220 volts, whichever applies.

CHAPTER 2

MEETING THE DEMAND FOR ELECTRICAL ENERGY

1. The Generation of Electrical Energy

Our idea of electricity is based largely on what it does and on its effects, rather than on what it is. We look upon electricity as something that makes light bulbs glow, or irons get hot, or refrigerators get cold. But what is electricity?

Electricity - that is, an electric current - is the flow of electrons in a conductor. An electron is a very, very small negatively charged subatomic particle. A conductor is a material which has free electrons that can be moved through it easily. Among the materials most familiar to us, metals are the best conductors of electricity.

The production of an electric current is fairly simple. All that is required is to make electrons run through a conductor. A loop of wire, preferably copper wire, can be the conductor. This wire conductor is loaded with free electrons. Since these free electrons are negatively charged, they will react to a magnet. If the conductor wire is formed into a loop and the loop is moved through the magnetic field which exists between the north (N) and south (S) poles of a magnet, an electric current will flow through the loop. Figure 5 shows a loop being pulled from right to left through the magnetic field lines of force (dotted lines) which cause an electric current (I) to flow in the clockwise direction shown by the arrows. The free electrons actually flow in the opposite direction from the electric current.

If the conductor loop is spun between the poles of the magnet, the electrons in the loop will move back and forth within the loop. As the loop passes back and forth through the magnetic field lines of force, the current is made to flow first in one direction and then in the reverse direction (Figure 6). Current produced in this way is called alternating current (a.c.); the electrons, and therefore the current, are moving in alternating directions in the conductor. This is the kind of current we use when we plug something into an electrical outlet.

The largest electric power generator makes electricity in the same way, by moving loops of conducting wire between the poles of magnets. Of course, a large plant uses miles and miles of wire in the loops and enormous magnets, but the same principles are at work.

The major difference in the many types of electrical generating plants is the method used to move the conductor wires in the magnetic field. In most types of plants, some type of fuel such as coal, oil or uranium - is used as an energy source to make steam. This steam then pushes on the blades of a turbine to make the turbine spin. The conductor loops are attached to the spinning turbine so that they spin between the poles of huge magnets. Any plant that uses steam to spin the turbine is called a steam generator, or steam electric station.

The hydroelectric station is different from the steam electric station, using falling water to make the turbine spin. Gas turbines use hot gases to spin the turbine, much like a jet engine.

Thus electricity is not in itself a source of energy, but is produced by our use of basic energy resources: fossil fuels, hydroelectric power, nuclear power and other energy sources.

Figure 7 shows the major United States steam generating centers as of 1970, by size and geographic distribution. Figure 8 shows the projected steam generating need for 1990. It should be noted that the major power expansion will occur in the eastern and far western sections of the nation.

2. Present Methods of Generating Electrical Energy

The basic resources that provided energy for electrical generation in 1974, along with the percentage of electricity produced for each resource, is shown in Table 2. Table 3 shows how the use of these resources for electrical generation compared with their use for all other purposes.

Why can't we just build more of these kinds of plants to satisfy our growing demands for electricity?

As far as hydroelectric stations are concerned, essentially all the economic dam sites are already in use in the United States. Remaining new sites are in remote areas away from the electrical demand. Developing these sites would have potentially adverse effects on increasingly scarce wilderness areas. Hydroelectric plants, unlike steam generating plants, produce no waste heat, but the effect of high dams on fishery resources in many rivers has generally been detrimental.

Thus, the major expansion of electrical generating capabilities utilizing current technology must involve fossil-fueled plants (those using coal, gas and oil) and nuclear plants. These two alternatives are compared in detail in subsequent chapters of this text.

Before this comparison is begun, however, a look into various other possibilities for electrical generation is in order. This discussion is included because coal, gas and oil are nonrenewable natural resources. We will deplete our supplies in the foreseeable future, and we must develop improved ways to extend and supplement these natural

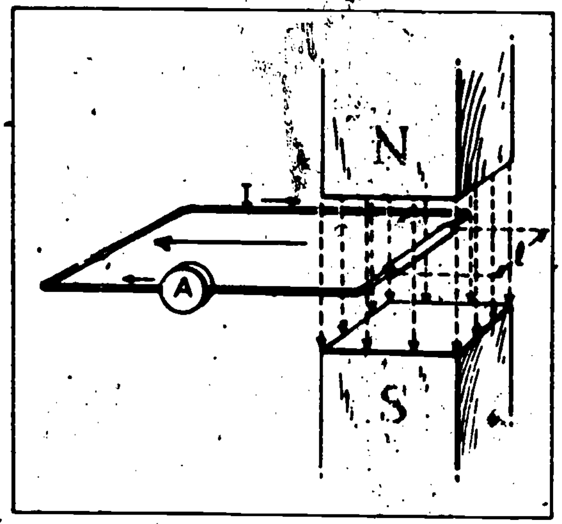


FIGURE 5

A loop being pulled through the magnetic field lines of force (dotted lines) which cause an electric current to flow.

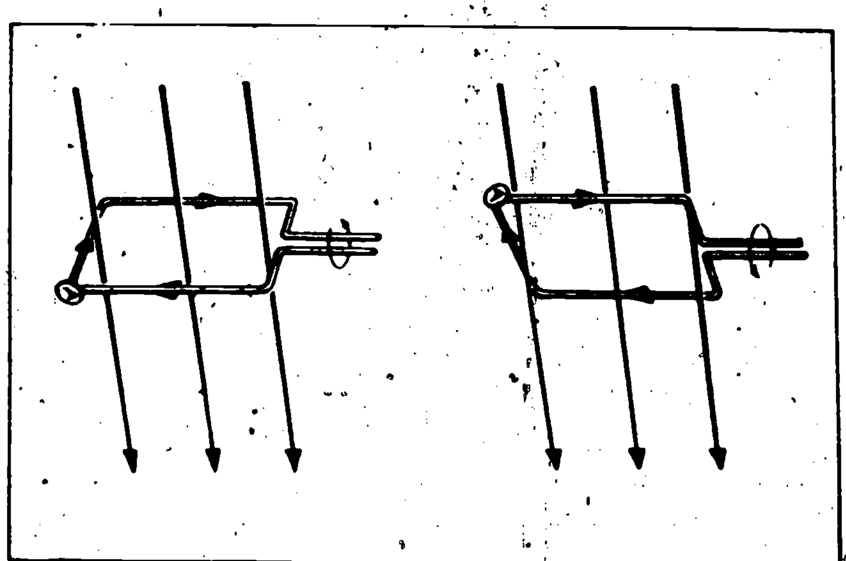
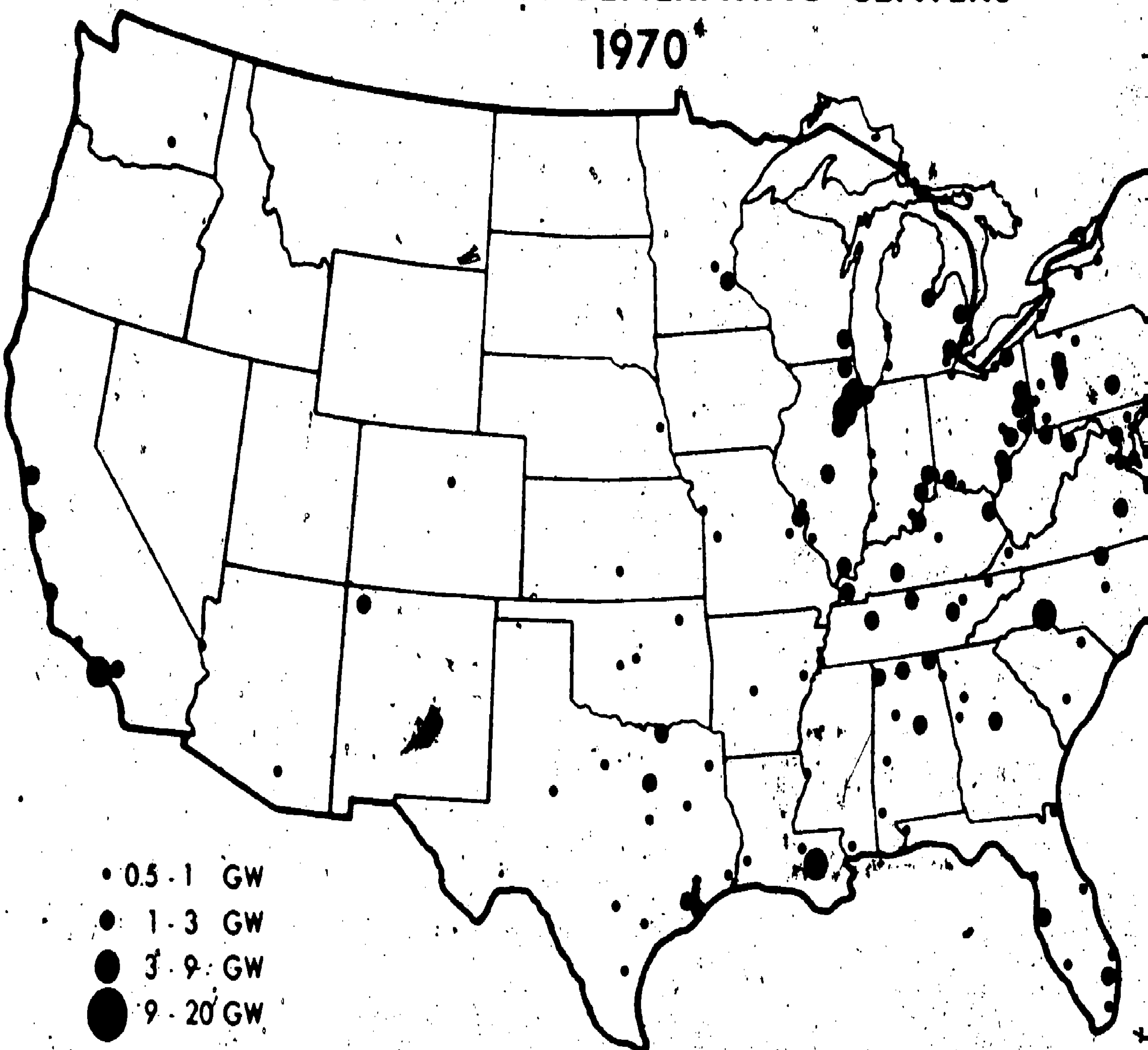


FIGURE 6

As a conductor loop passes back and forth through the magnetic lines of force an alternating current is produced.

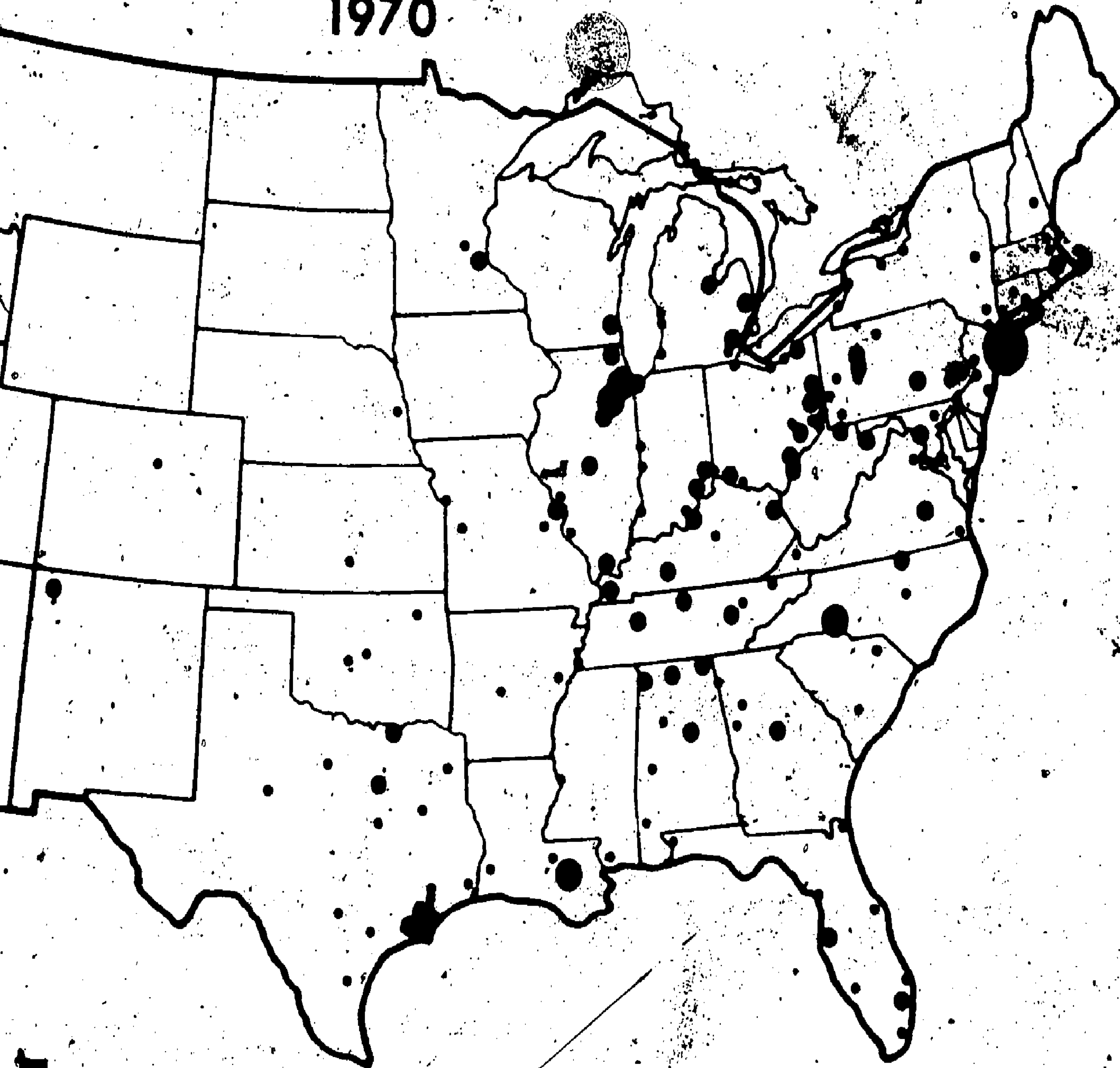
MAJOR STEAM GENERATING CENTERS
1970



1 gigowatt (GW) = 1 billion Watts

FIGURE 7

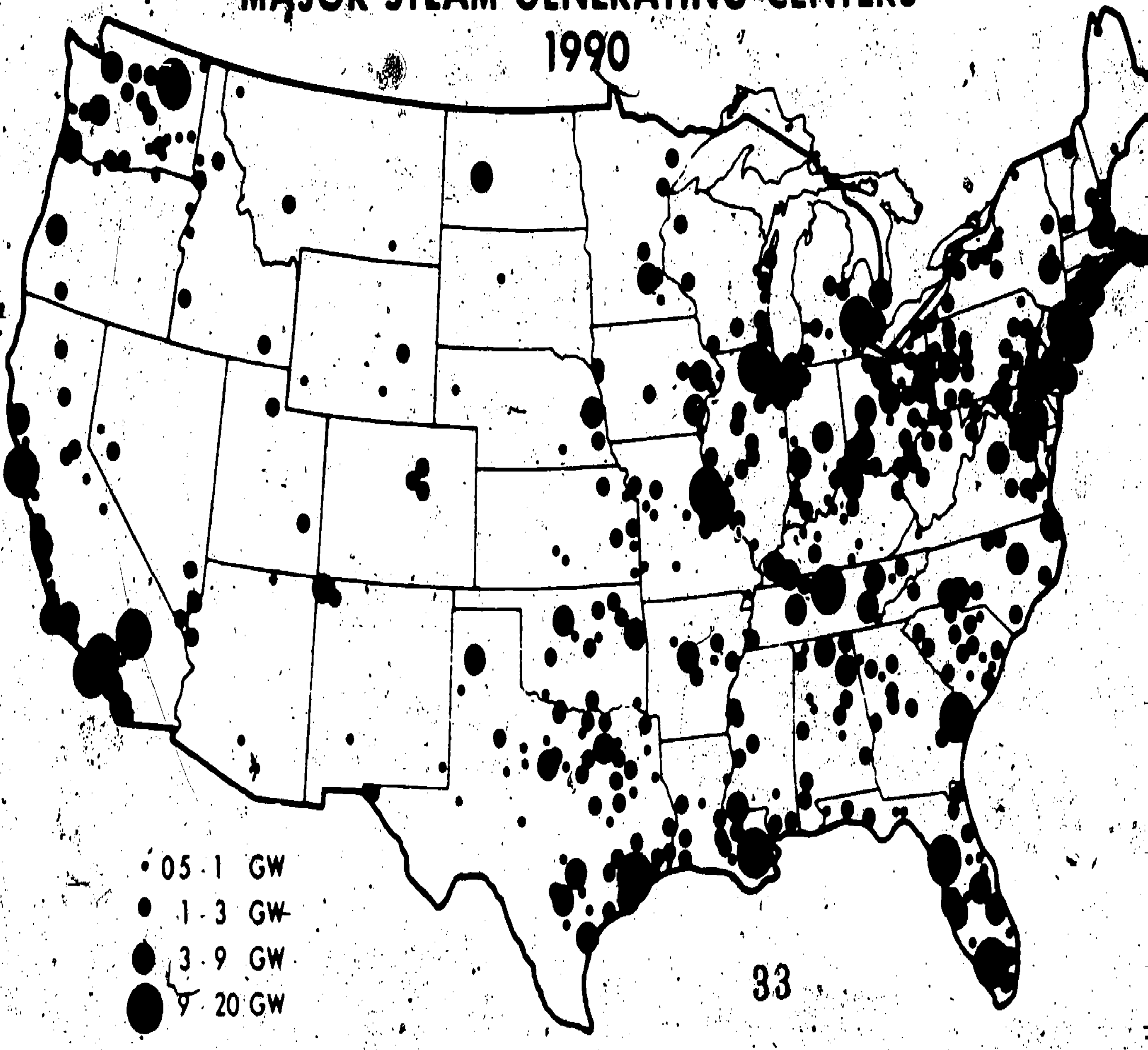
AJOR STEAM GENERATING CENTERS
1970



Jatts

FIGURE 7

MAJOR STEAM GENERATING CENTERS
1990



1 GW = 1 billion Watts

FIGURE 8

TABLE 2

Electrical Production by Energy Resources in 1974

Coal	45%
Gas	23%
Oil	10%
Hydroelectric	17%
Nuclear	5%
TOTAL	100%

Other sources, such as solar energy and geothermal energy, provide a minute amount of electricity at that time.

TABLE 3

Use of Energy Resources in 1974

Resource	For Electrical Generation	For all Other Purposes	Total
Coal	11%	6%	17%
Gas	6%	26%	32%
Oil	3%	43%	46%
Hydroelectric	4%	0	4%
Nuclear	1%	0	1%
TOTAL	25%	75%	100%

TABLE 4

Estimated Depletion of Economically Recoverable World Fuel Reserves

Fuel	Year
Mineable Coal	2400
Oil	2030
Gas	2020
Fissionable Uranium-235 (High grade ore)	2040

resources. Even our known reserves of high-grade uranium ores are limited. Table 4 shows estimates of when various fuels will be depleted on the basis of anticipated world-wide demands. It can be seen that except for coal, these fuels will probably be expended within the lifetime of our children or grandchildren.

3. Alternative Methods of Power Production

The following paragraphs describe some new methods for the use of conventional fuel sources, plans for use of new sources of energy, and new ways to store energy for later use. Some of these alternatives are already in use, while others are still under investigation. Bear in mind that most of these ideas will require enormous investments in time and money to become reliable and economical sources of power.

A. Power from Fossil Fuels

(1) Solvent Refining of Coal

A technique is being developed to purify coal. Pulverized raw coal is mixed with an aromatic solvent and reacted with hydrogen gas at high temperatures and pressures. This dissolves the coal and separates it from its ash, sulfur, oxygen and water. The solvent is then removed, leaving a pitch-like product low in sulfur and ash and with a heat content improved by as much as 60 per cent. This process will probably add significantly to the final cost of the cleaned coal.

(2) Coal Liquification

Processes are being developed to produce low-sulfur and relatively high-heat value fuel oil from coal. Coal is reacted with steam to produce a low cost gas with a high carbon monoxide content. Pulverized coal mixed with the oil product is reacted with the gas and more steam at high temperatures and pressures, producing oil, ash and hydrogen sulfide gas.

(3) Coal Gasification

Methods are being investigated for turning coal into a synthetic gas suitable as a substitute for natural gas. The basic process involves crushing coal to a powder, then heating this material in the presence of steam and oxygen. The gas produced is then refined to reduce the content of sulfur and other impurities and to increase the methane content. Also under investigation are methods of burning coal in *situ*, that is, burning the coal while it remains underground, to produce gas. This eliminates the need for physically recovering coal from areas difficult or impossible to mine.

One of the major problems of both coal liquification and coal gasification is the large amount of water used for the steam which the processes require. Unfortunately, in many of the areas where there are large coal supplies, there is a shortage of water. This will complicate the large-scale development of these uses of coal.

(4) Magnetohydrodynamics (MHD)

One advanced concept for improving the efficiency of generating electrical energy from fossil fuels is magnetohydrodynamics. In this concept, hot flowing ionized gas is substituted for the rotating copper coils of the conventional electric generators.

Gases from the high temperature combustion of fossil fuels are made electrically conductive by seeding with suitable chemicals. This electrically conducting gas then travels at high speed through a magnetic field to produce a flow of direct current. The hot gases can then be used to fire a steam turbine generator, making the overall efficiency of the composite systems as high as 60 per cent, one and one half times that of a modern fossil fuel plant. Though laboratory-scale MHD generators are now operating, it is unlikely that large-scale electrical production from this source will become practical before the end of this century. Although substantial problems remain to be solved in materials engineering, reliability, long-term durability and emission controls, MHD is one of the more promising concepts of electrical energy currently under study.

(5) Internal Combustion Engines

One approach which is becoming increasingly useful in helping to resolve short-term power shortages is the use of internal combustion engines in factory-assembled packages. These are currently available in 40 megawatt units which can be delivered and set up far more quickly than any other type of electrical generating systems. It is expected that 100 megawatt units will be available by 1990. These systems burn expensive, high quality fossil fuels and produce less environmental pollution. They are used primarily when the electrical demand exceeds the capacity of the cheaper electricity from turbine generators or as emergency power sources close to centers of large demand. This approach represents an inefficient use of our fossil fuel reserves.

(6) Fuel Cells

Developed initially for on-board power for the Gemini and Apollo spacecraft, fuel cells are attracting attention from utilities as small units or backup power sources. In fuel cells, hydrogen, which can be produced from just about any type of fossil fuel or the decomposition of water, is chemically reacted with oxygen from the air to produce electricity. Done electrochemically, without having to go through the inefficient combustion steps required by most other fossil-fueled electrical generating approaches, this process allows conversion efficiencies as high as 60 to 70 per cent.

Fuel cells emit almost no air pollutants, require no cooling water, and operate quietly. They would be relatively small and inconspicuous.

Small units (12.5 kilowatts) using natural gas as their energy source are now being installed in single-family residences to supply the entire electrical needs of the dwelling. Larger (10 megawatt) units have been built and are being tested by various utilities. Power plants with electrical generating capacities of up to several hundred megawatts are envisioned for the future. Such units would not replace other power generation sources but would rather supplement power systems, giving electric utilities additional flexibility for providing the right amount of power where and when it is needed.

B. Power from Renewable Natural Forces

(1) *Solar Power*

(a) Thermal Conversion Systems

Thermal conversion systems would involve an extensive array of steel pipes coated with materials heated by the sun's rays. In one concept nitrogen flowing through the pipes would gather the heat and transport it to tanks of molten salt. The molten salt can be heated to a temperature of about 1,000 degrees Fahrenheit for production of steam, which would power conventional turbines at a projected efficiency of about 30 per cent. The area required to supply energy to a 1,000-megawatt power plant would be about 10 square miles of collection surface, plus a 300,000 gallon reservoir of molten salt. Some type of energy storage would be necessary for nights and cloudy days. Unfortunately, technology has not yet produced practical energy storage systems. Current batteries are impractical because of their high cost and low efficiency.

On a smaller scale, solar energy collector cells are presently available for family home-heating.

(b) Direct Conversion Systems

Direct conversion devices can produce electricity from solar radiant energy. One direct conversion scheme is the launching of a satellite-mounted array of solar cells in synchronous orbit, which would permanently place the cells over a preselected position on the earth's surface. Radiant energy would be converted into direct current, which in turn would be converted electronically into microwave energy. Microwave energy would be beamed to huge antennas located on the earth's surface beneath the satellite. The energy could then be converted to alternating current. At the present stage of development, direct conversion devices are prohibitively expensive and not very efficient. The maximum efficiency of silicon cells so far achieved is about 16 per cent. To meet New York City's present power needs would require a 25-square mile solar collector panel and a 36-square mile receiving antenna on earth. Obviously, the initial cost of such a solar generating station would be much higher than that of present stations.

Another use of direct conversion devices when they become more efficient and less expensive would be to locate them on the roofs of buildings to supply a portion of the electrical needs of the buildings, especially that required to drive air conditioning systems on hot days.

(c) Solar Sea Power

Proposed initially by the French physicist Jacques D'Arsonval in 1881, solar sea power has recently received renewed interest. The concept involves the use of temperature differences between sun-heated surfaces and colder water deep under the surface to power heat engines. Vast areas of tropical waters offer a tremendous source of essentially pollution-free energy. Since the water retains the heat of the sun, such plants, unlike other types of solar plants, could operate at night and during cloudy periods.

The technology for such plants has yet to be developed, but they are envisioned to be large, extending a half mile or more under the water to reach the deep cold water. Since the temperature difference between this cold water and the surface waters is only in the range of 35 degrees Fahrenheit, such a power plant would have a thermal efficiency less than one-tenth of the efficiency of a conventional, modern fossil-fueled plant. This would necessitate the pumping of an enormous amount of water through the heat engine per kilowatt hour of electricity produced. The final problem with this approach is that the tropical areas where such plants can be set up are far from most of the places where the electricity is needed.

(2) *Geothermal Power*

Power plants using hot water or steam that is stored in the earth from volcanic activity have been in operation in Italy since the turn of the century. Sources of geothermal energy are currently under development in this country and New Zealand. Geysers in California presently produce electricity in the United States.

In a few places natural steam is available. In many places, hot water can be tapped as a usable energy source. Also, there are areas of intensely hot underground rock that can be used by fracturing the rock and forcing cold water down to it. The heated water can be returned to the surface to produce steam power.

For all its seeming simplicity, however, geothermal power is not without its problems. The hot water is corrosive and turbines must be operated at low efficiencies (10 to 15 per cent) because of the relatively low steam temperatures available. The salt water from these wells can become a pollutant, and there is often an emission of ammonia and hydrogen sulfide into the atmosphere. There also exists the possibility of land subsidence and an increase in seismic activity.

Total exploitation of all the country's known geothermal resources would amount to less than one

per cent of the projected consumption of electricity by the year 2000. So this energy source presents no significant solution to long-range energy problems.

(3) Tidal Power

Tidal power uses the energy of tides, which reverse direction four times a day. Power plants can be located only where a large tidal flow and head exist in a bay or estuary which can be dammed. The basin is allowed to alternatively fill and empty, the water being routed through reversible hydraulic turbines. Total exploitable tidal energy resources amount to less than one per cent of the projected United States electrical consumption by the year 2000.

(4) Wind Power

Propeller-driven generators can convert the wind's energy into electricity with an efficiency of approximately 70 per cent. Like water power, wind power has the advantage of producing no pollution and no waste heat.

It is envisioned that such generators would be located some 20 miles offshore on oceans or the Great Lakes where they could catch the strong prevailing winds. Because the wind is so variable, the success of wind power will depend on improvements in methods of energy storage.

C. Fusion Power

The most probable long-range resolution to the dilemma of dwindling fuel is fusion, the process which powers the stars. In fusion, two light nuclei are united to form a heavier nucleus, thereby releasing energy. The fusion reaction will use the heavy isotopes of hydrogen known as deuterium and tritium. Deuterium can be economically separated from sea water, and tritium can be obtained in a nuclear reaction involving lithium. Fusion is expected to produce amounts of long-lived radioactive waste that are insignificant compared with current fission reactors. So here may be the ultimate fuel—cheap, clean, abundant and available to all.

To make controlled fusion work, one must heat an electrified gas called a plasma to temperatures on the order of 300 million degrees centigrade, hotter than the interior of the sun. This gas must then be contained in some way so that it does not touch the walls of the vessel, and held in this condition until an adequate number of fusion reactions take place.

One approach is to confine a fusion plasma with the use of specially-shaped magnetic fields which control the motions of the plasma. However, when attempts were made to apply this technique, spontaneous turbulence and unstable plasma oscillations significantly weakened the confining effect of the magnetic fields in early experiments. After many years of intensive theoretical and experimental research, the plasma instability problem was brought under reasonable control by the late 1960's. In fact, there is enough understanding of instabilities and means for their control to permit experiments in confining the plasma and to renew optimism for the successful development of commercial fusion power.

In current fusion experiments, more energy is expended than recovered. Plants are now being considered to demonstate break-even fusion power generation under reactor conditions, in which the energy recovered will equal the energy expended. This accomplishment, if achieved, will be a major national achievement and a major step toward a U.S. commercial fusion power capability.

Another potentially feasible approach is the use of high-powered lasers to initiate and confine fusion reactions. Here the concept is to bombard small pellets of frozen dueterium and tritium with many high-powered laser beams aimed from different directions, instantaneously heating the pellets to ignite fusion and at the same time containing the atoms in the pellets in the converging beams long enough to obtain useful output of power. Lasers big enough to test the feasibility of this concept are just becoming available. The technical problems concerned with either fusion concept are immense, probably putting the time of the first commercial fusion power plants into the next century.

D. Power from Garbage and Organic Wastes

The same process for coal liquification can be used with garbage and organic wastes substituted for the coal. It produces a 20 to 30 per cent yield of oil, based on the weight of the dried raw material. The direct incineration of municipal garbage as fuel is already being accomplished.

E. Power from Stored Energy

The demand for electricity varies considerably from season to season, day to day, and even hour to hour, but electricity cannot be generated and stored for the peak times. It must be consumed as it is generated. Thus, the generating capacity of a system must be geared to meeting peak demand; there are periods of time, especially during the night and weekends, when much of the generating capacity is not being used. Methods are being sought to make greater use of this idle capacity by energy storage. storage.

(1) Pumped Storage

As mentioned before, hydroelectric plants are useful sources of power, but most sites on which hydroelectric plants can be built have already been exploited. In the pumped storage concept, electricity is used to pump water to high reservoirs during periods of low electrical demand. Then, during peak demand, the stored water is released to turn hydraulic turbines to produce the additional power needed.

While such systems make better use of power plant equipment, losses in the process amount to about 33 per cent. That is, for every three kilowatts used to pump the water to the reservoir, only two kilowatts are later recovered.

This type of facility is particularly well-suited for large communities with a concentration of industry and a heavy, but widely varying, demand for power. Suitable sites for this type of fluxuating water storage are limited, and this concept is meeting increasing opposition from environmentalists, because it involves the flooding of large areas with the stored water.

(2) *Compressed Air Storage*

Another method of storing reserve energy is by compressing air in large underground caverns. Unlike water, air can be stored almost anywhere that firm rock exists underground. A small water reservoir is necessary to maintain constant air pressure, and the air system is used only in conjunction with gas turbine generators. Off-peak electricity is used to run a large air compressor, which compresses air to about 40 atmospheres, about 1,500 feet underground. This air is later released to run the gas turbine. The overall effectiveness of an air system is better than pumped water storage, with losses amounting to about 25 per cent, or three kilowatts recovered for every four used to store the air.

(3) *Hydrogen Fuel Economy*

A proposed approach which is gaining more advocates is the use of hydrogen gas as a fuel. Unlike fossil fuels, hydrogen would not be a primary source of energy, since it is not found in any significant quantity in nature in its unreacted form. But it could be a carrier of energy with vast flexibility.

Hydrogen is virtually an ideal fuel, since it burns in air to form non-polluting water vapor. The only possible pollutants are the nitrogen oxides formed from the components of air. If it is burned in pure oxygen, even this pollutant is eliminated.

Hydrogen would be easily transported in existing natural gas lines and readily stored near where it is needed for power generation. Actually, for the long-distance transmission of energy, it would be more efficient to transmit hydrogen gas than to transmit electricity over power lines, where there are line losses.

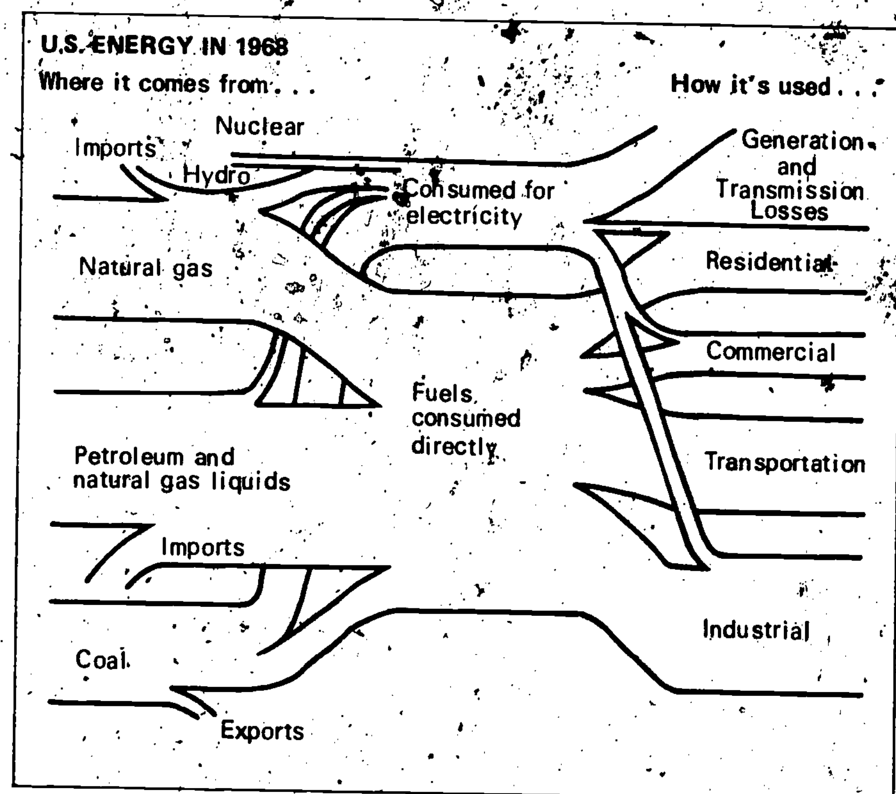
It is envisioned that large coastal power plants, such as nuclear or solar, would use their excess capacity to electrolyze water, producing oxygen and hydrogen gases. The efficiency of these electrolyzers would be 60 to 70 per cent. The large plants could, therefore, operate continually at 100 per cent of their installed capacity, and the hydrogen (and, if needed, the oxygen) would then be piped to terminals and dispersed throughout the local areas, where it would be stored until needed. The gas would then be burned in efficient combustion turbines or in even more efficient fuel cells.

SUPPLEMENTARY

MATERIALS

FOR

CHAPTER 2



BASED ON GRAPHICAL SCHEME BY EARL COOK, TEXAS A & M UNIVERSITY. RELATIVE VERTICAL SCALE IS BASED ON A 1972 STUDY BY THE U.S OFFICE OF SCIENCE AND TECHNOLOGY OF ENERGY CONSUMPTION.

The purpose of this meter reading information is to provide students an opportunity to practice conservation and see the results, to develop the ability to read accurately electric meters, and to develop in the student a desire to conserve energy.

The student exercise is designed as a two-week activity involving three meter readings. The teacher may wish to have the meters read each day at the same time for more practice, accuracy, and as a means of comparing daily consumptions. (How does a weekday compare to a Sunday? Why?)

The teacher may wish to contact the local power company to see if the school could obtain a used meter for demonstrations.

On some wall of your home–basement, garage, or most often outside–you will find an intricate glass-enclosed device. If you are like most people, you seldom pay any attention to it. Nor do you need to, for modern electric meters perform their job so accurately and reliably that you need never be troubled. But, every month or so, a man from your electric utility company comes to see it, and later you are billed for the exact amount of electricity used.

Meters Measure Electricity. Through your meter's glass enclosure, you can see a revolving aluminum disk and a series of dials and pointers, or digital numbers. Without explanation, they don't make much sense, but they are really quite simple.

The amount of electricity you use determines the speed at which the disk moves. The more electricity you use, the faster it turns. Each revolution represents a portion of an electric energy unit called watt-hour. This watt-hour measurement is transferred from the disk through a series of gears to the digital numbers or pointers on the dials.

Just What Is A Watt-hour? Every hour a 100-watt light bulb burns, it uses 100 watt-hours of electric energy. Since a watt-hour is such a small unit of energy, your electric utility company uses a unit equal to 1,000 watt-hours–a kilowatt-hour–to measure the amount of electricity used.

What Makes Your Meter Disk Turn? There are two sets of connections which cause your meter to register: (1) the amount of current flowing into your house, and (2) the pressure or voltage at which the current is flowing.

Electric current is like water flowing through a pipe. The rate of flow of electrons through a line is measured in amperes. Pressure is the force that pushes electric current through the lines, measured in volts. To determine the electrical power (watts) used, multiply amperes to current by volts of pressure. Your electric bill is stated in watt-hours.

Clock-Like Meter Accuracy. Friction inside the meter is all but eliminated with the use of a magnetic-suspension system which uses a magnetic field to float the disk and its shaft in air. To help maintain accuracy provided by magnetic suspension and other design features, the meter is sealed with filters which keep its interior free of dust and other contaminants that can cause inaccurate meter registration.

Your Meter–A Small Motor. Your meter is basically a small induction motor run by magnetic forces created by electricity in a set of coils. The voltage coil is a winding of wire connected to the power supply lines. The current coil is a winding of wire connected with the household wiring. When current passes through these coils, the disk is forced to turn at a speed exactly proportional to the number of watts (amps x volts) of electrical power being used.

Meter Progress To Meet Your Needs. Meters have changed a great deal in the last 20 years. They have had to. Television, electric heating, more lights, freezers, air conditioners, water heaters, and other new appliances have more than quadrupled the average family's consumption of electric power. Twenty years ago a meter rated at 600 watts was enough to meet average household requirements. Today's meters are capable of handling up to 48,000 watts.

How To Read Your Kilowatt-Hour Meter. The kilowatt-hour meter is an instrument used to measure electrical energy consumed by a customer.

Two types of meters used by the power companies are the digital- and dial-type meters. The digital meter is read directly from left to right as shown in Figure I. Readings on some digital meters are obtained by multiplying by 10.

	8	2	9	0		= 8,290 kwh
0	8	2	9	0		= 8,290 kwh
	0	8	2	9	X 10	= 8,290 kwh

FIGURE I

Digital Kilowatt-Hour Meters

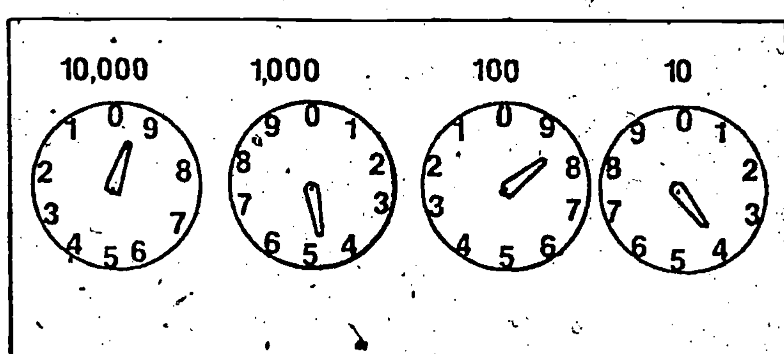
Most meters have four or five dials. (See Figure II, page .) The figures above each of the dials indicate the number of kilowatt-hours (kwh) registered by the meter during the time that the hand on that dial made one complete revolution. So, when the hand on the right-hand dial has passed from one figure to the next, 1/10 of 10 kwh, or 1 kwh, has been used.

Be sure to read the meter *"backwards"*–from right to left–and remember to read the smaller of the two numbers between which the pointer on the dial is standing. This is very important.

Note that the pointers of the 10 and 1,000 dials rotate clockwise, and counterclockwise on the 100 and 10,000 dials.

During the time that the pointer on any one dial is making a complete revolution from 0 to 0, the pointer on the next dial to the left will pass from one figure to the next. Therefore, although a pointer on one dial may appear to have arrived on a given figure, that figure should not be read unless the pointer on the dial to the right has reached or passed 0.

For example, in Figure II, the pointer on the 1,000 dial looks as if it is on the 5, but you should read that dial "4" because the pointer on the 100 dial, to the right, has not made a complete revolution to 0. The correct reading is shown under the dials.



9 4 8 4

FIGURE II

Dial Kilowatt-Hour Meters

Kilowatt-Hour Record
(Student Activity Sheet)

Read your kilowatt-hour meter at home and record the reading.	A. ______
Read 1 week later and record the reading.	B. ______
Subtract B from A to determine kwh used during the 1st week of your experiment.	C. ______
During the 2nd week, encourage your family to conserve all the electricity possible. At the end of your 2nd week, again read the meter and record.	D. ______
Subtract D from B to determine Kwh used during the 2nd week of your experiment.	E. ______
Subtract E from C to determine how much electric energy your family saved over the previous week.	F. ______

1. Were you successful or did you use more electricity?

2. If you used more, can you explain why?

3. Why would someone with an electrically-heated home have to consider the temperature during the 2 week

4. List all the energy-saving steps your family took.

ADVANCED METHODS OF POWER GENERATION IN THE EIGHTIES

L. G. Hauser[1] P.E.

Introduction

Starting with George Westinghouse and his now famous alternating current power system, inventors and engineers have continuously advanced the technology of electric power generation. Progress has been rapid and effective. The large, efficient steam turbine generators of today are indeed monuments to engineering ingenuity and dedication.

Obviously, engineering progress will not end with today's designs. What, then, might electric power generation of the 1980's be like? Will steam still be the basic working fluid? Will solid state generators become the workhorse of electric utilities? Or has the technology reached the limit justified economically? These are only samples of the many questions that face the long range utility planner today. This paper will present one author's assessment of power generation in the 80's - which, from a commitment date, begins just 5 years from now.

FORECAST OF NEW CAPACITY REQUIRED 1970-1990

It is common knowledge that the Electric Utility Industry has been growing at a rate which doubles its capacity every ten years. This annual growth rate in the seventies is expected to be slightly more than 7 per cent per year tapering off to a growth rate in the latter part of the 1980's of approximately 6 per cent per year.

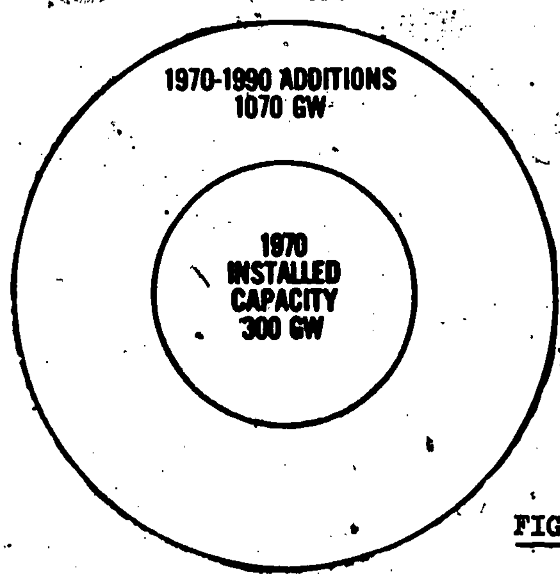


FIGURE 1

Figure 1 shows graphically what this means in required generation capacity. At the beginning of 1970 the installed capacity was slightly in excess of 300 gigawatts (a gigawatt is 1000 MW or 1 million KW). The outer circle in Figure 1 is drawn graphically to show that the planned and expected additions in the next twenty years will be equal to 1,070 gigawatts, or roughly three times the capacity in existence at the beginning of 1970. These additions are based on the growth rates mentioned above plus an installed reserve capacity of 20 per cent of the annual peak load.

GENERATION ADDITIONS BY TYPE OF DUTY CYCLE

In years past the general practice of utilities has been to add new generating capacity in the form of new base load units to their system, and to relegate the older units to a lesser duty cycle. This made economic sense, since new base load plants were obtainable in ever increasing unit sizes, at ever increasing efficiencies. Thus, the new plant, which would be the most efficient, would operate at base load and the less efficient plants would operate on cycling or standby service.

The significant change has occurred in this pattern and this change will continue throughout the next twenty years. That is, new, large, efficient base load units (boilers and turbines) which have recently been added to the systems, are not desirable units to operate in cycling, load-following types of service. Thus, as new base load units are added to utility systems, utilities can no longer place their present day base load units into a lesser duty cycle operation because they are not suitable, technically or economically, for operation in a cycling mode.

Therefore, the 1,070 gigawatts of new additions will be composed of three different types of generation capacity. The first is the normal, large, efficient units known as base load units.

[1] *Manager, Fuels and Energy Systems Power Systems Planning,* Westinghouse Electric Corporation, East Pittsburgh, Pa.

The second is intermediate generation capacity which operates, as shown in Figure 2, on the annual load duration curve, at 20 to 50 per cent load factor.

This intermediate type of generation normally has the following characteristics:

a. Unit size - 200 to 600 MW
b. Relatively low capital costs
c. Designed for daily start-up
d. Capable of rapid load change
e. Designed for hot-standby operation

The third type of generation capacity is the peaking and standby reserve generation which is identified on the upper portion of the annual load duration curve in Figure 2.

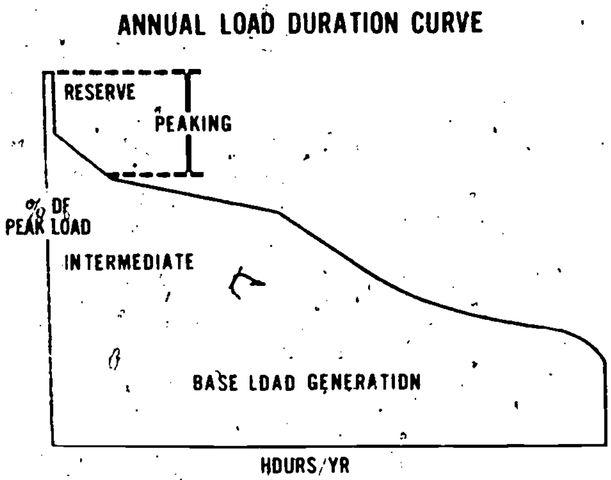


FIGURE 2

Figure 3 shows the distribution of the 1,070 gigawatts to the three types of generation. Westinghouse expects base load generation additions to approximate 500 gigawatts; intermediate generation, 400 gigawatts; and peaking generation, 170 gigawatts.

It is desirable to have this basic understanding in the growth of generation requirements by types of generation before an assessment of future methods of power generation is made.

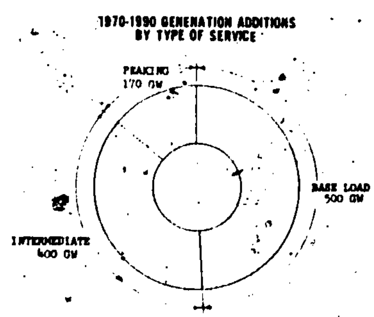


FIGURE 3

CONVENTIONAL GENERATION

The traditional systems of power generation have three basic steps as shown in Figure 4.

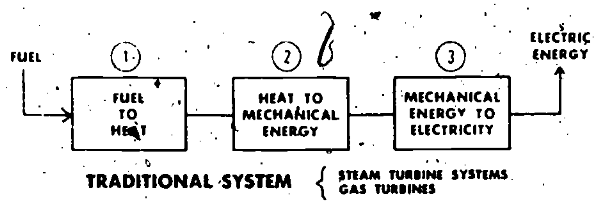


FIGURE 4

The first step is to convert fuel to heat, the second is to convert the heat to mechanical energy, and the third step is to convert the mechanical energy to electricity. This traditional system describes what happens in the boiler steam turbine-generator system and also in the gas turbine-generator system.

DIRECT CONVERSION GENERATION

A new type of generation which may find an application in electric utility use is known as direct conversion. This type has only two steps; in the first step the fuel is converted to heat, and in the second step the heat is converted directly to electricity. Types of direct conversion generation include fuel cells, MHD, thermionic conversion and thermoelectric generation. None of these systems is in use today for bulk power generation in the electric utility industry.

Now with the amount of new capacity required during the next twenty years determined, the type of duty cycle this capacity must satisfy identified, the different steps that are involved in conventional and direct conversion generation defined, it is logical to proceed to examine each of these steps for potential advances in power generation.

STEP ONE - FUEL TO HEAT

Presently there are four fuels utilized to generate kilowatt hours: namely, oil (12%), gas (28%), coal (58%) and nuclear (2%). However, by 1980 coal and nuclear fuel will supply 75 per cent of the kilowatt hours generated. Therefore, we will only consider advanced methods of generation that could be utilized in the conversion of coal or nuclear fuel to electricity.

TABLE 1

U.S. Coal Consumption
(Millions of Tons)

	1969	1980(Est.)
Total U.S.	595	793
Electric Utility Industry	325	508
E.U. % of U.S. Total	54.5%	64%

Table 1 shows a recent projection of U.S. coal consumption. In 1970 the total consumption in the U.S. was 595 million tons. Consumption is expected to increase to 793 million tons in 1980. Most of this increase, as is shown in the table, occurs in the electric utility segment of the coal market. As a result, the electric utility share of the total coal consumption increases to 64 per cent by 1980.

The present method of utilizing coal is in the very efficient steam boilers used by electric utilities today. These boilers approach 90 per cent efficiency which means that this is not a very fruitful area for additional research and development effort to produce significant improvements in efficiency.

However, there is a new type of boiler, known as the fluidized bed boiler, now under development which has the significant potential advantage of much smaller physical size. If this system of combustion is utilized at relatively high furnace pressures, such as 10 atmospheres, it is expected that boilers will be greatly reduced in size. For example, a 300 megawatt boiler could conceivably be transported on one railroad flatcar. In this type of combustion the heat transfer surface, or boiler tubes, are immersed directly in the pressurized, fluidized, combustion zone. It is expected that heat transfer coefficients would be markedly improved and the required furnace volume significantly reduced.

The United Kingdom has performed considerable development work on this type of boiler, and interest in the U.S. has recently increased because of reduced air pollution (SO_2 control) and potential cost savings that this system promises.

The other base load fuel, that is, nuclear fuel, presents an entirely different picture. The present light water nuclear reactor utilizes less than one per cent of the energy in uranium fuel. In other words, it has an equivalent *combustion efficiency* of less than one per cent. Therefore, new reactor systems need to be developed to increase this *combustion efficiency*. And this is exactly where the research and development effort is currently being expended. The type of system that is being developed in this country is known as the liquid metal fast breeder reactor or LMFBR. Westinghouse, in cooperation with electric utilities and the AEC, has an extensive program underway at the Advanced Reactors Division, located at Waltz Mill, to develop a liquid sodium fast breeder reactor.

Figure 5 shows a schematic of a typical fast breeder plant with the primary sodium loop, the intermediate sodium loop, and the final steam loop with 1000°F, 2400 psig steam. The significant difference between this and the present light water reactor in the utilization of the energy in uranium is approximately 80 to 1. In other words, this system will have an equivalent *combustion efficiency* approaching 80 per cent versus the light water reactor *combustion efficiency* of less than one per cent. Obviously, the development of the breeder reactor is of long range importance to this nation and it is a development which the economics of energy resources will encourage this nation to make.

STEP TWO - HEAT TO MECHANICAL ENERGY

The overall plant efficiency of a steam turbine plant is comparatively low in terms of absolute numbers. For example, a fossil burning, modern steam plant at 40 per cent overall efficiency would be about the best that can be done with present day technology and economics. This would be a supercritical, 3500 psi, single-reheat machine, operating at 1000°F. The reason for this, of course, is that the steam turbine is a heat engine and consequently must follow Carnot's Law. One or two more points in efficiency could be obtained if the unit were designed for 5000 psi, with double reheat to 1050°F, but very seldom is such a design economically justified.

Thus it is apparent that significant gains in steam turbine plant efficiency are not expected in the near future. On the other hand, perhaps reduced capital costs could be obtained with different cycle arrangements. At low pressures, steam occupies tremendous volumes. A fluid which has much higher density per unit volume might be preferable in turbine design. Such a fluid could be ammonia or freon.

TYPICAL FAST BREEDER REACTOR PLANT

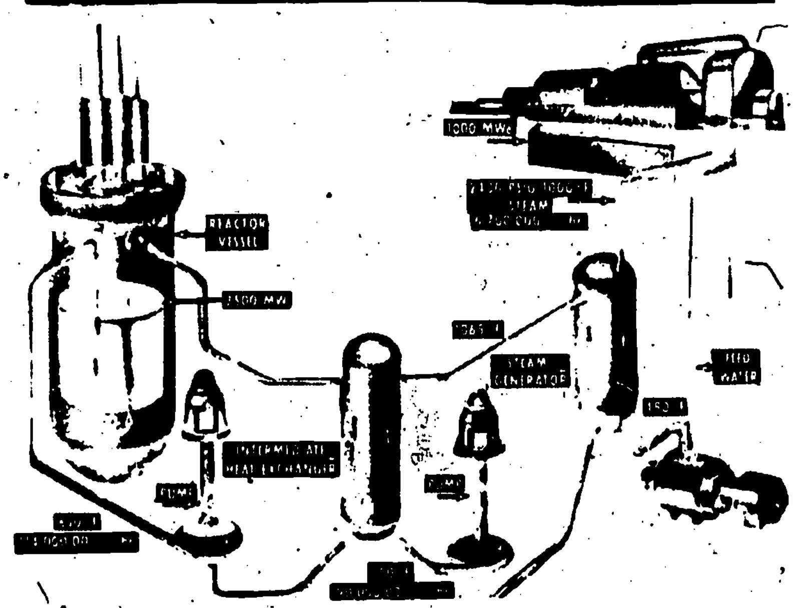


FIGURE 5

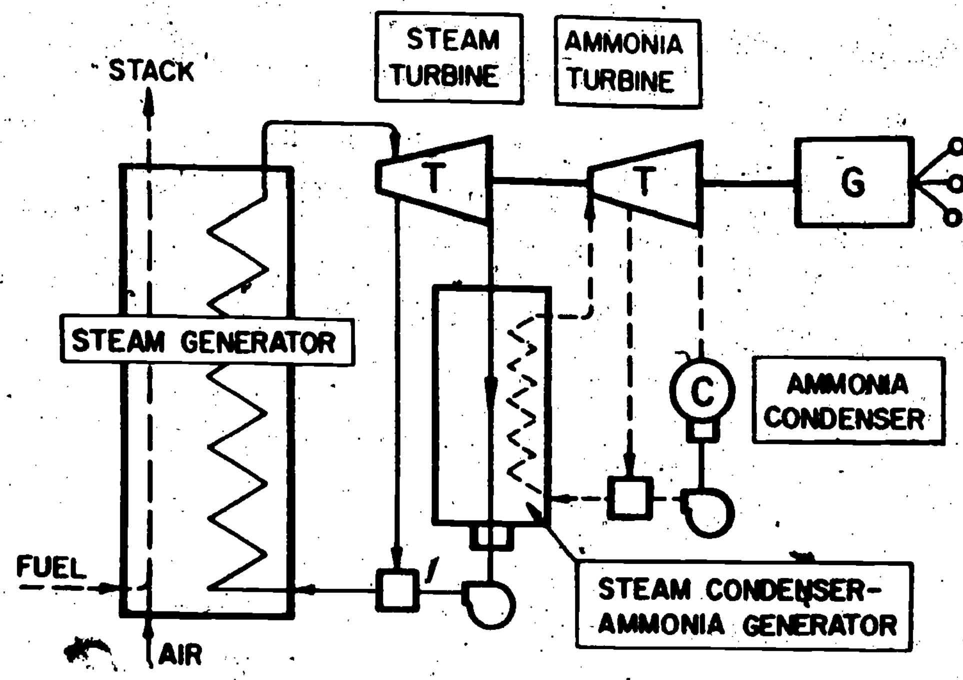


FIGURE 6

Figure 6 shows a schematic design of a binary cycle, utilizing steam in the high pressure and temperature part of the cycle, and ammonia in the low temperature part of the cycle. The steam generator would be a conventional boiler, fossil fired, producing 1000°F steam for a conventional high-pressure steam turbine. At the crossover point in the turbine, at about 250°F, 200 psig, the steam would exhaust into a steam condenser rather than going to a low pressure steam turbine. The cooling fluid in the steam condenser could be ammonia. The heat that the ammonia takes from the exhaust steam would then be utilized as a source of energy to drive an ammonia turbine on the same shaft with the HP steam turbine. The exhaust from the ammonia turbine would then go through an ammonia condenser with cooling water as the heat sink at the bottom end of this thermal cycle.

The advantages of a binary cycle are illustrated in Figure 7. A small ammonia turbine could replace a large, four flow, low pressure, steam turbine. This would lower turbine capital costs in the overall plant, but may increase the heat rate and fuel costs. Recent economic evaluations of this system have indicated that the cost and efficiency of a binary cycle is a standoff with a conventional steam cycle. However, as units become larger and larger, with larger and larger low pressure ends, it is possible that in the future, binary cycles will be more economical than conventional cycles.

A second area for examination is the gas turbine which, in essence, combines two energy conversion steps in one machine. It converts fuel to heat and heat to mechanical energy in the same piece of equipment. Compared to a steam turbine plant, the present simple cycle gas turbine is relatively inefficient. But the gas turbine also is a heat engine subject to Carnot's Law and therein lies the secret for improved gas turbine efficiencies. By increasing the turbine inlet temperature, significantly higher efficiencies and resulting higher outputs can be obtained from the gas turbine.

TABLE 2

Effect of Inlet Temperature on Gas Turbine Output

Turbine Inlet Temp. °F	KW/lb/sec of Air Flow
1600	90
2000	125
2400	160
3000	210

Table 2 shows the rapid increase in output for a given frame size of turbine versus the turbine inlet temperature. New models currently in production will operate at temperatures slightly less than 2000°F. By increasing this another 1000 degrees, we can almost double the output of the gas turbine. Extensive research and development is currently being expended on materials and blade cooling methods so that the turbine inlet temperature can be increased.

One of the reasons for the low efficiency of the simple cycle gas turbine is that the temperature of the exhaust gas is still relatively high resulting in a high fraction of the total heat input rejected to the atmosphere. Therefore, combining the gas turbine with a steam turbine would seem to be a logical course to follow to recover this heat. Westinghouse recently announced the PACE plant, which is a 250 megawatt combined cycle gas turbine, steam turbine

COMBINED CYCLE

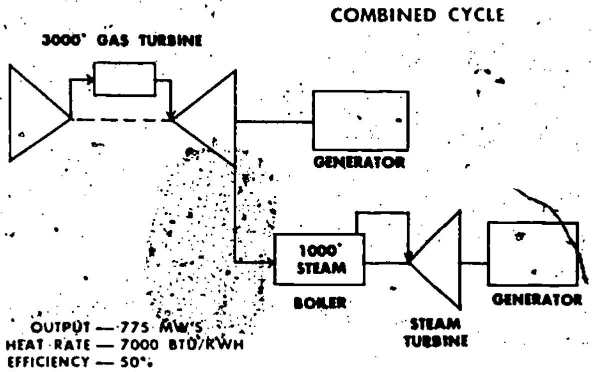


FIGURE 8

power plant. The exhaust gases from the gas turbine which are at approximately 1000°F are passed through a heat recovery boiler, with some post firing, to make 950°F steam for a steam turbine generator set. Figure 8 shows a future combined cycle plant utilizing a 3000 degree gas turbine and a 1000 degree steam turbine. The output of this plant would be 775 megawatts. The overall efficiency would be 54 per cent compared to the current steam plant rate of 40 per cent.

Figure 9 shows another concept for an advanced coal burning power plant. In this case the coal is gasified in a fluidized bed gasifier, and then the gas is fed to gas turbines in a combined cycle configuration with an air cooled steam condenser. The expected heat rate on this plant might be 9000 BTU per kilowatt hour with an installed cost of $150 per KW. Present technology will allow this plant to be built with a capacity of 250 MW, it would burn coal and would meet the most stringent air pollution regulations contemplated. The major developmental effort required is in the area of coal gasification technology. Several companies are investigating new methods of coal gasification and technical progress seems assured.

DIRECT CONVERSION - HEAT TO ELECTRICITY

One of the most promising methods of power generation by direct conversion is the fuel cell. Fuel cell power plants could have several advantages; medium high efficiency, essentially no cooling water requirement, minimum air pollution, and compactness. The efficiency and cell costs per unit of power do not vary appreciably with total plant

CONCEPT OF AN
ADVANCED COAL BURNING POWER PLANT

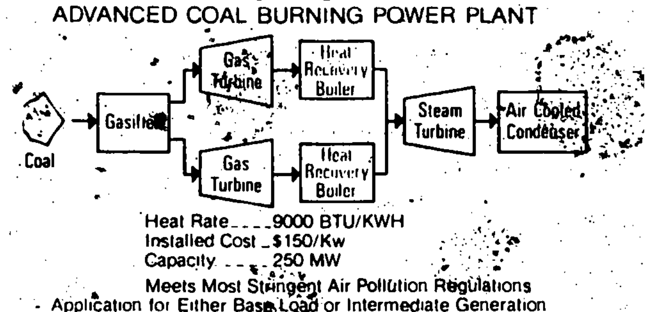


FIGURE 9

capacity. This allows the sizing of the plants to meet the optimum generation requirements without the necessity of considering the effect of scale economy. The second most important point to consider is that the fuel cell should be able to utilize an abundant electric utility fuel. This requirement eliminates natural gas as a source of fuel for fuel cells because of anticipated long term unavailability. However, most of the development effort today is directed to natural gas burning fuel cells. This does not appear to offer a long term solution to electric power generation. A fuel cell plant, to be a successful generating [illegible] must be able to utilize coal, the only fossil fuel that is readily available to electric utilities in sufficient quantities for long term bulk power [illegible].

An [illegible] was under development by Westinghouse in cooperation with the Office of Coal Research, Department of the Interior. This was a coal burning, high temperature solid electrolyte fuel cell. The solid electrolyte of the fuel cell was composed to zirconia which is a ceramic material with very unusual properties. If the zirconia is heated to 1000°C, it has the property that it is impervious to all gases

and ions except oxygen ions. In other words, negatively charged oxygen ions will pass through zirconia material but other ions and gases such as nitrogen, hydrogen, carbon monoxide or water vapor will not penetrate the material when its temperature

to 10,000°F. This is not feasible utilizing present fuels and materials technology. However, this requirement can be changed by adding a seeding material, such as cesium, to the hot air. When the hot gas stream is seeded, it becomes ionized at approximately

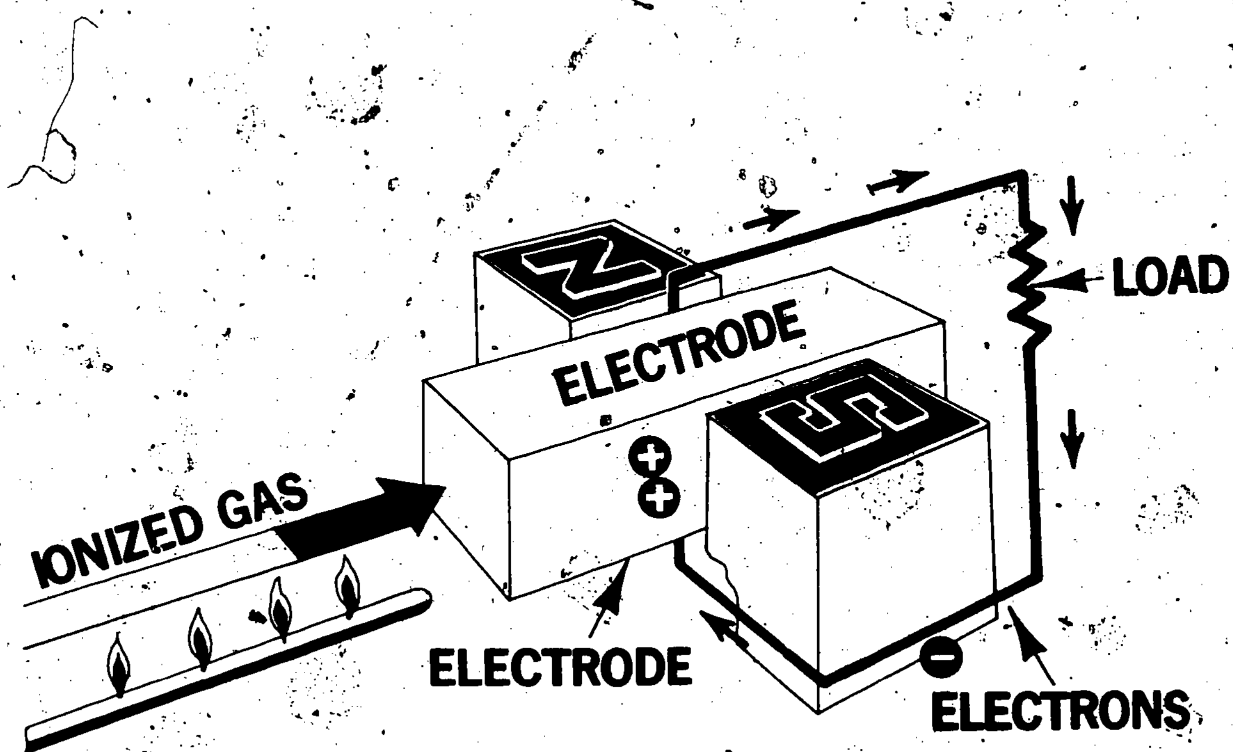


FIGURE 10

exceeds 1000°C. While the characteristics of zirconia seemed to be promising for fuel cell applications, progress towards a reliable, long life cell was disappointing. As a result, development effort on this cell has been suspended. Basic research in properties of materials continues.

Magnetohydrodynamics, commonly known as MHD, is another method of direct conversion of heat to electricity. Figure 10 shows schematically the principles involved in magnetohydrodynamics. If an ionized gas is passed through a strong magnet field, an electrical potential is created in much the same manner as a solid conductor passing between two magnetic poles creates an electrical potential. At first blush, this sounds like an exciting method to generate electricity. In fact, many political and industrial leaders, even today, are advocating the expenditure of tremendous efforts and monies to develop this method of power generation. Our corporation does not share this enthusiasm for some very valid reasons. First, for air to become ionized it must be heated

4000°F. Coal can be burned to 4000°F provided proper air preheating is utilized; however, the technology and equipment for this combustion temperature have not yet been developed.

In order to generate a practical voltage, the speed of the ionized gas in the MHD duct should approximate 2000 miles per hour. It is true, that industry knows how to build supersonic aircraft to approach this speed; however, they have not yet mastered, from the materials standpoint, this speed in ducts at the temperatures required.

A third point to consider is that the unit requires an ultra high magnetic field strength approximating 60,000 gauss. The only feasible method of obtaining this magnetic field strength is with superconducting magnets. The MHD duct would be surrounded by superconducting magnets operating at minus 450°F. It takes little imagination to

recognize the significant thermal stress problems that will be encountered with superconductivity temperatures on the outside of the duct wall and with 4000°F gases on the inside of the duct wall.

But even if all of this is developed and works properly, the efficiency of MHD would not be satisfactory because the entering temperature is about 4000°F and the exiting temperature from the machine is approximately 3000°F. MHD is a heat engine and hence will follow Carnot's Law. The efficiency, with such temperature conditions, would not be accepted for a method of bulk power generation.

Most proponents of MHD suggest the combined cycle approach as shown in Figure 11. The 3000 degree exiting gas from the MHD duct is passed through a waste heat recovery boiler producing steam. Figure 11 shows schematically some of the significant problems that must be solved in a 600 MW MHD plant. For example, the coal must be fed into the burner where it combines with preheated air to form a 4000 degree hot gas stream. The cesium seeding material is added in the burner so that the hot gas stream will be ionized at the 4000°F temperature. When the hot, seeded, ionized gas passes through the magnetic field in the MHD duct, approximately 300 megawatts of DC is generated.

After the hot, ionized gas passes through the air preheating heat exchanger, it is then fed to the heat recovery boiler where 1000 degree steam is produced. This steam turns the steam turbine which generates approximately 300 megawatts of AC. The exit from the boiler would be at conventional temperatures of approximately 300°F. However, it is necessary to recover the cesium seed and the fly ash. The economics of seeding dictate that 99.9 per cent of this seed be recovered. This will require electrostatic precipitators with performance values five times those currently in use in power plants to recover this seed and ash.

Since sulfur dioxide is produced in this coal combustion system, a sulfur dioxide removal system must be placed in the exit gas stream.

A third air pollutant, that of nitrogen oxide, would result from this process. In fact, this system is an excellent generator of nitrogen oxides because of the high temperature and long residence time in the combustor. Therefore, some type of nitrate recovery system would have to be devised and placed in the exit gas stream in order to make the system compatible with air pollution requirements.

One can appreciate the many development

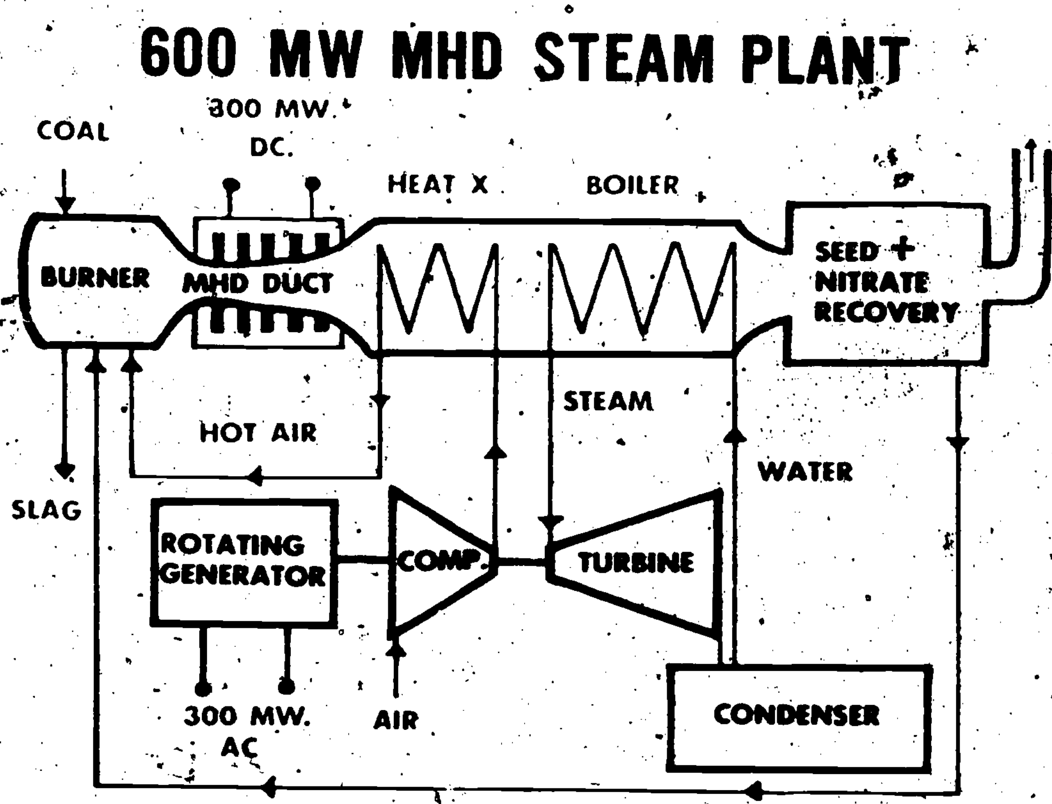


FIGURE 11

problems that have to be solved before this plant would be an acceptable bulk power generation plant. But the major point is that after all these development problems are solved, an overall plant efficiency of 50-55 per cent is the ultimate reward for the many significant developmental costs. This is the reason our corporation questions the MHD system as a promising avenue for advances in power generation.

There is a third method of direct conversion that holds promise. And that is nuclear fusion. This is on the very frontiers of science and it appears that a long period of development will be required. Present feeling in the scientific community is that fusion could be a major source of power generation after the year 2000. Of course such predictions are subject to revision by technological breakthroughs as they occur. Since this technology will be developed by exploring new areas of science, it is difficult for anyone to predict with any degree of confidence when, or if, fusion will become an acceptable economic method of power generation.

Summary

This paper is a brief overview of the new methods of power generation that may become available to the electric utility industry in the next 20 years. Table 3 shows a prediction of the time span required before these methods might become accepted in the utility industry. Note that a question mark has been placed after fuel cells because significant development still remains to be performed before the reliability of the individual fuel cells will reach the required values. It is very questionable if the MHD combined cycle will ever be developed as a source of bulk power generation.

TABLE 3

Predicted Timing for Advanced Methods of Power Generation

Type of Generation	In Operation
Light Water Reactors	Now
Gas Turbine Combined Cycle	Now
Fluidized Bed Boilers	1978-1980
Breeder Reactors	1980-1985
Binary Steam Cycles	1980-1985
Coal Burning Fuel Cells	1985?
MHD Combined Cycle	?
Nuclear Fusion	After 2000

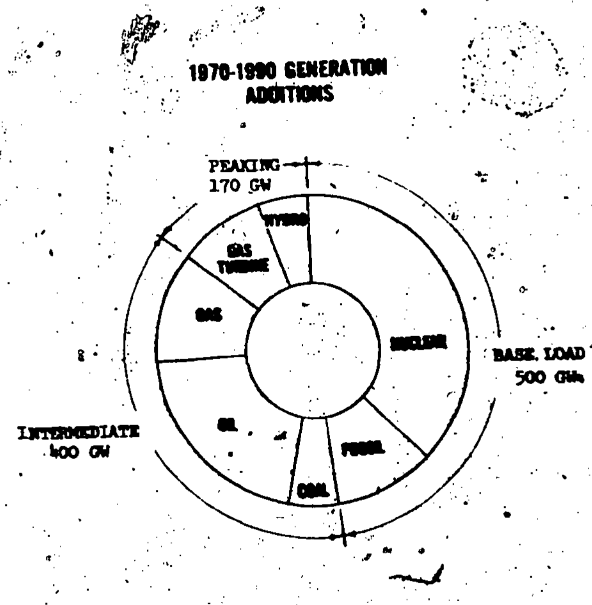


FIGURE 12

Figure 12 shows the Westinghouse prediction of the different types of generation additions by fuel source. In the base load portion of the circle, the fossil fuel will be mostly coal; however, a few residual oil plants may be installed for base load applications. In the intermediate generation portion of the circle, oil and gas will supply the major part because of the ease with which these types of boilers can be cycled and placed under load follow conditions. On the other hand, if coal gasification proves to be successful, coal will take a much larger segment of the intermediate market than is shown in Figure 12. In the peaking category the hydro capacity is mostly pumped storage and the gas turbine capacity will be mostly oil fired.

Some of the nuclear capacity will be of the breeder type and a portion of the fossil base load capacity will use the fluidized bed boiler. No significant generation capacity will be supplied by fuel cells, MHD, or other methods of direct conversion during this time span.

Between grandiose schemes for the future and esoteric research of the past, some applications of solar energy as a practical power source are beginning to emerge.

Joan M. Nilsen
Associate Editor

The outlook for harnessing solar energy is brighter as the energy crisis fosters new examinations of all possible power sources. Long considered an exotic concept, solar energy applications are coming down to earth as researchers at the university– as well as the industrial–level make intense efforts to solve the problems of collecting, storing and transmitting energy from the sun.

Solar-Heated Home–In late July, Solar One, an experimental solar house built for the University of Delaware's Institute of Energy Conversion, was dedicated. The 1,200-sq. ft. house has 24 solar roof-panels that will supply part of the house's heating and cooling needs and will also provide some of its electrical requirements. The 4 ft. by 8 ft. solar panels are about 6.5 in. thick and are positioned in a southerly direction. The weather-tight outer surface is made of acrylic sheet. Beneath this layer, but separated with air spaces, is a second layer of acrylic, a layer of 1/16-in. aluminum sheet that is painted black, and 1.5 in. of urethane foam. Cadium sulfide/copper sulfide cells located on the exterior side of the aluminum act as the heat collectors and generate electricity.

Air is introduced at the bottom of each panel and removed at the top by a manifold. Ducts then carry the heated air to the basement, where its heat is stored by the heat-of-fusion principle in 1.25 in. dia. plastic tubes containing a molten salt solution. Experiments by the University of Delaware researchers indicate that 150,000 Btu. of heat can be stored for up to a week. The energy cells are able to generate an average of 18 kw.hr./day of electricity for household use–on sunny days they are expected to generate about 50 kw. hr., about twice the house's needs.

If the solar house is successful, the developers envision a system whereby *excess* electricity that is generated during sunny days will be transferred to an electric utility. The utility will then *pay back* this electricity at night.

Solar Community–At a recent meeting of the Intersociety Energy Conversion Engineering group in Philadelphia, three full sessions (out of a total of 28) were devoted to solar power. For the most part, the 17 papers that were presented were practical discussions of present or proposed solutions to the many technical problems involved.

Members of the technical staff of Sandia Laboratories' Criteria and Heat Transfer Div. analyzed the feasibility of using solar energy to provide most of the residential-energy needs of a specially designed solar community. Their evaluation of five different community concepts led them to conclude that the most promising approach would be a *cascade system* using focused collectors. (The energy is *cascaded* from high-quality power generation to low-quality uses. See diagram.) The solar-collector system would consist of either a set of panels that concentrates the sun's radiation on parabolic mirrors and then focuses it on pipes similar to heat exchanger tubes, or a group of pipes coated with a material that allows the radiation to be selectively absorbed.

The admitted major problems in the use of solar energy lie in the collecting system and the storage units, and most research effort is being devoted to solving these difficulties.

Research–At the University of Minnesota, work is underway to fabricate a small-scale version of a solar-energy collector module, including concentrator, heat pipe, vacuum envelope, and calorimeter. The solar collector system will consist of several thousand trough-shaped mirror-surfaced devices that rotate with the sun. Each mirrored trough will be attached to a length of heat-absorbing pipe located in its center so that the sun's heat will be concentrated and directed onto the pipes. Fluid heated in the pipe will then flow to a heat exchanger at the end of the system.

Richard C. Jordan, professor of mechanical engineering at the University, notes that one of the most challenging parts of the project has been the development of selective surface-coatings for the reflectors. An analysis of various coatings is being conducted by researchers in the University's physical electronics laboratories, and studies of weather resistance are underway at test sites in Arizona, Florida and Minnesota.

In addition, a model heat-pipe (also see *Chem. Eng.*, Sept. 3, p. 58) has been built and tested with various transfer fluids, particularly water, mercury and potassium. Several hundred mixtures of chemicals that might be used for storing the collected energy also have been studied.

At the University of Houston, scientists are developing a slightly different approach to collecting and utilizing solar energy. The installation being proposed for study would use several thousand heliostats mounted on a 1,500-ft. tower. These would track the sun and solar energy would be intercepted and converted to heat. Lorin L. Vant-Hull and Alvin F. Hildebrandt, members of the University's Physics

Chemical Engineering
October 1, 1973

Dept., are working under a grant from the National Science Foundation in conjunction with McDonnell Astronautics Co., Huntington Beach, Calif. A possible way to use the solar energy, say the scientists, would be to place the collector-tower adjacent to a standard generating plant–at night or on cloudy days the generating plant could be operated on natural gas.

Another Approach–Although much of the research in solar energy utilization has involved converting solar radiation to heat, another approach is photo-voltaics, the direct conversion of light to electricity.

At the Philadelphia Energy Conversion Conference, researchers from Exxon Enterprises, Inc., discussed work underway in direct conversion. Noting that this has been technically successful with solar cells made from inorganic conductors–silicon, cadmium sulfide, cadmium telluride–they conceded that the major drawback has been costs, roughly three orders of magnitude higher than fossil-fuel power costs. *This high cost,* explain the scientists, *has been due to the extreme purity of the starting material, low yields, and high costs of processing single-crystal material batchwise.*

However, a new company formed by Exxon, Solar Power Corp., is marketing a 1.5 peak-watt* module packaged for terrestial applications. Developers admit that applications will be mainly where other power sources are unavailable. One of the uses is a system set up by Tideland Signal Corp. to power the aid-to-navigation equipment for an off-shore gas platform. Because of developments in semiconductor technology and engineering, and packaging innovations, Solar Power has been able to reduce the price of these solar module systems by a factor of five.

Sun and Sea–Still another approach to using the energy from the sun is being explored at the University of Massachusetts. William Heronemus and his associates are looking at a combination of sun and sea to generate electricity through thermal-gradients in the ocean. Different water temperatures at the equator and the poles produce a flow-the heated water moves towards the Arctic regions, and the colder water, at a deeper depth, flows toward the equator. Oceanographers say this causes a temperature gradiant of about 20 C. at about 100 meters below the surface. In theory, the warmer water would flow through a heat exchanger containing a working fluid that would boil. Expansion of the vapor would operate a turbine to produce electricity. The cooler ocean water would then be used to condense the vapor. Heronemus has plans to build a submerged plant using this concept somewhere in the Gulf Stream–probably in the Straits of Florida between the U.S. coastline and the Bahamas Banks.

* 1 watt of power produced at standard conditions i.e. 100 milliwatts/sq. cm. solar intensity, O C.cell temperatu

THE FUTURE OF POWER FROM THE SUN

by P. E. Glaser
Arthur D. Little, Inc.

The time to study solar power is now. This is clear to the student of long-term energy trends. In the recent past, about 50 years was required for significant shifts in fuel source patterns. Obvious factors were responsible for the length of time: the fuel had to be made available and the machinery to convert energy had to be developed.

Projection of power generation over the next several decades gives us charts like the two shown. The righthand chart shows us the proportions of energy that various fuel sources will supply up to the year 2200. By that far-off date, perhaps 30 per cent of the total power will come from energy sources other than those available today. These new sources will begin contributing much earlier–around 2030. We will have to find new ways to obtain energy by this data.

There are three major sources of energy available to us today: fossil fuels, nuclear energy, solar energy.

Fossil fuels represent a finite reserve, however. The smaller figure shows that the estimated width of the fossil-fuel impulse function measures only hundreds of years. Decline of fossil fuels' usefulness will occur when the availability curve drops to around 10 per cent of peak value. The precise location of this point is unimportant. What is important is to recognize that the pulse width is only a few hundred years not thousands.

Nuclear power will reduce our dependence on fossil-fuel reserves for a time. If we can remove present obstacles in the development of fusion power, we can meet our future energy requirements. The control of fusion is still the dream of physicists, however.

Our deteriorating environment is another factor suggesting a close look at solar power.

Air pollution and water pollution already plague us. Thermal pollution from nuclear power plants could threaten rivers and lakes in heavily populated areas. Cooling towers may partly offset this problem, but the cost will be high. Utility companies may need to spend \$2 billion in the next 13 years alone in addition to the basic \$19 billion that the companies plan to invest in nuclear plants. Estimates for U.S. investment in electric-power-generating plants of all types over the next 20 years range to \$100 billion. Extrapolation of investments for environmental control 30 to 50 years ahead shows us that our major concern will be alternative approaches to reduce the cost of controlling undesirable effects on our environment.

Keeping the long-range view in mind, we should look on solar energy as our major future resource. We should begin immediately to evaluate various means for harnessing it.

Our space program really first showed that solar energy can be directly converted. The major successes of Ranger, Mariner, and Surveyor spacecraft and orbiting satellites came with the support of power from solar cells. Right now, except for these space applications, solar-generated power's economics is questionable, but remember that we are looking ahead 50 years or more to the time when solar energy becomes vital.

Power from the sun is not, of course, a new concept. In 1901, the sun's energy ran at 4 1/2-hp steam engine in Pasadena. Twelve years later, a larger solar engine near Cairo, Egypt, was built to generate 50 horsepower. Since then, man has built many energy systems to use solar heat. Examples are solar water heaters, solar distillation plants, and solar ponds, along with solar-powered engines. Any of these devices suffers a loss in efficiency because of absorption of solar energy by the atmosphere, obscuration of the sun by clouds, dust deposition on reflecting surfaces, wind effects on structures, and partial utilization when the sun is near the horizon.

At least two basic concepts have focussed on generating power in amounts interesting for U.S. needs.

One concept sought to obtain 100 megawatts from sun-produced temperature differences in the waters of the Caribbean or the Gulf Stream. The colder lower layers would be a heat sink in this plan. A floating power plant would do the conversion.

The other concept, stemming from the space program advances, is one that deserves our special attention.

In this second concept, equipment orbiting the earth at 22,300 miles altitude would intercept sunlight on a huge flat collector, convert solar energy to electricity, and beam the electricity as microwaves to a receiving antenna on the earth.

The problem is a four-part one, involving orbit characteristics, efficiency of the conversion devices, transmitters to beam the energy, and the earth receiving stations.

We can highlight these problems by roughing out a possible system, such as that shown previously.

The orbit location would be 22,300 miles above the earth and parallel to the earth's equatorial plane. In this orbit, a satellite moving from east to west would appear stationary to an earthbound observer, because the satellite would be rotating around the earth at the same angular speed as the earth. The

satellite would pass through the earth's shadow once a day, however, so the concept requires two satellites, in the same orbit but separated by 21 degrees. This phase difference would keep the satellites above the horizon and give both of them a direct line of sight to the same point on earth.

When we look at solar-energy conversion devices, we find that efficiencies, costs per unit weight, and costs per unit collector will be unattractive if we confine ourselves to present state-of-the-art solar devices.

The table on Solar Collector Areas shows the collector areas needed for production of the power requirements at various dates in various regions. The collector efficiency is assumed to be 100 per cent. Present-day silicon photo cells have only 15 per cent efficiency, so that the collector areas would be about seven times those for 100 per cent efficiency.

Newer conversion devices, microcrystalline cells based on single-crystal solar-cell principles, have a higher efficiency (about 24 per cent is the theoretical limit), but this is still too low to make such devices useful.

Organic compounds have been discovered, however, that show characteristic semiconductor properties, including the photovoltaic effect. Organic semiconductors are still in their infancy. Both theoretical and experimental results show promise that organic systems can give us high efficiency and low weight and cost.

The lower figure shows a possible form for the thin-film solar cells. Each cell would consist of the four thin layers shown. The polymer film exhibiting the high photovoltaic effect would be only 1/4000 in thick, and the other films would be even thinner. In chemical terms, the polymer might be a compound of the oxazolc type or a base film containing an aromatic dye compound.

Organic compounds can be used in p-n junction semiconductors, but it is also possible to develop other types of systems having charge mobilities and conductivities that do not depend on single structure. These systems depend on the long-range intramolecular charge transfer in the heavy molecules found in such biological systems as nerves. The semiconducting properties of these molecular systems may be very different in character from those of inorganic semiconductors and therefore may not be limited in their maximum efficiency. Unlike inorganic single-crystal semiconductors, in which charge creation and motion are related to the primary act of light absorption, the high-molecular-weight organic systems distinguish between charge formation in a molecule and diffusion through the bulk medium. In the organic system the charge may be intra-molecularly transferred before motion occurs to an adjacent molecule or vacancy site.

The real promise of organic conversion systems is not only their high potential efficiency but also their low weight and cost. All these benefits will be necessary. At 80 per cent conversion efficiency, a collector to supply the 1966 needs of the U.S. Northeast would weigh 330,000 lbs exclusive of support.

This is a heavy weight, but studies have already explored the possibility of deploying large arrays like this in space. One study has looked at a large radioastronomy antenna which would consist of two satellites separated by a 10-kilometer adjustable-length tether.

Pointing accuracy is not critical for the solar energy collector. A gas-fueled reaction control system at the edges of the structure would accomplish the necessary changes in direction to keep the collector pointing at the sun.

On the collector itself, wires would pick up power from the elementary areas comprising a few square yards. From a junction point of several wires, another wire would feed the current on toward successively more central junctions. At a location near the collector center, equipment would pass the power into superconducting lines to the transmitter several kilometers away. At the transmitter, an amplifier having an efficiency of about 90 per cent would generate microwave radiation to transmit power to the earth. High CW power amplifiers having high efficiency are close to reality now.

Attitude control devices would carefully point the antenna, of paraboloidal shape, at the receiving antenna on earth. Success in pointing at chosen areas on the moon indicates that we can achieve the necessary accuracy.

Will humans be necessary in the orbiting part of the system? Most likely, humans will have to be present during deployment of collector and antenna. In operation, men will perform the functions of station keeping, equipment monitoring, and maintenance.

With a 2-kilometer diameter antenna, sufficient for the U.S. Northeast's 1966 power requirements, the power density would be less than one watt per square centimeter. The voltage gradient in the upper atmosphere would be less than 100 V per centimeter, so that ionization of the atmosphere would be unlikely.

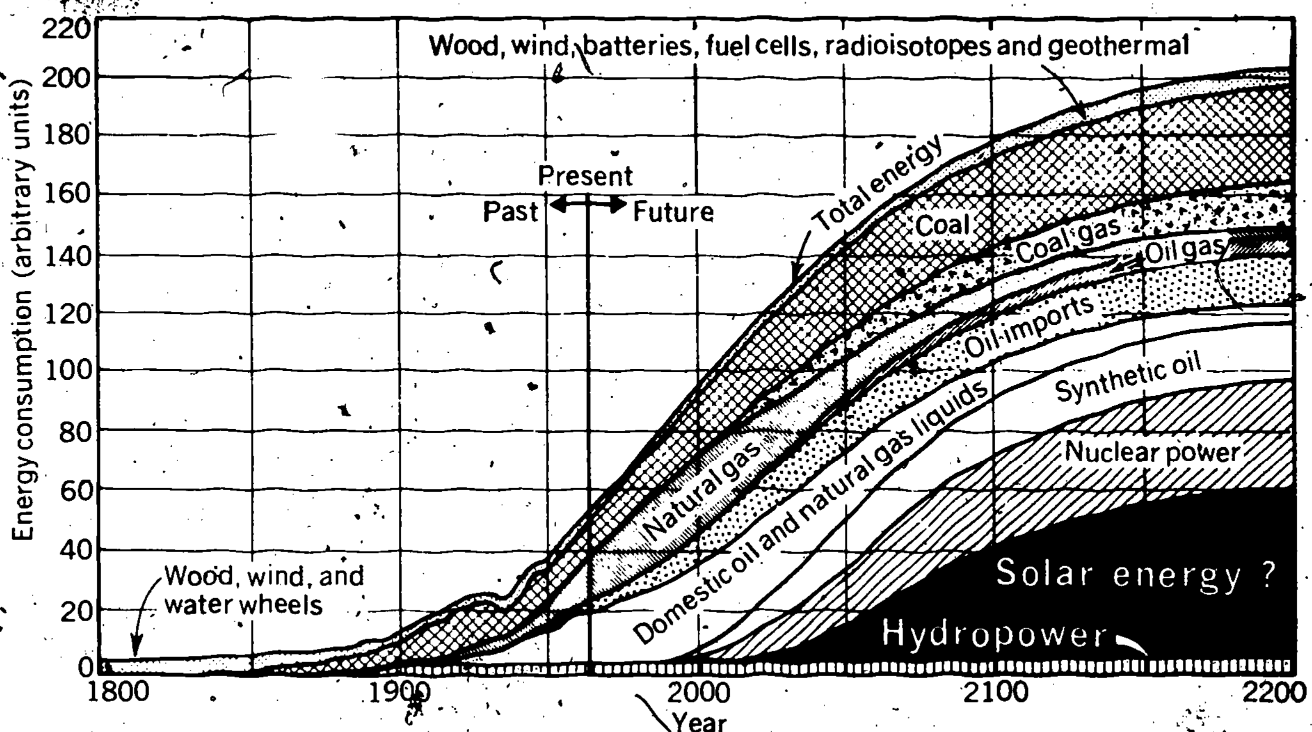
The beam density of less than one watt per square centimeter would be an order of magnitude larger than the sun's radiation received on earth. This density might damage objects or living tissues entering the beam accidentally, but it is not high enough to cause major destructive effects.

On the earth itself, a dipole receiving field using

highly efficient solid-state rectifiers would absorb the energy. A distribution network of superconducting transmission lines would carry the power to local destinations. Research underway now will assist in developing this method.

The development effort for the suggested solar power generating satellite will be an extensive one. At present, development is not far enough along to allow detailed cost vs. benefit analyses. Nevertheless, costs can be broadly estimated, and we should then compare them with the projected costs of nuclear power plants during the next two decades.

The search for power from the sun appears to be less of a technological gamble than when we first announced our objective to land a man on the moon and return him to earth by 1970. The developments stemming from the space program may find projects such as solar power a logical outgrowth of achievements in space, leading the world into an era where abundant power could free man from his dependence on fire.



THE ENERGY GAP that is foreseen in the chart as starting about 2030 will require new power sources. Nuclear fission and solar energy are two possibilities

CHAPTER 3

NUCLEAR FUEL GENERATING STATIONS

1. The Fission Process

The building block for all matter is the atom. An atom can be considered to be a dense core of particles called protons and neutrons forming a positively charged nucleus, surrounded by a swarm of negatively charged electrons.

Any one of the more than 1300 known species of atoms characterized by the number of neutrons and protons in the nucleus and by energy levels is called a nuclide. For example, an atom of chlorine with 18 neutrons in its nucleus is a nuclide, while an atom of chlorine with 20 neutrons is another nuclide.

All nuclides can be placed into one of two categories: radioactive or stable. Radioactive nuclides (radionuclides) undergo spontaneous nuclear changes which transform them into other nuclides. This transformation is called radioactive decay, and through the decay, the radioactive nuclide is changed eventually into a stable nuclide.

There are some 265 stable nuclides and 66 radionuclides found in nature. All the rest of the nuclides are man-made radionuclides. Thus about 5/6 of all known nuclides are radioactive.

In changing to a stable state, the nucleus of a radioactive atom emits radiation. Radiation may be in the form of particles, or in the form of electromagnetic rays called photons. Some radionuclides decay by the emission of alpha particles, which are high energy helium nuclei. Others decay by the emission of beta particles, which can be either high energy negatively charged electrons (negatrons) or positively charged electrons (positrons). Decay by the emission of these particles is usually followed by the emission of photons of two types: gamma rays, which are produced in the nucleus of the decaying atom, and x-rays, which are produced as a result of the rearrangement of orbital electrons. Except for their origin and the fact that x-rays are usually lower in energy and therefore less penetrating, x-rays and gamma rays are the same.

Less of this radiation changes the atomic structure of the radioactive nuclide, a process which continues until a stable (nonradioactive) nuclide is reached. Uranium, for instance, is radioactive; it decays slowly into elements like radium, radon and polonium, and finally stops at lead. The time required for one-half of the radioactive atoms of a nuclide to decay to its daughter nuclide is known as the half life of that nuclide. An atom with a short half life quickly decays. Half lives vary from minute fractions of a second to billions of years.

When atoms of certain heavy nuclides are bombarded by neutrons, the nuclei of some of these atoms will capture a neutron and become unstable so that they fission, or split, into two or more smaller atoms. Together the fission products weigh slightly less than the original atom and the bombarding neutron combined; this missing mass is converted into energy, as described by Einstein's formula: energy equals mass times the velocity of light squared ($E = mc^2$). As fission fragments fly apart, most of this energy appears almost instantaneously as heat as the fragments lose their energy of motion to the surrounding material. The heat from this fission reaction can then be used to boil water to make steam, which in turn spins turbines that generate electricity. Thus, the principal difference between nuclear and fossil-fueled electrical power is the source of the heat energy.

When an atom fissions, several free neutrons are released. These are available to strike other atoms, causing them to fission. This is the chain reaction (Figure 9). If a chain reaction is to continue, there must be enough fissionable atoms packed closely enough to insure the capture of enough neutrons to keep the rate of fission constant. The amount of material required for this is called the critical mass.

Generally, the smaller atoms produced by fission are radioactive. These fission fragments usually decay by negatron emission followed by gamma ray emission. Figure 10 shows one of more than 30 possible chains of decay following the fissioning of an atom of uranium-235. The fission fragments are atoms of radioactive bromine and xenon, and they each decay through many steps by emitting beta particles. The half life for each part of the chain is shown. Note the diversity of half life lengths.

2. Nuclear Fuel

Uranium is the basic nuclear fuel because it contains uranium-235, the only nuclide found in nature that readily undergoes fission. The natural concentration of uranium-235 in uranium is seven-tenths of one per cent; the balance is uranium-238, which does not readily undergo fission.

The United States has become the leading producer of uranium in the free world. Practically all the deposits of commercial-grade uranium ore found in the United States to date are in the western part of the country. Some shallow deposits are mined by open-pit techniques; however, most is taken from underground mines.

Uranium mining disturbs land, though not as much as coal mining. It takes about 30,000 tons of uranium ore to produce the 30 tons of uranium needed to fuel a nuclear reactor for a year. On the other hand, about 12 million tons of overburden must be removed to get the two million tons of coal needed to fuel a comparable plant for a year.

3. Nuclear Reactors

A nuclear reactor serves to provide an environment in which fission reactions can be initiated, sustained and controlled, and to make possible the removal of heat for power production.

Certain components are common to all reactors, regardless of their design. These are the core, coolant, control rods and shielding. Most current types of power reactors also include a moderator.

The core itself is generally made up of bundles

NUCLEAR FISSION CHAIN REACTION

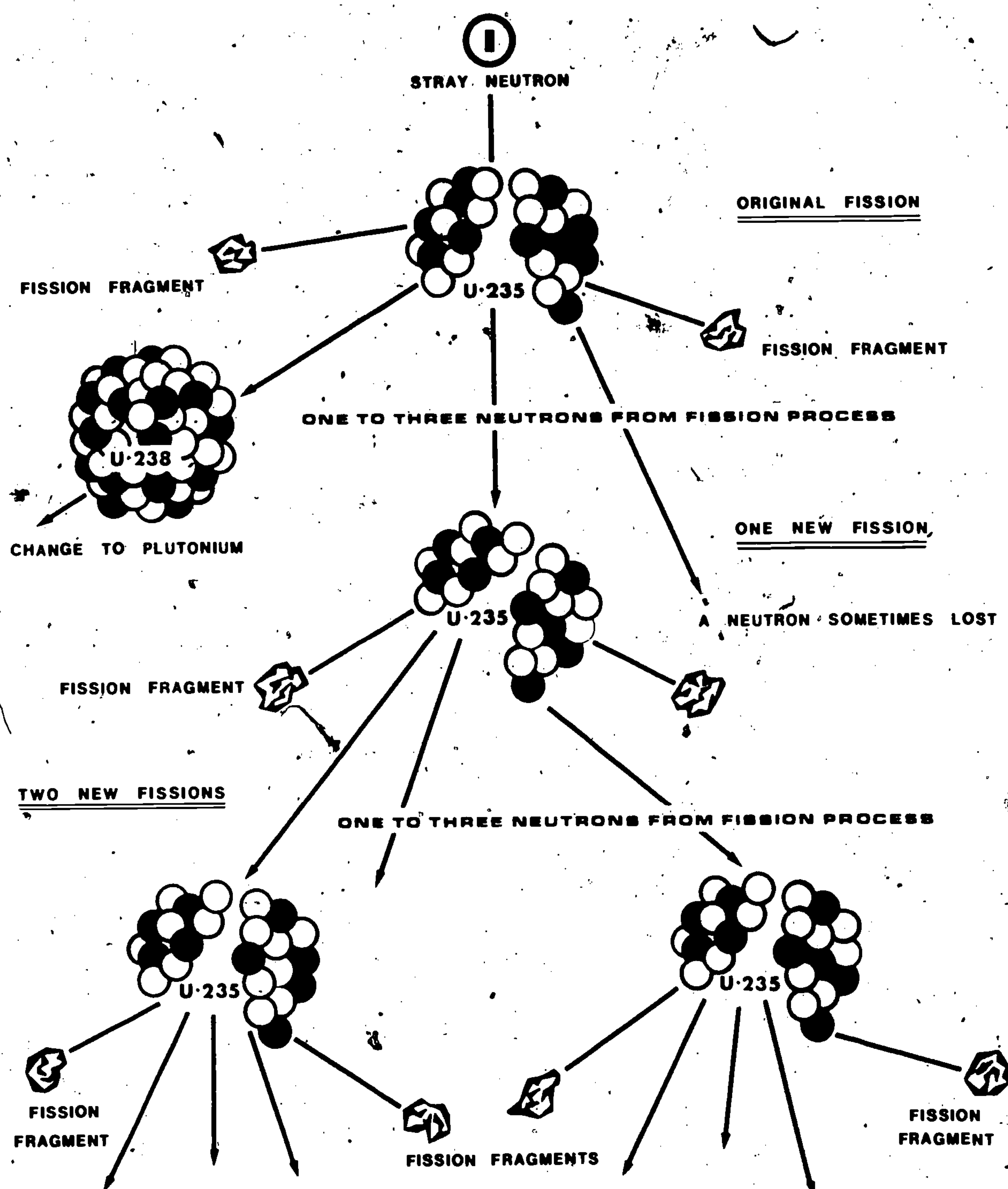


FIGURE 9

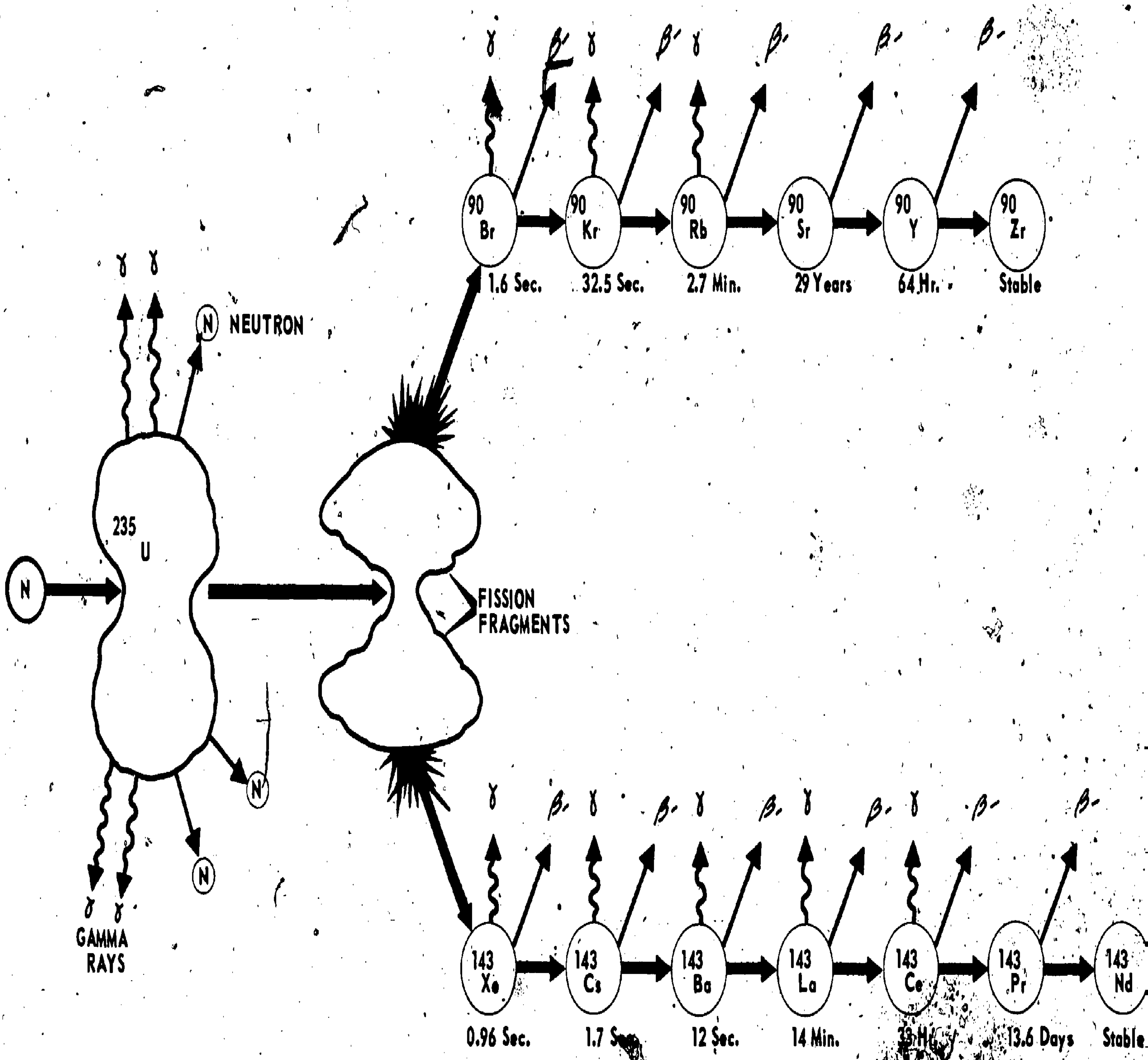


FIGURE 10

URANIUM FISSION AND BETA DECAY CHAINS

of fuel rods which contain uranium oxide pellets. When a number of bundles of rods are assembled, a critical mass is reached and the chain reaction starts. Individual fuel rods do not contain sufficient fuel for a critical mass.

The coolant, either liquid or gas, flows over the fuel rods, removing heat from the fuel. The coolant does not come in contact with the actual fuel, since the radioactive material itself is sealed within the fuel rods.

The control rods, made of materials that readily absorb neutrons, are usually strips of metal (boron or cadmium alloy) positioned inside the fuel assembly. If the rods are pulled out of the bundle, more neutrons are available to cause fissioning of the fuel, so the rate of reaction increases. If the rods are inserted into the fuel bundle, they act as a neutron sponge, so that there are fewer neutrons available to the fuel. Thus, the chain reaction slows or even stops completely. This makes it possible to produce heat at a desired rate, or to shut down the reactor.

The moderator, a material in the core, is used to slow down the neutrons as they emerge from the fissioning atoms. Slowing is necessary because neutrons travelling too fast are less readily captured and do not create more fissions. Graphite, water or heavy water are common moderators.

Shielding consists of special materials which surround different portions of the reactor system to prevent radiation from escaping into the environment. Some shielding components reflect stray neutrons back into the reactor. Others soak up radiation to protect important structural parts from radiation damage. Still other shielding components prevent biological damage from escaping radiation.

In many designs, one reactor part may serve to complement other parts. For example, a moderator may also act as a neutron reflector. The coolant in some reactors also serves as a moderator. Many combinations like these have been developed; each has certain advantages and disadvantages.

4. Types of Reactors

The more common types of reactors are the light water reactors, including the boiling water reactor and the pressurized water reactor; and the gas-cooled reactor. A major research and development program is underway to develop another type, the fast breeder reactor.

In the fall of 1974, 52 nuclear power reactors operating in the United States supplied between seven and eight per cent of the electrical power generated. An additional 59 nuclear plants were under construction, and 118 were being planned. At the close of 1973, 65 per cent of all nuclear power reactors sold were pressurized water reactors, 31 per cent were boiling water reactors, and 3 per cent were gas cooled reactors.

During the latter months of 1974, the construction of some 80 nuclear plants was halted, perhaps for months or years to come, because of problems involving money, labor, material shortages and licensing requirements. These delays may lead to a severe electrical shortage in the early 1980's.

A. Boiling Water Reactors (BWR)

In the boiling water reactor (Figure 11), water is used as the coolant and serves a secondary function as the moderator and neutron reflector. The water brought into the reactor is allowed to boil. It is then expelled from the reactor vessel as saturated steam, which drives a turbine to produce electrical power.

A typical boiling water reactor core is approximately a right cylinder with a diameter of about 11 feet and a height of 13 feet (Figure 12). The core is made up of many fuel assemblies (Figure 13). The fuel assemblies contain the fuel rods, which are zirconium alloy tubes. Within each zirconium tube, called cladding, is a vertical stack of uranium dioxide fuel pellets containing slightly enriched uranium. Enriched uranium contains more fissionable uranium-235 than natural uranium-for example, 2 to 3 per cent instead of 0.711 per cent.

Typically, a BWR operates at a pressure of about 1,000 pounds per square inch and produces steam at about 550 degrees Fahrenheit. The BWR has the advantage of simplicity and the disadvantage of requiring a large core for cooling. Some of the materials in the water may become radioactive and be carried through to the turbine section, increasing the size of the area where radiation exists. The early models of boiling water reactors had high emissions of radioactive gases as compared with other reactors, but this has been significantly reduced in newer models.

B. Pressurized Water Reactors (PWR)

In a pressurized water reactor (Figure 14), pressure keeps the water from boiling. Instead, water is pumped through the core and removed at the top as a heated liquid. The water is then circulated through a heat exchanger, where steam is produced from water in a secondary loop. The steam drives the turbine. The cooled water in the primary loop is returned to the reactor to again cool the core.

A pressurized water reactor core is made up of fuel assemblies such as the one in Figure 15. The fuel assemblies contain the fuel rods which hold the uranium dioxide pellets (Figure 16). As with BWR's, the uranium is slightly enriched so that it contains more fissionable uranium-235.

The PWR primary loop normally operates at a pressure of 2,000 pounds per square inch and at an average temperature of 590 degrees Fahrenheit. The coolant in the PWR core does not directly contact the turbine, so the turbine area remains uncontaminated with radioactive materials. The higher pressure allows more efficient heat transfer and requires a smaller surface area for the core. The

BOILING-WATER REACTOR

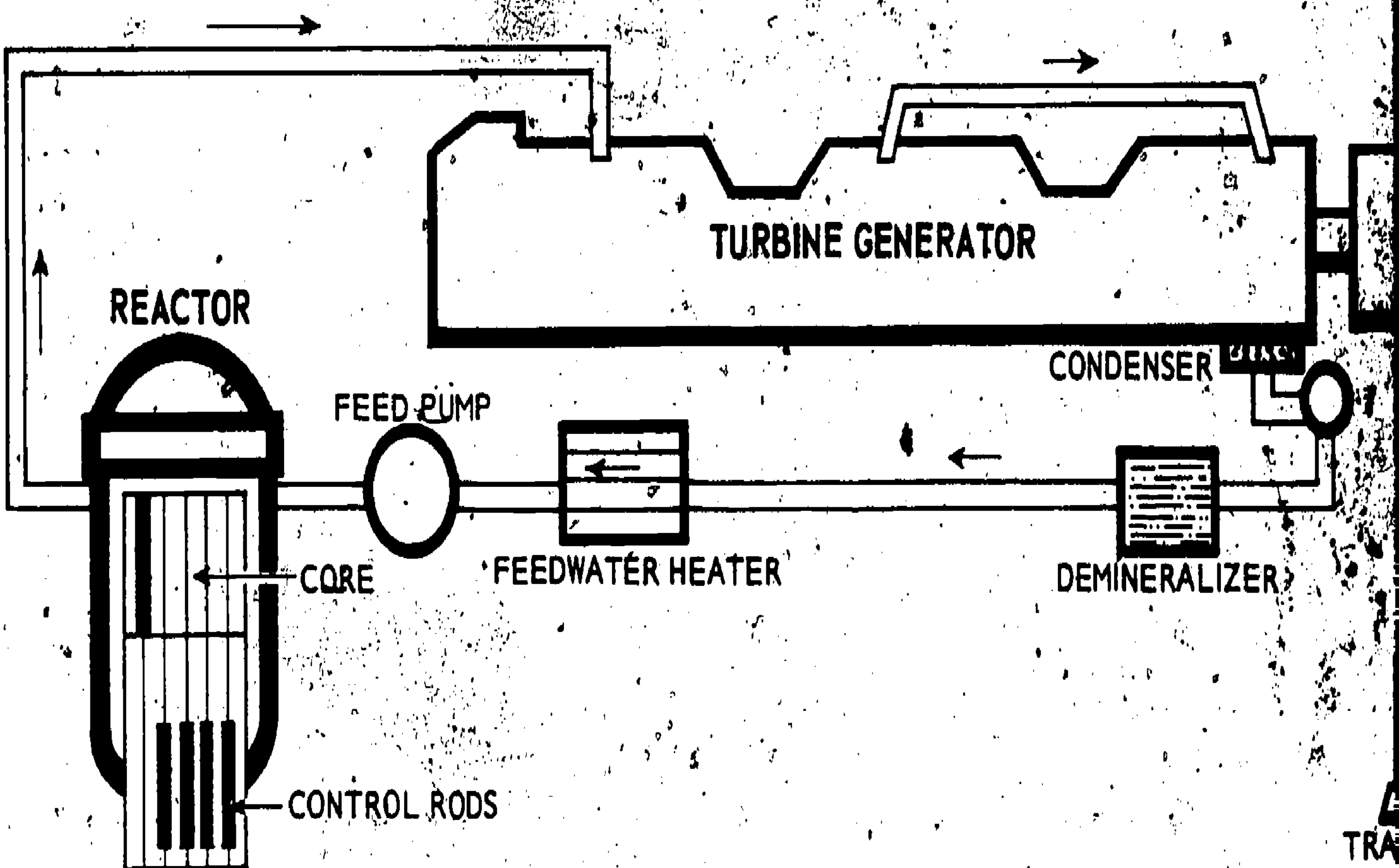


FIGURE 11

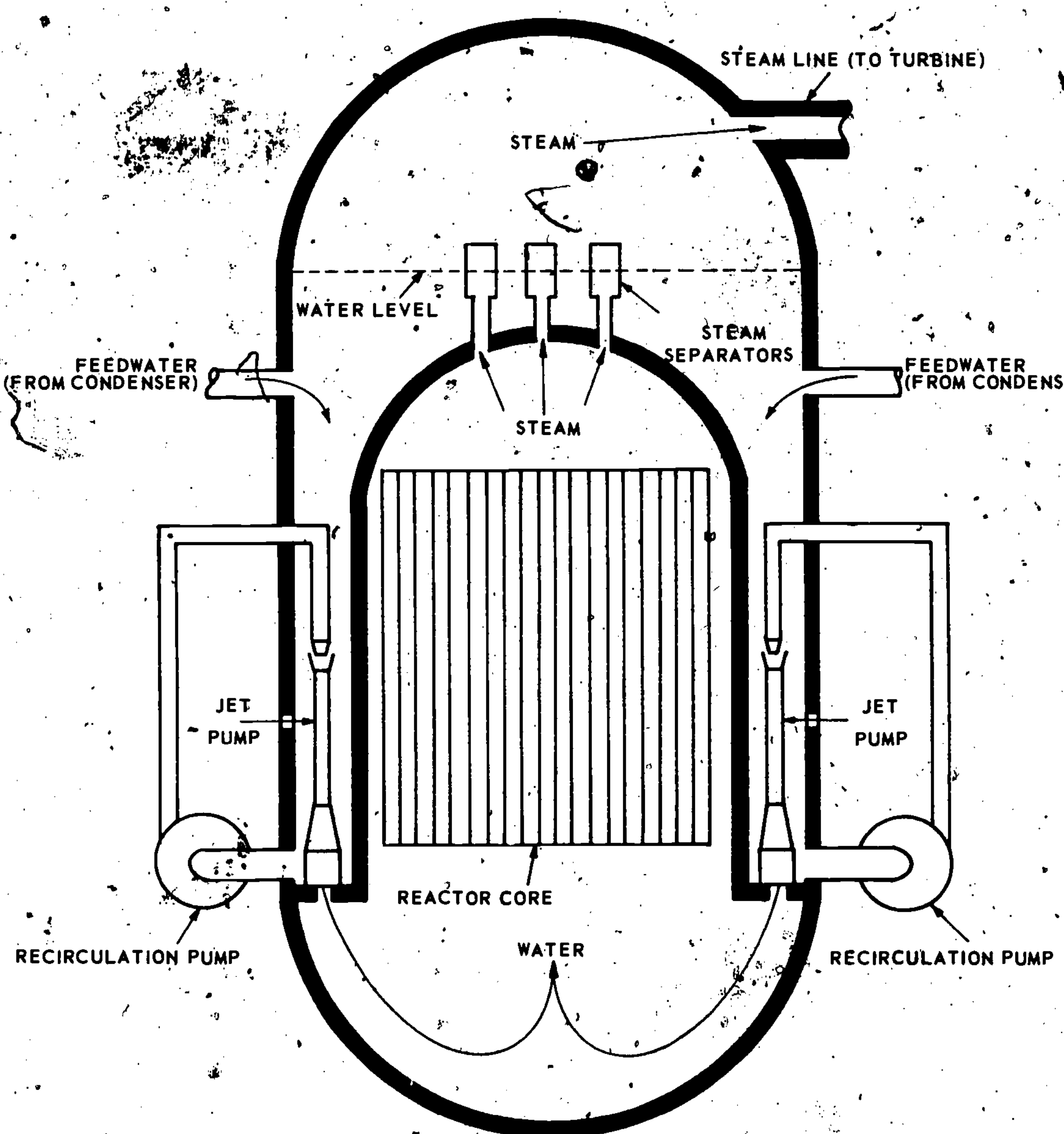
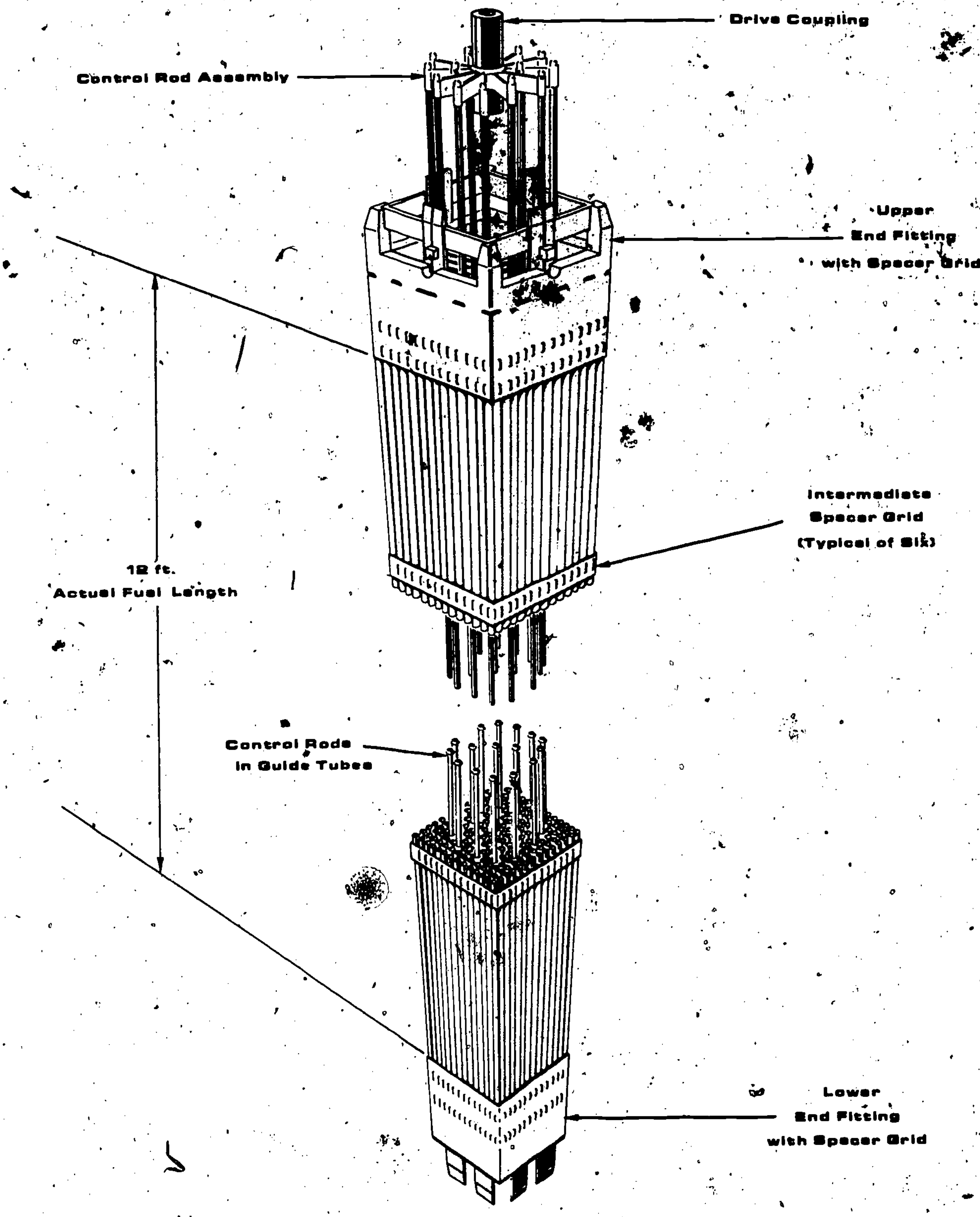


FIGURE 12
SCHEMATIC ARRANGEMENT OF BOILING WATER REACTOR

FUEL ASSEMBLY

For Boiling Water Reactor



FUEL ASSEMBLY - Cutaway Showing Partially Inserted Control Rod Assembly

FIGURE 13

PRESSURIZED WATER REACTOR

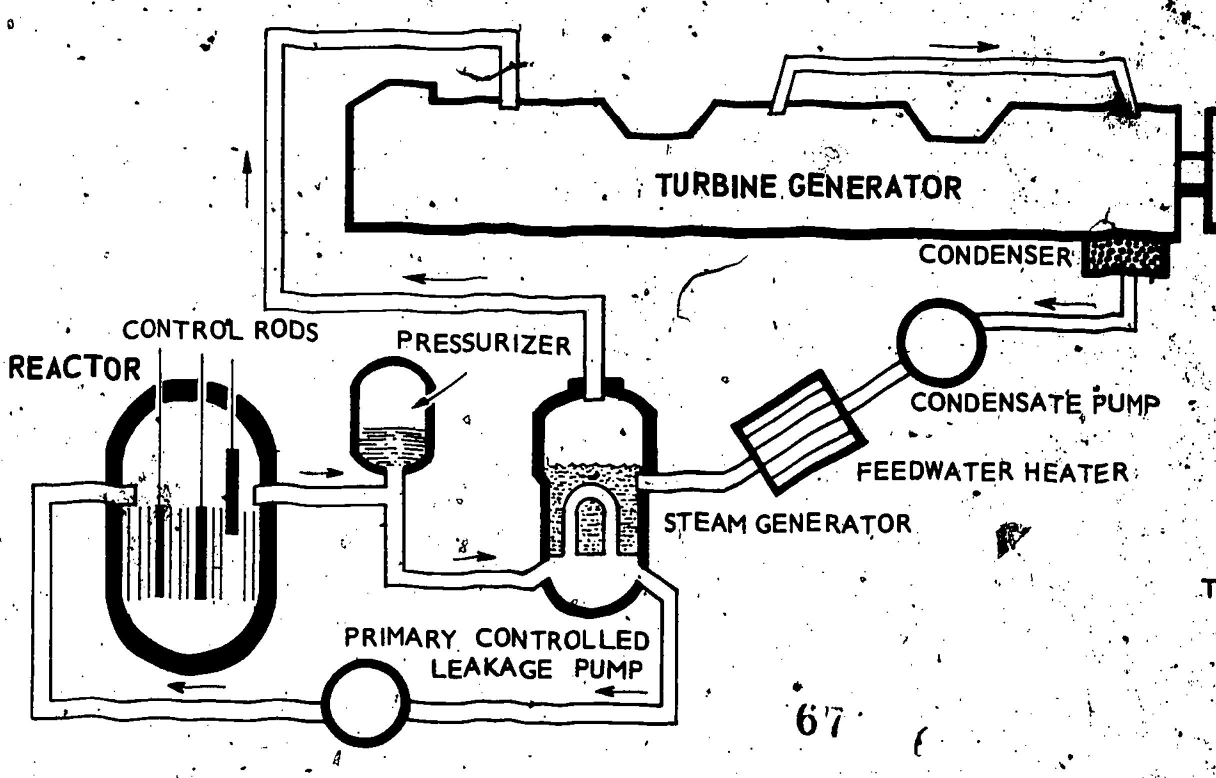


FIGURE 14

FUEL ASSEMBLY
For Pressurized Water Reactor

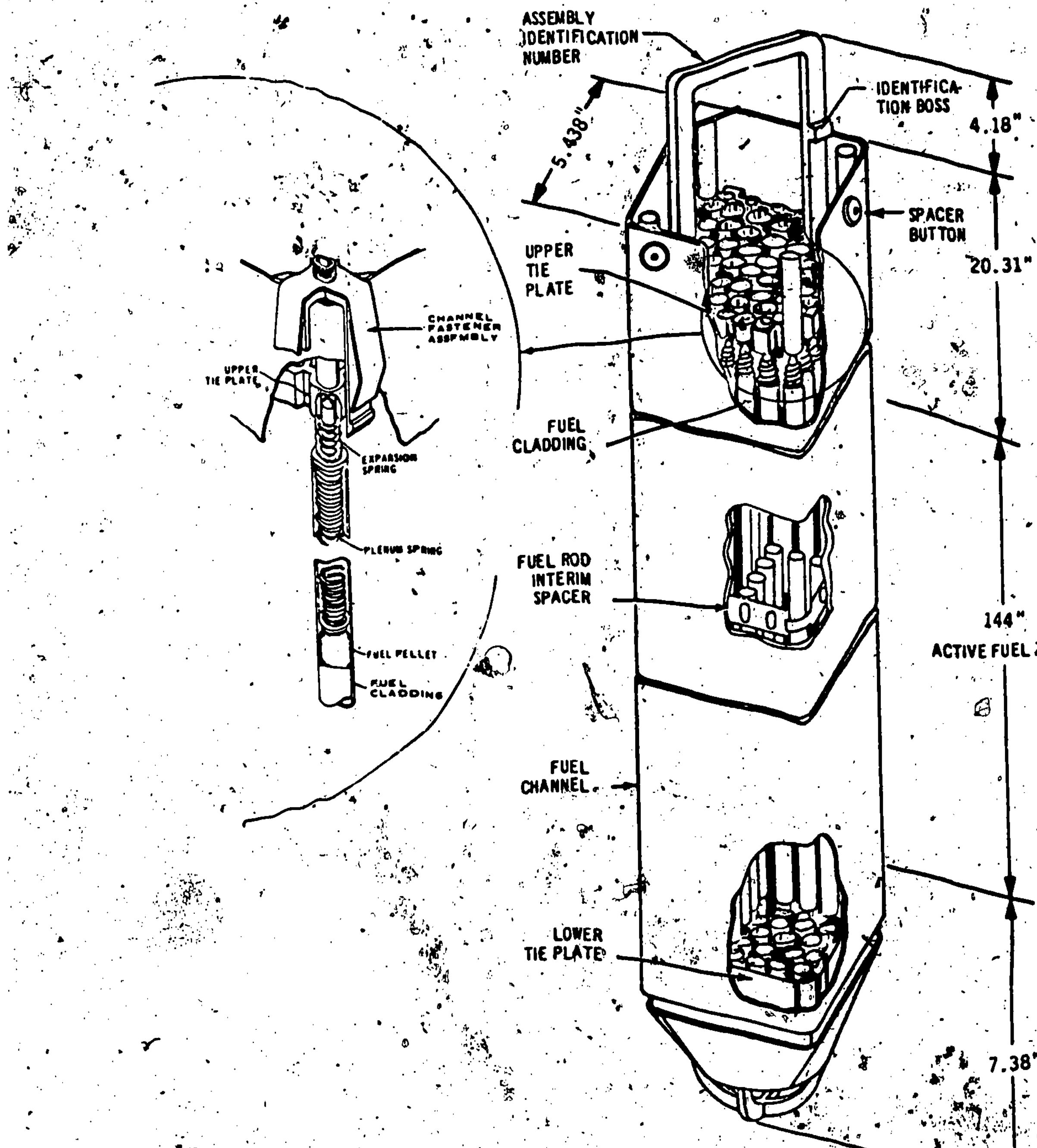


FIGURE 15

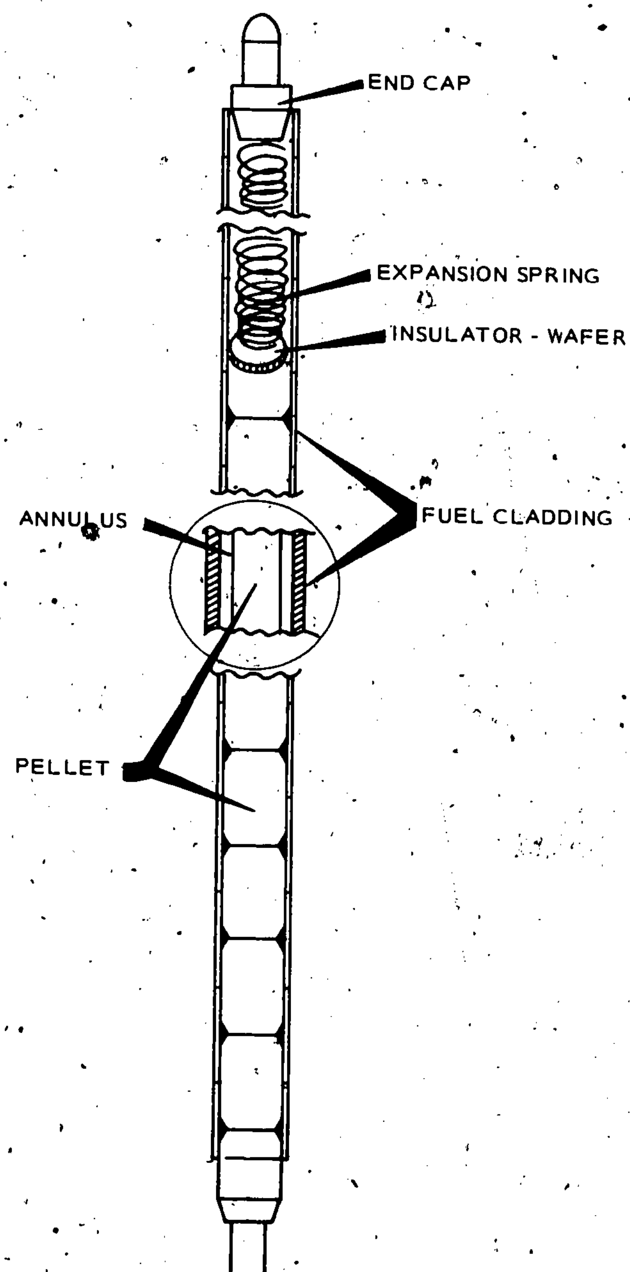


FIGURE 16
CUTAWAY OF FUEL ELEMENT
FOR NUCLEAR REACTOR CORE

PWR, however, requires higher operating pressures and additional heat exchangers, which lower its efficiency. The high temperature increases the corrosion of the fuel rods, the cladding and the vessel.

C. High Temperature Gas-Cooled Reactors (HTGR)

In the high temperature gas-cooled reactor (Figure 17), as the name suggests, the core is cooled by certain gases passing over it, usually purified carbon dioxide or helium. This type of reactor has a low fuel-consumption rate because very few neutrons are captured by the coolant, but it has a few drawbacks. Since gases are not as efficient heat transfer agents as liquids, a large volume of gas must be circulated. The circulation system requires very large blowers, and the core must also be large in order to present enough surface area for effective cooling. Gases also are poor moderating materials, so a separate moderator system must be installed. This moderator system usually consists of graphite blocks pierced to contain the fuel. Graphite is used because it is very strong when hot, permitting the reactor to operate at a high temperature. Neither helium nor carbon dioxide will react with the graphite. The gas coolant gives up its heat to water circulating through a steam generator. Since the gas coolant can be heated to much higher temperatures than water coolant, it can produce steam at much higher temperatures than water-cooled reactors. This high temperature operation allows the use of the best turbine technology and reduces the release of waste heat. These factors may give this type of system a thermal efficiency equal to that of the best fossil-fueled plants. Current water-cooled plants have somewhat lower efficiency than modern fossil-fueled plants and, therefore, are potentially sources of greater thermal pollution. This concept will be discussed in Chapter 6.

D. Breeder Reactors

It has been noted that uranium is the basic fuel for nuclear reactors because it contains fissionable uranium-235. It was also seen in Table 4 that the high-grade ores of this material are estimated to be depleted by the year 2040. Breeder reactors are looked upon as a method of extending this limited fuel supply by hundreds of years because they produce more fissionable material than they consume.

Although uranium-238 is not readily fissionable, it converts under neutron irradiation into plutonium-239, which is fissionable. For this reason, uranium-238, which constitutes more than 99 per cent of all uranium, is called a fertile material. The element thorium, which is abundant in nature, is composed of thorium-232, another fertile material that converts under neutron irradiation to fissionable uranium-233. Uranium-233 and plutonium-239 can be recovered for use in other reactors.

This conversion from fertile to fissionable material also takes place in current power reactors, but not at such a high rate as in breeders. When an atom of uranium-235 fissions, it produces an average of about 2.5 neutrons. To maintain a chain reaction, one of these neutrons on the average must be captured by another atom of uranium-235 to produce the next generation of fission events. This leaves about 1.5 neutrons per fission which can be captured in the core, or be captured by the uranium-238 in the fuel to produce plutonium. In current water- and gas-cooled reactors, it takes the fission of two atoms of fuel to convert one atom of uranium-238 to an atom of plutonium-239.

In a breeder reactor, for each atom of fissionable material consumed, more than one atom of fertile material becomes fissionable material. This is achieved by increasing the number of free neutrons released in fission and by decreasing the number of neutrons wasted, thereby making a larger number available for absorption in fertile material.

Fuel produced in breeder reactors may greatly extend our energy resources, since breeder reactors could utilize more than 50 per cent of the available energy in the world's fissionable and fertile fuel reserves as compared to only one or two per cent for light-water reactors. One other favorable aspect of breeder reactors is that their fuel can be produced economically from lower-grade ores. We will need to turn to these ores as supplies of high-grade ores run out.

Just as there were initially many thermal reactor concepts, with the PWR, BWR and gas cooled reactors winning general acceptance in this country, there have been a number of breeder reactor concepts proposed. The concepts which have undergone initial development include the light water breeder reactor (LWBR) and the molten salt breeder reactor (MSBR), which are based primarily on the thorium-232-uranium-233 fuel system; and the gas-cooled fast breeder reactor (GCFBR) and the liquid metal cooled fast breeder reactor (LMFBR), based primarily on the uranium-235-plutonium-239 fuel system. Of these, the LMFBR concept is receiving the major focus of the research and development efforts in this country and abroad. Thus only this concept will be treated further.

The LMFBR would be able to produce more fuel (plutonium-239) from the fertile uranium-238 than it would consume. A diagram of the liquid metal fast breeder reactor appears in Figure 18.

It is called a fast reactor because it contains no moderator material to cause a rapid slowdown of the fission neutrons. Thus the average neutron velocity in the core will be considerably greater than in conventional reactor cores. At these higher energies, there is a much greater probability that the neutrons not needed to maintain the chain reaction will be captured by the fertile uranium-238 than by reactor core components.

HIGH-TEMPERATURE, GAS-COOLED REACTOR

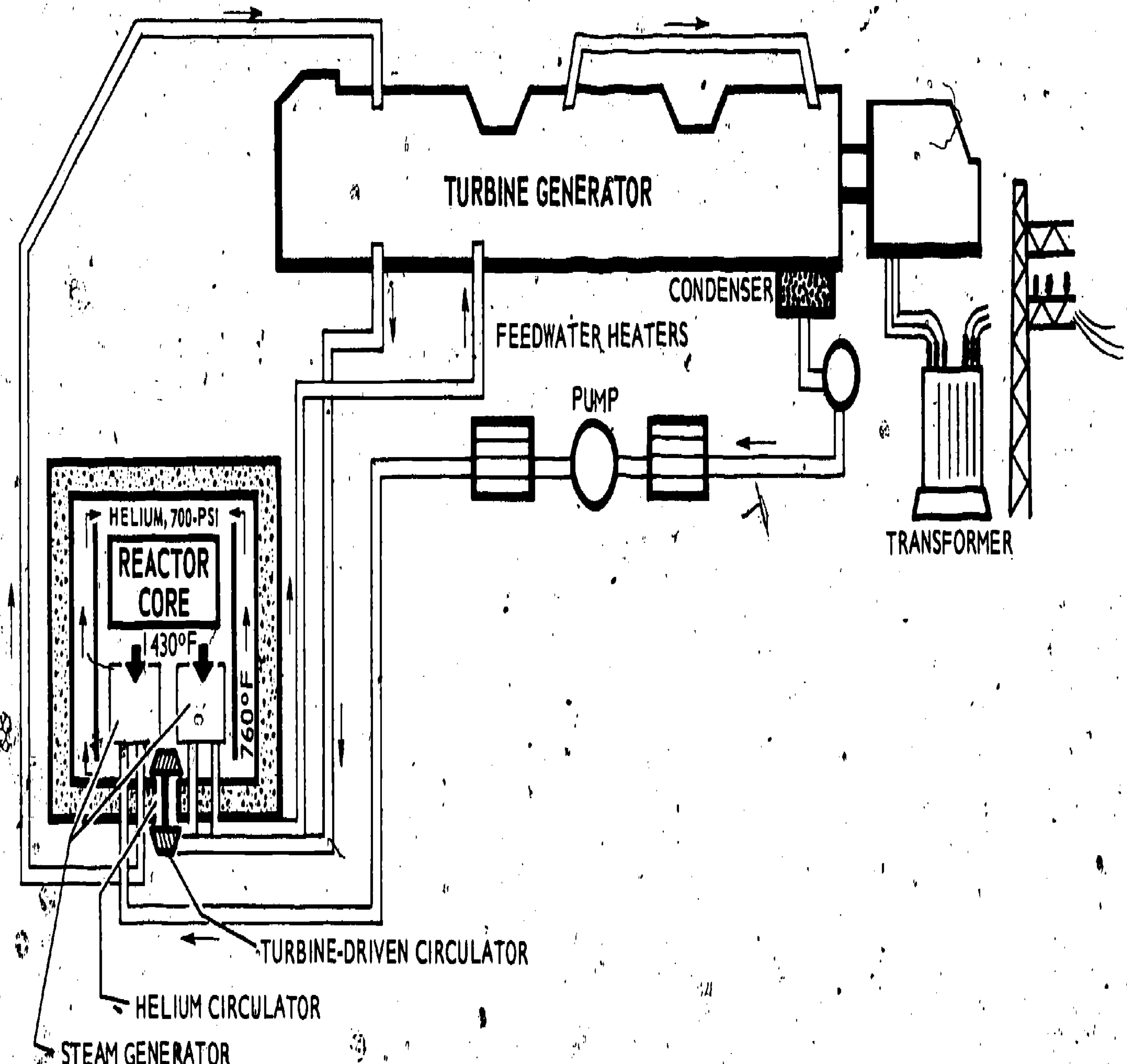
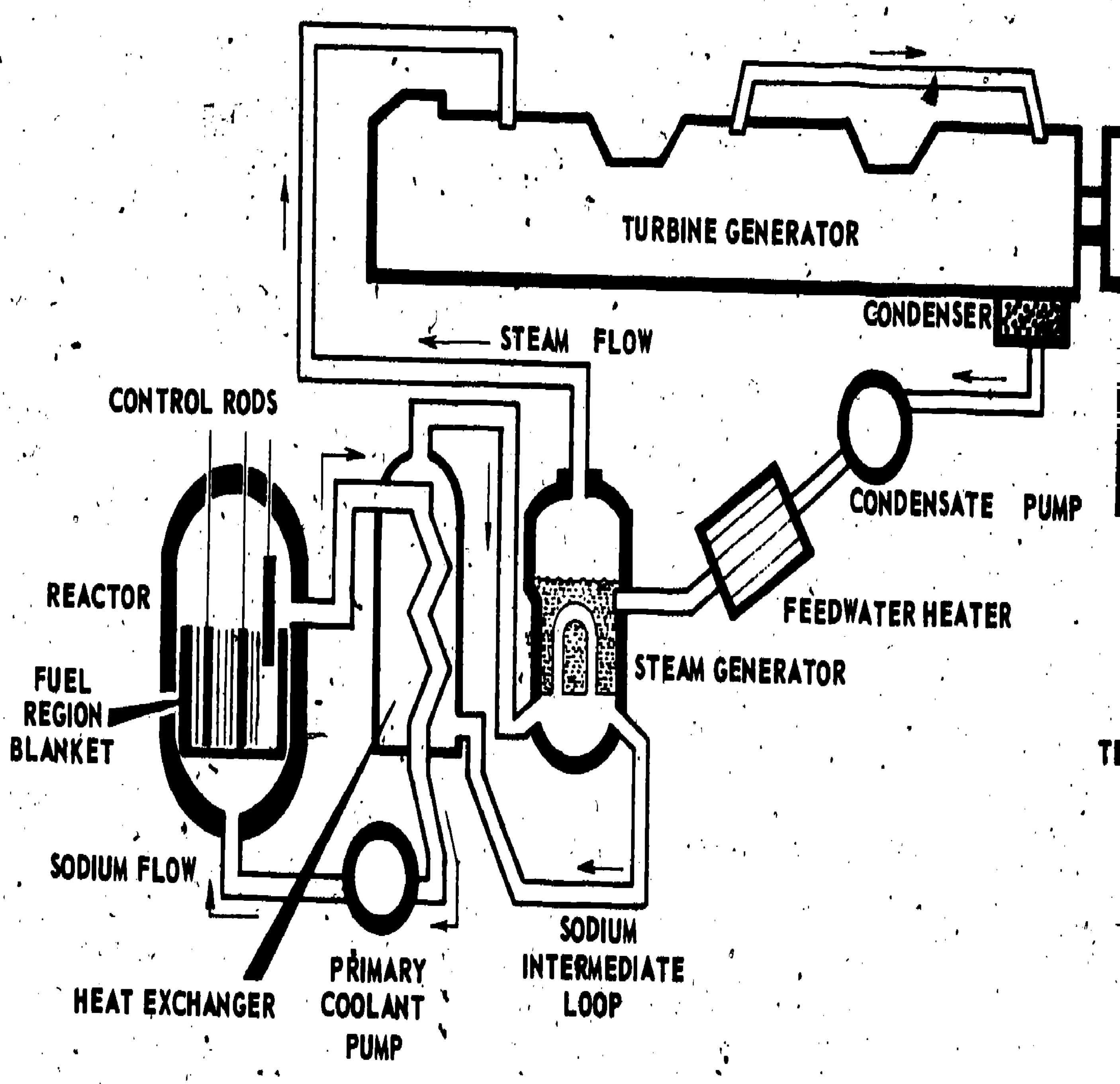


FIGURE 17

FIGURE 18

LIQUID METAL FAST BREEDER REACTOR



The term liquid metal is used because liquid sodium is the reactor coolant. An inert cover gas (argon) is used to blanket the sodium.

The fuel in such a system would probably be a mixture of oxides of uranium and plutonium.

Liquid metal fast breeder reactors have the potential of being more efficient than light water reactors. Sodium is considerably more efficient than water in transferring heat from the core. Also, the reactor core can be operated at a higher temperature without pressurization, since sodium has a much higher boiling point than water. As a consequence, the thermal efficiency of such a power plant will be 39 per cent or more, compared to 31 to 33 per cent for light water reactors. This means a decrease in waste heat.

The LMFBR has some disadvantages when it is compared to light water reactors. These disadvantages are due mainly to the sodium coolant. Sodium is a highly chemically reactive metal that will burn if it is exposed to either water or air. Further, it is a solid at room temperature and requires an elaborate heating system to assure that it will remain liquid throughout the coolant system. Sodium is not transparent to light, which complicates refueling and maintenance.

The sodium coolant captures some of the reactor neutrons and becomes intensely radioactive. Since the main radionuclide produced (sodium-24) has a 15 hour half life and emits extremely penetrating gamma rays, refueling of the reactor and maintenance of the primary coolant system require remote control equipment.

The LMFBR is more difficult to control than a light-water reactor, because an accidental loss of the sodium coolant from the core increases reactor power. The opposite occurs in light-water reactors.

The cost of building a LMFBR is considerably greater than that of light-water reactors, primarily because of the more exacting specifications and closer tolerances required.

These problems are now being solved in small prototype systems, like the Experimental Breeder Reactor operating in Idaho for over 10 years. Besides generating electrical power, it has demonstrated breeding and sodium technology and, more recently, has served as a fuel-testing unit. This effort is being expanded through the Fast Flux Test Facility in Washington, the forerunner of the Clinch River Breeder, which is expected to deliver about 350 megawatts of electricity in the late-1980's.

Other nations, notably France and Russia, appear to be moving more quickly into the use of breeder reactors. In mid-1974, the French put into operation a fast breeder in their Phoenix project, which is routinely generating 250 megawatts of electricity. The U.S. program is to develop a sound scientific and engineering base to assure performance and safety. It remains for the future to tell us whether the French plan of acceleration of the breeder or the U.S. plan of margin assurance, is the better.

5. Safety Systems in Nuclear Reactors

No accident affecting public health and safety has occurred in a commercial nuclear power plant, nor has a radiation injury ever occurred to a worker in such a plant. This record is due to stringent safety precautions taken by the builders of nuclear plants, which cannot be built or operated without a license from the Nuclear Regulatory Commission, charged by law with the responsibility of satisfying itself that the plant will not endanger public health and safety. Licensing was previously done by the Atomic Energy Commission(AEC), which was abolished in 1974. The AEC's research and development activities were taken over by the Energy Research and Development Administration (ERDA), while the regulatory and licensing activities are now the function of the Nuclear Regulatory Commission (NRC).

A. Control During Normal Operations

Nuclear power plants form small quantities (several pounds per day) of radioactive substances. In normal operation, more than 99.99 per cent of these substances stay within the fuel assemblies. The small amount that escapes from the fuel enters the reactor coolant system, where almost all of it is removed by purification equipment. A minute amount of radiation is released to the environment under strict control, subject to conservative and rigidly enforced health and safety regulations that require that releases be kept *"as low as practicable"*. Releases must thus be reduced as improved technology permits. This is discussed in greater detail in Chapter 7.

B. Accident Prevention

(1) Natural Safeguards

Today's water-moderated power reactors use uranium dioxide fuel which is enriched with the uranium-235 isotope to only three or four times its natural level. If the rate of fissions were to increase significantly, more heat would be produced. The heat would increase the energy of the neutrons in the fuel, and thus increase the proportion of neutrons escaping from the core and captured by non-fissioning atoms. The rate of fission would thus slow down. This effect is automatic and instantaneous, and is one reason why a nuclear reactor cannot possibly become a bomb. In a bomb, essentially pure fissionable material is required, and it must be rapidly compressed and held together for the chain reaction to increase to an intensity of a nuclear explosion.

The use of water as a coolant and moderator

74

provides another safety feature of today's power reactors. If the reactor were to exceed its designed power level, it would raise the temperature of the water, which would in turn decrease the water's ability to act as a moderator. This tends to reduce the reactor's power level.

(2) Engineered Safeguards

In addition to natural safeguards, many safety features are built as an integral part of any reactor facility. These are a *"defense in depth"* against the release of radioactive and include: ceramic fuel, fuel cladding, primary coolant system, safeguard systems and, finally, a containment system surrounding the entire reactor. The safeguards include:

(a) Monitoring of Reactor Neutron Intensity

Since neutrons initiate fission reactions and relate to the reactor power level, measurements of the number of available neutrons are made by a number of independent monitoring systems at various locations in the reactor core. These instruments are connected to a rapid shutdown system in case neutron intensity rises above a preselected limit.

(b) Reactor Control System

Materials such as boron or cadmium are able to absorb neutrons and, by removing neutrons from the system, shut down a reactor, preventing new fissions from occurring. Common methods of introduction include the mechanical insertion of control rods into the core and the additon of liquid solutions of these neutron-absorbing elements to the water moderator. Most water reactors have both methods of control available.

(c) Reactor Safety Circuit Instrumentation

Instruments constantly monitor what is happening in the core. Improper signals concerning temperature, pressure or other unwanted conditions will immediately shut down the reactor. Each safety system has one or more backup systems in case there is a failure in the primary system.

(d) Electric Power Requirements

Reactor designers assume that at some time electric power to a nuclear plant may be shut off. To allow for this possibility, they usually design reactor systems that require no electric power to achieve safe shutdown. Those which may require power after shutdown, to keep the coolant circulating for instance, are equipped with emergency diesel generators and batteries to operate when no outside power is available.

(e) Emergency Core Cooling Network

If, for some reason, there is a rapid loss of coolant water in a nuclear reactor, it is conceivable that the core might melt due to heat from the fission reactions, releasing a dangerous amount of radioactive material. Two independent emergency core cooling systems are available to provide automatic emergency core cooling. The network does not require an operator to get it started. The effectiveness of some of the current emergency core cooling systems has been seriously questioned, so they are now under very close study.

C. Containment in the Event of Accidents

It has been seen that multiple physical barriers in reactor systems guard against radioactive substances escaping to the environment. There is, first of all, the ability of the fuel material to retain most of the fission products, even when they are overheated. Then there is the fuel element cladding, through which fission products must pass to get into the reactor coolant. Next, there are the walls of the reactor vessel itself. Finally, there is the containment system, constructed to halt any release of radioactive material that gets past all the other barriers. The reactor building itself may be sealed off as a secondary containment system.

6. Price-Anderson Act

When nuclear power began to emerge as a [illegible] of power generation, the U.S. Co[illegible] this question: What is the best method of [illegible] for damages arising from a nuclear [illegible]n though such an event is extremely [illegible] Price-Anderson Act evolved to answer [illegible]. It requires a utility which operates a [illegible]er plant to purchase the maximum [illegible]bility insurance it can obtain, currently [illegible] The federal government provides [illegible]surance, up to a total of $560 million, to [illegible]blic for damages from a nuclear accident. [illegible] government currently provides $450 million [illegible]urance. Each utility pays a premium to the government for Price-Anderson coverage.

The Price-Anderson Act relieves all parties of liabilities in the event that damages from a nuclear accident should exceed the $560 million maximum. Critics of nuclear power are quick to point out this provision, and say that the maximum is not enough.

A private insurance pool provides insurance on nuclear facilities themselves. There is no government-backed coverage on nuclear facility property.

7. Nuclear Power Problems and Promises

The development of nuclear power stations has suffered from sharply escalating construction costs and numerous construction delays.

Original schedules for many proposed nuclear plants have not been met because utilities had difficulty obtaining the necessary licensing. Hearings for various licenses by the Nuclear Regulatory Commission, state agencies, and other groups have become battles between the utilities and environmentalists and other concerned about radiological safety, plant siting, thermal pollution, the storage of radioactive wastes and the possibility of fissionable materials being diverted for use in bombs. Such concerns have contributed to increased safeguards and security. The results of the reactor safety study included in this chapter's supplementary reading list show the low risk of nuclear power compared with other human activities.

Even though the electrical power industry generally regards nuclear power plants as an answer for the long term, it has been less than happy with nuclear plant performance. Many plants are operating at lower than expected availabilities and have had problems causing them to shut down for long periods. But the operational performance of nuclear plants is improving, as shown in a recent Commonwealth Edison Company report which compares the availability, reliability and economy of their seven nuclear power plants with their six large fossil-fueled plants built since 1964. The four nuclear plants in use between 1972 and 1974 operated at an average of 60 per cent of their capacity, while the fossil units operated at 54 per cent of their capacity. The lower figure for the fossil-fueled plants comes about because at periods of less than peak load, the nuclear plants were used to a greater extent than the fossil-fueled plants because of their lower fuel cost. The nuclear units were available 75 per cent of the time, the fossil units 71 per cent of the time. Commonwealth Edison gives their use of nuclear power plants the credit for keeping increases in the cost of electricity well below increases in other parts of the country.

SUPPLEMENTARY

MATERIALS

FOR

CHAPTER 3

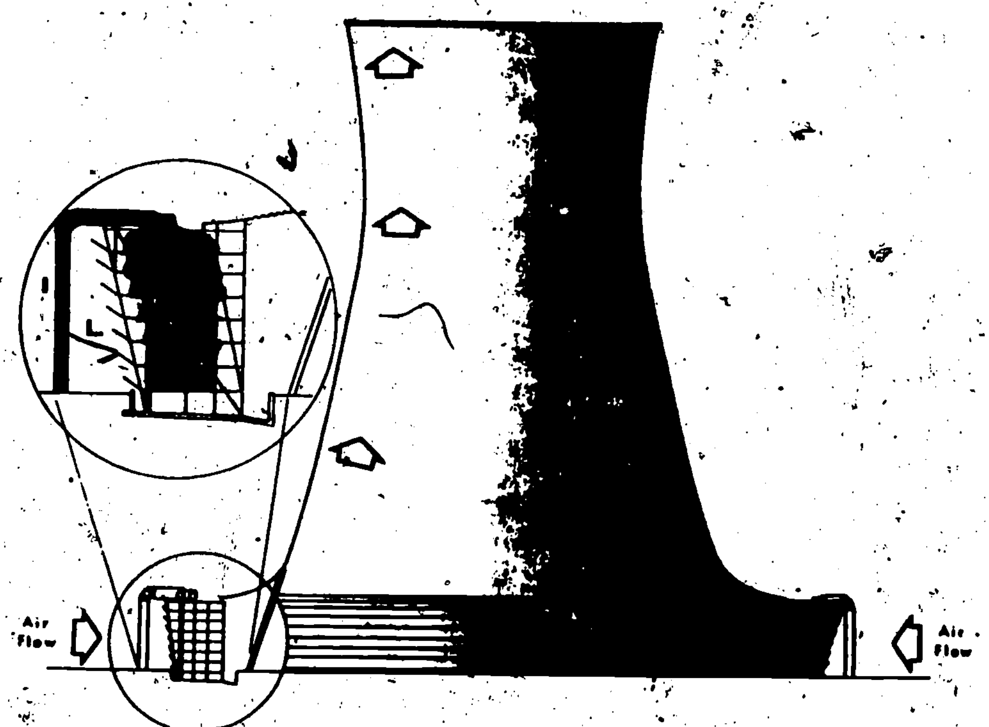
The Heat Goes Up and Away!

During this period of mounting concern about our environment, there has been considerable discussion about the amount of heat that nuclear plants could add to our waterways. Popular public terminology for this problem has become "thermal pollution." This is not pollution as we normally think about it; it is the addition of heat to the water, which changes the ecology, or natural balance of nature, in the stream.

At Three Mile Island, we are not presenting this problem. We are not adding heat to the Susquehanna River, because we are using cooling towers to cool the water used in the nuclear plant. We installed these 37-story towers at a cost of some $15-million to totally protect against affecting the river temperature.

Since the reactor water is one enclosed system and the water from the condenser to the cooling towers is in another enclosed system, the river water is not "polluted," nor is its temperature affected. As the water in the cooling tower is cooled, some of it evaporates and leaves the top of the tower as water vapor, the same principle as when you see vapor from your breath on a cold day.

The 372-foot-high natural draft cooling towers at Three Mile Island will stand as servants of life, present and future. As gigantic as they are, they really are very simple machines, especially when compared with the complexity of the other parts of the station. The "what" and the "how" of these devices are explained briefly in the diagram below.



The hyberbolic natural draft cooling towers at Three Mile Island are, in effect, huge chimneys which, for most of their 372-foot height, consist of a reinforced concrete shell. The more complicated part of each structure is contained in the bottom 40 feet—the portion shown encircled in the cut-away above.

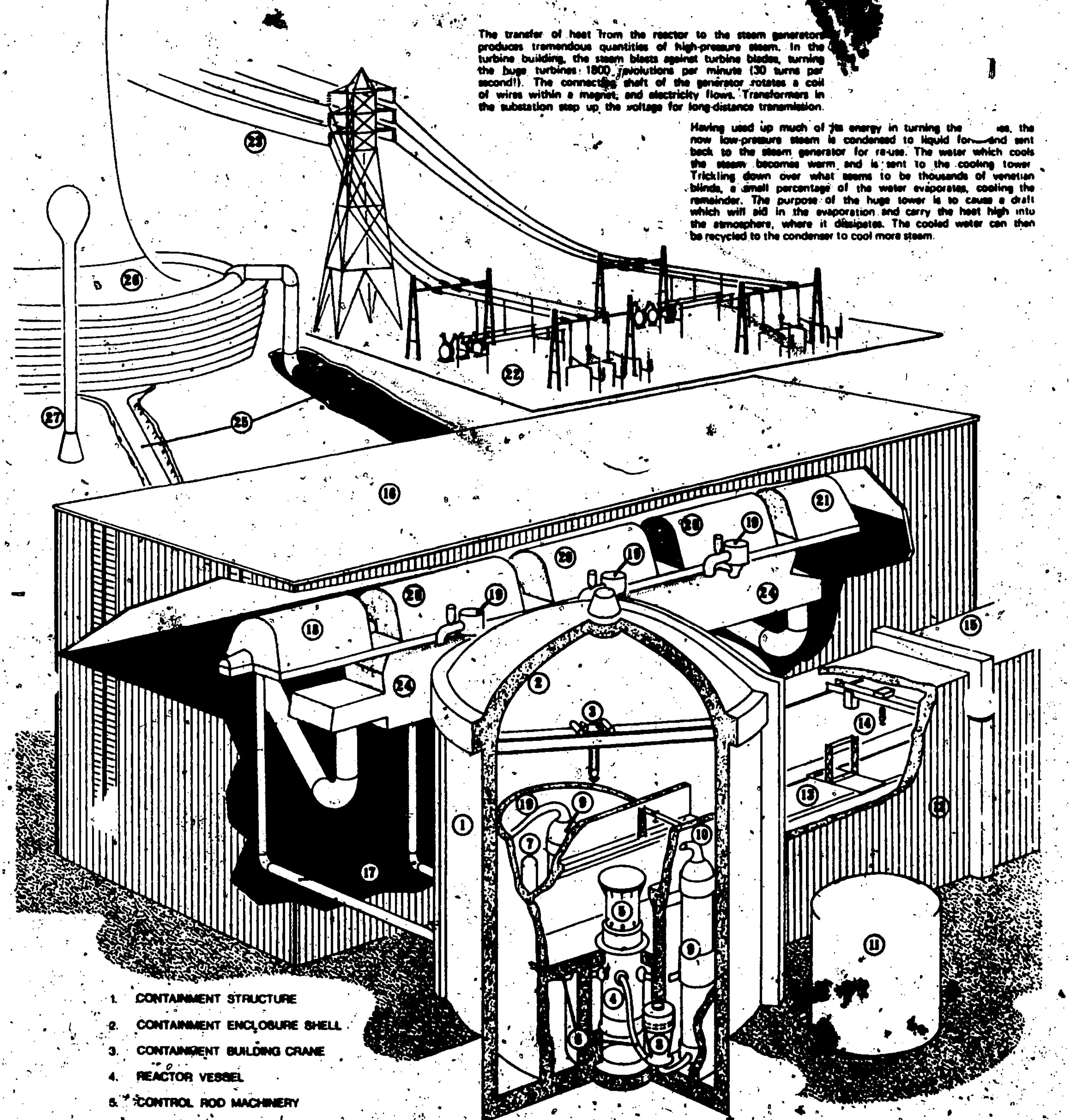
The hot water enters through the inlet (I) at the top of the crossflow water cell completely encircling the base of the tower. Air flowing through louvers (L) and up through the giant tower, cools the water (W) as it trickles down through the crossflow filling.

The cooled water is then returned to the plant for re-use in condensing the steam exhausting from the turbines.

Three Mile Island Nuclear Generating Station

The transfer of heat from the reactor to the steam generators produces tremendous quantities of high-pressure steam. In the turbine building, the steam blasts against turbine blades, turning the huge turbines 1800 revolutions per minute (30 turns per second!). The connecting shaft of the generator rotates a coil of wires within a magnet, and electricity flows. Transformers in the substation step up the voltage for long-distance transmission.

Having used up much of its energy in turning the [illegible]es, the now low-pressure steam is condensed to liquid form and sent back to the steam generator for re-use. The water which cools the steam becomes warm and is sent to the cooling tower. Trickling down over what seems to be thousands of venetian blinds, a small percentage of the water evaporates, cooling the remainder. The purpose of the huge tower is to cause a draft which will aid in the evaporation and carry the heat high into the atmosphere, where it dissipates. The cooled water can then be recycled to the condenser to cool more steam.



1. CONTAINMENT STRUCTURE
2. CONTAINMENT ENCLOSURE SHELL
3. CONTAINMENT BUILDING CRANE
4. REACTOR VESSEL
5. CONTROL ROD MACHINERY
6. REACTOR COOLANT PIPES
7. PRESSURIZER
8. REACTOR COOLANT PUMP
9. STEAM GENERATORS
10. MAIN STEAM LINES
11. BORATED WATER TANK
12. FUEL HANDLING BLDG.
13. SPENT FUEL STORAGE POOL
14. FUEL MANIPULATOR CRANE, PLATFORM BRIDGE, & HOIST
15. FUEL SHIPPING AREA
16. TURBINE BUILDING
17. MAIN STEAM PIPING
18. HIGH PRESSURE TURBINE
19. MOISTURE SEPARATOR
20. LOW PRESSURE TURBINES
21. ELECTRICAL GENERATOR
22. ELECTRICAL SUBSTATION
23. HIGH VOLTAGE TRANSMISSION LINES
24. CONDENSER
25. COOLING WATER LOOP
26. COOLING TOWER
27. WATERSPHERE (FOR FILTERED WATER) AND FIRE SERVICE

THREE MILE ISLAND NUCLEAR STATION
FACT SHEET
(As of mid-1972)

UNIT NUMBER ONE		UNIT NUMBER TWO
818,900 kilowatts	NET CAPACITY	904,500 kilowatts
	REACTOR BUILDINGS	
137 feet	Outside Diameter	138 feet
201 feet	Overall Height	202.9 feet
3.5 feet	Wall Thickness	4 feet

REACTOR VESSELS

Outside Diameter: 15' 8"
Overall Height: 41' 3"
Weight: 804,500 pounds
Wall Thickness: 8.4 inches

FUEL

Uranium dioxide, 2 1/2 - 3% enriched
Form: Glazed pellets, 1 inch long, 1/2 inch diameter
Number: 144 pellets in each 12-foot long fuel rod
Fuel Rods: 208 in each assembly
Fuel Assemblies: 177 in each reactor,
each 12 feet long and 15 inches square

CONTROL

Control rods in 69 of the 177 fuel assemblies
16 control rods in each of the 69 assemblies
Boric acid mixed with reactor water (Chemical Shim)

PERSONNEL

Approximately 155 for both units

COST

Total Project - Over $700,000,000

COMMERCIAL OPERATION

November 1973		May 1975

THE CASE FOR THE BREEDER, excerpt from *National Journal CPR*, July 17, 1971.

Promoters of the breeder reactor support their case with three principal arguments.

They cite projections of immense increase in demand for nuclear power; they argue that the breeder is economical because it produces its own fuel, and further, that it is an essential next step in nuclear power development since uranium resources are limited.

They say the breeder would be less harmful to the environment than present reactors.

They say that the United States stands to lose its lead in nuclear technology to other nations unless it proceeds with the breeder.

Breeder and energy needs: The Federal Power Commission projects that the nation's total energy demands will more than double by the year 2000.

Some of the demand will be met by increased production of fossil fuels-coal, oil and gas. But the greatest increase by far will have to come in production of electricity.

In 1965, fossil fuels supplied 78.4 per cent of the nation's energy requirements; but the FPC projects that their share of the energy market will drop to 50 per cent by the end of the century. U.S. electrical generating capacity must grow six-fold by that time to meet the demand, according to the commission's projections.

Since there are relatively few hydroelectric sites left that can harness falling water, most electricity will have to be produced by thermal plants in which heat produces steam to turn electric turbines.

The fossil fuels now used to produce heat in most thermal plants are either limited in supply or contaminating to the environment. Thus, 65 per cent of the projected increase in generating capability is expected to come from nuclear plants.

Assuming that the nation inevitably will turn to nuclear power as its most important source of electrical energy, the promoters of the liquid metal fast breeder reactor argue that the characteristics of its technology will result in major savings.

"With the breeder reactors," said AEC Commissioner James T. Ramey, *"We can extend our use of uranium reserves from decades to a thousand years or more."*

Current commercial reactors use only 1 to 2 per cent in the energy in uranium. But breeders would effectively use up to 75 per cent of energy contained in the ore.

In addition, the breeders would be able to use plutonium wastes efficiently as fuel-both the wastes they would produce in using uranium and the wastes produced at conventional nuclear plants.

Savings in cost of power generation would stem largely from the reduced need for uranium. A conventional present-day nuclear plant needs 150 tons of uranium a year; a breeder of the same size would use only 1.5 tons. Over the course of the next 50 years, the breeder could reduce to 1.2 millions tons the amount of uranium required to supply the nation's energy needs.

This will have the side effect of reducing the pressures for a steep rise in the price of uranium ore, producing additional savings for the utilities.

A recent completed AEC cost-benefit analysis concluded that introduction of commercial breeders in 1986 would save the United States $21.5 billion in power costs through the year 2020, assuming that the funds invested in the reactors would earn 7 per cent a year if invested otherwise.

Environment: Breeder reactors are expected to reduce the environmental impact of nuclear power plants in two ways.

They will reduce thermal pollution. The breeders will achieve a thermal efficiency of 39 per cent or better, which compares with 32 per cent for the light water reactors and a national average of 33 per cent for all fossil-fuel plants.

They, also will reduce the escape of radiation into the air and water. The reactor core will essentially be sealed, and the small amounts of radioactive fission products now released by light water reactors will be largely bottled up in the core.

[Most environmentalists concede that these features of the breeder are attractive. Some, however, have attacked the breeder on grounds that major environmental disasters could result from widespread handling of radioactive plutonium. The plutonium will have to be stored before use, and transported across the country to reactor sites. In addition, there will be the problem of disposing of the radioactive wastes produced in increasing quantities by the breeder plants.]

International competition: A final argument that is likely to surface more fully in coming months and years concerns U.S. competition with other advanced industrial countries for the lead in high technology programs.

While the United States does not have a monopoly on the sale of light water reactors, it has far overshadowed all other countries. General Electric Co. and Westinghouse Corp. have sold 27 LWRs abroad to date.

There are now, however, six nations–the Soviet

Union, West Germany, Britain, France, Japan and Italy—which have embarked on ambitious programs to demonstrate the technical and commercial feasibility of breeder reactors.

For the period 1978-81, all except Japan expect to complete construction of liquid metal fast breeder reactor plants of 1000 megawatts [electric] or more. This is twice the size of the demonstration plant planned here.

Commenting on this worldwide effort, GE executive Karl P. Cohen said: *"I think the U.S. demonstration program, though somewhat slower and more cautious, will ultimately pay off in better results, the problem, however, is not in the program but in the political arena."*

"We are faced with a political, intellectual and social climate in this country that is hostile to major new technological efforts like the breeder. So it's hard to say how fast we will be able to proceed."

Cohen is general manager of GE's reactor development division.

California's Rep. Craig Hosmer, the ranking House Republican on the Joint Atomic Energy Committee, said: *"Well, if we don't build them, then we'll end up buying them from other countries and further eroding our position as the lead nation in high technology."*

FAST BREEDER COMES UNDER ATTACK
Excerpt from *Industrial Research*, June, 1972.

In government circles today, the most popular solution to the impending energy crisis is the fast breeder reactor; the Uranium-238 device that not only produces power, but also breeds more fuel than it uses.

Increased funding of the Atomic Energy Commission liquid metal fast breeder reactor (LMFBR) program, including construction of a demonstration plant in Tennessee, was a central theme of the President's 1971 energy message. But now the breeder concept is coming under attack.

Central to the criticism has been an analysis of the AEC's claims for the breeder by Thomas B. Cochran, a physicist for the Washington think tank, Resources for the Future, which questions many of the economic assumptions the commission used to justify its faith in breeders.

Cochran suggests, for example, that the agency used an unrealistic discount rate in economic projections, that it underestimated the extent of uranium reserves in the U.S., that it overestimated the demand for electric power in the last decade of this century when the breeders should become truly economic, and that it skated over the costs of the advanced technology that will be necessary to bring breeders to commercial use.

Other critics have focused on potential hazards of commercial breeder reactors. Their fears were summarized in a recent statement put out by thirty prominent scientists, including Nobel Laureates Linus Pauling, Harold Urey, James Watson, and George Wald.

"The (LMFBR) reactor's cooling system will utilize liquid sodium, which is highly reactive and burns on contact with air or water," reads the statement. *"Breeder reactors are inherently more difficult to control than today's commercial fission reactors, they operate closer to the melting point of their structural materials, and they generate and use much larger quantities of plutonium. Plutonium has a half-life of 24,000 years and is one of the most toxic substances know to man."*

The AEC's critics do not go as far as to remove breeders from contention as energy sources for the future. They do, however, call for the ACE to spend more money on *"such basic problems as reactor safety, waste storage, and plutonium management"*—as well as alternative energy sources such as solar power, fission, and magnetohydrodynamics.

The AEC's reply to its critics is that its economic and safety calculations are correct—that there is an immediate need to develop breeders because the alternative energy sources are either inadequate or too far from commercial development, and that safety precautions are sufficient. To back up its position, the agency notes that it has been transporting and storing plutonium for more than a quarter of a century, as part of the nation's nuclear weapons program, with an essentially perfect safety record. And the agency loses no chance to plug the excellent environmental qualities of breeder reactors—they produce no air pollution and only minimal thermal pollution.

THE NUCLEAR FUEL CYCLE

The major steps in a nuclear fuel cycle are presented schematically in Figure . Because each reactor concept employs its own fuel cycle, this figure is generalized in order to present briefly the basic principles involved.

To begin the cycle, uranium is mined by conventional means and is then shipped to mills where the uranium is separated from the extraneous bulk material and concentrated. At this point, the uranium compound is refined and converted to gaseous uranium hexofluoride (UF_6) and sent to one of the government owned gaseous diffusion plants.

Enrichment is the process by which the concentration of fissionable uranium is increased to a desirable level. At present the only way to produce significant quantities of enriched uranium is the gaseous diffusion process, although some investigative work is being carried out to determine the feasibility of gas centrifugation. The gaseous diffusion process operates on the principle that the lighter $^{235}UF_6$ passes through a barrier faster than the $^{238}UF_6$. By passing the UF_6 through a certain number of barriers, the desired enrichment is obtained. Typically, the concentration of Uranium-235 is increased from 0.7 per cent for the naturally occurring uranium to the one per cent to five per cent levels which are used in nuclear power plants.

The gaseous diffusion process is the only part of the nuclear fuel cycle that is not done by private industry. The electric power companies pay a service charge or toll for the enrichment.

The next step in the cycle shown in Figure is the fuel preparation, in which the output of the diffusion plant is converted to UO_2 and shaped into pellets.

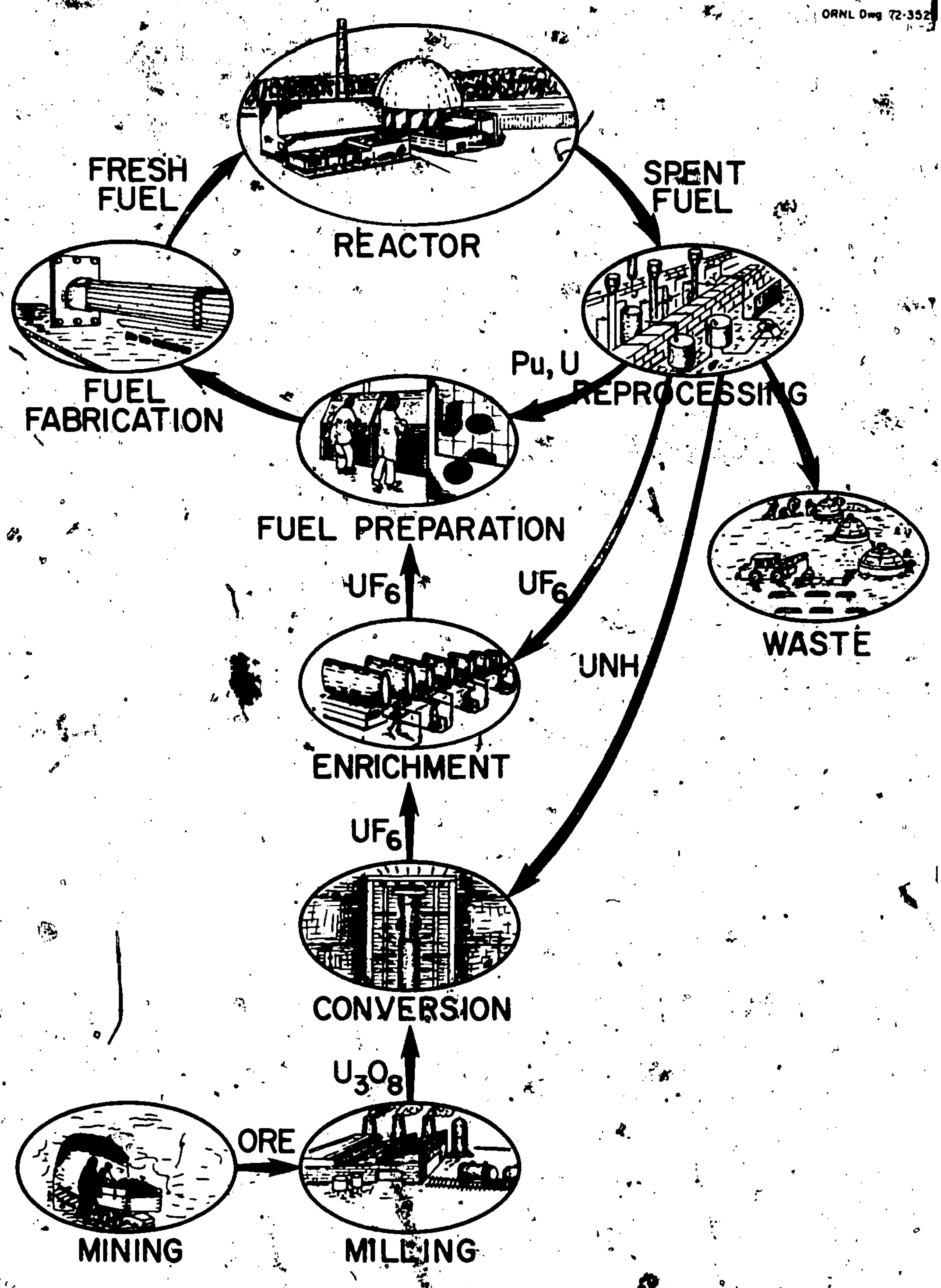
The fuel fabrication step is one of the most expensive, representing almost 1/3 of the fuel cycle cost. This cost is due partly to the fact that there are so many types of fuel rods and fuel rod assemblies and partly due to the requirement for exotic clodding materials. The latter is important since clodding represents the primary containment for both the fuel in the reactor, and later for the fission products which build up as the fuel is used.

The heart of the nuclear fuel cycle is the reactor itself, which has already been discussed.

Following this phase, the complexion of the fuel cycle is drastically altered. The fuel elements that are withdrawn from the reactor are now highly radioactive as the result of fission product generation and, furthermore, the fission products produce so much heat that cooling is required.

Basically, the function of the reprocessing step is to separate the unfissioned uranium and plutonium from the fission products.

After reprocessing, the currently unusable fission products will be fed into the waste management program discussed in Chapter 6. The fissionable uranium and plutonium are then sent to the conversion enrichment and fuel preparation steps of the fuel cycle, depending on the nature of the material and the demands of the fuel cycle.



MAJOR STEPS IN NUCLEAR FUEL CYCLE

WASH-1400
(NUREG 75/014)

REACTOR SAFETY STUDY

AN ASSESSMENT OF ACCIDENT RISKS IN U.S. COMMERCIAL NUCLEAR POWER PLANTS

EXECUTIVE SUMMARY

U.S. NUCLEAR REGULATORY COMMISSION
OCTOBER 1975

Executive Summary

Table of Contents

List of Figures

List of Tables

Section 1

Introduction and Results

The Reactor Safety Study was sponsored by the U. S. Atomic Energy Commission[1] to estimate the public risks that could be involved in potential accidents in commercial nuclear power plants of the type now in use. It was performed under the independent direction of Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. The risks have to be estimated, rather than measured, because although there are about 50 such plants now operating, there have been no nuclear accidents to date resulting in significant releases of radioactivity in U.S. commercial nuclear power plants. Many of the methods used to develop these estimates are based on those that were developed by the Department of Defense and the National Aeronautics and Space Administration in the last 10 years and are coming into increasing use in recent years.

The objective of the study was to make a realistic estimate of these risks and, to provide perspective, to compare them with non-nuclear risks to which our society and its individuals are already exposed. This information may be of help in determining the future reliance by society on nuclear power as a source of electricity.

The results from this study suggest that the risks to the public from potential accidents in nuclear power plants are comparatively small. This is based on the following considerations:

a. The possible consequences of potential reactor accidents are predicted to be no larger, and in many cases much smaller, than those of non-nuclear accidents. The consequences are predicted to be smaller than people have been led to believe by previous studies which deliberately maximized estimates of these consequences.

b. The likelihood of reactor accidents is much smaller than that of many non-nuclear accidents having similar consequences. All non-nuclear accidents examined in this study, including fires, explosions, toxic chemical releases, dam failures, airplane crashes, earthquakes, hurricanes and tornadoes, are much more likely to occur and can have consequences comparable to, or larger than, those of nuclear accidents.

Figures 1-1, 1-2, and 1-3 compare the nuclear reactor accident risks predicted for the 100 plants expected to be operating by about 1980 with risks from other man-caused and natural events to which society is generally already exposed. The following information is contained in the figures:

a. Figures 1-1 and 1-2 show the likelihood and number of fatalities from both nuclear and a variety of non-nuclear accidents. These figures indicate that non-nuclear events are about 10,000 times more likely to produce large numbers of fatalities than nuclear plants.[1]

b. Figure 1-3 shows the likelihood and dollar value of property damage associated with nuclear and non-nuclear accidents. Nuclear plants are about 1000 times less likely to cause comparable large dollar value accidents than other sources. Prop-

---

[1] The work, originally sponsored by the U.S. Atomic Energy Commission, was completed under the sponsorship of the U.S. Nuclear Regulatory Commission, which came into being on January 19, 1975.

[1] The fatalities shown in Figs. 1-1 and 1-2 for the 100 nuclear plants are those that would be predicted to occur within a short period of time after the potential reactor accident. This was done to provide a consistent comparison to the non-nuclear events which also cause fatalities in the same time frame. As in potential nuclear accidents, there also exist possibilities for injuries and longer term health effects from non-nuclear accidents. Data or predictions of this type are not available for non-nuclear events and so comparisons cannot easily be made.

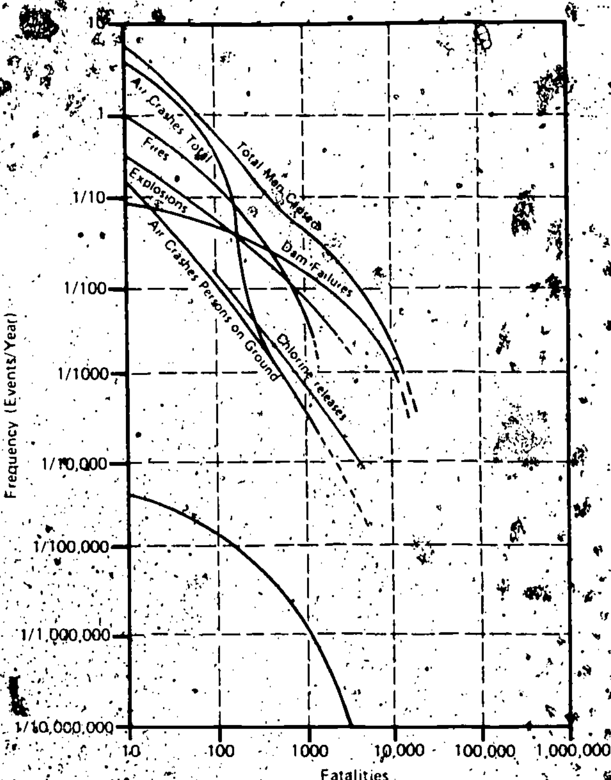


FIGURE 1 Frequency of Fatalities due to Man-Caused Events

Notes: 1. Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

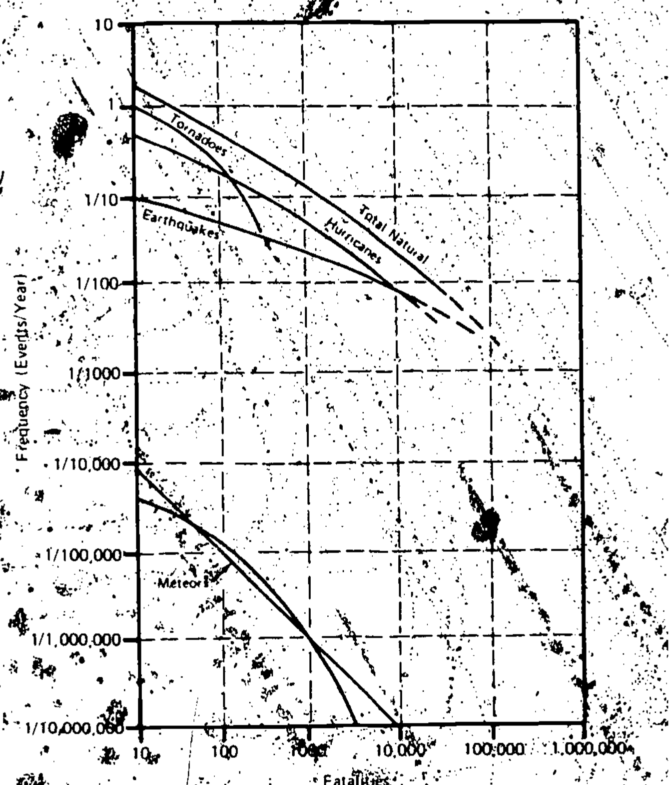


FIGURE 2 Frequency of Fatalities due to Natural Events

1. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

erty damage is associated with three effects:

1. the cost of relocating people away from contaminated areas,

2. the decontamination of land to avoid overexposing people to radioactivity.

3. the cost of ensuring that people are not exposed to potential sources of radioactivity in food and water supplies.

In addition to the overall risk information in Figs. 1-1 through 1-3, it is useful to consider the risk to individuals of being fatally injured by various types of accidents. The bulk of the information shown in Table 1-1 is taken from the 1973 Statistical Abstracts of the U.S. and applies to the year 1969, the latest year for which these data were tabulated when this study was performed. The predicted nuclear accident risks are very small compared to other possible causes of fatal injuries.

In addition to fatalities and property damage, a number of other health effects could be caused by nuclear accidents. These include injuries and long-term health effects such as cancers, genetic effects, and thyroid gland illness. The early illness expected in potential accidents would be about 10 times as large as the fatalities shown in Figs. 1-1 and 1-2. For comparison there are 8 million injuries caused annually by other accidents. The number of cases of genetic effects and long-term cancer fatalities is predicted to be smaller than the normal incidence rate of these diseases. Even for a large accident, the small increases in these diseases would be difficult to detect from the normal incidence rate.

FIGURE 3 Frequency of Property Damage due to Natural and Man-Caused Events

Notes: 1. Property damage due to auto accidents is not included because data are not available for low probability events. Auto accidents cause about $15 billion damage each year.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/5 and 2 on consequence magnitudes and by factors of 1/6 and 5 on probabilities.

3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

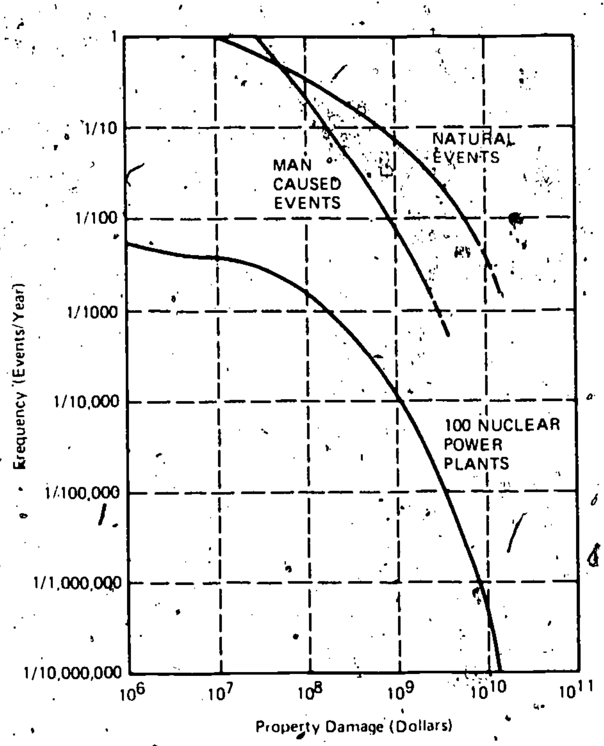


TABLE [illegible]-1. AVERAGE RISK OF FATALITY BY VARIOUS CAUSES

Accident Type	Total Number	Individual Chance per Year
Motor Vehicle	55,791	1 in 4,000
Falls	17,827	1 in 10,000
Fires and Hot Substances	7,451	1 in 25,000
Drowning	6,181	1 in 30,000
Firearms	2,309	1 in 100,000
Air Travel	1,778	1 in 100,000
Falling Objects	1,271	1 in 160,000
Electrocution	1,148	1 in 160,000
Lightning	160	1 in 2,000,000
Tornadoes	91	1 in 2,500,000
Hurricanes	93	1 in 2,500,000
All Accidents	111,992	1 in 1,600
Nuclear Reactor Accidents (100 plants)	-	1 in 2,000,000,000

Thyroid illnesses that might result from a large accident are mainly the formation of nodules on the thyroid gland; these can be treated by medical procedures and rarely lead to serious consequences. For most accidents, the number of nodules caused would be small compared to their normal incidence rate. The number that might be produced in very unlikely accidents would be about equal to their normal occurrence in the exposed population. These would be observed during a period of 10 to 40 years following the accident.

While the study has presented the estimated risks from nuclear power plant accidents and compared them with other risks that exist in our society, it has made no judgment on the acceptability of nuclear risks. The judgment as to what level of risk is acceptable should be made by a broader segment of society than that involved in this study.

Section 2

Questions and Answers About the Study

This section of the summary presents more information about the details of the study than was covered in the introduction. It is presented in question and answer format for ease of reference.

2.1 WHO DID THIS STUDY AND HOW MUCH EFFORT WAS INVOLVED?

The study was done principally at the Atomic Energy Commission headquarters by a group of scientists and engineers who had the skills needed to carry out the study's tasks. They came from a variety of organizations, including the AEC, the national laboratories, private laboratories, and universities. About 10 people were AEC employees. The Director of the study was Professor Norman C. Rasmussen of the Department of Nuclear Engineering of the Massachusetts Institute of Technology, who served as an AEC consultant during the course of the study. The Staff Director who had the day-to-day responsibility for the project was Mr. Saul Levine of the AEC. The study was started in the summer of 1972 and took two years to complete. A total of 60 people, various consultants, 70 man-years of effort, and about four million dollars were involved.

2.2 WHAT KIND OF NUCLEAR POWER PLANTS ARE COVERED BY THE STUDY?

The study considered large power reactors of the pressurized water and boiling water type being used in the U.S. today. Reactors of the present generation are all water cooled, and therefore the study limited itself to this type. Although high temperature gas cooled and liquid metal fast breeder reactor designs are now under development, reactors of this type are not expected to have any significant role in U.S. electric power production in this decade; thus they were not considered.

Nuclear power plants produce electricity by the fissioning (or splitting) of uranium atoms. The nuclear reactor fuel in which the uranium atoms fission is in a large steel vessel. The reactor fuel consists of about 100 tons of uranium. The uranium is inside metal rods about 1/2 inch in diameter and about 12 feet long. These rods are formed into fuel bundles of about 50-200 rods each. Each reactor contains several hundred bundles. The vessel is filled with water, which is needed both to cool the fuel and to maintain the fission chain reaction.

The heat released in the uranium by the fission process heats the water and forms steam; the steam turns a turbine to generate electricity. Similarly, coal and oil plants generate electricity using fossil fuel to boil water.

Today's nuclear power plants are very large. A typical plant has an electrical capacity of 1,000,000 kilowatts, or 1,000 megawatts. This is enough electricity for a city of about five hundred thousand people.

2.3 CAN A NUCLEAR POWER PLANT EXPLODE LIKE AN ATOM BOMB?

No. It is impossible for nuclear power plants to explode like a nuclear weapon. The laws of physics do not permit this because the fuel contains only a small fraction (3-5%) of the special type of uranium (called uranium-235) that must be used in weapons.

2.4 HOW IS RISK DEFINED?

The idea of risk involves both the likelihood and consequences of an event. Thus, to estimate the risk involved in driving an automobile, one would need to know the likelihood of an accident in which, for example, an individual could be 1) injured or 2) killed. Thus there are two different consequences, injury or fatality, each with its own likelihood. For injury, an individual's chance per year is about one in 130 and for fatality, it is about one in 4000. This type of data concerns the risk to individuals and can affect attitudes and habits that individuals have toward driving.

However, from an overall societal viewpoint, different types of data are of interest. Here, 1.5 million injuries per year and 55,000 fatalities per year due to automobile accidents represent the kind of information that might be of use in making decisions on highway and automobile safety.

The same type of logic applies to reactors. From the viewpoint of a person living in the general vicinity of a

reactor, the likelihood of being killed in any one year in a reactor accident is one chance in 2 billion, and the likelihood of being injured in any one year in a reactor accident is one chance in 75,000,000.

2.5 WHAT CAUSES THE RISKS ASSOCIATED WITH NUCLEAR POWER PLANT ACCIDENTS?

The risks from nuclear power plants are due to the radioactivity formed by the fission process. In normal operation nuclear power plants release minute amounts of this radioactivity under controlled conditions. In the event of highly unlikely accidents, larger amounts of radioactivity could be released and could cause significant risks.

The fragments of the uranium atom that remain after it fissions are radioactive. These radioactive atoms are called fission products. They disintegrate further with the release of nuclear radiations. Many of them decay away quickly, in a matter of minutes or hours, to non-radioactive forms. Others decay away more slowly and require months, and in a few cases, many years to decay. The fission products accumulating in the fuel rods include both gases and solids. Included are iodine, gases like krypton and xenon, and solids like cesium and strontium.

2.6 HOW CAN RADIOACTIVITY BE RELEASED?

The only way that potentially large amounts of radioactivity could be released is by melting the fuel in the reactor core. The fuel that is removed from a reactor after use and stored at the plant site also contains considerable amounts of radioactivity. However, accidental releases from such used fuel were found to be quite unlikely and small compared to potential releases of radioactivity from the fuel in the reactor core.

The safety design of reactors includes a series of systems to prevent the overheating of fuel and to control potential releases of radioactivity from the fuel. Thus, for a potential accidental release of radioactivity to the environment to occur, there must be a series of sequential failures that would cause the fuel to overheat and release its radioactivity. There would also have to be failures in the systems designed to remove and contain the radioactivity.

The study has examined a very large number of potential paths by which potential radioactive releases might occur and has identified those that determine the risks. This involved defining the ways in which the fuel in the core could melt and the ways in which systems to control the release of radioactivity could fail.

2.7 HOW MIGHT A CORE MELT ACCIDENT OCCUR?

It is significant that in some 200 reactor-years of commercial operation of reactors of the type considered in the report there have been no fuel me[illegible] accidents. To melt the fuel requi[illegible] failure in the cooling system or the occurrence of a heat imbalance that would allow the fuel to heat up to its melting point, about 5,000°F.

To those unfamiliar with the characteristics of reactors, it might seem that all that is required to prevent fuel from overheating is a system to promptly stop, or shut down, the fission process at the first sign of trouble. Although reactors have such systems, they alone are not enough since the radioactive decay of fission fragments in the fuel continues to generate heat (called decay heat) that must be removed even after the fission process stops. Thus, redundant decay heat removal systems are also provided in reactors. In addition, emergency core cooling systems (ECCS) are provided to cope with a series of potential but unlikely accidents, caused by ruptures in, and loss of coolant from, the normal cooling system.

The Reactor Safety Study has defined two broad types of situations that might potentially lead to a melting of the reactor core: the loss-of-coolant accident (LOCA) and transients. In the event of a potential loss of coolant, the normal cooling water would be lost from the cooling systems and core melting would be prevented by the use of the emergency core cooling system (ECCS). However, melting could occur in a loss of coolant if the ECCS were to fail to operate.

The term "transient" refer[illegible] any one of a number of condition[illegible]ch could occur in a plant and would [illegible]ire the reactor to be shut down. Following shutdown, the decay heat removal systems would operate to keep the core from overheating. Certain failures in either the shutdown or the decay heat removal systems [illegible]lso have the potential to cause melting [illegible] the core.

2.8 WHAT FEATURES ARE PROVIDED IN REACTORS TO COPE WITH A CORE MELT ACCIDENT?

Nuclear power plants have numerous systems designed to prevent core melting. Furthermore, there are inherent physical processes and additional features that come into play to remove and contain the radioactivity released from the molten fuel should core melting occur. Although there are features provided to keep the containment building from being damaged for some time after the core melts, the containment would ultimately fail, causing a release of radioactivity.

An essentially leaktight containment building is provided to prevent the initial dispersion of the airborne radioactivity into the environment. Although the containment would fail in time if the core were to melt, until that time, the radioactivity released from the fuel would be deposited by natural processes on the surfaces inside the containment. In addition, plants are provided with systems to contain and trap the radioactivity released within the containment building. These systems include such things as water sprays and pools to wash radioactivity out of the building atmosphere and filters to trap radioactive particles prior to their release. Since the containment buildings are made essentially leaktight, the radioactivity is contained as long as the building remains intact. Even if the building were to have sizable leaks, large amounts of the radioactivity would likely be removed by the systems provided for that purpose or would be deposited on interior surfaces of the building by natural processes.

Even though the containment building would be expected to remain intact for some time following a core melt, eventually the molten mass would be expected to eat its way through the concrete floor into the ground below. Following this, much of the radioactive material would be trapped in the soil; however, a small amount would escape to the surface and be released. Almost all of the non-gaseous radioactivity would be trapped in the soil.

It is possible to postulate core melt accidents in which the containment building would fail by overpressurization or by missiles created by the accident. Such accidents are less likely but could release a larger amount of airborne radioactivity and have more serious consequences. The consequences of these less likely accidents have been included in the study's results shown in Figs. 1-1 through 1-3.

2.9 HOW MIGHT THE LOSS-OF-COOLANT ACCIDENT LEAD TO A CORE MELT?

Loss of coolant accidents are postulated to result from failures in the normal reactor cooling water system, and plants are designed to cope with such failures. The water in the reactor cooling systems is at a very high pressure (between 50 to 100 times the pressure in a car tire) and if a rupture were to occur in the pipes, pumps, valves, or vessels that contain it, then a "blowout" would happen. In this case some of the water would flash to steam and blow out of the hole. This could be serious since the fuel could melt if additional cooling were not supplied in a rather short time.

The loss of normal cooling in the event of a LOCA would stop the chain reaction, so that the amount of heat produced would drop very rapidly to a few percent of its operating level. However, after this sudden drop the amount of heat being produced would decrease much more slowly and would be controlled by the decay of the radioactivity in the fuel. Although this decrease in heat generation is helpful, it would not be enough to prevent the fuel from melting unless additional cooling were supplied. To deal with this situation, reactors have emergency core cooling systems (ECCS) whose function is to provide cooling for just such events. These systems have pumps, pipes, valves, and water supplies which are capable of dealing with breaks of various sizes. They are also designed to be redundant so that if some components fail to operate, the core can still be cooled.

The study has examined a large number of potential sequences of events following LOCAs of various sizes. In almost all of the cases, the LOCA must be followed by failures in the emergency core cooling system for the core to melt. The principal exception to this is the massive failure of the large pressure vessel that contains the core. However,

the accumulated experience with pressure vessels indicates that the chance of such a failure is small. In fact the study found that the likelihood of pressure vessel failure was so small that it did not contribute to the overall risk from reactor accidents.

2.10 HOW MIGHT A REACTOR TRANSIENT LEAD TO A CORE MELT?

The term "reactor transient" refers to a number of events that require the reactor to be shut down. These range from normal shutdown for such things as refueling to such unplanned but expected events as loss of power to the plant from the utility transmission lines. The reactor is designed to cope with unplanned transients by automatically shutting down. Following shutdown, cooling systems would be operated to remove the heat produced by the radioactivity in the fuel. There are several different cooling systems capable of removing this heat, but if they all should fail, the heat being produced would be sufficient to eventually boil away all the cooling water and melt the core.

In addition to the above pathway to core melt, it is also possible to postulate core melt resulting from the failure of the reactor shutdown systems following a transient event. In this case it would be possible for the amounts of heat generated to be such that the available cooling systems might not cope with it and core melt could result.

2.11 HOW LIKELY IS A CORE MELT ACCIDENT?

The Reactor Safety Study carefully examined the various paths leading to core melt. Using methods developed in recent years for estimating the likelihood of such accidents, a probability of occurrence was determined for each core melt accident identified. These probabilities were combined to obtain the total probability of melting the core. The value obtained was about one in 20,000 per reactor per year. With 100 reactors operating, as is anticipated for the U.S. by about 1980, this means that the chance for one such accident is one in 200 per year.

2.12 WHAT IS THE NATURE OF THE HEALTH EFFECTS THAT A CORE MELT ACCIDENT MIGHT PRODUCE?

It is possible for a potential core melt accident to release enough radioactivity so that some fatalities might occur within a short time (about one year) after the accident. Other people may be exposed to radiation levels which would produce observable effects which would require medical attention but from which they would recover. In addition, some people may receive even lower exposures, which would produce no noticeable effects but might increase the incidence of certain diseases over a period of many years. The observable effects which occur shortly after the accident are called early, or acute, effects.

The delayed, or latent, effects of radiation exposure could cause some increase in the incidence of diseases such as cancer, genetic effects, and thyroid gland illnesses in the exposed population. In general these effects would appear as an increase in these diseases over a 10 to 50 year period following the exposure. Such effects may be difficult to notice because the increase is expected to be small compared to the normal incidence rate of these diseases.

The study has estimated the increased incidence of potentially fatal cancers over the 50 years following an accident. The number of latent cancer fatalities are predicted to be relatively small compared to their normal incidence. Thyroid illness refers mainly to small lumps, or nodules, on the thyroid gland. The nodules are treated by medical procedures that sometimes involve simple surgery, and these are unlikely to lead to serious consequences. Medication may also be needed to supplement the gland function.

Radiation is recognized as one of the factors that can produce genetic effects which appear as defects in a subsequent generation. From the total population exposure caused by the accident, the expected increase in genetic effects in subsequent generations can be estimated. These effects are predicted to be small compared to their normal incidence rate.

2.13 WHAT ARE THE MOST LIKELY CONSEQUENCES OF A CORE MELT ACCIDENT?

As stated, the probability of a core melt accident is on the average one in 20,000 per reactor per year. The most

likely consequences of such an accident are given below.

MOST LIKELY CONSEQUENCES OF A CORE MELT ACCIDENT

	Consequences
Fatalities	<1
Injuries	<1
Latent Fatalities per year	<1
Thyroid Nodules per year	<1
Genetic Defects per year	<1
Property Damage[(a)]	<$1,000,000

(a) This does not include damage that might occur to the plant or costs for replacing the power generation lost by such damage.

2.14 HOW DOES THE AVERAGE ANNUAL RISK FROM NUCLEAR ACCIDENTS COMPARE TO OTHER COMMON RISKS?

Considering the 15 million people who live within 25 miles of current or planned U.S. reactor sites, and based on current accident rates in the U.S., the annual numbers of fatalities and injuries expected from various sources are shown in the table below.

ANNUAL FATALITIES AND INJURIES EXPECTED AMONG THE 15 MILLION PEOPLE LIVING WITHIN 25 MILES OF U.S. REACTOR SITES

Accident Type	Fatalities	Injuries
Automobile	4,200	375,000
Falls	1,500	75,000
Fire	560	22,000
Electrocution	90	--
Lightning	8	--
Reactors (100 plants)	2	20

2.15 WHAT IS THE NUMBER OF FATALITIES AND INJURIES EXPECTED AS A RESULT OF A CORE MELT ACCIDENT?

A core melt accident is similar to many other types of major accidents such as fires, explosions, dam failures, etc., in that a wide range of consequences is possible depending on the exact conditions under which the accident occurs. In the case of a core melt, the consequences would depend mainly on three factors: the amount of radioactivity released, the way it is dispersed by the prevailing weather conditions, and the number of people exposed to the radiation. With these three factors known, it is possible to make a reasonable estimate of the consequences.

The study calculated the health effects and the probability of occurrence for 140,000 possible combinations of radioactive release magnitude, weather type, and population exposed. The probability of a given release was determined from a careful examination of the probability of various reactor system failures. The probability of various weather conditions was obtained from weather data collected at many reactor sites. The probability of various numbers of people being exposed was obtained from U.S. census data for current and planned U.S. reactor sites. These thousands of computations were carried out with the aid of a large digital computer.

These results showed that the probability of an accident resulting in 10 or more fatalities is predicted to be about 1 in 3,000,000 per plant per year. The probability of 100 or more fatalities is predicted to be about 1 in 10,000,000, and for 1000 or more, 1 in 100,000,000. The largest value reported in the study was 3300 fatalities, with a probability of about one in a billion.

The above estimates are derived from a consequence model which includes statistical calculations to describe evacuations of people out of the path of airborne radioactivity. This evacuation model was developed from data describing evacuations that have been performed during non-nuclear events.

If a group of 100 similar plants are considered, then the chance of an accident causing 10 or more fatalities is 1 in 30,000 per year. For accidents involving 1000 or more fatalities the number is 1 in 1,000,000 per year. Interestingly, this value coincides with the probability that a meteor would strike a U.S. population center and cause 1000 fatalities.

The table shown below can be used to compare the likelihood of a nuclear accident to non-nuclear accidents that could cause the same consequences.

AVERAGE PROBABILITY OF MAJOR MAN-CAUSED AND NATURAL EVENTS

Type of Event	Probability of 100 or More Fatalities	Probability of 1000 or More Fatalities
Man-Caused		
Airplane Crash	1 in 2 years	1 in 2000 years
Fire	1 in 7 years	1 in 200 years
Explosion	1 in 16 years	1 in 120 years
Toxic Gas	1 in 100 years	1 in 1000 years
Natural		
Tornado	1 in 5 years	very small
Hurricane	1 in 5 years	1 in 25 years
Earthquake	1 in 20 years	1 in 50 years
Meteorite Impact	1 in 100,000 years	1 in 1,000,000 years
Reactors		
100 plants	1 in 100,000 years	1 in 1,000,000 years

These include man-caused as well as natural events. Many of these probabilities are obtained from historical records, but others are so small that no such event has ever been observed. In the latter cases, the probability has been calculated using techniques similar to those used for the nuclear plant.

In regard to injuries from potential nuclear power plant accidents, the number of injuries that would require medical attention shortly after an accident is about 10 times larger than the number of fatalities predicted.

2.16 WHAT IS THE MAGNITUDE OF THE LATENT, OR LONG-TERM, HEALTH EFFECTS?

As with the short-term effects, the incidence of latent cancers, treatable latent thyroid illness, and genetic effects would vary with the exact accident conditions. The table below illustrates the potential size of such events. The first column shows the consequences that would be produced by core melt accidents, the most likely of which has one chance in 20,000 per reactor per year of occurring. The second column shows the consequences for an accident that has a chance of 1 in a million of occurring. The third column shows the normal incidence rate.

In these accidents, only the induction of thyroid nodules would be observable, and this only in the case of larger, less likely accidents. These nodules are easily diagnosed and treatable by medical or surgical procedures. The incidence of other effects would be low and should not be discernible in view of the high normal incidence of these two diseases.

INCIDENCE PER YEAR OF LATENT HEALTH EFFECTS FOLLOWING A POTENTIAL REACTOR ACCIDENT

Health Effect	Chance per Reactor per Year: One in 20,000 (a)	Chance per Reactor per Year: One in 1,000,000 (a)	Normal (b) Incidence Rate in Exposed Population (per year)
Latent Cancers	<1	170	17,000
Thyroid Illness	<1	1400	8000
Genetic Effects	<1	25	8000

(a) The rates due to reactor accidents are temporary and would decrease with time. The bulk of the cancers and thyroid nodules would occur over a few decades and the genetic effects would be significantly reduced in five generations.
(b) This is the normal incidence that would be expected for a population of 10,000,000 people who might receive some exposure in a very large accident over the time period that the potential reactor accident effects might occur.

2.17 WHAT TYPE OF PROPERTY DAMAGE MIGHT A CORE MELT ACCIDENT PRODUCE?

A nuclear accident would cause no physical damage to property beyond the plant site but may contaminate it with radioactivity. At high levels of contamination, people would have to be relocated from their homes until decontamination procedures permitted their return. At levels lower than this, but involving a larger area, decontamination procedures would also be required, but people would be able to continue to live in the area. The area requiring decontamination would involve a few hundred to a few thousand square miles. The principal concern in this larger area would be to monitor farm produce to keep the amount of radioactivity ingested through the food chain small. Farms in this area would have their produce monitored, and any produce above a safe level could not be used.

The core melt accident having a likelihood of one in 20,000 per plant per year would most likely result in little or no contamination. The probability of an accident that requires relocation of 20 square miles is one in 100,000 per reactor per year. Eighty per cent of all core melt accidents would be expected to be less severe than this. The largest accident might require relocation from 290 square miles. In an accident such as this, agricultural products, particularly milk, would have to be monitored for a month or two over an area about 50 times larger until the iodine decayed away. After that, the area requiring monitoring would be very much smaller.

2.18 WHAT WOULD BE THE COST OF THE CONSEQUENCES OF A CORE MELT ACCIDENT?

As with the other consequences, the cost would depend upon the exact circumstances of the accident. The cost calculated by the Reactor Safety Study included the cost of moving and housing the people that were relocated, the cost caused by denial of land use and the cost associated with the denial of use of reproducible assets such as dwellings and factories, and costs associated with the cleanup of contaminated property. The core melt accident having a likelihood of one in 20,000 per reactor per year would most likely cause property damage of less than $1,000,000. The chance of an accident causing $150,000,000 damage would be about one in 100,000 per reactor per year. The probability would be about one in 1,000,000 per plant per year of causing damage of about one billion dollars. The maximum value would be predicted to be about 14 billion dollars, with a probability of about one in 1,000,000,000 per plant per year.

This property damage risk from nuclear accidents can be compared to other risks in several ways. The largest man-caused events that have occurred are fires. In recent years there have been an average of three fires with damage in excess of 10 million dollars every year. About once every two years there is a fire with damage in the 50 to 100 million dollar range. There have been four hurricanes in the last 10 years which caused damage in the range of 0.5 to 5 billion dollars. Recent earthquake estimates suggest that a one billion dollar earthquake can be expected in the U.S. about once every 50 years.

A comparison of the preceding costs shows that, although a severe reactor accident would be very costly, the costs would be within the range of other serious accidents experienced by society and the probability of such a nuclear accident is estimated to be smaller than that of the other events.

2.19 WHAT WILL BE THE CHANCE OF A REACTOR MELTDOWN IN THE YEAR 2000 IF WE HAVE 1000 REACTORS OPERATING?

One might be tempted to take the per plant probability of a particular reactor accident and multiply it by 1000 to estimate the chance of an accident in the year 2000. This is not a valid calculation, however, because it assumes that the reactors to be built during the next 25 years will be the same as those being built today. Experience with other technologies, such as automobiles and aircraft for example, generally shows that, as more units are built and more experience is gained, the overall safety record improves in terms of fewer accidents occurring per unit. There are changes in plants now being constructed that appear to be improved as compared to the plants analyzed in the study.

2.20 HOW DO WE KNOW THAT THE STUDY HAS INCLUDED ALL ACCIDENTS IN THE ANALYSIS?

The study devoted a large amount of its effort to ensuring that it covered those potential accidents of importance to determining the public risk. It relied heavily on over 20 years of experience that exists in the identification and

analysis of potential reactor accidents. It also went considerably beyond earlier analyses that have been performed by considering a large number of potential failures that had never before been analyzed. For example, the failure of reactor systems that can lead to core melt and the failure of systems that affect the consequences of core melt have been analyzed. The consequences of the failure of the massive steel reactor vessel and of the containment were considered for the first time. The likelihood that various external forces such as earthquakes, floods, and tornadoes could cause accidents was also analyzed.

In addition there are further factors that give a high degree of confidence that the important and significant accidents affecting risk have been included. These are: 1) the identification of all significant sources of radioactivity located at nuclear power plants, 2) the fact that a large release of radioactivity can occur only if the reactor fuel were to melt, and 3) knowledge of the physical phenomena which can cause fuel to melt. This type of approach led to the screening of thousands of potential accident paths to identify those that would essentially determine the public risk.

While there is no way of proving that all possible accident sequences which contribute to public risk have been considered in the study, the systematic approach used in identifying possible accident sequences makes it unlikely that an accident was overlooked which would significantly change the overall risk.

2.21 WHAT TECHNIQUES WERE USED IN PERFORMING THE STUDY?

Methodologies developed over the past 10 years by the Department of Defense and the National Aeronautics and Space Administration were used in the study. As used in this study, these techniques, called event trees and fault trees, helped to define potential accident paths and their likelihood of occurence.

An event tree defines an initial failure within the plant. It then examines the course of events which follow as determined by the operation or failure of various systems that are provided to prevent the core from melting and to prevent the release of radioactivity to the environment. Event trees were used in this study to define thousands of potential accident paths which were examined to determine their likelihood of occurrence and the amount of radioactivity that they might release.

Fault trees were used to determine the likelihood of failure of the various systems identified in the event tree accident paths. A fault tree starts with the definition of an undesired event, such as the failure of a system to operate, and then determines, using engineering and mathematical logic, the ways in which the system can fail. Using data covering 1) the failure of components such as pumps, pipes and valves, 2) the likelihood of operator errors, and 3) the likelihood of maintenance errors, it is possible to estimate the likelihood of system failure even where no data on total system failure exist.

The likelihood and the size of radioactive releases from potential accident paths were used in combination with the likelihood of various weather conditions and population distributions in the vicinity of the reactor to calculate the consequences of the various potential accidents.

FOSSIL-FUELED ELECTRICAL GENERATING STATIONS

1. General Operation

Many millions of years ago the earth laid down thick deposits of organic materials. Under heat and pressure, these materials became coal, oil and gas, composed mainly of hydrogen and carbon. When these fossil fuels burn, they release heat energy and produce carbon dioxide and water vapor, plus by-products such as sulfur dioxide, oxides of nitrogen, unburned hydrocarbons, carbon monoxide and ash.

Most large fossil fuel-burning plants are similar in design (Figure 19). Fuel, in the form of crushed coal, oil or gas, is blown under high pressure into a boiler, where flames and hot gases pass over and around thousands of tubes. Water inside the tubes is converted to steam.

Part of the fuel's energy is transferred to steam; part of it remains with the combustion products which are discharged to the atmosphere; and part of it is lost by convection and conduction to the surroundings.

Steam from the boiler is fed into a turbine, where part of its energy is converted into mechanical energy, while the remainder is lost in the condenser and to the surroundings. The mechanical energy produced by the turbine drives the electric generator, where it is converted to electrical energy. Again some loss occurs in the conversion. The overall thermal efficiency for most recently-built steam electric plants falls between 35 and 40 per cent. In an average fossil-fueled steam electric plant, 5,587 Btu's out of 9,000 Btu's are lost in the production of one kilowatt hour of electrical energy.

One of the most noteworthy developments in fossil-fuel generation in recent years has been the increase in plant size from about 300 megawatts to 2,000 megawatts. These plants have increased their efficiency by going to higher steam pressures and temperatures.

Fossil-fueled generating plants must be located to insure that an adequate fuel supply is available for the life of the plant. The total cost of fuel over the life of the plant will normally be the most important single consideration in the selection of the type of fuel and the plant site.

2. Natural Gas-Fired Power Generation

Gas is considered the cleanest of the fossil fuels, since it is essentially methane, which can be readily and completely burned to carbon dioxide and water. It usually has a very low sulfur content. The burning of natural gas creates little noise, water or air pollution, with the main pollution being the oxides of nitrogen formed in the combustion chamber from the nitrogen and oxygen in air. Transmission of gas is normally through underground pipelines, which are reasonably safe and have little environmental impact.

Unfortunately, natural gas is being used up faster than new reserves are being discovered. Electric utilities are among the fist to suffer from the growing deficiency. By 1990 there will probably be none available for electric utilities. More and more, the natural gas will have to be supplied by oil and coal gasification and from places as far away as Siberia. Thus, no new natural gas-burning power plants are being planned or built.

3. Oil-Fired Power Generation

To produce 2,300 megawatts of electric power, a company would usually install two oil-fired generating units. Each unit would consist of an oil-fired generator and a reheat turbine generator.

In each of a station's two boilers, steam is produced by the burning of residual fuel oil. At full power, 550,000 pounds of fuel oil would be consumed per hour. In a year, the plant would require about forty 100,000-ton tankers of oil. A month's supply of oil stored at the plant would require five tanks 50 feet high and 300 feet in diameter, covering 40 acres. This area would be surrounded by a dike in case the tanks should spring a leak. Other facilities include pumphouses, pipes, an unloading dock for barges or tankers and waste treatment facilities.

Because of lack of economical technology removing sulfur from coal, many utilites and industries especially in the northeastern states turned to oil to meet 1970 Clean Air Act requirements. The slowdown in the building of nuclear power plants has added to this burden on the oil resources.

Wells in the United States (except Alaska) are currently pumping oil at capacity, and still the demand for oil cannot be met by domestic sources. Already the United States imports nearly one-third of its oil. Those responsible for national security worry about becoming dependent on foreign oil sources, especially oil-rich, politically volatile Middle East sources. In the fall of 1973, the U. S. had a sample of what it is like when Arab states cut off oil shipments. The embargo then was not completely successful, and our dependence on imported oil was not as great as it would have been a few years later.

Economists also worry about the huge increase in the balance-of-trade deficit if we turn increasingly to foreign supplies of oil. For example, Saudi Arabia has more crude oil reserves than the United States and Latin America combined. In fact, Saudi Arabia and several other oil-producing countries are now earning enough from oil sales to purchase a major U.S. corporation each year, if our government would allow such purchases.

In addition to the oil supply problem, there is also a problem of refinery capacity. Most U.S. refineries are running at maximum capacity. There are no longer sufficient overseas refining capabilities, dock and terminal facilities or tankers to meet increased needs. Super-sized tankers and ports are needed for receiving increased oil shipments.

Competition exists for the available oil. For example, because of an increase in the number of cars, plus engine modifications to reduce emissions and increasing use of air conditioning and power accessories, gasoline consumption has increased, thereby reducing the capacity for fuel oil production. Oil and gas are rapidly becoming too valuable to burn directly and the nation must begin to think in terms of conserving them as raw materials for making the chemicals and foodstuffs needed in the more distant future.

On-shore oil production rarely creates any significant pollution problems, although accidental pollution sometimes occurs when wells blow out or when oil is lost in storage or transportation. Off-shore operations present more problems with oil spills and fires at the wells.

Oil-fired plants in the United States usually burn imported, low sulfur residual oil and are located near the coast, where there are facilities for unloading large tankers. Oil spills and discharges from tankers need to be prevented, along with the contamination of inland waterways and harbors during the transfer of oil between, or from, vessels.

4. Coal-Fired Power Generation

A station designed to produce 2,300 megawatts of power from coal would use two coal-fired units. The station is similar to the oil-fired station, except it contains a coal-fired steam generator rather than an oil-fired generator. The plant would require coal from approximately 59,800 freight cars of 100-ton capacity each year. Coal storage and handling facilities would occupy about 25 acres.

Oil and gas supply three-quarters of U.S. energy needs, including transportation, and domestic sources are in short supply. On the other hand, coal represents three-quarters of the fossil fuel reserves but supplies only 20 per cent of the U.S. energy. Coal is found in 38 states, and there are some 1.5 trillion tons of known reserves (Figure 20). The United States has more known coal reserves than the rest of the free world combined.

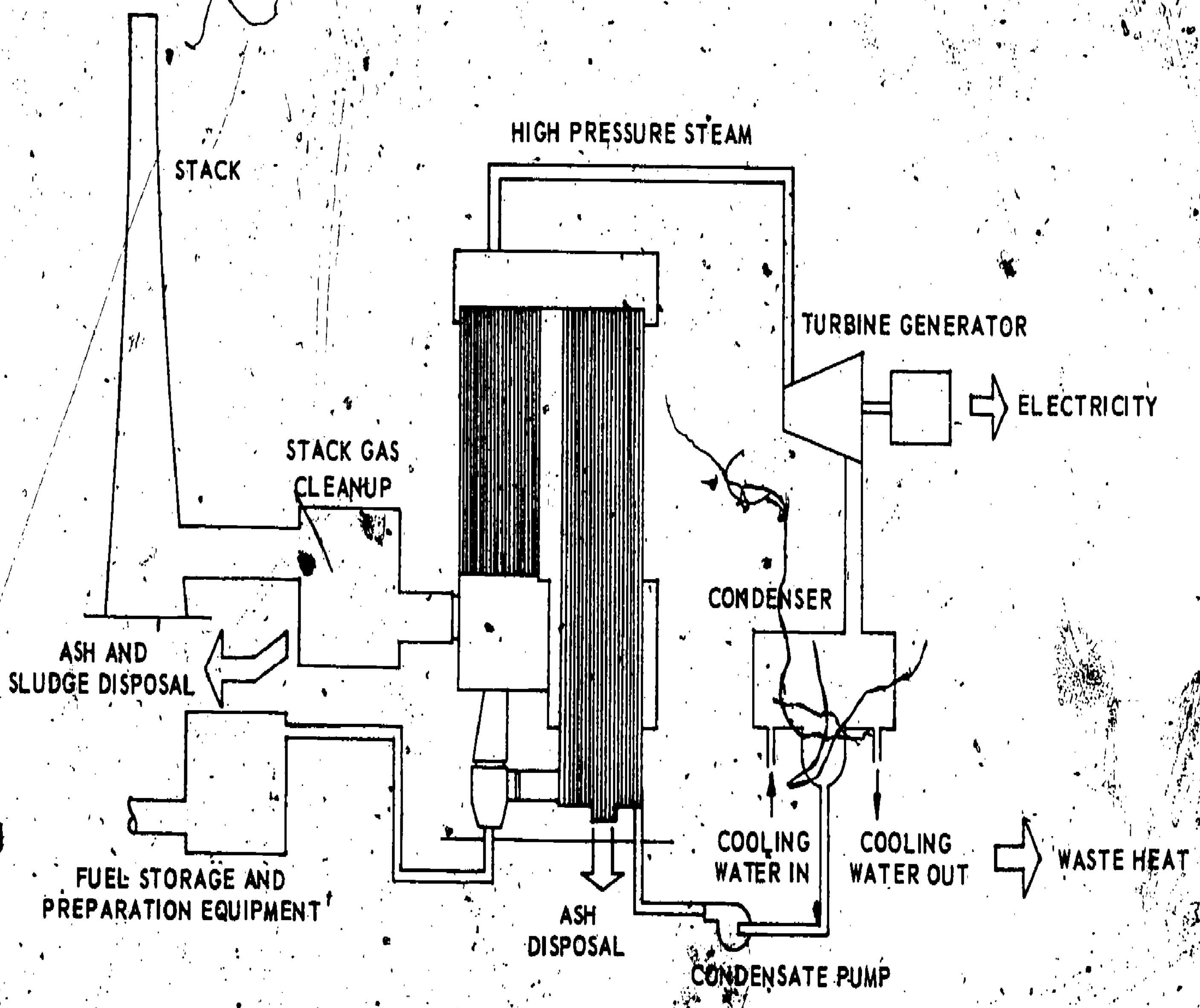
On the face of it, this substantial reserve should last for hundreds of years. But coal offers special problems. It is the worst offender in producing sulfur compounds, which are harmful pollutants. This problem is discussed in Chapter 7.

Furthermore, getting coal out of the ground without major damage to the environment has become a serious problem. Underground coal mines have polluted the water table, harbored fires and caused millions of acres of surface land to subside, breaking roads and sewers and collapsing buildings. Underground mining is a hazardous industry in terms of mine accidents and disabling black lung disease.

Strip mining is safer and much cheaper—it costs only about half as much to mine by stripping as by deep mining. Currently, about 50 per cent of all coal comes from strip mining. But strip mining destroys landscapes and can pollute river and water supplies with silt and acid mine drainage. It is possible, however, to prevent much of this damage through proper land reclamation, adequate drainage and planting to achieve soil stablization. Supporters of tough antistripping legislation estimate that meaninful reclamation of strip mines would add less than 15 cents per month to the average consumer's electric bill. Some states now have partial bans on strip mining, and others have some type of reclamation requirements. But of the more than 1.5 million acres of American land stripped for coal, two-thirds are unreclaimed, and these areas keep on producing acid drainage, erosion and esthetic blight.

Delivery of coal is often hampered by a shortage of railroad hopper cars and the closing of mines by strikes.

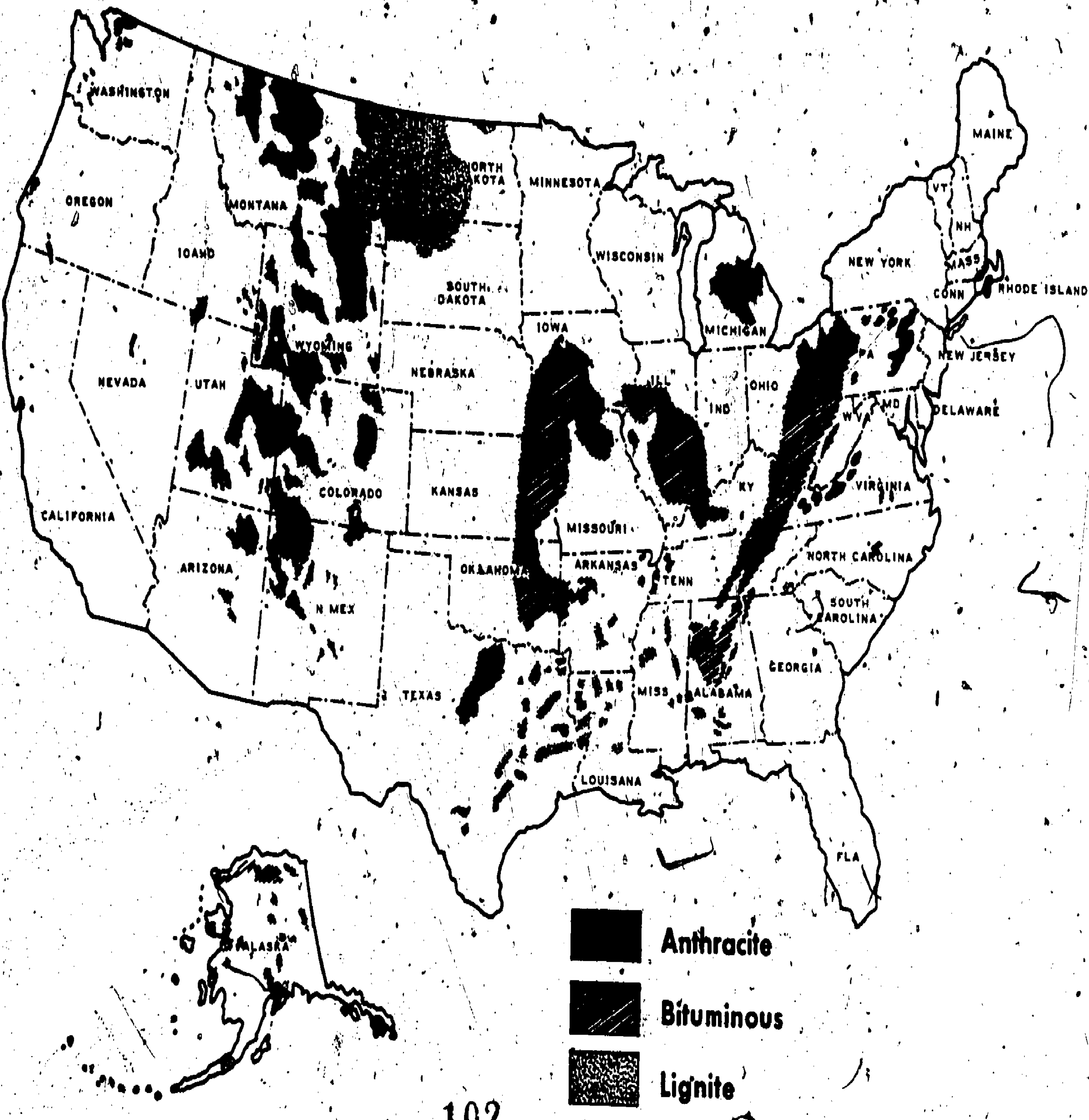
Since transportation of coal is so expensive, some utilities are building power plants atop the coal mine and sending the electricity to market by wire. For example, many Philadelphia-Baltimore-Washington consumers get a portion of their electricity from a trio of huge mine-mouth plants near Chestnut Ridge, an immense coal-bearing mountain in Western Pennsylvania. An added benefit of constructing a plant near a coal mine is the ease of ash disposal. The ash can be used as back-fill during reclamation of the coal fields.



*NOT REQUIRED FOR GAS

FIGURE 19– SCHEMATIC DIAGRAM O[illegible]SIL-FUELED POWER PLANT

COAL FIELDS OF THE UNITED STATES
(FROM UNITED STATES GEOLOGICAL SURVEY)



102

FIGURE 20

CHAPTER 5

BASIC ECOLOGY: PRINCIPLES AND IMPLICATIONS

1. What is Ecology?

The term *"ecology"* is widely used today, but often it is only vaguely understood. We hear that pollution has *"damaged the ecology"* and that we should *"save the ecology."* What exactly is this ecology? Recently, people have become increasingly aware that all living things are greatly influenced by their environment. Ecology is the study of this relationship of an organism or group of organisms to each other and to their environment. More simply, ecology is environmental biology.

2. Nutrient and Energy Cycles

Circular rhythms called cycles are basic to the health and maintenance of the environment. Sunlight provides the energy source for all these life cycles. Radiant energy from the sun is absorbed by plants and is used for photosynthesis and growth. The plant uses minerals from the soil and water. When the plant dies, the energy (now converted into plant tissue) enters the soil and provides food for decay-causing organisms. These organisms release into the soil nutrients that were once held in the plant. The nutrients are then free to be absorbed by other plants rooted nearby, continuing the cycle. Inorganic nutrients which were orginally in the soil, such as calcium and phosphorus, are part of this nutrient cycle.

Every organism represents a certain tropic (food) level in this cycle of nutrients and energy. If, for example, the plant is eaten by a rabbit and the rabbit is eaten by a fox, the cycle becomes more complex. The nutrients will eventually return to the environment, but they may travel many complex paths before they do. The relationship of who eats what or whom is called the food chain. Usually a system is quite complicated, and there are many possible food relationships. These are more accurately called a food web, illustrated in Figure 21. As more organisms enter the food relationship, the food web becomes more complicated; and the more complicated this energy relationship becomes, the more stable the relationship will be, increasing the chances for healthy maintenance and survival. For example, if a fox has the possibility of eating not only a rabbit but a squirrel or a mouse, his chances of survival (or his stability within the system) is increased.

The levels of production and consumption can be illustrated in an ecological pyramid (Figure 22). At the base is primary input-radiant energy from the sun and raw materials such as water and minerals. This base supports the primary producers, the plants, which in turn support herbivores, or plant eaters. Herbivorous animals are the food source of carnivores, the flesh eaters, and these carnivores may be the food source of other carnivores. The herbivores and carnivores together are called consumers. As plants and animals die and drop out of the pyramid, they are attacked by decomposers (usually decay-producing bacteria and fungi), which reduce the tissues to their chemical components in the soil, where they re-enter the cycle through uptake by growing plants.

Much usable energy is lost as it passes from one level of the pyramid to the next in the form of food. This energy is lost largely in maintaining the life of the organism through respiration. As a general rule, only about 10 per cent of the energy at any one level will be transferred to the next level. Primary producers are not limited by this energy loss, because they obtain their energy from the sun, and herbivores are usually not limited due to the presence of the primary producers. But the energy loss can cause food shortages which affect the abundance of carnivores.

3. Communities and the Ecosystem

A community is composed of all the plant and animal species that live and interact in a particular environment. A pine forest with its associated plants and animals is a community, as are an open prairie, a tropical rain forest, a lake and a pond. Each community, a unit which can usually function independently of any other community, is composed of plant species which can grow in the environmental conditions present (amount of sunlight, temperature, rainfall, soil type, etc.). The animal species in a community must be able to live under the same environmental conditions and be able to obtain energy from the plants or other animals present. A system of relationships between a living biological community and its nonliving physical environment is called an ecosystem.

All communities originally developed on bare soil. An open field soon becomes covered with grass and weeds. Then shrubs take root, and eventually tree seedlings grow up through the shrubs. Finally, a forest may stand where there was once an open field. The forest may undergo changes until only a few dominant species of plant life remain. If left undisturbed, this forest community will maintain itself indefinitely by recycling of necessary nutrients through the food webs in its ecosystem. Such a forest is called a climax community. It is the final product of what is called succession. Succession refers to the replacement of one community with another more complex one, as conditions permit. Therefore, communities are usually changing systems, with the goal of becoming a climax community. What constitutes a climax community will vary, depending on environmental conditions. When the westward-moving pioneers saw the vast tall grass prairies of the midwest, they were seeing a climax community, which could not progress beyond

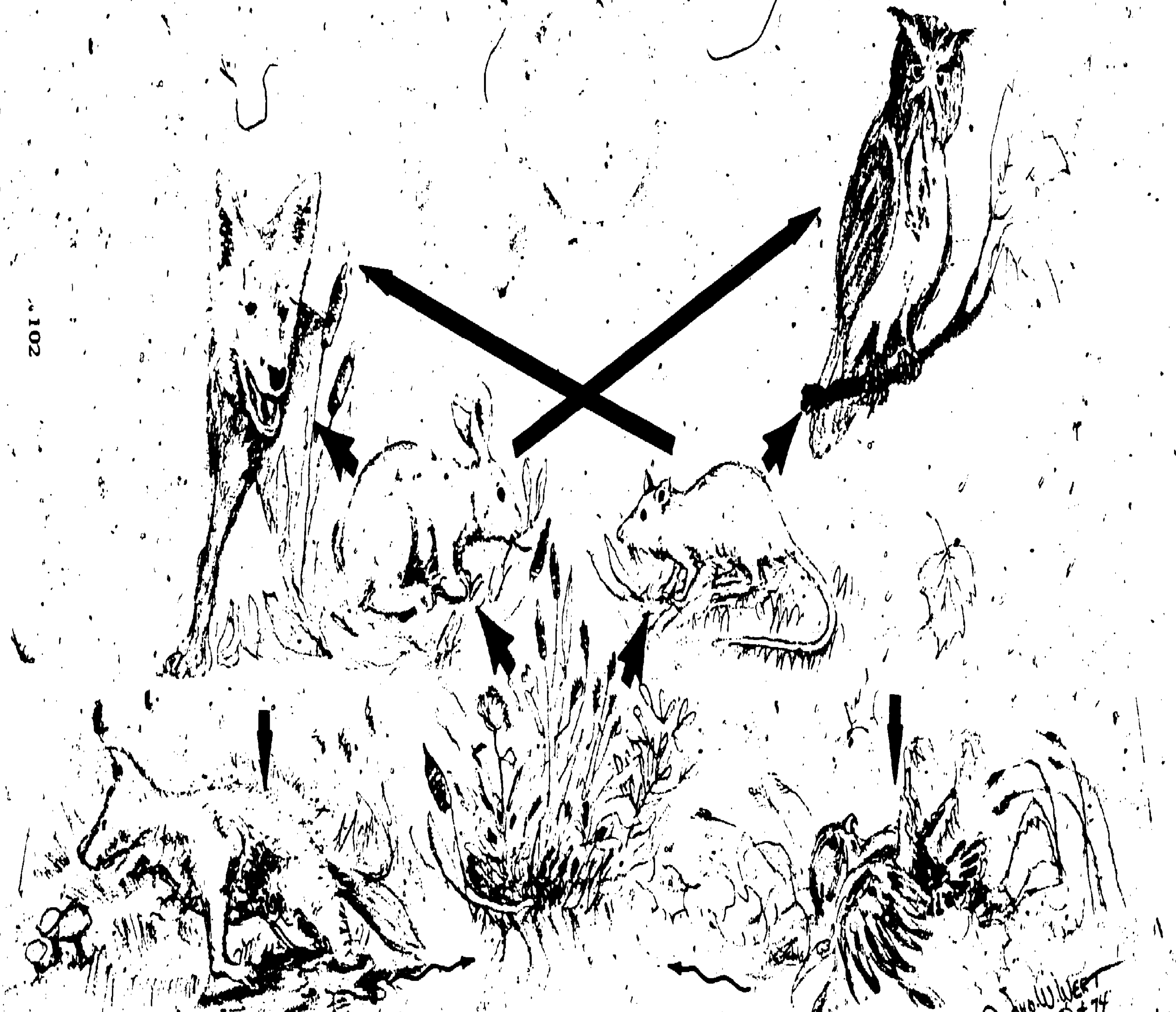


FIGURE 21

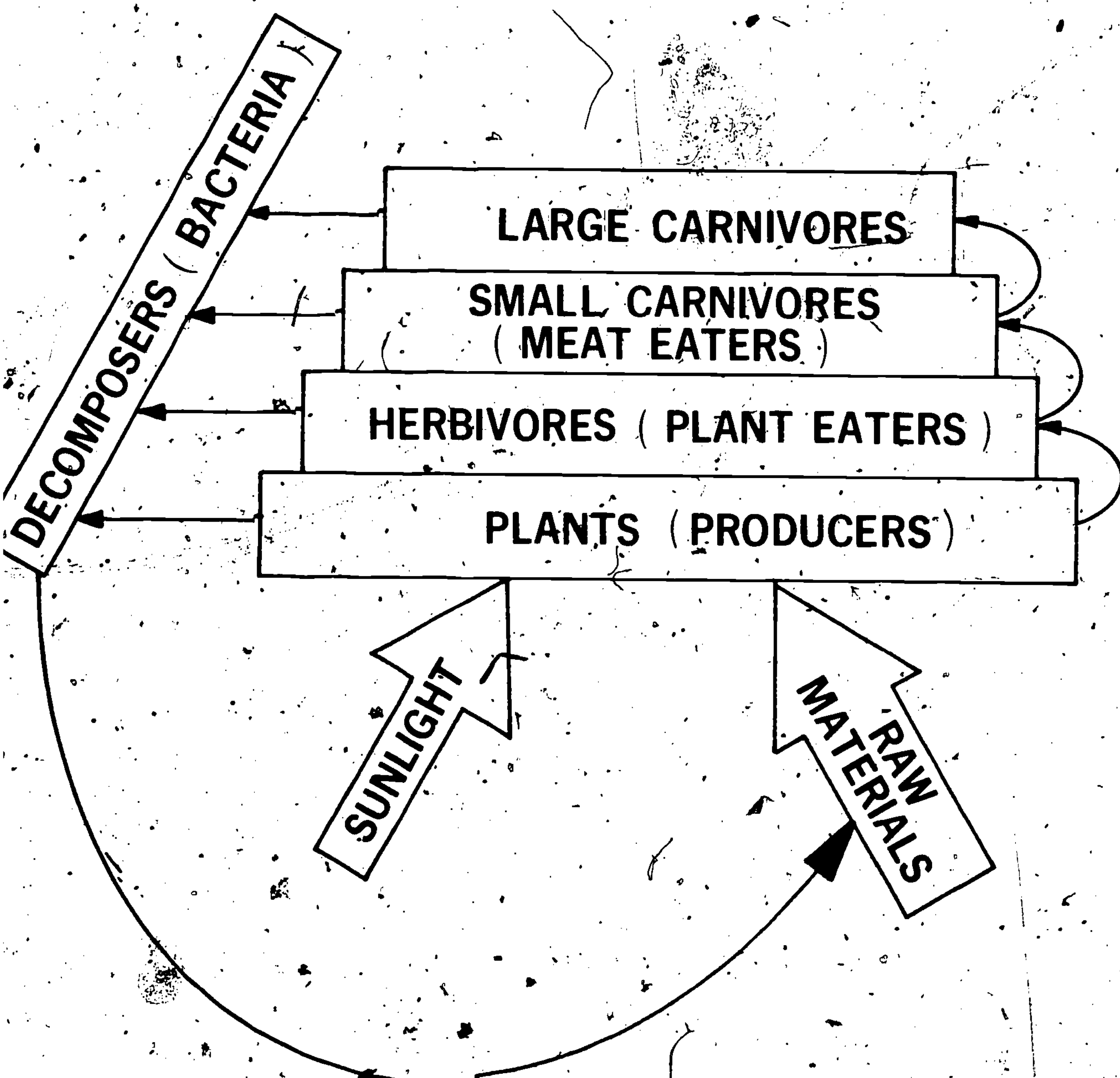

DECOMPOSERS (BACTERIA)
LARGE CARNIVORES
SMALL CARNIVORES
(MEAT EATERS)
HERBIVORES (PLANT EATERS)
PLANTS (PRODUCERS)
SUNLIGHT
RAW MATERIALS

FIGURE 22

grassland because of lack of water. In other cases, temperature, light and soil can be the limiting factors restricting community development through succession.

4. Ecological Balance

All ecosystems, whether they are composed of one community or many communities, maintain themselves through a complicated system of natural control and balance. For example, certain animals are directly dependent on plants for food and shelter. These animals are in turn the source of food for other animals—a predatory-prey relationship. Such predators are necessary to keep the animal population stable. Very young or old prey, as well as sick and weak prey, are easily caught by predators, who naturally expend only as much energy as necessary to obtain their food. This removal of the weaker prey increases the overall strength of the prey population while maintaining the predator population. By the same principle, only the healthy predator can consistently catch its prey, so that the weaker members do not survive. Such a relationship proves to be mutually beneficial. Should animal populations become too large through some fluctuation in the system, they are usually reduced by starvation and disease, but rarely before they cause some damage to the ecosystem which they occupy.

The most important factor in maintaining an ecological balance is competition. When two organisms use the same limited resource, they must compete for it. Such a resource could be light, water, food, space or many other things. The organisms may be forced to share the resource, with neither getting all it needs, or possibly one organism will use all the resource. Such competition can exist between similar species, between different species or between individuals of the same species. As the population increases, so does the competition; all this gives a measure of stability to the population.

5. Upsetting the Balance

The delicate balance in entire communities can be altered by changes in any one of the major ecosystem components. Such changes occur frequently in nature. Usually, major changes take place over long periods of time. Dinosaurs were predominant on the earth for millions of years when temperatures were tropical and plant growth lush. Then they slowly faded away to extinction, giving up their place of dominance to the newly-emerging mammals. The saber-toothed cat and giant cave bear roamed the continent for thousands of years, only to be replaced by the smaller, more adaptable carnivores which exist today. These were major changes in the ecosystem, yet they happened slowly. The animals that were lost were replaced by others, keeping the ecosystem in balance.

There are also natural occurrences which bring about rapid changes in the ecosystem such as fires, floods, drought, volcanic eruptions and earthquakes. But these are not common phenomena, and a natural balance returns in time.

In the short time since modern humans have entered the picture, however, ecological balances have been upset on a large scale. Within the last 200 years, people have dammed rivers; polluted oceans, streams and air; cut forests; drained swamps; and caused the extinction of many species. The search for more energy sources has resulted in mountains and plains being strip-mined and left in barren rubble. Air and water pollution has resulted from the tremendously increasing use of energy.

Although misuse of the environment has been going on for many years, we have only recently begun to understand the complexity of environmental relationships. It has been found that pollutants dumped into streams adversely affect ecosystems, destroying natural resources. Many species of wildlife have been pushed to the verge of extinction through the destruction of their natural habitats. When ecosystems are disturbed, the effects are far-reaching and cannot always be predicted. For example, it was not realized at first that DDT used on crops would be cycled to the bald eagle at such concentrated levels that it would affect its nesting success, or that cutting the forests would force the passenger pigeon to extinction. Such elimination of species without their successful evolution and replacement is a permanent loss and harms the stability of communities.

6. Maintaining the Balance

The first step in maintaining the ecological balance would perhaps be to try to correct the damages already done. More importantly, however, would be careful planning for the future. In view of the style of life we expect to have, it seems unlikely that damage to the ecosystem will stop. But this damage can be minimized, or avoided, with careful planning and wise use of natural resources. In some cases, ecosystems and individual plants and animals can adapt to the changes caused by human activities. In many cases, they cannot. Careful planning serves to limit or eliminate the situations where irreversible harm is likely to occur.

This careful planning must be done at every step in the generation of electric power, including the mining of fuel, the selection of plant location and type, the operation of the plant, the transmission of the electricity and the disposal of waste products.

CHAPTER 6

WASTES IN THE PRODUCTION OF ELECTRIC POWER

1. Heat as a Waste Product

Heat is not normally thought of as waste, but it is put into the environment in large amounts by nuclear and fossil-fueled power plants. Most of the energy used by humans is produced by the conversion of heat energy into other energy forms, such as electrical or mechanical energy. The efficiency of this conversion is limited by natural laws. Thus, a large portion of the energy involved in the conversion is lost, usually in the form of heat. Modern steam turbine equipment provides relatively high thermal efficiency compared to other engines. Even with this modern equipment, the thermal efficiency of most electrical generating stations is slightly more than 30 per cent. This means that almost 70 per cent of the total available energy is not used and must be discarded into the environment as heat.

The problem of heat removal is greater for nuclear plants than for fossil-fueled plants. One reason is that nuclear power plants discharge almost all their waste heat into their cooling water. Fossil-fueled plants, on the other hand, discharge about 15 per cent of their waste heat directly into the air with the stack gas, so that only about 85 per cent must be removed by the water.

The thermal efficiency of most nuclear power plants is slightly lower than that of modern fossil-fueled plants. Using high temperatures (1,000 to 1,100 degrees Fahrenheit) and high steam pressures (1,800 to 3,500 pounds per square inch), modern fossil-fueled plants may attain a thermal efficiency of 37 to 40 per cent. However, less than half the presently operating plants attain this thermal efficiency. The average efficiency of all fossil-fueled plants, the older as well as the newer, is about 33 per cent. Because of their design, most nuclear plants produce steam at lower temperatures (500 to 600 degrees Fahrenheit) and at lower pressures (800 to 1,000 pounds per square inch). Thus their thermal efficiency is lower than that of the best fossil-fueled plants, averaging about 32 per cent. Because of this lower efficiency, they must reject more heat.

Today's average nuclear-fueled plant is larger than the average fossil-fueled plant. Thus larger amounts of heat must be dissipated at one location.

2. Methods of Heat Disposal

As previously stated, heat from the combustion of fossil fuels or from the fission of nuclear fuels is used to make steam in a steam electric station. The steam drives a turbine connected to an electrical generator. As the heat energy of the steam is converted to mechanical energy, the temperature and pressure of the steam decrease. This steam, called "spent" steam, is converted back to water in a condenser and returned to the boilers, where it is reconverted to high pressure steam for reuse in the cycle. The heat removed from the spent steam in order to condense it is the waste heat released to the environment.

Condensation is accomplished by passing large amounts of cooling water through the condenser. In the least costly method, the cooling water is taken directly from a nearby river, lake or other large body of water. The cooling water is heated 10 to 30 degrees Fahrenheit, depending on plant design and operation, and then returned by cooling canals to its source. Usually only a small fraction of the volume of a body of water is used for cooling water. Thus, the temperature change is usually less than one degree Fahrenheit at points 1,000 feet from the point of discharge of the heated water. The body of cooling water eventually loses the added heat to the atmosphere. This type of cooling system is called a once-through system. If the volume of the body of water is not sufficient, the heated water may be critically low in oxygen, therefore favoring the rapid growth of some aquatic plants. If the temperature change in the cooling water is excessive, it may create critical ecological problems. The use of once-through cooling is restricted in many areas; and new installations of this type are permitted only if the volume of water allows only negligible temperature changes.

Other methods of cooling are more expensive, but they place less strain on natural waterways. Each has its own environmental effects and economic penalties, so that the best system for a particular plant must be decided on a case-by-case basis in an attempt to gain the greatest environmental benefits at the least cost.

A cooling method which is finding favor in many areas is the use of wet or dry cooling towers. In such systems, water is drawn from a nearby source, passed through the condensor, and then passed through a cooling tower, where at least part of the waste heat is transferred to the air. The cooled water may then be returned to its source or be reused in the condenser.

In wet cooling towers, the cooling water is brought in direct contact with a flow of air, and the heat is dissipated primarily by evaporation. The flow of air through the cooling tower can be provided by either mechanical means or natural draft, and make-up water must be added to replace evaporative losses. Wet cooling towers for a 1,000-megawatt nuclear plant may evaporate up to 20 million gallons of water per day. A comparable fossil-fueled plant would evaporate about 14 million gallons. This excess water burden in the atmosphere may affect local weather conditions. In cold or humid weather, the

likelihood of fogging and precipitation increases, and in some cases in cold weather, moisture from these towers create icing problems on nearby plant structures and roads.

Dry cooling towers are similar to automobile radiators, in that the heat dissipates by conduction and convection rather than evaporation. Dry cooling towers probably produce the least environmental effects of all cooling systems. However, they are much more costly, because they require a larger surface area for heat transfer and the circulation of a larger volume of air. They also reduce the plant's efficiency.

In yet another method of cooling, artificial ponds or lakes are constructed to provide water for circulation through the condensers. A 1,000-megawatt plant might require as much as 3,000 acres for such a pond. These ponds create some local fogging on cold days as warm surface water evaporates.

Although these alternatives offer relief from potential thermal effects, they are not a satisfactory answer to the heat problem. The probable answer is two-fold: finding a use for the excess heat and increasing the efficiency of electrical generation to decrease the amount of excess heat.

Research is under way on uses for the excess heat. One study involves the beneficial uses of low-grade heat in compatible urban systems. An example is the use of discharge heat to increase the rate and effectiveness of secondary sewage treatment processes. Another possibility is the use of treated sewage effluent in cooling towers, where the nutrients can be substantially concentrated by evaporation. If the evaporated water could be condensed and collected, it could become a source of pure water, while the concentrated nutrients could be recovered and recycled to the environment. Sea water might be desalinated in the cooling towers, providing pure water and minerals.

Controlled heated water has been found to benefit a few forms of fish life, particularly shellfish. Tests demonstrate that rejected heat can be used to extend the growing season for crops.

These concepts and many others, such as home heating and cooling, are incorporated into the idea of the *"Nuplex,"* or *"Energy Center Complex."* It is envisioned that an entire city would grow up associated with, and complimentary to, a nuclear electric power source. In this futuristic city practically all the reject heat would be a beneficial resource instead of waste product.

3. Radioactive Wastes

A great deal of controversy exists concerning the transfer, storage, and disposal of the radioactive wastes from the nuclear power fuel cycle. Some opponents of nuclear plants cite these as insoluble problems, while other people regard them as merely technical problems to be solved. Certainly these wastes are potentially dangerous. Fortunately, the amount of radioactive waste is small enough to make storage feasible. In fact, of all the radioactivity ever generated in radioactive wastes, most of that which has not decayed is still in storage. A major goal is to develop a technology, where these wastes would still be in one place, but so isolated from the human environment that no maintenance and only minimal surveillance would be required.

A. Sources of Radioactive Wastes in Electrical Power Generation

The first point where radioactive wastes appear in the nuclear power fuel cycle is with the mining and milling of the uranium-bearing ores. More radioactive wastes result from the refining and enriching of the uranium and the fabrication of fuel elements. The radioactivity in all these wastes is due to the presence of naturally-occurring radioactive nuclides.

The nuclear reactor is the first point in the cycle where man-made radioactivity is introduced. Large quantities of radioactivityare created in reactor coolants, shielding, and structural materials by the absorption of neutrons from the fissioning of the fuel. Most of this radioactivity is of short half life; so that it decays rapidly. It does appear to some extent as a contaminant in effluent streams, in solid wastes from the treatment of effluents, or from maintenance work.

Another type of man-made radioactivity from the nuclear reactor is the fission products. These are generated within the fuel in much larger quantities than are needed for research, medical, or industrial applications, and will therefore eventually become waste.

The last type of man-made radioactivity from the nuclear reactor is known collectively as the transuranium radionuclides—materials heavier than uranium, formed by uranium-238 atoms absorbing neutrons from the fissioning of the uranium-235.

The operating characteristics of most U.S. power reactors are such that for maximum efficiency, the fuel elements are removed at a time when they still have a potential fuel value (from unconsumed uranium-235 plus plutonium-239) of roughly one-half their original value. In addition, the unconverted uranium-238 is theoretically all convertible to fissionable plutonium-239 in the prospective breeder reactor program. For these reasons, the partly spent nuclear fuel elements, as removed from present-day light water reactors, are generally considered to be a potential energy source and not a waste. Although no processing of such fuel elements to recover the usable portions is presently operational in the U.S., nuclear engineers and economists have generally assumed that this would be standard practice some day and that

the recovered fissionable materials would be refabricated and re-inserted into reactors (hence the term "nuclear fuel cycle"). The necessary transportation, processing, and fabrication technologies would all be adapted from comparable technologies in the long-established national defense nuclear programs.

In this recycling, the partly spent fuel elements would probably not be sent to a processing plant until after months of storage in a water-filled basin at the reactor. This would permit the decay, before shipment, of much short-lived fission product activity. The elements would be shipped in a rugged container with dense shielding material such as lead or uranium between double steel walls. These containers are designed to withstand severe impact, fire, and submersion without loss of radioactive contents.

At the processing plant, the fuel elements would be chopped into small pieces to destroy the integrity of the very tough cladding which protected the fuel in the reactor. The mixture of fuel and fission products would then be dissolved in strong acid, and an organic solvent used to separate the uranium and plutonium from the acidic solution. The two fuel materials would be chemically separated from each other and put through additional purification steps.

The remaining acidic solution is known as "high-level liquid waste." This is the most important radioactive waste in terms of radioactivity content, containing almost all (greater than 99 per cent) of the fission products remaining in the fuel elements at the time of processing. Naturally, its management requires close attention, both for shielding the high levels of penetrating radiation and for confining the potentially toxic radioactive materials.

B. Radioactive Waste Management

Some radioactive wastes may be released to the environment under present standards. Other types of radioactive wastes require varying degrees of controlled storage.

(1) Released Materials

Most nuclear facilities generate gaseous and liquid wastes (air and water effluents) which are actually or potentially contaminated with radioactive materials. Over a number of years, a great deal of experience has been developed in dealing with these wastes so that they can be safely released into the environment. The air effluents can be filtered, and in the case of reactors, can sometimes be stored temporarily to permit the decay of short-lived radioactive atoms. Water effluents can be treated by evaporation, ion exchange, or precipitation, so that the remaining concentration of radioactivity in the effluent is very low.

The gaseous fission product krypton-85 presents a more difficult problem. It is released from partly spent fuel elements especially when they are dissolved at the processing plant. Since it is a chemically inert gas, it is difficult to remove from the air effluent, and its 10-year half life makes it impractical to store the air effluent until the krypton decays. Studies of possible population exposures from krypton-85 under future expanded nuclear power programs have indicated the desirability of removing the krypton-85 to keep radiation exposures as low as economically and technically practical. Cryogenic (extremely low temperature) methods have been used on an interim basis to remove krypton-85 from processing plant air effluents for research and industrial uses, and such methods could probably be adapted to continuous operation. The removed krypton could be stored in pressurized gas cylinders, or perhaps adsorbed on some suitable solid material.

(2) Shallow Burial

A wide variety of solid objects of no value, containing or contaminated with radioactive materials, are shipped from nuclear facilities to burial grounds which are operated under licenses from either the Nuclear Regulatory Commission or by certain states which operate their own radiation control programs under agreements with the NRC. These burial grounds are selected after studies of local soil and weather conditions have shown an acceptable probability that the buried radioactive materials will not migrate away from the site. The radioactive waste is packaged for shipment to meet Department of Transportation safety regulations, but the soil itself and not the shipping container is assumed to be the confinement barrier after burial.

This general class of waste is frequently called "low-level solid radioactive waste," although the term is not precise. Almost all facilities in the fuel cycle send wastes to the burial grounds. Some of the types of waste involved are as follows: filters from the clean-up of air exhaust streams; ion exchange resins, precipitates, or evaporator sludges from the clean-up of water effluents; concrete or other solids made from small batches of radioactive liquid waste not practical to clean up; absorbent paper, swabs, plastic sheeting, and similar materials from contamination control or clean-up work; scrap from chemical or metallurgical operations; defective or obsolete piping, motors, instrumentation, or other process equipment.

The annual volume of this general category of waste is a few million cubic feet per year. This will increase with expansion of the nuclear power industry, but will still be very small compared with the volumes of nonradioactive industrial or municipal solid wastes.

Another solid radioactive waste which is managed at the surface of the ground is the uranium mill tailings. Although the decay of natural uranium eventually yields stable lead, there is a long series of

intermediate radioactive daughter nuclides which account for more than 90 per cent of the total radioactivity present in a speciman of natural uranium ore. These daughter products are left behind in the tailings, which is the residue from the milling process in which the uranium is chemically extracted from the crushed and ground ore. These tailings are normally stored on the surface near the mill, graded and diked as necessary to prevent erosion by surface waters, and watered to prevent wind erosion. When addition of tailings to a particular pile has been completed, a vegetation covering can be added as additional wind protection. It is theoretically possible for radon, a radioactive gas, to diffuse through a tailings pile from decay of the radium, and disperse into the air. Studies of both covered and uncovered mill tailings piles have shown no significant concentrations of radon from them beyond one-quarter to one-half mile.

In the city of Grand Junction, Colorado, uranium mill tailings were used for construction purposes between the early 1950's and the mid-1960's, including some usage as fill in residential construction. This was later found to lead to significant levels of radon within some homes. There is now general agreement that uranium mill tailings should not be used for any structure intended for human occupancy.

(3) *Geological Disposal*

Radioactive waste which presents particular disposal problems may be expected from the prospective processing of partially spent nuclear fuel. As stated previously, more than 99 per cent of all the fission product wastes within the fuel element at the time of processing go into the acidic residue from the first extraction of uranium and plutonium from the dissolved fuel. This high-level liquid radioactive waste would be solidified, and then would be simply "high-level radioactive waste." On a short term basis, there is a need for careful confinement of this waste because of the fission products themselves, especially strontium-90, and also a need to shield the penetrating radiation emitted and to dissipate the heat produced by radioactive decay.

On a long-term basis, confinement is necessitated by the presence in these wastes of transuranium nuclides, especially plutonium-239. These nuclides have two properties which make them particularly hazardous: they decay by emitting alpha particles, which are much more biologically damaging then beta particles; and they are retained to a high degree by the metabolism of the human body, once inhaled or ingested. These transuranium nuclides (especially plutonium-239) may be expected in highly radioactive waste from the prospective processing of partly spent nuclear fuel because a small amount of the plutonium in the fuel (perhaps as much as one-half of one per cent) will not be able to be recovered. Plutonium contamination will also be present in the discarded equipment, ion exchange resins, and other kinds of solid waste described previously, when they come from nuclear facilities where recovered plutonium is being recycled into fresh fuel.

To store high-level waste or transuranium-contaminated waste in any kind of man-made tank, vault, or other structure would require human effort for surveillance and maintenance over unacceptably long periods, because of the 24,000 year half-life of the key contaminant plutonium-239. The only way to avoid putting this burden on future generations appears to be permanent placement of the waste within a deep, stable geological formation. The desired very long-term confinement would then be provided by nature itself. No rebuilding or repair of man-made structures would be needed, and the only surveillance required would probably be the keeping of property records.

In 1970, a salt mine at Lyons, Kansas, was tentatively selected (subject to satisfatory completion of some additional tests and studies) as a permanent geological repository for high-level and transuranium waste. However, technical questions arose as to the integrity of the protective overburden of rock at this specific site, involving old oil and gas wells and nearby salt mining activities. These questions led to the abandonment of this specific site, but the general theory of geological disposal was still considered valid. A program was then begun to evaluate geological formations in addition to bedded salt (such as domed salt, granite, and tight shales) and to identify specific promising sites within the better formations. Present expectations are that this geological evaluation program will lead to construction in the late 1970's of a "pilot", or demonstration, geological repository for transuranium waste, with a demonstration repository for solidified high-level waste to follow, not necessarily at the same site. During the demonstration phase of each of these repositories, the waste would be placed in the geological formation in a way permitting its ready retrieval if necessary, leaving no contamination behind. If studies during the demonstration period, with a realistic inventory of waste in place, showed that the repository site had been wisely selected, the waste would be left in place permanently; if not, the waste could be removed.

This approach obviously requires safe storage space to be ready in case it becomes necessary to remove the inventory in the demonstration repository, plus additional space for any additional waste not needed for the demonstration. Storage of transuranium-contaminated solid waste presents no unusual problems, since most of this material emits little or no penetrating radiation and very little heat. However, a development program has been necessary for the prospective solidified high-level waste which might be received from commercial spent fuel processing plants, and three conceptual designs are ready for selection. Each is basically an adaptation of various radioactive materials handling techniques already in use for other purposes.

In one approach, each canister (probably about a foot in diameter by 10 to 15 feet long) received from the commercial plant would be enclosed in a welded steel cask of several inches wall thickness, providing rigidity and some shielding. This cask would be placed within an outer cask of concrete of several feet wall thickness, providing the additional shielding needed. These casks would be stored in an open but fenced area. The radioactive decay heat would be removed by air rising under natural draft through an annular space between the steel and concrete casks.

In the second approach, the decay heat would still be removed by a natural draft of air, but the shielding would be provided by a reinforced concrete vault around a group of canisters. In the third approach, the canisters would be stored within a pool of water in a reinforced concrete vault, with the decay heat removed by circulating some of the pool water through a heat exchange system. This storage pool approach is very similar to the way partly spent fuel has been handled for years at either end of the transport step from reactors to processing plants. In all three approaches, the incoming canisters would be inspected and prepared as necessary for storage in a remotely operated "hot cell" similar to those used for a variety of purposes in nuclear research and production facilities.

A retrievable repository for high-level waste, using one of the above engineering concepts and presumably at one of the large existing government nuclear sites, would be an intermediate step between the management of the waste at the generating site and the permanent placement in a geological formation. Regulations of the Nuclear Regulatory Commission permit commercial spent fuel processors to store high-level waste in liquid form no more than five years after processing of the fuel, and in solid form no more than an additional five years. In other words, no more than ten years after processing of fuel, the resultant high-level waste must be transferred to Federal custody, with either continuing retrievable storage or permanent placement in a geological formation following under Federal management.

Several methods for converting high-level liquid waste to solid form have been developed through the "pilot plant" stage, and another method has been in routine use at one of the government nuclear sites for over ten years. Research is continuing to increase the margin of safety against dispersion of the solid waste material in any kind of accident situation by developing a more monolithic, insoluable form.

Although one prospective commercial fuel processor plans to convert high-level liquid waste to solid almost immediately after generating it, a more general assumption has been that storage in liquid form for at least part of the permitted five years would be desirable to permit decay of much of the short-lived fission product content and thus reduce the heat output per unit volume of the eventual solidified waste.

Considerable concern has been expressed over storage of high-level liquid waste based on experiences at the government's Hanford plant where, over a period of years, several hundred thousand gallons have leaked from tanks into the ground. The radioactivity was all absorbed in the soil beneath the tanks, and did not cause any water pollution. It is even more important, however, to note that all of the Hanford leaks were from single-walled tanks of an early design which was dropped from use in new construction in the later 1960's. Conversely, there have been no cases of liquid waste leaking into the soil from tanks of the more recent double-walled design, either at Hanford or at the Savannah River site, and there have never been any leaks from the tank—within—a—vault arrangement used at the government's third fuel processing site in Idaho. The regulatory authorities have taken the position that only the double-walled tank or the tank—within—a vault approach will be approved at commercial processing plants, so that it is not correct to assume that the Hanford leak experience must be expected at future commercial processing sites.

The management of high-level radioactive waste is a shielding and confinement problem, but not a volume problem. A nuclear power reactor generating 1000 megawatts of electricity discharges about 30 tons of partly spent fuel per year. After eventual processing, this can be expected to yield about 65 cubic feet of solidified high-level waste, or 10 canisters of one foot diameter and 10 foot length (a possible practical size). From past projections of U.S. nuclear power growth, the cumulative inventory by the year 2000 would be about 80,000 such containers. Such an inventory could be handled in a single repository of practical working size, although multiple (regional) repositories might be sought to reduce transportation costs. Since the U.S. industry has not processed partly spent fuel from overseas nuclear power reactors and has no prospective commitments to do so, it has been assumed that no space in U.S. waste repositories will be needed for waste of foreign origin. The U.S., however, is cooperating in the radioactive waste management efforts of other nations, both through organizations such as the International Atomic Energy Agency and through direct exchanges of technical information.

(4) *Breeder Reactor Waste Management*

Since prospective breeder reactors are important in the long-term energy picture, a few comments on their radioactive waste management aspects are pertinent. Breeder reactor fuels will be irradiated to a higher degree than light water reactor fuels, and processing plant wastes may thus have a higher radioactivity content per unit volume. This might require longer interim storage for decay of short-lived activity, or more shielding; however, these are differences in degree of technology only, so that no new basic technology would be required. The use of metallic sodium as a reactor coolent will require

112

expansion of present sodium safety technology to include handling of contaminated solid wastes generated during breeder reactor repairs. The potential exploitation of low-grade uranium (and possibly thorium) deposits for breeder reactor programs may generate large volumes of mill tailings containing very low concentrations of radium. These tailings could be stabilized by methods in use today to prevent dispersion to air and water.

4. Wastes from Fossil-Fueled Plants

Other than a small amount of air and thermal pollution, gas-fueled electrical generating stations produce little waste.

In on-shore oil production, nearly three barrels of brine pumped from the ground must be disposed of for every barrel of oil produced.

Oil-fired power plants produce liquid cleaning wastes, drainage from the oil storage areas and liquids from precipitator systems. These wastes are channeled to large sedimentation basins where the resulting sludge is chemically neutralized. Later it is removed to a disposal site.

An oil-fired station would require air quality controls to reduce emissions to allowable levels and a tall stack to disperse gases and particulates.

Coal is responsible for large amounts of waste. Mention has already been made of the large areas disturbed by mining. If these areas are not reclaimed, they must be considered waste. Large quantities of wastes are generated during the washing of coal to improve its quality. Over 62 per cent of all coal mined each year is washed, producing 90 million tons of waste annually. The unsightly piles of waste, called *culm* sometimes ignite and burn for years, creating air pollution. Rainwater leaching salts and acid from the piles can contaminate nearby streams.

Recently the Environmental Protection Agency started requiring coal-burning plants to use wet scrubbers to remove pollutants from stack gases, including oxides of sulfur, nitrogen and ash. This produces large quantities of wet sludge, which is extremely difficult to dry and dispose of. It becomes a potential source of pollution of surface and underground waters.

Burning coal also produces solid waste in the form of ash and slag. About 30 million tons of these materials are collected each year in addition to that discharged into the atmosphere. In its 35-year life, a 1,000-megawatt coal-burning plant would produce enough ash to cover a football field to a height of about three-quarters of a mile. Some of this ash is being used, for example, to make cinder block, but other uses need to be found for the vast amounts of waste which are being generated.

SUPPLEMENTARY
MATERIALS
FOR
CHAPTER 6

THERMAL DISCHARGES: ECOLOGICAL EFFECTS

Environmental Science and Technology, March, 1972.

During the past several years, public interest in environmental quality as it relates to central-station power generation has intensified. The continued dominant role of thermal power plants to meet expanding electrical demands has focused attention on the effects of power plant-heated effluents on aquatic life.

Thus, one of the most important questions being asked today is, *"What are the environmental effects resulting from waste heat additions to rivers, lakes, estuaries, and oceans?"* Possible thermal effects are of concern to sports and commercial fishermen who want game and commercial species of fish available for their enjoyment and livelihood; conservationists who want the ecosystem preserved in its *"natural"* state; government regulatory agencies that set water temperature criteria and standards; and various users of water for cooling purposes who must discharge heated water within certain criteria and standards.

Water Use

Estimated projections indicate that future electric power requirements in the U.S. are expected to double approximately every 10 years. Even though hydroelectric power generation is expected to increase, steam-electric power (including both fossil- and nuclear-fueled plants) is expected to supply over 90% of the requirements in 2020. By the year 2000, nuclear power will supply over 50% of the energy produced.

Of utmost importance to the steam-electric power industry is available water for condenser cooling. Estimated water use and projected requirements, by purpose, for the U.S. was forecasted in the 1968 report of the Water Resources Council. In 1965, the steam-electric power industry used approximately 33% of the total water withdrawals. In 1980, the electric power industry will use about 44% of the total water withdrawals, and the forecast for water withdrawal for the year 2020 will be 67% of the total. Projected consumptive use (nonreusable) of the total water withdrawal is about 25%, while projected consumptive use for water withdrawal for steam-electric power is only slightly greater than 1%.

Waste heat rejected to cooling water will be a function of the thermal efficiency of the particular steam-electric plant. With the steam temperature currently in use in large fossil-fueled plants, the maximum theoretical thermal efficiency is slightly above 60%. The thermal efficiency of the best operating fossil-fueled plants is presently about 40%.

Because of a lower thermal efficiency for nuclear plants (about 33%) cooling water requirements are presently greater than for fossil-fueled plants of the same electrical generation capacity. Approximately 10% of the gross waste heat is dissipated directly to the atmosphere through the stack in the fossil-fueled plant, while none is dissipated in this manner for the nuclear-fueled plant. Thus, about 50% more waste heat is rejected to the condenser cooling water from the nuclear plant.

Any method of reducing waste heat discharged into aquatic ecosystems would be useful where a temperature rise in receiving waters is unacceptable. Several options can reduce waste heat discharged from steam-electric plants into the aquatic ecosystem. Although thermal efficiencies from fossil-fueled steam plants have reached a plateau, molten salt breeder reactors and high-temperature gas reactors should increase thermal efficiencies for nuclear plants almost to 45%. However, these improvements will probably not be available for at least a decade. Since a dramatic increase in thermal efficiency for steam-electric plant is not forecast for the immediate future, recycling or retaining condenser cooling water may be necessary to reduce waste heat effects on aquatic ecosystems.

By utilizing projections of both fossil- and nuclear-fueled electrical generation capacity, data on thermal efficiencies of steam-electric plants, and water withdrawal forecasts, the quantity of waste heat that will be dissipated into the condenser cooling waters of steam-electric plants can be determined. The total quantity of waste heat discharged to condenser cooling waters by the electric utility industry will more than double from the year 1967 to the year 1980. The contribution of heated effluents from nuclear-fueled power plants in this time period increases from 1% to 45%, while contribution of heated effluents from fossil-fueled power plants decreases from 99% to 55%.

These waste heat values should be placed in proper perspective. For example, the total quantity of water used for steam-electric power for 1980 (assuming once-through cooling water) is estimated to be 193 million gallons per day, while the estimated annual heat rejection for steam-cycle systems for the same year is 11,700 trillion Btu's. This quantity of heat, assuming a once-through cooling cycle, will raise the temperature of the cooling water approximately 20°F. Temperature increase in the condenser cooling water for condensers installed in the past ranges between 10° and 30°F. Thus, the estimated 20°F rise in once-through condenser cooling water seems to be a reasonable estimate although this will vary according to each specific site location.

Most studies directly concerning the effects of heated effluents on aquatic biota at the site of electrical power generating stations are relatively recent, and few results have been published to date. Most field investigations are presently in progress.

Continuing studies of the ecological effects of

thermal discharges have been conducted at the Hanford Nuclear Complex on the Columbia River (Wash.). These studies conducted over the last 25 years were mainly oriented toward the salmonid fishes because of their high value to the Columbia River commercial and sports fisheries. Although the temperature of the undiluted reactor effluent would be lethal to the fish, waste heat discharged by the Hanford reactors to the Columbia adds only a relatively small heat increment to the widely variable seasonal river temperature (less than 40°F to greater than 65°F). Also, because of the hydraulic characteristics at the outfall and the swimming behavior of the fish, many seaward migrant salmonids may be swept to cooler waters and not actually experience the direct effluent plume.

Laboratory and field studies concerning biological effects of Hanford waste-heat on salmonids show no demonstrable evidence of damage to the salmonid resources. There simply has not been any evidence to indicate kills or unreasonable risks despite a long history of heated discharges from the Hanford reactors. However, direct extrapolation of Hanford's results to another site, even in the Columbia River system, must be made only with due consideration for the uniqueness of each ecosystem as the snow-fed Columbia River is a large, cool river and not typical of many U.S. river systems.

The Chalk Point fossil-fueled steam generating plant on the Patuxent River (Md.) has been studied since 1963. Two 335-MW units use estuary water for condenser cooling with a once-through cooling system. The condenser cooling water temperature increase is designed to be 23°F under winter operating conditions and 11.5°F during summer conditions. While no major detrimental effects of thermal additions have been noted, changes have occurred in various populations which may be attributed to heated cooling water discharges. Equifaunal populations in the intake and effluent canals of the Chalk Point plant provide a number of interesting results. Among them was: A higher rate of production was found in the effluent canal than in the intake canal during all months studied - average production in the effluent canal was nearly three times as great as production in the intake. An increase in the maximum size of the barnacle, *Balanus*, was noted in the intake and effluent canals over those in the Patuxent River itself. During July and August, the warmest months, there was a decline in the number of species in the effluent canal and the anemone, *Sagartia*, and, the tunicate, *Molgula*, were not noted in the effluent canal, although both were in abundance just outside the effluent canal.

The power plant has not added enough heat to the Patuxent River to exceed the thermal tolerance of the zooplankton species studied. On the other hand, phytoplankton destruction and productivity suppression have been reported in the cooling water supply of the Chalk Point plant, although chlorination may be partly responsible for the mortality. Also, oysters in the Patuxent River have high copper levels. The rate of copper uptake in the oysters could have been enhanced by the water temperature increase, or concentrations in the water may have increased due to operation of the Chalk Point plant. However, no major effects on growth, condition, or gonad development were shown by oysters on natural bars near the plant.

At the Contra Costa Power Plant (1298 MW) on the San Joaquin River, (Calif.), studies showed that passing young salmon and striped bass through cooling condensers was far less hazardous than screening them at the intake. At the same point, young salmon could tolerate an instantaneous temperature increase to 25°F for 10 min. with no mortality.

At the Morro Bay Power Plant (1030 MW) (Calif.) on the Pacific Ocean, healthy populations of the pismo clam, *Tivela stultorum*, have been maintained over the full 13 years that the plant has been in operation.

The Humboldt Bay Nuclear Plant (172 MW) in California is the first nuclear plant in the U.S. utilizing estuarine waters for cooling and is located on the Pacific Ocean about five miles from an important shellfish area. Studies at Humboldt Bay showed that the elevated temperature regime of the discharge canal was favorable for the natural setting of native oysters (*Ostrea lurida*), cockles (*Cardium corbis*), littleneck clams (*Protothaca staminae*), butter clams (*Saxidomus giganteus*), gaper clams (*Tresus nuttalli*), and a half dozen other bivalves (even though some passed through the plant's condenser system).

The effects of heated discharges from the Connecticut Yankee Nuclear Plant into the Connecticut River (Conn.) are examples of a well-documented study started in 1965, about 2 1/2 years before the plant began operation. The plant was designed to produce 562 MW with a temperature rise of 20°F in the condenser cooling water. The major thermal study areas were fish studies; benthic organisms studies; bacteriology, micro-biology, and algae studies; hydrology studies; and temperature distribution predictions and measurements.

The Connecticut Yankee Plant has now been in operation for about four years. No drastic changes have been observed to date in the overall ecology of the Connecticut River as a direct result of the addition of thermal effluents.

However, a statement in the summary of all the environmental studies that were done at Connecticut Yankee, emphasizes that as yet no information is available on the possible sublethal effects of the thermal discharge. Although no fish kills have occurred since the plant operation began, the white and brown bullhead catfishes undergo a marked weight loss (average of 20%) in the warm water of the effluent canal despite a constant availablity of food in the canal.

Studies are being conducted at Turkey Point in Biscayne Bay, Fla., where two fossil-fueled units of 432 MW each are in operation, and two nuclear plants of 721 MW each are scheduled to begin operation. Heated effluents from the plant have reduced the diversity and abundance of algae and animals in small areas adjacent to the mouth of the effluent canal. Many plants and animals in a 125-acre area where temperatures have risen 4°C (7.2°F) above ambient have been killed or greatly reduced in number. In a second zone of about 170 acres, corresponding to the +3°C (5.4°F) isotherm, algae have been damaged, and species diversity and abundance have been reduced. In the latter area, mollusks and crustaceans increased somewhat, but the number of fishes decreased.

Studies at the Martins Creek Plant on the Delaware River (Pa.) showed that the heated waters appeared to have attracted fish and enabled them to actively feed throughout the colder months of the year to a greater extent than they normally would, although there was no conclusive evidence that heated waters actually increased fish production or growth rates.

Studies at the Petersburg, Ind. Plant (220 MW) on the White River (Ind.), report that there is no evidence that any adverse effects on fishes, such as death, impaired growth, insufficient reproduction, increased disease, and movement or lack of movement are being observed at Petersburg or in the entire White River with the exception of fish movement away from water above 93°F.

The White River has a sandy bottom and is quite turbid. The principal pollutants are floodwater and suspended material in the water. The major aquatic species at Petersburg are the spotfin shiner, bullhead minnow, spotted bass, longeas sunfish, gizzard shad, carp, and white crappie. Since sand and silt are deposited when floodwaters recede, researchers who studied the White River believe that money for thermal pollution abatement could be better *"applied to the certain and very real need for flood and bank control."*

Recommendations

The result of several ecological studies around actual operating power plants is that, with a few exceptions, there has not been any major damage to the aquatic environment from the heated effluents of existing power plants. However, in the future years, as larger power plants become operational, accompanied by multiple units at a single site, environmental management of heated effluents at these sites will become more difficult.

Standards for limiting the thermal loads imposed on aquatic systems have evolved with the expansion of the electrical generating industry. However, without feasible alternate methods to produce electrical power without waste heat, there are only a limited number of alternatives. At one extreme is employing methods which recycle cooling water and add no waste heat to natural waters. This extreme is not required to ensure well-balanced aquatic communities. The other extreme is to permit unlimited thermal loading on aquatic systems which would, no doubt, be disastrous (based on the projected use of marine and freshwater resources for industrial cooling purposes). The only option remaining is discharging waste heat to waters in amounts approaching the assimilative capacity of the waters in question. Heat generated beyond those amounts will have to be dissipated by methods which recycle cooling water. Based on the knowledge available at the present time, the last option seems to be the only reasonable approach.

Pursuing this course requires total commitment to determine the assimilative capacities of freshwater and marine resources. Management and surveillance programs will be essential as will cooperation between industry and regulatory agencies. Many factors contribute to receiving capacities, and requirements for producers of waste heat will be highly variable depending on their location. Power plant sites should be chosen with the advice of competent ecologists, and base line ecological surveys should begin as soon as a suitable site is selected.

While lethal effects of heated water discharges on fish and other aquatic organisms should present little problem, assuming proper discharge procedures, the sublethal effects of these heated water discharges may produce significant changes in populations. These sublethal effects could produce physiological changes that would decrease growth rate and prevent reproduction. Future studies should be designed to obtain a better understanding of sublethal effects.

The entire food chain is of extreme importance in the balanced aquatic ecosystem. Particular aquatic organisms or plants that fish eat can be affected by waste heat from power plants. Eliminating a single component of this ecosystem would affect the feeding and growth of organisms on all higher tropic levels.

Data are not yet sufficient to permit a proper understanding of the dynamics of this ecosystem. Many laboratory studies have led to understanding many of the physical-chemical functions of aquatic organisms as well as dispersion in water systems. Consequently, regulations based on these studies will be designed to minimize all possible risks of catastrophic kills of desirable organisms. Field studies are necessary to determine the *"real-life"* mechanisms occurring in the aquatic ecosystems. While laboratory studies are a necessary part of understanding, extrapolating laboratory measurements to field conditions must be done cautiously.

Answers to considerations which could alter regulations will have to be provided from nongovernmental sources such as the electric utilities. As the assimilation capacity of the environment is reached, it is increasingly important to consider

long-term effects. Modest investment programs looking at the ecosystem to develop and verify predictive capabilities could themselves pay handsome dividends.

To utilize more fully the assimilative capacities of natural waters to dissipate waste heat, greater ecological management will be required, and operators of steam-electric stations will have to play an important role. In addition to considering effects of heat rejection during normal plant operation, attention must be focused on the effects of temperature changes, even though the actual temperatures may be below the lethal limit.

An effort should be made to establish the assimilative capacity of all natural waters to be utilized for cooling purposes. Based on predictions from the biological, chemical, and physical studies, limiting conditions should be established to accommodate the idiosyncrasies of each site. There is no substitute for on-site experimentation utilizing the resident populations and the local water. After a new unit comes on-line, a less intense program of surveillance should become a matter of routine at all plant sites.

As more of the larger power plants become operative and as more sites are required, the ability to predict the response of the aquatic ecosystem to the heated water discharges must be improved. The systems approach to study ecosystem dynamics offers a valuable tool to individuals who make decisions concerning siting and design criteria for power plants.

Criteria and regulations can only be altered with confidence when accurate predictions can be made. The pre- and post-construction studies by the utilities, if expanded to consider predictive aspects, offer an opportunity to obtain needed data on the system and to verify the predictions.

The satisfactory performance of existing steam-electric plants supports the belief that controlled amounts of heated water can be added to aquatic systems without producing adverse biological consequences. Therefore, in the absence of evidence of damage to the ecosystem involved, it would be difficult to justify requiring steam-electric stations, which have been operating for some time, to install cooling devices because they are not meeting newly adopted state or federal regulations. A careful investigation of the issue at each specific plant site should be done prior to any action being taken.

In order to understand the dynamic behavior of the aquatic ecosystem some long-term studies are required. Of course, there are many and varied types of aquatic ecosystems so that typical rivers, lakes, estuaries, and ocean systems should be studied in a variety of climates. Industry, and, in particular, the steam-electric industry, should participate in these studies since the power plants will be the major waste heat contributor to the aquatic ecosystem. Waste heat from the power plants will become a more significant discharge to the aquatic ecosystem in the future. It may be that the effects of waste heat could be beneficial when other pollutants, such as sewage and industrial waste, are limited or removed (as reported for the Thames River in England).

Although there has been no apparent major damage to the aquatic ecosystems by cooling water discharge, there have been ecological changes. The complex interrelationships of species, populations, and communities in an ecosystem is the result of years of evolutionary trial and error. Therefore, although no major mortalities are noted, shifts in species diversity or abundance might upset delicate balances which exits, and results might not be known for years.

There are some bodies of water presently capable of accommodating more thermal loading without incurring adverse effects on the aquatic biota, while the assimilative capacities of some others have already been exceeded. Thus, it is imperative to evaluate dynamic changes which are presently taking place in aquatic ecosystems, and to be able to predict what is likely to occur as the electrical generating capacity of the nation increases.

Additional reading

Coutant, C. C., *"Thermal Pollution-Biological Effects,"* J. Water Pollut. Contr. Fed., 43, 1292-1334, 1970.

Levine, A. A., Birch, T. J., Hillman, R. E., Raines, G. E., *"A Comprehensive Appraisal of the Effects of Cooling Water Discharge on Aquatic Ecosystems,"* Battelle Memorial Institute, Columbus Laboratories, Columbus, Ohio, 45 pp. 1970.

Krenkel, P. A., Parker, F. A., Eds., *"Biological Aspects of Thermal Pollution,"* Vanderbilt University Press, 407 pp. 1969.

Parker, F. A., Krenkel, P.A., Eds., *"Engineering Aspects of Thermal Pollution,"* Vanderbilt University Press, 340 pp. 1969.

COOLING TOWERS BOOST WATER REUSE

Environmental Science & Technology, March, 1971.

Water, the colorless, transparent liquid in rivers, lakes, and oceans, is a major environmental concern. Water use and pollution increase as population and industry grow, until man is made aware of the necessity for conserving this precious natural resource. U.S. industrial manufacturers require 42 billion gallons of water per day (gpd); agriculture's demand is even greater, 140 billion gpd. Utilities require 95 billion, and household use of water totals 36 billion gpd. Although the water consumption figure will jump to 500 billion gpd by 1980, there will be *"no water famine if it is intelligently used,"* says Bob Cunningham of Calgon Corp.

One major but relatively unpublicized means to conserve water–through recycling as well as reducing the incidence of chemical and thermal pollution–is through the use of cooling towers. Cooling towers-their uses, problems, and the growth potential of the industry–were discussed at the annual meeting of the Cooling Tower Institute in January held in Houston, Tex. Since effluent volumes and subsequent treatment costs can be reduced by use of cooling towers, this means of increasing the cycles of water use can *"save industry millions of dollars per year,"* Jim Axsom of Sun Oil Co. emphasizes. A major Gulf Coast chemical processor further asserts that cooling towers are generally more economical than a dry-air cooling system.

Design

A cooling tower is a component of an open recirculating cooling system which is generally used for cooling water that has been heated by passage through process heat-exchange equipment. (A heat exchanger is a metal device consisting of a large cylindrical shell with tubes inside the shell. As a hot process fluid passes through the shell and cool water flows through the tubes, or vice versa, heat exchange takes place across the tube wall).

Hot water, pumped to the top of the tower, trickles through the fill-redwood boards or polyvinyl chloride placed in a crisscross pattern in the tower-which in turn spreads the water uniformly and assists the cooling process. Air is pulled into the base or sides of the tower and exhausted through the fan stack. As air and hot water mix, the water is evaporating and condensing thus causing cooling. Finally, the droplets fall into the sump (concrete collection basin at the bottom of the tower); and the cooled water is ready for recycling through the heat-exchange equipment. Chemicals are added to the water to prevent scaling or corrosion of the cooling system components due to various problems aggravated by the chemicals in the water and the high temperatures.

The open recirculation system is compared with two other types of water systems–the once-through system and the closed-recirculating system. The once-through system merely borrows water, usually from a surface stream, warms it a few degrees, and discharges it further downstream. Of course, chemical treatment is required to prevent pollution, and these costs can become excessive due to the large volumes of water treated.

The closed-recirculating system is used, for example, in office building heating and cooling refineries, and chemical plants. There is no intentional water loss; therefore, little makeup water is required, allowing more exotic chemical treatment than would be feasible in one of the other systems. Typical chemical treatments in this system are usually very high in chromates (up to 2000 ppm) and boraxnitrite mixtures (2000 ppm).

Prototype

The forerunner of the modern cooling tower was a spray pond where water was sprayed into the air to be cooled. However, high drift rates (water droplets carried by the air) hindered this early method, so the first towers were built. These original *"atmospheric towers"* were narrow and tall (56-ft high and 12 to 13-ft wide), depended on the wind velocity moving through the tower to cool the water trickling down, and were usually inefficient. Fans were later mounted at the bottom of these towers to blow the air up through the structure (forced draft). However, the air velocity coming out of the tower could be so low that wind sometimes forced the air back into the tower, cutting efficiency by as much as 50%.

Then fans were mounted on top of the tower to pull the air through (induced draft). This operation is the most widely used in the U.S. today. *"The forced draft tower is only built periodically-just for special orders. No manufacturer has a forced draft as a standard model,"* says Jim Willa, vice president of Lilie-Hoffman Cooling Towers, Inc. However, under certain installation parameters, the forced draft tower is the most feasible model to install, according to a spokesman for the Marley Co.

There are two types of induced-draft cooling towers:

In the counterflow tower, water enters as a spray at the top of the tower and trickles through the fill down to the sump. Air is sucked through inlet air louvers in both sides of the tower, travels up through the tower, and flows out of the top. The air and water mixtures travel counter to each other–the water down, the air up.

The induced-draft crossflow tower still has water entering the top, but only at each side. The center of the tower, where the fan is located, is left open. As the water falls through the fill on each side of the tower, the air is pulled through the fill across the water. The air moves horizontally-through the

side louvers, the fill, and then to the center of the tower. Here, it makes a 90° turn and flows out the top. The air moving horizontally across the water moving vertically creates a crossflow.

Tower Costs

The typical image but recent example of a cooling tower is the natural draft or hyperbolic tower which is, though tall and graceful, expensive and perhaps unreliable in this country. These towers have a large chimney rather than a fan to force or induce the air. Air densities inside and outside the chimney create a differential in pressure that causes a draft to be sucked through the cooling area.

The only justification for building this tower, Willa contends, is its low power requirement for a 20-year period or more. The hyperbolic tower costs 5 to 10 times more to build than the crossflow or counterflow unit. However, other major companies contend that the ratio rarely goes higher than 2:1 or 3:1. Presently, the major market for these towers is the eastern electric utility plants that previously used rivers and lakes to cool their hot water. Not one client in the U.S. who has ever owned a standard cooling tower has purchased a hyperbolic tower, says Willa. Besides the prohibiting difference in cost, the hyperbolic tower is not efficient functionally in the U.S. Designed, introduced, and built in parts of Europe where latitude is equivalent to that of Labrador, the hyperbolic tower (in the U.S.) may yield the least performance at the peak period of demand—during the hottest days of the summer months (because of the small pressure differential), according to Willa. (Willa's company, Lilie-Hoffman, does sell and build hyperbolic cooling towers, incidentally). On the other hand, Marley Co. customers are ordering additional hyperbolic towers as well as the mechanical draft models.

Cooling tower prices range from cheap models (untreated wood or plywood fill, galvanized steel hardware), whose cost is estimated at $5 per gallon of water it will eventually recycle, to the more expensive ones (pressure-pretreated redwood fill, and yellow brass, silica bronze, 304 or 316 stainless steel hardware), which will cost $12 to $13 per gallon of recycled water. Performance requirements also affect the cost considerably. Short range, long approach (large temperature difference between the cold water leaving the tower and the wet bulb temperature of the air), easy-duty cooling towers are naturally less expensive than the long range, close approach, heavy-duty tower. For example, petroleum and petrochemical industries capitalize only on a five-year basis. If the tower cost cannot be justified in five years, the system stands a good chance of being obsolete.

Water Treatment

Cooling towers have four common operational problems: corrosion, scale, deposition fouling, and microbiological attack. In cooling tower systems, the problems are related to cooling tower blowdown (the intentional removal of a portion of the recirculated water in the cooling system to limit the buildup of dissolved solids beyond a certain concentration), high temperatures, and the air scrubbing action of the cooling tower itself. The untreated makeup water added after blowdown to maintain constant volume may also cause these problems.

Corrosion is an electrochemical phenomenon occurring in the system's piping, heat-exchange equipment, and other metallic components. Water soluble corrosion inhibitors, added to the water to reduce corrosion, form a monomolecular film at the metal-water interface. These compounds are:

.Inorganic polyphosphates.

.Inorganic polyphosphates plus zinc.

.Chromate-zinc and chromate-zincphosphate.

.Nonchromate inhibitors, which include amino-methylene-phosphonate (AMP) plus zinc, polyol-ester phospate with or without zinc, and polyacrylamide-silica polymers.

The choice of treatment depends upon the existing water pollution control laws, since some cooling water will reach receiving streams during blowdown. A high-phosphate chemical also contributes to pollution problems. Usually, corrosion is controlled with a mixture of chromate and zinc, with or without additives.

Scale formation is a result of precipitation of limited solubility salts. Essentially, during continuous recycling, a salt reaches a concentration that exceeds its solubility product, and it is deposited as scale (usually $CaCo_3$ or $CaSO_4$). Scale formation can be prevented by pH control. If the cycles of concentration cannot be economically reduced in a system, various phosphates are used to alter the crystalline structure of the precipitate and to prevent deposition, or to cause the deposit to form a soft sludge which can be easily washed away. However, using phosphates in cooling towers with high temperatures and long residence times may cause reversion. (The metaphosphate that controls scale can rever to orthophosphate, forming an insoluble salt with calcium that will deposit in the system.) Sulfuric acid addition will lower the pH to prevent scale, but this will accelerate corrosion. Using phosphate-zinc combination lowers the amount of potentially revertible phosphate; however, much emphasis today is placed on AMP, which is resistant to reversion and can therefore be used with little or no pH control.

Fouling occurs when silt, mud, and debris accumulate in the cooling tower system. Silt is treated with a synthetic polymer to *"fluff up"* the material, thus creating a larger surface area. The particle size expands allowing the force of the flowing water to scrub effectively the lower velocity areas. Dispersants have also been used to prevent deposition. *"A major break-through for pollution control, performance, and ease of control,"* explains

Paul Puckerius of W. E. Zimmie, Inc., *"is obtained with a combination of organic polymers with inorganic polymers. These treatments with effective scale inhibitors, give a complete scale, fouling, and corrosion control system."*

Microbiological attachers – fungi, bacteria, and slime – get into the cooling system through the makeup water or air. These organisms can foul lines as well as damage wood fill. The most effective and least expensive biocide available is chlorine. With proper pH control and correct dosages, chlorine will not cause wood deterioration and will prevent pollution in the blowdown effluent. Over 90% of industrial cooling tower users favor chlorine treatment. Many nonoxidizing microbiocodes, chlorophenols, or organo metallic, can also be used for good micro-organism control without significant contribution to wood deterioration.

Market growth

The major cooling tower manufacturers (Marley, Lilie-Hoffman, and Flour) forecast rapid growth for the industry. Air-conditioning uses contribute to this growth. Cooling towers are now widely used in the petroleum and petrochemical industries, especially with the present drive for pollution control. The largest market for cooling towers is electrical plants. Electrical power use doubles every 10 years, and the number of cooling towers required by the electrical industry will grow proportionately. Cooling towers and their contribution to environmental control will become more evident as time passes.

FUELS MANAGEMENT IN AN ENVIRONMENTAL AGE

Environmental Science & Technology, January, 1971

Until the late 1960's, the selection of a fuel for any use was a matter of choosing one with the lowest overall costs, with little regard for its effects on the environment. The rising concern about the environment, however, has changed the traditional concept of what is desirable.

In selecting a fuel, the effects of production, processing and utilization of each fuel on the land, water and air must now be considered. This presents a complex situation since all the principal energy sources-coal, oil, gas, nuclear, and hydro–have differing environmental effects. Moreover, the severity of the pollution trade-offs must be evaluated and decisions must be made as to which fuel is likely to have the least harmful environmental impact.

Two fuels management problems are particularly urgent. The first, automobile fuels, is undergoing rapid change, and little can be done in the short term to replace gasoline as a fuel. The second, generation of electricity, does have much substitutability from competing energy sources. Both pose unique management problems that must be solved if the nation is to benefit from low-cost energy that is produced and used in a manner that does not further degrade our environment.

Energy demand and resources

Energy demand is growing exponentially, and the established trends are expected to continue through 1980. Demand for oil and gas is expected to show the greatest increase in absolute terms; however, in relative terms, the increase in nuclear energy is the greatest. Projecting to the year 2000, many technological, economic, environmental and political factors will influence the demand and supply for various energy sources. These factors have been studied by the Bureau of Mines, with the conclusion that demand for each of the most-used fuels–petroleum, natural gas and coal–will at least double between 1968 and 2000. Uranium, however, will increase by a factor of about 15.

The cumulative requirements for these energy resources are enormous. However, the nation's resource base is adequate to supply the demand through 2000. But, if these demands are to be met, the nation's coal and oil shale resources will have to play an important role, whether they are used to generate electricity or are converted into gases or liquids and used in these more convenient, pollutant-free forms.

The nation's fossil fuel resources are not unlimited, and a maximum of producibility is expected to be reached early in the next century. Thus, after 2000, the nation's energy demand could set the stage for the emergence of unproved systems, such as nuclear fusion, and the widespread use of solar and geothermal energy.

Imported liquid fuels (crude and residual oils and products) now provide 23% of all liquid petroleum consumed in the U.S. Management of fuel resources to solve environmental problems depends upon policy decisions made with respect to future oil import programs, as well as public land leasing, tax treatment, and prorationing policies which, in turn, are intertwined with other factors of national interest such as military security and balance of payments.

The consumption of fuels must also be considered according to the use–household and commercial, industrial, transportation, or electricity generation. By comparing the expected fuel consumption in the year 2000 with use patterns for 1968 (see table), it can be seen that total gross energy inputs are expected to increase from 62 to 163 quadrillion Btu. Electricity generation will dominate in the future, increasing both absolutely, from 14.0 to 72.3 quadrillion Btu, and as a per cent of total gross energy input, from 23 to 44 per cent. Nuclear generation is expected to dominate the generation of electricity, increasing from 0.1 to 38 quadrillion Btu; but coal used for this purpose will increase more than threefold, from 7 to 24 quadrillion Btu.

Consumption patterns of different fuels up to about 1968 are a good indication of the amounts and types of fuels that would be used if environmental problems could be largely ignored. Environmental considerations, however, have begun to alter these supply patterns sharply. For example, sulfur dioxide emission standards in 1969 caused a shift from coal to residual fuel oil at east coast electricity generating plants. By early 1970, the initial penetration of residual oil into the Chicago market had been approved.

The production, processing, and utilization of fuels cause the most environmental problems for the nation. Let us, then, look at the most significant of these pollution problems, and the impact on land, water and air.

Land Use

About 3.6 million tons of solid wastes are generated each year in the U.S. Agricultural wastes constitute nearly two-thirds of the total, and mineral wastes account for most of the rest. Mineral wastes, not including the large amounts of overburden removed in surface mining but including those wastes generated by mining, processing and utilization of all minerals and fossil fuels, amount to about 30% of the total wastes. But fuels account for only 125 million tons, or about 3% of all solid wastes generated.

The last complete survey of mining operations in the U.S. indicated that, in 1965, about 3.2 million acres of land had been distrubed by surface mining. Of this total, about 41% resulted from activities associated with coal production.

As yet, only a few tenths of 1% of the total land area of the U.S. has been disturbed by surface mining. Effects of such mining upon the environment, however, vary widely and depend upon such factors as the type of mining, characteristics of overburden, steepness of the terrain, amount of precipitation, and temperature. Where land reclamation is not practiced, water pollution from acid mine drainage and silt damage occur. It is possible, however, to prevent much of this damage through proper land reclamation, adequate drainage, and planting to achieve soil stabilization. In the principal coal mining areas, the average costs of completely reclaiming coal lands range from $169 to $362 per acre, an average cost of 4 to 8 cents per ton.

Underground coal mining can cause subsidence unless the mining systems are designed to prevent deterioration and failure of abandoned mine pillars. Underground fires may weaken or destroy coal pillars that support the surface, causing subsidence with consequent damage to surface structures. An additional threat is the possible collapse of buildings and openings of surface fissures and potholes.

Fuel processing also contributes large quantities of wastes during the washing of coal to improve its quality. Over 62% of all coal mined is washed, producing 90 million tons of waste annually. If not returned to the mine, the water accumulates in piles near the plant and mine. At times, these piles ignite and burn for long periods, thus creating air pollution. Rainwater leaches salts and acid from the piles to contaminate nearby streams.

Utilization of coal also produces solid waste in the form of ash and slag. About 30 million tons of these materials are collected each year; an estimated 8 million tons are discharged into the atmosphere.

Uranium mined by either open pit or underground methods creates similar land effects. Mining in quantity is a relatively new industry, the volumes and tonnages involved are only 1% of those for coal, and the adverse effects are much smaller. Estimates of the solid wastes from the mining of ore and the subsequent extraction of the desired uranium product are 38 million tons annually.

Solid wastes resulting from nuclear generation of electricity involve only small tonnages of materials, but have a very great potential for environmental damage for long periods because of their radioactivity. As nuclear plants become more numerous, the magnitude of this problem will grow.

Transportation of oil and gas, which is largely by underground pipelines, does not normally produce land problems. However, the special case of transporting oil from Alaska by pipeline raises numerous and, as yet, unresolved land-use problems.

Water problems

Two distinct water problems are of growing concern in fuels management-water quality and water temperature. Questions of quality relate to individual energy sources; thermal problems, however, are common to use of all fuel commodities.

Poor water quality, whether it be through chemical pollution or sedimentation, is a major damage resulting from both surface and underground mining. Available data make no distribution between the two, but it has been estimated that approximately 48% of mine water pollution, primarily sediment, results from surface mining. In the U.S., some 5,800 miles of streams and 29,000 surface acres of impoundments and reservoirs are seriously affected by such operations. Acid drainage from underground mines is more difficult to control than that from surface mines, but preventing water from entering the mine and the rapid removal of water which does get into the mine are effective methods for reducing pollution. The effects of acid mine drainage can be reduced by decreasing the amount of acid produced at the source, or by neutralization of the mine water before it is discharged to the streams. The latter technique, though highly effective, is more costly. Erosion and sedimentation from surface mining are serious problems in many areas, but they can be prevented by controlling the surface runoff that follows rainstorms.

In processing uranium ores, some of the potentially hazardous radioactive elements or isotopes, particularly Ra-226 and Th-230, are partly dissolved during the leaching operation used to recover uranium oxide. While most processing plants are located in very isolated areas, steps are taken to avoid pollution of water supplies by radioactive constituents of liquid effluents.

Disposal of the effluent is accomplished principally by impoundment and evaporation, controlled seepage into the ground, and injection through deep wells into saline or nonpotable aquifers. Where ore processing plants are adjacent to rivers or streams, the effluents may be released directly to the streams at controlled rates if, after dilution, the concentration is within predetermined limits. During periods of low stream flow, effluents are impounded or may be chemically treated before release.

Onshore oil production, except for accidental occurrences, does not present any difficult pollution problem. Nevertheless, nearly three barrels of brine must be disposed of for every barrel of oil produced.

Accidental pollution may occur from blowouts of wells, dumping of oil-based drilling muds, or losses of oil in production, storage or transportation. At sea, the blowout at Santa Barbara, the oil slicks and the fires and oil spills in the Gulf of Mexico in recent months have demonstrated that these dangers are more than academic in offshore operations. Methods must be found for their prevention and control. Spills and discharges from tankers are also important. However, the greatest, if less dramatic, problem is the contamination of inland waterways and harbors resulting from transfer of oil between or from vessels.

Thermal pollution

By far the most important water problem resulting from fuel use is thermal pollution. Over 80% of all thermal pollution arises from the generation of electricity. The amount of heat rejected to cooling water represents 45% of the heating value of the fuel used in the most efficient fossil fuel plants, and 55% in nuclear plants. If projected use of electricity is accurate and if nuclear energy, as expected, supplies nearly 50% of the electricity demand, more than 10 times as much heat will be rejected to turbine cooling water in 2000 as is being rejected now. Even with greatly increased use of brines or seawater for cooling, the demands for fresh cooling water will be larger than its supply.

This suggests that the solution is not in treating the heat as a "*waste*" product. Rather, the heat must be viewed as a resource that can be used. Evolution of such concepts must not be constrained by current uses, for huge amounts of heat may be used in systems not considered practical or feasible at this time. For example, the heating and cooling of whole cities whose environment is controlled by a protective membrane is one possibility.

Air Pollution

Nearly 80% of all air pollution in the U.S. is caused by fuel combustion. About 95% of all sulfur oxides, 85% of all nitrogen oxides, and over half of the carbon monoxide, hydrocarbons, and particulate matter are produced by fuel use. Management of fuels, therefore, is critical for the minimization of the nation's air pollution problems.

The most competitive market for fuels is the generation of electricity. Not only do the fossil fuels compete with each other, but they also compete with hydropower and, more recently, with nuclear energy. Obviously, from an air pollution standpoint, hydropower is the perfect method of electricity generation. During the generation of electricity from fossil fuels, production of oxides of nitrogen or carbon monoxide is not greatly different for any of the fossil fuels used. The production of electricity using natural gas produces no sulfur oxide emissions, but the use of coal and residual oil in electric generating plants is the source of 74% of all the oxides of sulfur emitted into the air.

About seven times as much coal as oil is used in electricity generating plants. For this reason, and because of its relatively high sulfur content, coal accounts for nearly two-thirds of the sulfur oxides emitted to the atmosphere. In addition, nearly one-third of the particulate matter emitted into the atmosphere is from burning coal for generation of electricity.

About one-half of the coal consumed by industry is used to make coke. Part of the sulfur appears in the coke oven gas and, if this is used as a fuel, it eventually appears as sulfur remains in the coke and is released as hydrogen sulfide in the blast furnace gas. When the gas is used as a fuel or flared, the sulfur appears as sulfur dioxide.

Local air pollution problems in the vicinity of plants that make coke are severe. Alternatives to the use of coke for the production of pig iron are available, and these processes might reduce the amount of air pollutants released to the air. Uncontrolled surface and underground coal fires emit smoke, fumes, and noxious gases.

About 17% of all the oil consumed in this country is used by industry. Much of it is residual oil, which in most cases is high in sulfur. Moreover, residual oil is difficult to burn efficiently and is usually burned in large equipment at high temperatures. Because of these two factors, industrial use of oil tends to contribute larger amounts of carbon monoxide, hydrocarbons, and oxides of nitrogen than the household and commercial sector, which consume about 25% of the fuel oil.

The largest use of oil is for gasoline to power the nation's 100 million vehicles. About 42% of each barrel of oil is used in this manner. If we include diesel and jet fuels, about 54% of each barrel of oil is used for transportation.

The use of fuels in transportation causes approximately one-half of all the air pollution in the U.S. There are alternatives to the use of gasoline for automobiles and trucks, such as natural gas and liquefied petroleum gases. But it is doubtful that the massive changeover that would be required by two of the country's largest industries would occur if other solutions could be found to reduce air pollution generated by the transportation sector. Moreover, if a switch to electric cars were made, the total pollution load might actually be increased, although controls would be needed on a relatively few electric power plants, rather than on millions of autos and trucks.

Management Problems

Ideally, the management of fuels to satisfy environmental requirements should be guided by a system model that relates energy needs to damage, emissions and fuel availability. Included in the model would be an assessment of the relative damage among

dissimilar pollutants, for example, esthetics of land vs. air pollution, as well as comparisons between a small, constant hazard (nitrogen oxide) vs. a large, infrequent hazard (nuclear). Detailed knowledge of what happens to specific pollutants both geographically and over time would also be included in the model. In addition, economics, supply availability and the broader question of national security would all need to be examined.

No such model now exists. However, many factors can be approximated so that a number of problems associated with fuel use can be examined. Two such problem areas are the automobile and the generation of electricity.

Autos and Air Pollution

Much that is written and said about automotive pollution indicates that very little is really being done to change the pollution characteristics of internal-combustion engines. It is alleged that, in fact, little can be done. Such negative views are unwarranted, since both engines and fuels offer opportunity for modification to reduce markedly the pollution from internal-combustion engines in all applications. Nevertheless, in the long run, other supplementary methods of transporting people may be needed. All of the alternatives proposed to eliminate automobile-caused air pollution have great implications for fuels and materials management.

Some reduction in pollution from the automobile has resulted from federal standards already enacted through 1971. These standards will result in a continuous improvement in air quality through the 1970's as the controlled vehicles comprise an increasingly larger portion of the car population. Unless further progress is made to clean up exhaust emissions, however, an upturn in emission output is expected near the end of the 1970's as the increasing number of vehicles in use begins to overcome the effects of the standards. Technology is available for continued progress, but lead times of two years or more are required to manufacture and distribute modified fuels and (or) engines. Thus, continued progress will depend upon the decisions made between 1970 and 1975.

The impact of change in fuels and engine design will be far reaching and long lasting. Trends now developing and those established within the next few years will be, in practice, largely irreversible within the next decade. In terms of today's dollar, costs will be higher for each mile driven, and some of the broad options that are now available for fuels manufacture and for designing high-performance engine and fuel system will be lost.

The types and effectiveness of control methods depend upon the composition of the automobile population in the 1970's. Early in this decade, pre-1968 cars will represent 50% of the automobile population. Even in the last half of the decade, pre-1968 cars will still be a significant part of the population. These vehicles are important, since they generally do not have exhaust-emission controls.

There are options available to reduce pollution from the various automobile populations. Relatively simple engine and fuel-system modifications have been or will be made in 1968-74 model vehicles to meet emission standards. But the major impact of these changes will not be seen until the mid-1970's. Extensive engine redesign and exhaust treatment is expected for the 1975-79 cars. This possibility is widely discussed in the popular press, but the maximum effectiveness of such technology as catalytic conversion of exhaust gases will not be until 1980 or later–a decade away. Gasoline-composition modification is applicable to all cars on the road today, and its effect would be immediate. Field tests of this control method have met with dissappointing public response and, in the absence of compulsory legislation, engine returning will probably not result in a significant reduction of polluted air.

Changes in the composition of gasoline which limit volatility during the summer months and eliminate C_4 and C_5 olefins would reduce smog by 25% or more, according to recent research by the Bureau of Mines. This is the most rapid solution toward improving air quality, because such modifications can be accomplished quickly and are applicable to all cars now in use, without requiring any changes in the cars themselves. However, the olefins to be replaced have high octane ratings and their removal would make it more difficult to maintain the octane levels of fuels without using lead. Thus, this control method must be carefully coordinated with lead removal if undue losses in engine performance are to be avoided. It has been estimated that the modifications to gasoline can be achieved without significant changes in the product mix from refineries and at a cost to the consumer of less than 1 cent per gallon of gasoline. No estimates are yet available on the cost of accomplishing the same thing with lowlead and unleaded fuels, but the cost should not be significantly higher provided all fuel composition changes are carefully coordinated.

The lead-in-gasoline issue evokes a strange mixture of emotion, politics, and fact. Lead does contribute to the contamination of our environment–nearly 170,000 tons are released annually. It also forms deposits that foul engines and emission-control systems, unless controlled by additives, leading to increased emissions. Of particular importance, it presents difficult problems in developing exhaust-treatment catalysts. For effective use of these advanced control systems, the lead content of gasoline should be near zero.

Any move to modify fuels must be guided by the types of vehicles already in use. Many of these vehicles may have marginal acceptable performance using a low-octane, unleaded gasoline. High-octane

unleaded fuels that contain large amounts of aromatics blended into the gasoline could increase the smog-forming potential of the exhaust gases up to as much as 25%; depending on the octane level to be achieved. The cost of manufacturing unleaded gasolines with acceptable octane levels, would be reflected in gasoline price increases of 1 to 4 cents per gallon.

The lead issue demonstrates the difficult fuels management problem that has arisen as the result of environmental awareness. For example, if engine compression ratios are lowered to accommodate lower octane unleaded gasoline, the efficiency of the engine may drop and gasoline consumption increase. This would significantly reduce our already declining petroleum reserves. The manufacture of high-octane unleaded gasoline could set up severe competition for the stocks normally used as raw materials for the petrochemical industry. Significantly greater amounts of new oil may be required, and the needed fractions would be stripped from this oil. In this case, large volumes of oil products without aromatics would need to find a market.

A sweeping change-over to unleaded gasoline would be a massive technical and economic undertaking, the results of which have not yet been adequately delineated. For these reasons, the gradual transition to unleaded gasoline must be encouraged, the timing to depend on the distribution of the existing car population and on the types of vehicle yet to be manufactured.

Materials management will also become vastly more complex in the 1970's. New metal alloys are being developed for use in thermal reactors. A new horizon is opening in the catalytic field--both in refining of modified gasoline and in materials for catalytic conversion systems. And, as lead may be removed, a significant jump in the use of additives to maintain engine cleanliness is expected. All of these will have significant impacts on the current use of raw materials.

Natural gas (methane) and propane have had wide publicity as substitutes for gasoline.Although these fuels have chemical characteristics that permit cleaner exhausts, the crisis over natural gas supplies, problems of distribution, and the added complexities of the fuel system probably preclude general use by the motoring public. Use of these fuels in urban-operated fleets, however, is feasible and will probably increase in the future. Moreover, synthetic gas from coal or oil shale could be an added source for the needed fuel.

All of the alternatives proposed as substitutes for the internal-combustion engine must meet three key tests: Will there be a significant change in pollution? If so, at what cost? Is near-comparable performance obtained? Ultimately, it may be cheaper to meet air-quality standards by a totally different approach that involves engine systems yet to be developed. Present analyses of all competing systems indicate that into the 1980's the best combination of costs, utility and potential for reduced pollution output is the current gasoline-powered automobile.

The need for further reductions in total pollution output, however, may force a move to limit the size of both the vehicle and the engine. The increasingly severe problem of urban traffic congestion will result in increasing efforts to develop mass transportation systems. These pressures may cause a significant reduction in the demand for gasoline. This, when combined with adoption of proven technology that will enable a 95% reduction in all automobile pollutants, indicates that air pollution caused by automobiles can and will be ~~solved. However, the~~ accomplishment of this task will present a challenge of fuels and materials management unexcelled in a peace-time economy.

Sulfur and Electricity

The immediate and pressing question concerning fossil fuels for generation of electricity relates to their sulfur content. Of the coals shipped to electric utility plants in the U.S. in 1964, 21% had a sulfur content above 3%, 60% had between 1.1 and 3.0% S, and only 19% had less than 1% S. Regulations being established for sulfur in fuels are based on sulfur dioxide believed allowable in the air. Each community translates its requirements into a certain maximum sulfur content of the fuel. For a number of communities, a 1% sulfur maximum has been established. Obviously, much of the coal being mined and that in the ground cannot meet this requirement. Moveover, some regulations already scheduled call for a fuel having an effective sulfur content not exceeding 0.3%. Such coal is not available, and only exceptional supplies of petroleum residuum meet this requirement.

The options for solving the sulfur problem are:

.Fuel substitution.
.Fuel preparation (coal).
.Stack gas removal of sulfur oxide.
.Coal and oil shale conversion low-sulfur fuels.
.New combustion methods.

Substitution of naturally occurring low-sulfur fuel (gas for coal) is not practical in the immediate future since adequate supplies are not available in the U.S. Two promising options for the next several years are removal of sulfur before combustion and removal from the process gases after combustion. Conversion of coal to other low-sulfur fuels and new combustion processes are long-range options.

Fuel Preparation

Improvement in coal preparation involves the removal of iron pyrite from coal. Often, the pyrite content accounts for a half of the sulfur in the coal. However, even with improved pyrite removal, it is evident that the degree of sulfur removal necessary to meet anticipated regulations cannot be achieved by this means alone.

Lignitic coal, mostly located in the West, represents a vast national resource, and it typically has a sulfur content of about 0.6%. (The effective sulfur content is a little higher than this, since lignite contains about 7,000 Btu/lb, compared with about 12,500 Btu/lb for bituminous coal). Moreover, lignite is an inexpensive fuel, priced at only about $1.50 per ton, which is equivalent to about 10 cents per million Btu. Lignitic coals should be helpful in certain areas, but obviously do not solve situations where regulations call for 0.3% S. Moreover, lignite deposits are generally far removed from population centers, and shipping costs can be excessive. One possiblity is the generation of electricity in huge plants in the West; coupled with a system of long-range, low-cost electrical transmission through a cable cooled to very low temperature.

Stack gas removal

The once-through process for removing sulfur oxides from combustion gases, typified by wet carbonate scrubbing (Combustion Engineering), and being installed in three plants, ranges from 125 to 450 MW. It offers the advantage of relatively low capital investment in plant equipment (perhaps $6 to $13 per kW) and low operating cost ($1.50 per ton of coal). However, it does pose problems in disposal of calcium sulfate (or magnesium sulfate) product–indeed, there is the uneasy fear that an air pollution problem may transform into a land or water pollution problem. It seems likely that with pressure for meeting new regulations, systems such as wet limestone scrubbing will be adopted to some extent in the short-term future.

Regenerative processes for stack gas sulfur removal are expensive to install and to operate. Investments might run from $17 per kW to more than $30 per kW, and operating costs would be in the $3 to $5 per ton of coal range. Such systems involve a solid or liquid which chemically reacts with and removes sulfur oxides. The sorbent is regenerated, in a separate step, usually with the production of sulfur. Included in the *"regenerative absorbent"* group are potassium bisulfite (Welman-Lord), magnesia (Chemico), caustic plus electrolytic regeneration (Stone and Webster/Ionic), molten carbonate (North American Rockwell), potassium formate (Consolidation Coal), copper on silica (Houdry), alkalized alumina (Bureau of Mines), and others. Recently, it was announced that a regenerative-type plant, based on magnesia sorbent and costing $5 million, would be installed in the Boston area.

The conversion-type process is typified by the Monsanto Cat-Ox process. Although well defined, it is relatively costly to install and produces sulfuric acid that may not be desired. Bureau of Mines estimates an investment cost of more than $30 per kW for such a process, and an operationg cost of about $4 per ton of coal.

New combustion methods, such as fluidized-bed combustion, offer opportunity for some improvement, if not prevention, of air pollution. However, conversion of a high-sulfur to a low-sulfur fuel appears to present the fundamentally best opportunity for a long-term solution.

Synthetic fuels

From a supply standpoint, natural gas–essentially methane–is now in the most critical stage of all fossil fuels. For the second consecutive year, recoverable reserves have declined–that is, more gas was used than discovered. Yet the use of gas is the most rapidly growing of all the fossil fuels (about 7% annually) compared with a growth rate for energy as a whole of about 3%.

Looking ahead to 1985, projected rates of development will not fulfill the projected need for natural gas, even including importation of gas by pipeline from Canada and Alaska, or by cryogenic tanker from overseas. Anticipating this situation, and in the search for new markets for coal, a vigorous research and development program has been in progress for a number of years to provide processes for conversion of coal to gas. Several processes are currently in advanced stages of development.

Pilot plants are under construction for the Hy-Gas (Institute of Gas Technology) and the CO_2 acceptor processes (Consolidation Coal Co.) under the sponsorship of the Office of Coal Research of the Department of Interior. Scale-up of the Bureau of Mines steam-oxygen, fluidized-bed coal gasification process has also been initiated.

In the Bureau of Mines process, coal is reacted with steam and oxygen in a fluidized bed at about 600 to 1,000 psi, to produce a mixture of CH_4, H_2, CO, H_2S, and CO_2. After the CO_2 and H_2S are removed, the CO and H_2 are reacted to form additional methane. For a 250-million ft^3/day plant, the capital requirement has been estimated to be $160 to $180 million, the manufacturing cost 43 cents/ft^3 and selling price 54 cents/1,000 ft^3 using utility company-type financing. It now appears that if the price of gas increases enough, or if adequate technologic-economic improvement in coal gasification can be made, synthetic gas from coal may soon become a commercial reality.

The price of synthetic pipeline gas noted above is too high to be used by electrical utilities. There is a very interesting related possibility–the production of low-Btu gas from coal using air instead of oxygen, followed by sulfur and ash removal, and generation of electricity by gas turbines. In this case, a high-temperature sulfur removal process is needed, in cooling the gas and heating it up again.

Underground gasification of coal and

127

gasification of oil shale offer additional possibilities for gas supply if new technical advances can be achieved. It should be emphasized that all processes contemplated for manufacture of synthetic gases or liquids from coal result in a low-sulfur product.

It is possible to convert coal to liquid fuels, including high-quality gasoline. Moreover, the cost of doing so is approaching the cost of refining gasoline from petroleum. Therefore, probably within the next 15 years, it will be both necessary and economically feasible to make gasoline synthetically.

Another very important possibility which has not yet received emphasis is the conversion of coal to a low-sulfur, low-cost utility fuel. In such a process, coal is contacted with hydrogen and solvent with or without an added catalyst, thus transforming the coal into a new fuel product low in sulfur and ash. It is not important to upgrade the product by removing asphaltenes as in the case of gasoline production. By operation of relatively low pressure and relatively mild temperature, a minimum of hydrogen is used, so that a low-cost fuel can be manufactured.

Petroleum desulfurization

With new regulations and increased demand, it has become necessary to desulfurize petroleum to achieve a more adequate supply. Fortunately, the petroleum industry has developed effective hydrodesulfurization processes. Of a total of about 14 million barrels of oil produced per day, about 4 million are being desulfurized in the U.S. At present, most desulfurized oils consist of lighter petroleum fractions. Significantly, processes for desulfurizing residua are now coming on stream in different parts of the world. The cost of desulfurization ranges from about 20 to 80 cents a barrel. As an example, for a high-sulfur (2.6%) residuum costing 32 cents per million Btu ($2.00 a barrel), it would cost 4 cents per million Btu for each 0.5% by which the sulfur content were reduced. Desulfurization to 0.5% would thus add 16 cents, bringing the cost to 48 cents per million Btu, a 50% increase over the undesulfurized oil. Costs rise sharply, however, below about 0.5% sulfur.

The natural sulfur content of oil varies greatly. For example, residuum from Algeria is low in sulfur, about 0.5%, whereas that from Venezuela is relatively high, about 3%. No large supply of domestic low-sulfur residuum is available. The importation of a high proportion of utility fuel from abroad poses a problem from the viewpoint of national security since the east coast now imports nearly 94% of its requirements. Part of the current shortage in available residuum is due to its increased initial costs and increased tanker rates.

During the past few years, the substitution of low-sulfur petroleum residuum from abroad for high-sulfur domestic coal has been widely adopted on the east coast, where there is no oil import quota on fuel oil. Moreover, governmental approval recently provided for one plant to use imported residuum in the Chicago area. In this instance, the oil, containing 1% sulfur, will replace coal, at a reported cost of 46 cents per million Btu at that location as compared to about 30 cents for coal. This illustrated forcefully that pollution control is expensive.

New technology

Finally, we should not overlook new energy conversion devices which can become important if certain technological breakthroughs are achieved. Specific cases are fuel cells and magnetohydrodynamics. The former would permit the widespread use of gas for the transmission of energy, followed by generation of electricity, in the home or community.

Management of fuels also should take into account one human habit sometimes not recognized in the fuels system—that is, the production of so-called urban and agricultural refuse. Much of this is about half paper. In the U.S., 7 lbs. of urban refuse is collected per person per day, and nearly 10 times that amount of agricultural wastes is produced. In the past, urban refuse has been used as landfill or incinerated, causing significant air pollution. Now it is possible to recover energy by controlled incineration, by pyrolysis to make gas and oil, or by hydrogenation to produce a low-sulfur oil. Recent experiments by the Bureau of Mines have shown that heating a tone of garbage to 380°C for 20 minutes in the presence of carbon monoxide and water under high pressure produced over two barrels of low-sulfur oil per dry ton of garbage. Perhaps some such novel means will be necessary for conversion of cellulose, grown by solar energy and discarded by man, into a fuel that can be utilized with less pollution.

CHAPTER 7

HEALTH EFFECTS: A COMPARISON

1. Health Effects of Nuclear Power Plants

The greater part of this chapter will describe the effects of exposure to radiation. The reason for this is two-fold: much more research has been done on the effects of radiation than on the effects of pollutants from fossil-fueled plants; and radiation effects are poorly understood by the average person.

Humans have always lived with low level background radiation and were unaware of its existence until about 1895, when ionizing radiation was discovered. Early experiments with x-rays soon produced a number of injuries to the experimenters. Almost immediately, the use of radiation began to be controlled. By the time power reactors began to be built in the mid-1950's, radiation emissions from these plants and radioactive by-products were under strict regulation. This is in contrast to the case for fossil fuels, which were not regulated until long after their use as energy sources.

A. Fundamental Information

As noted in Chapter 3, all matter is made up of simple units called atoms. Each atom has a nucleus with an electrically positive (+) change. A cloud of electrically negative (-) electrons orbits the positive nucleus. Ordinarily, the number of negative electrons equals the number of positive charges in the nucleus. The atom is then electrically neutral. If energy is supplied to an orbital electron, it can be moved to a position further from the nucleus; then the atom is said to be in an excited state. If large amounts of energy are supplied, the electron can escape from the atom completely. When one or more electrons is separated from the atom, the atom is said to be ionized. The atom has a net positive charge since it is missing an electron. This positively-charged atom, taken with its separated negative electron, is called an ion pair. (See Figure 23.)

As discussed in Chapter 3, some atoms are radioactive and emit radiation as they decay to a stable state. Table 5 shows the composition of the various kinds of decay radiation.

When these types of radiation pass through matter, they interact with the electron clouds of the atoms in the matter. In this process the radiation loses its energy by exciting the atoms and/or producing ion pairs in the matter. This basic process is essentially the same for all kinds of materials-air, water, people, cement blocks, or steel.

The most penetrating of these types of radiation are the gamma rays. High energy gamma rays can completely penetrate a person, a concrete block or a sheet of lead.

Beta radiation, which is high energy electrons or positrons, is capable of penetrating a piece of aluminum foil or several layers of a person's skin. In air, its range may be as much as a yard.

Alpha radiation, which is high energy helium nuclei, can sometimes penetrate a very thin piece of paper but cannot penetrate conventional aluminum foil. However, alpha particles are the most hazardous of all types of radiation if they enter the body as a result of swallowing or inhaling an alpha emitter.

The potential of injury from any kind of radiation depends on the rate of energy loss as the radiation travels through matter. This rate of energy loss in turn depends on the type of radiation, its electrical charge and its energy. The energy loss produces chemically reactive species, such as ion pairs in the absorbing material, and these species do the damage, such as disrupting the functions of cells of living organisms.

B. Radiation Detection

Atomic radiation is not detectable by the human senses except in massive doses, but it is easily detected by several types of instruments. One of the simplest radiation detectors is ordinary photographic film, which darkens on exposure to radiation and is routinely used in film badges for measuring the cumulative amount of exposure received by people who work with sources of radiation. Other types of detectors such as Geiger counters, ionization chambers and proportional counters, are used to detect the presence and measure the intensity of atomic radiation. These instruments can detect the presence of extremely small amounts of radioactive materials. Radiation detection is also very sensitive in its ability to identify specific radioactive substances. This is possible because every species of radioactive atom has a characteristic pattern of radioactive decay.

C. Units for Measuring Radiation Exposure

The roentgen is the unit of exposure related to the number of ion pairs produced in air by x-rays and gamma rays. It is the amount of such radiation required to produce ions carrying a standard electrical charge in a standard amount of air. The roentgen can be measured directly since the electric current can be measured by an ammeter.

The radiation absorbed dose (rad) indicates the amount of energy deposited in material by any type of radiation. It is a measurement of not only ion pairs, but of all energy deposited. A rad is a very small unit. For example, one rad equals the energy required to raise the body temperature by two-millionths of a degree Fahrenheit.

The roentgen equivalent man (rem), is the unit of dose equivalent. It is a measure not only of energy deposited but also the resulting biological effects.

For instance, suppose 500 rads of gamma rays

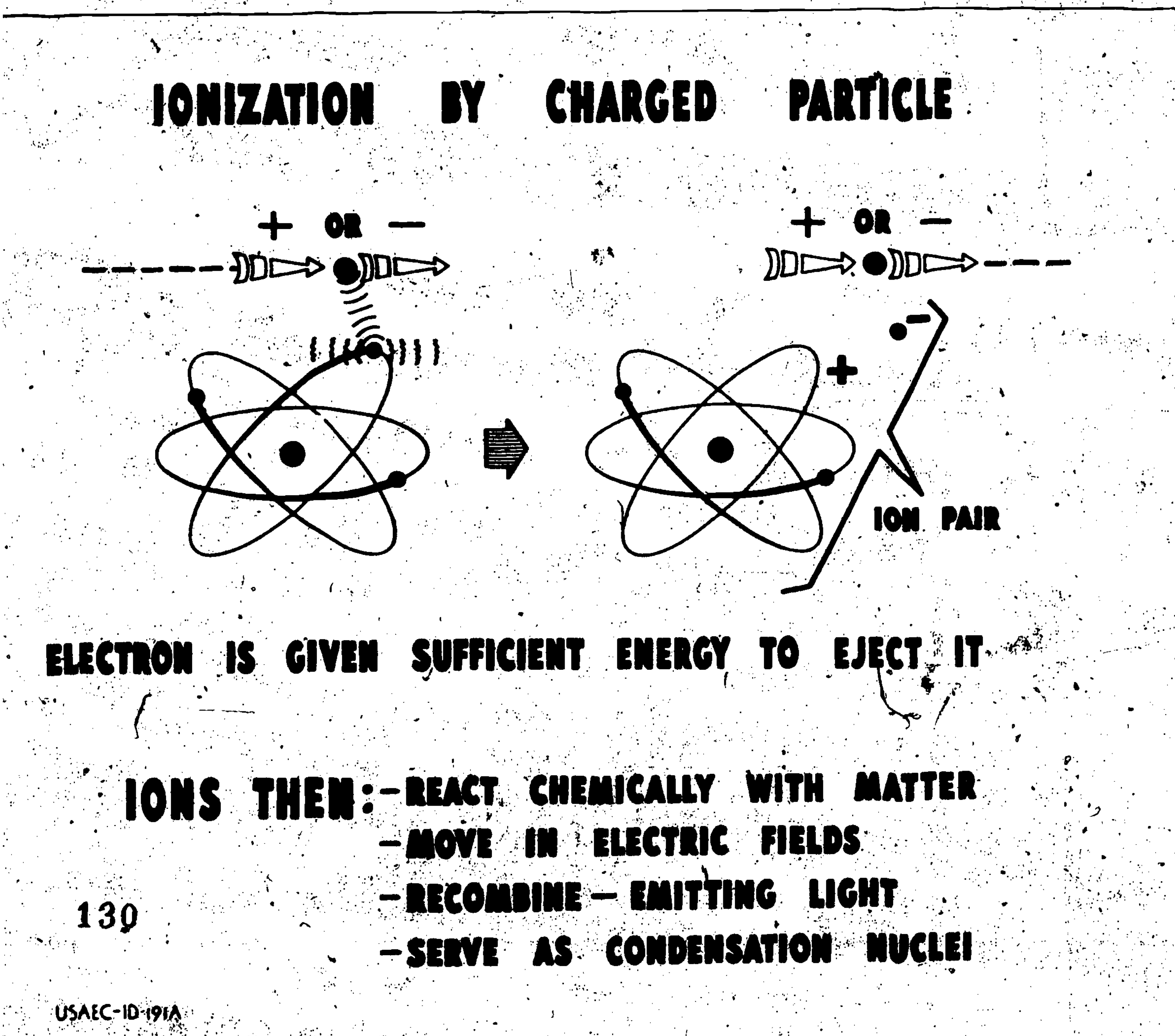

IONIZATION BY CHARGED PARTICLE
+ OR −
+ OR −
+
ION PAIR
ELECTRON IS GIVEN SUFFICIENT ENERGY TO EJECT IT
IONS THEN:-REACT CHEMICALLY WITH MATTER
-MOVE IN ELECTRIC FIELDS
-RECOMBINE — EMITTING LIGHT
-SERVE AS CONDENSATION NUCLEI
USAEC-ID-191A

FIGURE 23

TABLE 5

Definition of Types of Decay Radiation

	Radiation	Protons	Neutrons	Electrons	# Charge
	Alpha (α)	2	2	0	+2
Particulate	Beta (negatron) (β^-)	0	0	1	-1
	Beta (positron) (β^+)	0	0	1	+1
Electromagnetic (Nonparticulate)	Gamma (γ)	0	0	0	0
	X-Rays	0	0	0	0

produce a certain change in a tissue and 50 rads of alpha particle radiation produce the same change. We then would say that the alpha radiation was 10 times as powerful as gamma radiation in causing this change. In other words, the alpha radiation would have a quality factor of 10 when it is compared to the gamma ray.

We can use the formual rems = rads x quality factor to convert to rems. In our example, the quality factor for gamma radiation is 1. Therefore, 500 rads multiplied by a quality factor of 1 gives 500 rems. For the alpha radiation, 50 rads multiplied by a quality factor of 10 gives 500 rems. The number of rems is thus the same for the two types of radiation which produced the same biological effect.

Since radiation protection deals with the safeguarding of people from unnecessary radiation exposure, regulations and recommendations are usually written in terms of rems. However, it is often desirable to work with smaller units, so millirem (mrem), which is one-thousandth (.001) of a rem, is often used. For example, the maximum permissible exposure allowed for a radiation worker is 5 rems, or 5000 mrem, per year.

To summarize the units of radiation exposure, a roentgen refers to the ions produced in air by x- and gamma radiation. A rad refers to the energy deposited in any material by any ionizing radiation. A rem refers to the results of that energy deposited in tissue.

D. Sources of Radiation

As mentioned, humans have always been exposed to radiation. This natural or background radiation comes from many sources.

One source of natural radiation is high energy cosmic radiation from the sun and stars. This radiation interacts with our atmosphere to produce a shower of charged particles.

Another source of natural radiation is radioactive nuclides like the uranium and thorium widely distributed in soil and rocks. The more energetic radiation from these radionuclides irradiate us continuously. Also, a small part of all potassium is radioactive potassium-40, and a small part of all carbon is radioactive carbon-14. This radionuclide is constantly formed in the upper atmosphere by the interaction of cosmic radiation with atmospheric nitrogen. These naturally-occurring radionuclide add about 50 mrem/year to our exposure.

The amount of radiation dose from natural background varies according to location. For example, the cosmic radiation dose increases with altitude; it doubles from about 40 mrem/year to about 80 mrem/year when someone moves from Philadelphia to a town high in the Rocky Mountains 10,000 ft. higher. Exposure also increases by 15 per cent as one moves from the equator to a geomagnetic latitude of 50 degrees.

Similarly, the dose from radiation in rocks varies with location. Moving from one part of New York City to another may add an additional 15 mrem/year dose, because of this difference in the natural background.

Even the type of house a person lives in affects the amount of background radiation received. People living in a wooden house receive about 100 mrem/year. If they move to a brick-and-concrete house, they may get as much as 300 mrem/year because of higher radiation levels in the earthen building materials.

Man-made radiation adds to the average dose that everyone receives. Most significant is the dose from medical and dental x-rays. A small amount of radioactivity is also received from fallout from weapons-testing and from nuclear reactors (See Table 6). The radiation doses in this table are genetically significant doses, which means that they estimate the potential genetic effects of radiation on future generations.

E. Factors Which Influence Radiation Effects

Radiation effects are not dependent solely on the amount of radiation received. Other factors must be considered.

(1) Dose Rate Effects

The rate at which a radiation dose is received is an important factor in determining its effect. This is because living tissue is not inert. As soon as damage is produced, healing begins. Thus, if a particular dose is delivered over a long period, it is possible that repair may keep up with the damage, so that no detectable change would be produced. On the other hand, if the same dose is delivered all at once, the change may be noticeable.

Knowledge of the effects of radiation has generally resulted from data on large doses received in a short time. Data sources include Hiroshima survivors, victims of radiation accidents and patients receiving radiation therapy. However, most humans are exposed to low doses and low dose rates. To see the biological effects of this type of radiation, one would have to observe large groups of people over many generations. Because of this difficulty, the general practice is to predict the results of the low doses and low dose rates on the basis of high dose and high dose rate data.

Furthermore, in order to be conservative in estimating radiation effects, one must assume that some injury results from any exposure to radiation. According to the International Committee on Radiation Protection (ICRP): *"The objectives of radiation protection are to prevent acute radiation effects, and to limit the risks of late effects to an acceptable level. For purposes of radiation protection, any exposure is assumed to entail a risk of biological damage."* It should be stressed that this

TABLE 6

Sources of Man-made Radiation

Source	Average Genetically Significant Dose (mrem/year)
Medicine and Dentistry	
Diagnostic (1970)	35
Therapeutic	5
Internal (Radionuclides)	1
Environmental	
Weapons fallout	4
Reactors (Living at site boundary)	0.03
Reactors (Average person in the population)	.01 to .001

is not known to be the case. There are certainly levels of radiation that produce no detectable effects-background radiation and routine diagnostic x-rays, for example. But the most conservative assumptions are used to insure maximum protection for the population.

(2) Age of the Individual

The age of the exposed individual can greatly affect his/her sensitivity to radiation. When organs are developing before birth, sensitivity is high, because differentiating cells and cells undergoing rapid division are more easily damaged. Similarly, from birth to maturity, high rates of cell division and possible further differentiation make a child more sensitive to radiation exposure. An adult is more resistant to radiation effects. Exposure, however, may give rise to genetic effects in the exposed adult's children. For a person beyond the reproductive age, genetic effects are not important. Similarly, radiation effects which might appear only after a long time (for example, tumor induction) would not be as significant to older people as to younger people.

(3) Part of Body Irradiated

Some parts of the body are more sensitive to radiation effects than other parts. For example, if the upper abdomen is irradiated, the radiation effects are more severe than if a body area of similar size elsewhere were exposed to the same dose. This is because of the presence of vital organs in the upper abdominal area. The ICRP has recommended dose limits for the general public for different parts of the human body. These doses range from a low of 500 mrem/year to the reproductive organs and red bone marrow to a high of 7,500 mrem/year for the hands, forearms, feet and ankles.

(4) Extent of Body Irradiation

Irradiation of a small part of the body surface will have much less general effect than an equal dose per unit area delivered to the whole body, since the unirradiated portions can help the affected portions recover.

(5) Biological Variation

Although it is possible to determine an average dose which produces certain effects, individual responses will vary from the average. For instance a dose of about 600 rads in a single exposure killed half a group of rats within 30 days. On the other hand, some rats died after 400 rads and some lived after 800 rads. This is biological variation.

F. Internal Radiation

Most of what has been said so far about radiation effects has been in terms of external dose, that is, from sources outside the body. When radioactive materials are taken into the body, whole body effects may occur. Radioactive material may enter the body through food, water or air, but the most common source of significant levels of radioactive materials inside the body results from nuclear medical techniques. These radioactive materials move through the body in the same manner as nonradioactive materials. They are also eliminated in the same manner and constantly become weaker through radioactive decay.

External radiation doses to an individual can be reduced by shielding, i.e., placing dense material between the individual and the source; distance, i.e., moving away from the source; or shortening the time that the individual is exposed to the source. When the radiactive source is inside the body, reduction of the dose is not to simple. Also, the amount of internal radiation necessary to bring about a given effect is much smaller than that required from an external source. This is because the internal radioactive material becomes a part of the living tissue.

The effect of internal radiation depends on several factors. One is the sensitivity to radiation of the organs or tissue to which the material goes. Another factor is the type and energy of the radiation emitted; this determines the quality factor. The physical and chemical form of the radioactive material also helps determine its effects. A major factor in the effect of internal radiation is the effective half-life (TE) of the radioactive material. This is the time it takes a person to reduce the amount of radioactive material to one-half the original amount. The effective half life is in turn determined by the biological half life (T_B), which is the time it takes the body to remove one-half of the radiactive material; and the physical half life (T_P) of the radioactive material, as defined in Chapter 3. These three terms are related by the expression

$$\frac{1}{T_E} = \frac{1}{T_P} + \frac{1}{T_B}$$

Thus a long-lived radionuclide emitting alpha particles and deposited in bone would be more harmful than an equivalent amount of a short-lived radionuclide emitting gamma rays, which are not readily absorbed into tissue and do not concentrate in any organ.

G. Radiation Effects

Biological effects of radiation are divided into two general classes. Somatic effects are those observed only in the person who has been irradiated. Genetic effects are those seen in the off-springs of the person irradiated.

(1) Somatic Effects

(a) Cellular Response

The first event in the absorption of ionizing radiation is the production of excited atoms and ion pairs. When these are produced in the chemical systems of a cell, new and possibly harmful chemicals are produced as the original chemical structure of the cell is disturbed by the radiation. Thus, toxic materials may be produced. Furthermore, if the radiation affects chromosomal material within the cell nucleus, cell division may be effected. Thus, a cell may respond to irradiation in several ways: chromosomal charges, cell death before division,

failure to specialize, failure to divide completely or slowing its division rate. Some cells will be unaffected by the radiation.

The cellular response to radiation is determined by a number of factors. Among these are the cell's stage of specialization, its activity and its division rate. These factors partially account for an embryo's great sensitivity to radiation. In the embryo, a small group of cells will eventually specialize or form an organ, so these cells are especially radiosensitive.

These factors also help to make radiation therapy possible. A patient with cancer, for example, receives a number of exposures, giving him/her a large total radiation dose. Through the phenomenon of repair following radiation exposure, the cells begin to repair the radiation damage between exposures. However, the rapidly dividing cancer cells have a greater chance of being destroyed because they are more frequently in the radiosensitive stages of cell division.

(b) Organ Sensitivity

The radiosensitivity of organs and tissues depends on cell multiplication. In the lining of the gastrointestinal tract, for example, some cells are mature. These are continuoulsy being discarded and replaced by new cells produced nearby. If a high dose of radioactivity is received, these rapidly dividing cells will be severely decreased in number. If the dose is not too high, the surviving cells will be able to replace those destroyed.

If a large dose is given to a small area of the body, the general and local effects depend on which organ is irradiated. For instance, a large radiation dose to an arm will very likely cause detectable changes in the arm. But it will not result in death or severely damage the blood-making system, because the majority of this system was not exposed to the radiation. On the other hand, a moderate dose to the small reproductive organs can result in temporary sterility.

(c) Total Body Doses

A large, sudden, whole-body dose of radiation produces the acute radiation sickness syndrome: nausea, vomiting, general aches and pains and possibly a decrease in the number of white cells. Localized phenomena, such as reddened skin or loss of hair, may be produced. Larger doses cause weakness, drastic depression of all blood elements and possibly sterility. Exposure to the eyes may cause cataracts. At still higher dose levels, death will probably occur.

It has been shown in animals that high radiation doses cause the bodily changes that occur with aging. It is obviously difficult to obtain such data for humans, but it is probable that some degree of life-shortening may occur following high dose exposure.

Identifying the effects of low levels of radiation is difficult because no new type of malady is produced. Instead, there is an increased frequency of disorders which are also produced by other environmental factors or which occur spontaneously with no known cause. For example, cancer and leukemia may be long-delayed consequences of a single large exposure to radiation, and they may also follow chronic exposure. But they are by no means an inevitable result of any form of human exposure to radiation.

Much recent attention has been directed at the increased incidence of lung cancer in uranium miners. This may be due to the inhalation and deposit of the decay products of radon in the lining of the lung. Radon is a natural occurring radioactive gas resulting from the decay of uranium and thorium radioisotopes.

(2) *Genetic Effects*

Genetic effects refers to the production of mutations, which are permanent, transmissible changes in the characteristics of an offspring from those of its parents.

Mutations occur in all living organisms. They may occur of their own accord, apart from any known alteration in the environment. Whatever their origins, most mutations are undersirable. Every individual has some of these undesirable mutations.

Radiation-induced mutations are divided into two classes: gene mutations and chromosomal abnormalities. Most radiation-induced alterations are gene mutations, which tend to be recessive. In other words, the effect of the mutation is not seen in the offspring unless the altered gene is carried by both parents. Even though the mutation may not be seen in first-generation offspring, it makes such offspring slightly less fit.

Chromosomal abnormalities include chromosome loss and chromosome breaks. These effects are severe, the result usually being the death of the embryo before birth. This type of genetic effect happens much less frequently than does gene mutation.

The increase in genetic damage to be expected from radiation is sometimes discussed in terms of doubling dose. This dose would eventually cause a doubling in the rate of gene mutations that occur spontaneously.

In the United States, about 100 million children are born in a generation. Of these, about two per cent will have detectable genetic defects as a consequence of spontaneous, unavoidable genetic changes passed on by all their ancestors. If a doubling dose of a radiation were applied to present and future generations, it would eventually lead to a gene mutation rate of four per cent. It would take on the order of 10 generations to reach the four per cent rate. The doubling dose cited by the National Academy of Sciences report, "*The Effects on Populations of Exposure to Low Levels of Ionizing Radiations,*" is estimated to be 40 rads (40,000

mrads) per generation. In other words, if the average dose to the reproductive cells of all of the individuals of the population was a total of 40 rads from conception to age 30, or 1.3 rads per year above background for every generation, after about 10 generations the rate of impairing mutations would gradually increase so as to eventually double from two per cent to four per cent. This amount of radiation is far above that obtained from any current man-made source. (See Table 6).

It should be pointed out that only between five and 12 per cent of all genetic changes are caused by environmental radiation. The bulk of all genetic changes is produced by other natural substances, including environmental pollutants.

H. Nonhuman Biological Effects

In nature, hundreds of thousands of species of plants and animals have been identified. It is reasonable to expect that a wide range of sensitivities to radiation would be seen in this great variety. While radiation protection guides are written for the protection of humans, much of the data upon which such guides are based was derived from animal experiments.

The basic conditions that tend to predict radiosensitivity in humans, such as cell division rate and age, apply to all other life forms. However, there is a wide range of variation among species. The more complex the organism, the more sensitive it is to radiation effects.

A number of types of organisms have been known to reconcentrate radioactive materials in their bodies. An example is shellfish such as oysters and clams. These organisms can reconcentrate certain radionuclides up to 100,000 times the levels found in the water in which they live. This reconcentration does not appear to affect the well-being of the animal, but people who use these shellfish as their sole source of food could receive a significant fraction of their maximum permissible dose in the process. For this reason, edible shellfish living near the outfall of a nuclear plant are used as monitors for crosschecking radioactive discharges.

I. Radiation Effects from Nuclear Power Plants

What is the risk of harmful radiation effects from nuclear power plants? To quote Lauriston S. Taylor of the National Council on Radiation Protection and Measurements: *"There is a considerable region of radiation exposure about which we have very little positive knowledge. This is in the region of doses of one or two or even a few rads, delivered all at once and not repeated too frequently; larger doses, say up to 10 or 20 rads received essentially all at once but rarely, if ever repeated; and finally, exposures at very low levels and at low dose rates, say at millirads or less per day, but persisting over long periods and totalling only some five or ten rads distributed over a lifetime.*

"It is particularly this latter condition which is of concern to the public with the use of nuclear reactors, and it is this range and kind of exposure upon which we have little positive and direct knowledge. But it is in the same range of exposure that we have made a tremendous effort of attempting to discover effects, with all results so far being convincingly negative. This inability to find effects is itself extremely important, but it must be recognized that the test samples may not have been large enough.... The levels of dose about which the public is concerned in the nuclear power industry are at the most a few thousandths of a rad per year, and more likely less than a thousandth.... The upper dose limit to the population for all man-made radiation is 700 times less than the lowest dose of gamma rays which has been statistically shown to cause leukemia.

"At the same time the population dose limit is at least some hundred times higher than the average dose to the population from all the reactors expected to be installed between now and the year 2000, assuming no improvement in our protection techniques."

Perhaps the only problem is that we do not know how to measure the effects of such very low doses of radiation, because they are too small or happen too infrequently to be measured by any present techniques. This means that if the effects cannot be measured by any of the fairly sophisticated methods available today, the potential hazard-if it exists at all–is sufficiently small so that there is time to further study and analyze the problem without a serious risk.

However, this very fact of being unable to detect any effect, accompanied by an unwillingness to say that there is no effect at all, has led us into a dilemma. In order to avoid setting standards which would expose the public to unnecessary radiation, and what future knowledge may show to be dangerous amounts of radiation, the National Council of Radiation Protection and Measurements has set exposure limits based upon the following very cautious assumptions:

1. There is a single, linear dose-effect relationship for the effects of radiation, from zero dose with no effect to the known effects of high level doses.
2. There is no threshold of radiation below which there is no effect.
3. All doses received by an individual are additive–that is, their effects add up.
4. There is no biological recovery from the effects of radiation.

Much of the available evidence indicates that several of the above assumptions are probaly not true, but in the interest of safety, we assume that they are, under the conservative philosophy that it is far better to be oversafe than to be sorry at some future date.

The radiation protection guide, arrived at as a result of these assumptions, gives a maximum permissible dose to the general population. The maximum is presently 170 mrem/year above natural background. This figure does not include an individual's radiation dose from medical procedures. The NCRP does not attempt to regulate or limit radiation exposure for necessary diagnostic and therapeutic purposes, but it does recommend reductions in the exposure which does not contribute to treatment or diagnosis.

To keep the dosage which we may expect to receive from nuclear power plants in perspective, the maximum exposure to the public from the combined effects of all nuclear power plants expected to be constructed by the year 2000 will not be a total dose greater than 10 millirems.

The Nuclear Regulatory Commission insures that release of radioactivity from nuclear power plants is as low as practicable. Proposed guidelines for defining these as-low-as-practicable levels would keep radiation exposure of persons living near nuclear power stations to less than five per cent of the average natural background radiation. Such exposure would be about one per cent or less of that which federal projection guides allow individual members of the public.

2. Health Effects of Fossil-Fueled Power Plants

Health effects from fossil-fuel use come mainly from the air pollution caused by the burning of such fuels. Fossil-fueled plants produce air pollution in the form of oxides of sulfur and nitrogen, carbon monoxide, unburned hydrocarbons and particulates in the form of fly ash. Table 7 shows typical amounts of pollutants released to the environment by a 1,000-megawatt power station. The figures in Table 7 assume the use of 2.3 million tons of coal containing 2.5 per cent sulfur, 460 million gallons of oil containing 1.6 per cent sulfur by weight and 68 billion cubic feet of gas. They also assume a nine per cent fly ash content for the coal and 97.5 per cent fly ash removal efficiency. No other pollution control equipment is assumed in determining these figures.

In talk about air pollutants, the term parts per million is frequently encountered. This term is an expression of the concentration of one material within another material. For example, it is used to express the concentration of a gaseous pollutant, such as sulfur dioxide, in another gas, such as air. One part per million (ppm) means one part of the pollutant to one million parts of air.

A. Sulfur Dioxide

Sulfur dioxide (SO_2) is an air pollutant of major concern. Power plants emit more of it than any other pollutant. It is a colorless gas produced when fuels containing sulfur are burned. Most people can taste it at concentrations greater than 1 ppm, and it has an irritating smell at concentrations above .7 ppm. In the environment, sulfur dioxide is transformed to sulfur trioxide or to sulfuric acid and particulate sulfate salts. These transformations depend on the presence of moisture in the air, on the presence of dusts and smokes, and on the intensity and duration of sunlight.

Oxides of sulfur affect the respiratory system, which includes the lining of the nose, the throat and lungs. Laboratory studies have shown that sulfur dioxide constricts the bronchial tubes in experimental animals' lungs.

In general, the laboratory work performed thus far is not entirely relevant to the real environment. In the real environment, the concentrations of a whole spectrum of pollutants are constantly changing. The amount of moisture in the air changes. So do the intensity of sunlight and temperature. Although it is very difficult to reproduce all these changes in the laboratory, valuable information on sulfur dioxide has been gathered. It has been shown, for instance, that it is not wise to measure only one pollutant in the air and then use that data alone to describe the quality of the air. The interaction of the various pollutants can have effects different from those produced by an individual pollutant. For example, sulfur dioxide alone acts as a bronchial restrictor that can cause breathing problems, especially for those who already have a breathing impairment. Certain aerosols, such as iron, manganese and vanadium, which may be present in particulate matter, react with the sulfur dioxide to form sulfuric acid. Sulfuric acid, a more severe irritant to the bronchial system, can penetrate deeper into the lungs. Therefore, combinations of particulate matter and sulfur dioxide are potentially more damaging than either alone.

Another way to study the problem of the oxides of sulfur is through epidemiology, the branch of medicine that deals with epidemic diseases or illnesses. The epidemiologist must think of all the possible causes for the disease in the group of people and then carefully eliminate all the causes but one. Epidemiological studies lack the controlled conditions of the laboratory, but they are carried out in the real-life environment. From these studies, it is clear that the oxides of sulfur in the air affect the health of people, and that the severity of the effect is directly related to pollution levels.

The results of some epidemiological studies of the effects of sulfur dioxide are listed in Table 8.

TABLE 7

Typical Emissions from a 1000 Megawatt Fossil-Fueled Generating Station

Pollutant	Annual Emissions (Millions of pounds) Coal	Oil	Natural Gas
Oxides of Sulfur	306.0	116.0	0.027
Nitrogen Oxides	46.0	47.8	26.6
Particulates	9.9	1.6	1.02
Hydrocarbons	0.46	1.47	–
Carbon Monoxide	1.15	0.018	–

TABLE 8

Effects of Sulfur Dioxide

Location	SO_2 Concentration (ppm)	Effects
England	0.040	This annual mean produced an increase in death from bronchitis and lung cancer, with cigarette smoking, age, occupation and class taken into consideration.
England	0.046	This long-term level increased frequency and severity of respiratory diseases in children
London	0.20	This one-day average accentuated symptoms in persons with chronic respiratory disease.
London	0.25	Rise in daily death rates after abrupt rise to this level.
London	0.35	Distinct rise in deaths with concentration over this level for one day.
London	0.52	Death rate appeared to rise 20 per cent over baseline levels.
Rotterdam	0.19	Apparent increase in total mortality after a few days at a mean concentration of this level.
New York	0.007 to 0.86	Rise in upper respiratory infections and heart disease complaints during the 10-day period.
New York	0.5	Excess deaths were detected after 24 hours at concentrations over 0.5 ppm.
Chicago	0.25	This one day average increased illness in older patients with severe bronchitis.

Under the 1970 Clean Air Act, the Environmental Protection Agency has set air quality standards for several pollutants, including SO_2, to be met July 1, 1975. The act limits the use of high sulfur fuel unless some practical method of SO_2 removal is devised. This regulation was the primary cause of a large number of power plants converting from coal to oil in the 1970's, thereby aggravating the problem of increased dependence on foreign oil sources.

Since coal is relatively plentiful in the United States, some practical method for reducing the SO_2 emission from coal-burning plants would greatly increase our usable fuel supply. Four approaches seem possible: mine and burn low-sulfur coal; mine high-sulfur coal and clean it before burning; burn high-sulfur coal and take out the SO_2 with scrubbers; and burn high-sulfur coal and disperse the SO_2 from tall stacks.

As noted in Chapter 2, there is not much low-sulfur coal in eastern U.S., where much of the demand for electricity is found. One solution would be to ship low-sulfur coal from western fields to power plants in the east, but our current transportation system inhibits this to a significant degree. Numerous studies are underway to develop efficient rail systems, and research is also being done on making coal slurry (coal particles carried in water) and transporting it in a pipeline. However, there are problems in getting the right-of-way for such a pipeline and in obtaining enough water in the arid regions where the coal is found. This water shortage also limits building mine-mouth power plants in the west and sending the electricity to population centers by transmission lines. Another problem in the use of the western coal is the uncertainty of when large-scale mining will be permitted because of its environmental impact.

Because of these limitations, attention must be focused on finding ways to use high-sulfur coal. There is currently a great deal of debate on the acceptability of tall-stack dispersal. The Environmental Protection Agency is unwilling to accept it as a permanent solution, but since tall stacks do reduce the SO_2 concentration at ground level, it is willing to accept it as a temporary solution. The EPA is thus insisting that electric utilities either burn low-sulfur coal, remove the sulfur before burning the coal, or remove the sulfur before stack gases are released.

Today, several systems are used to control the emission of SO_2. Most of these systems use a slurry of ground limestone and water to convert the SO_2 to compounds of calcium sulfate and calcium sulfite. A description of one such system is as follows: the hot exhaust from the furnace is passed through a large electrostatic precipitator, where most of the fly ash is removed. It then goes through a series of scrubbers, where the hot gases react with the limestone slurry, removing 90 per cent or more of the SO_2. The gases, now containing mainly water vapor, carbon dioxide and nitrogen, are then reheated so that they can be exhausted out the stack. Such systems produce large amounts of wet sludge, which has little or no commercial value, poses formidable disposal problems and has the potential for polluting ground water. Research is underway to develop ways of solidifying this sludge so that it can be used as fill material in depleted coal mines, both underground and strip mines. It is estimated by some developers that these systems would increase the cost of electricity to the consumer by about 10 per cent. Some utilities fear that the cost will be 30 to 50 per cent, especially when the sludge disposal problem is considered. This illustrates that having a cleaner environment will require the additional expenditure of energy and make the energy which we use more expensive.

B. Particulates

Particulates are primarily mineral ash, plus 0.5 to 5 per cent unburned fuel. The effects of particulate air pollution on health relate to the respiratory system. The damage may be due to the particulate itself or to the gases, like sulfur dioxide, which are carried on the particles. Here again, it is difficult to separate the effects of particulates from the effects of other known pollutants in the air. The particulate load in the air was proportional to the sulfur dioxide concentrations in most of the studies cited in Table 8.

In one system for removing particulates, hot flue gas is passed through a dust removal system as it leaves the boiler. This dust removal system, a combination electrostatic precipitator and mechanical dust remover, traps more than 99 per cent of the particulates in the flue gas before it is released to the atmosphere. The ash, often referred to as fly ash, can then be collected and transported to a disposal site.

C. Oxides of Nitrogen

This class of pollutant includes four different oxides, but most studies have been conducted on nitrogen dioxide (NO_2). During combustion, the nitrogen in air (79 per cent by volume) combines with oxygen to form nitric oxide. Although the amount of sulfur oxides released by a plant can be readily calculated, the concentration of oxides of nitrogen depends on the temperature of the furnace, the gas-cooling rate, the amount of excess air in the furnace and the method of firing. The concentration is thus difficult to calculate.

Nitrogen dioxide was significantly correlated to increases in respiratory disease when mean daily concentrations between 0.062 and 0.109 ppm were recorded in Chattanooga, Tennessee. Nitrogen oxides also play a significant part in the formation of smog.

Combustion modifications and stack-gas scrubbing offer possible control of pollution from oxides of nitrogen, but no process has yet been proven really effective. Some exploratory work has

been reported on simultaneous removel of the oxides of both nitrogen and sulfur.

D. Hydrocarbons and Carbon Monoxide

The production of hydrocarbons and carbon monoxide in power plants is currently overshadowed by their large-scale release from motor vehicles. Both of these pollutants can be reduced by more efficient fuel combustion, which converts them to relatively harmless carbon dioxide and water.

Hydrocarbons can react with nitrogen dioxide to become a major cause of smog. They have also been directly linked with an increase in the incidence of lung cancer.

Carbon monoxide primarily affects persons suffering from poor blood circulation, heart disease, anemia, asthma and various lung diseases.

E. Radiation from the Burning of Coal

All coal contains a small amount of naturally-occurring radiactive materials, such as potassium, uranium, thorium and their decay products. On the assumption that there are five parts per million of radioactive material is coal (0.01 pound per ton), then a 1,000-megawatt electrical generating plant, burning about 10,000 tons of coal per day, liberates about 100 pounds of radioactive materials. Most of this radioactive material is contained in the unburned particulate matter and ash, but some of it, such as radon gas, is released to the atmosphere. Thus, the average coal-burning plant will release more radioactivity into the environment than many modern nuclear power plants. These amounts of radioactivity are well below established radiation levels. No environmental damage by radiation has been detected near such plants, and so no effort has been made to date to control it.

F. Occupational Health Hazards from Mining Coal

An occupational health hazard frequently associated with the mining and handling of coal is a family of respiratory diseases commonly known as *"black lung."* Black lung, also known as miners' asthma, includes anthracosilicosis, coal miners' pneumoconiosis, chronic bronchitis and emphesema.

These diseases result from the inhalation of coal dust and its associated materials. The lung injury frequently occurring is a kind of fibrosis, which is an abnormal growth of lung tissue which displaces working lung structures. This injury severely restricts a person's ability to breathe and work. The added stress on the heart contributes to heart attacks.

The degree of impairment appears to depend on the type of coal mined and the smoking history of the victim. More significant impairment occurs in anthracite miners who smoke (about 40 per cent of the miners), as compared to a rate of nine per cent among nonsmoking bituminous miners.

Federal health and safety regulations regarding the control of dust and the medical surveillance of miners will have a beneficial effect on the incidence and severity of this disease.

3. How Safe is Safe Enough? Risk Versus Benefit

Following closely behind the tremendous technological growth in recent years in the advanced countries of the world have been social and economic benefits. But each advancement has also brought a cost or risk to the people. Both benefits and risks affect the quality of life of the population. Benefits include higher standards of living, better health care and more leisure time. Risks include urban problems, pollution, technological unemployment and the social stress and strain of modern life.

There is no precise definition of *"quality of life,"* but the identification of several major components is possible. First, the National Environmental Policy Act of 1969 is strong evidence that most citizens accept the conservation of the natural environment as important to the quality of life. Second, there is little doubt that relatively full employment and at least modest affluence for most individuals are important to the public. Third, goods and services dependent on electrical power play a large part in shaping the man-made environment, especially indoors, where most people spend the majority of their time. The typical citizen wants lighting, forced-circulation heating, radio, television, air conditioning and scores of other things requiring electricity.

We cannot demand more benefits from electric power without accepting the risks involved in its generation. We have seen some of these risks in this chapter-risks from radiation and risks from the fossil fuel pollutants. What must be done is for the public to assure that through proper regulation and engineering these risks are minimized, so that we can continue to enjoy the benefits of electricity.

SUPPLEMENTARY
MATERIALS
FOR
CHAPTER 7

Student Activity: Compute Your Own Radiation Dosage

We have seen that radiation is all about us and is part of our natural environment. In this exercise you will get an idea of the amount you are exposed to every year. The unit of radiation used here is the millirem.

	Common Source of Radiation	Your Annual Inventory (mrem/year)
WHERE YOU LIVE	Location: Cosmic radiation at sea level	40
	Add 1 for every 100 feet of elevation where you live	
	House construction: Wood 35 Concrete 50 Brick 75 Stone 70	
	Ground (U.S. Average)	56
WHAT YOU EAT DRINK AND BREATHE	Water and food (U.S. Average)	25
	Air (U.S. Average)	5
HOW YOU LIVE	Jet Airplanes: Number of 6000-mile flights x 4	
	Radium Dial Wrist Watch: Add 2	
	Television Viewing: Black and white: Number of hours per day x 1 Color: Number of hours per day x 2	
	X-ray Diagnosis and Treatment Limb x-ray: 420 Chest x-ray: 150 Stomach x-ray: 350 Colon x-ray: 450 Head x-ray: 50 Spinal x-ray: 250 Gastrointestinal tract x-ray: 2000 Dental x-ray: 20	
HOW CLOSE YOU LIVE TO A NUCLEAR PLANT	At Site Boundary: Number of hours per day x .2	
	One Mile Away: Number of hours per day x 0.02	
	Five Miles Away: Number of hours per day x 0.002	
	TOTAL	

Compare your dose to the U.S. Average of 200 mrem/year

Courtesy of San Diego Section
American Nuclear Society

A COMPARISON OF PUBLIC HEALTH RISKS: NUCLEAR VS. OIL-FIRED POWER PLANTS

C. Starr, M. A. Greenfield, and D. H. Hausknecht, *Nuclear News*, October, 1972.

Unless there is a major breakthrough in the technology and production of gas (as by coal gasification), there are probably insufficient supplies of gas to meet the near-term requirements without substantial increases in cost and unreliability of supply. Consequently, this analysis will be restricted to the comparative public health aspects of oil-fired and nuclear power plants and their associated activities of a typical urban setting. Operations of these plants upon conditions up to the present federal regulatory limits are estimated in this example to cause 60 times more respiratory deaths due to fossil fuel pollution than cancer deaths due to nuclear plant effluents. In normal practice, neither plant would be expected to expose the public to these limits, primarily because the routine effluents must be reduced below regulatory levels to meet a variety of conditions, and would thus be expected to be substantially less (by a factor of 10 or more) under average circumstances.

In both types of plants, public risks of continuous operation at regulatory limits are in the range of those due to other activities of man which have general societal acceptance. They are in the *"low"* part of this socially acceptable range for the oil-fired plant (60 deaths per year in a population of 10 million) and in the *"negligible"* part of the range for the nuclear plant (one death per year in a population of 10 million).

In both cases the integrated accident risk (averaged over time and all episodic events) is about 10^{-5} of the continuous exposure, for either the nuclear plant or the oil-fired plant. For the analyzed accident and *equal* probability of occurrence, the oil-fired plant has a substantially worse public health impact than the nuclear. For example, the one-in-a-million-years event for the oil-fired plant would lead to approximately 700 respiratory deaths in a population center of 10 million people; while the one-in-a-million-years event for the nuclear plant would result in approximately one death in the same population.

Table 1 summarizes the estimates of mortality for exposure of large populations to routine and accidental releases from both the nuclear and the oil-fired plant.

Pollutants and their effects

Information on steady-state releases to the atmosphere and to bodies of water is plentiful and well established for both fossil and nuclear fuel plants. Estimation of the frequency and magnitude of transient or accidental releases is less firm. In either case, the correlation of levels of pollutants and public health risks is primarily based on epidemiological studies. These characteristically represent small samples of the population with many variables that are not as controllable as in a laboratory study. Experiments on animals in controlled situations are numerous but extrapolations to humans do not generally rest on a proven model. Hence the correlation of public health risks with pollutant levels is on a much less firm basis than the correlation of pollutant emissions with plant size or type.

The central difficulty in making a comparison of the health effects of power plants that use different fuels arises from the problem of comparing pollutants with totally different effects on humans. For example, the somatic risks due to sulfur dioxide or radioactive iodine depend not just on the relative quantities involved but on the nature and severity of their effects on humans. Considering an oil-fired plant alone, the types of pollutants released may change significantly when different fuel supplies are used. For example, some available South American oil reserves yield an ash that is 60 per cent vanadium pentoxide, the health effects of which are not well known. For chronic low-level exposures of the public to any pollutant, the difficulty is compounded by more subtle synergistic effects, which have been less susceptible to quantitative measurements–such as the ubiquitous combined of sulfur oxides and particulates. In addition, the sensitivity of individuals varies widely.

In spite of the lack of precision in our knowledge, some perspective on the relative effects of important pollutants is possible. Figure 1 summarizes available data and uses known lethal levels as a benchmark for radiation, sulfur dioxide, and nitrogen dioxide. Because of the uncertain data for large population, the transition from medically perceivable effects to disability and lethality are indicated as three approximate ranges in Figure 1. Ranges of medically perceivable effects are about 10 times lower than lethal levels for radiation and sulfur dioxide and about 100 times lower for nitrogen dioxide. In this discussion *"medically perceivable"* is being used to mean *"in vivo"* clinical measurements on man, in contrast to studies on other forms of life. Included on the graph are the natural background levels which have been man's normal environment during most of his evolutionary history. For all three pollutants the natural background levels are about 100 times lower than the ranges of medically perceivable effects.

Included in Figure 1 are regulatory limits governing radiation, sulfur dioxide, and nitrogen oxide. Each of these limits applies to an average level to which large populations might be exposed on a continuing basis. They are, however, not all

143

implemented in the same way. The limit for average radiation dose to large populations is complied with by continuous monitoring of reactor effluents. In the case of fossil fuel pollutants, measurements are usually conducted off-site and the ambient levels are usually the resultant of contributions from power plants and other sources–e.g., fuel combustion for other purposes such as industrial plants and transportation.

In examining the figure and noting that the AEC limit on reactor emission levels is the only regulation that is below background, it is enlightening to calculate the per cent above background permitted by the various regulations. The values are 1 per cent, 10,000 per cent, and 400 per cent for radiation, sulfur dioxide, and nitrogen dioxide, respectively. Much greater excursions above background levels are allowed for pollutants that are less well understood as to their medical implications. This is especially true with respect to the possible carcinogenic or genetic effects of sulfur dioxide and nitrogen dioxide when compared to the information on radiation.

In revising its regulations in June 1971, establishing 1 millirem as the maximum acceptable large population exposure, the AEC explicitly stated that no new biological evidence had been presented, but that the new regulations reflected a further implementation of the *"as low as practicable"* point of view. Similarly, the very low ambient concentration level required for nitrogen dioxide might also reflect a practicable limit. The high regulations for sulfur dioxide implies that abatement methods are not presently economically feasible. This suggests that federal regulations are not consistently or solely determined by the available medical data or public health criteria.

Cellular effects of pollutants

Chemical attack on DNA, the genetic material of living cells, [illegible] produce mutations–changes in the structure of DNA that are inherited by succeeding cell generations. When the DNA is in a germ cell, the mutation becomes part of our load of mutations; it may result in increased frequency of occurrence in children of [illegible] major afflictions as cystic fibrosis, sickle cell a[illegible]a, hemophilia, and phenylketonuria, or oc[illegible] of one of the innumerable minor genetic disabilities that are *"the differential cause of the death or failure to reproduce of between one-fifth and two-thirds of the persons who escape being killed before reproduction, or being prevented from reproducing, by other, purely extrinsic causes."* When the DNA is in the developing fetus, the mutation may result in fetal wastage on in one or another of the congenital birth defects that afflict some six to eight per cent of the newborn. When the DNA is in a somatic cell of a child or an adult, the mutation may result in the transformation of the normal cell to a malignant cell and thus induce a potentially lethal cancer.

One of the principal modes of action of ionizing radiations on living cells is through the production of free radicals in the water within the cell. These free radicals–chemical species with an odd number of electrons–are highly reactive and attack DNA at many sites. But radiations are not unique in their ability to initiate free radicals within cells. Ozone, for example, when dissolved in water, decomposes to form free radicals. The normal amount of ozone at sea level, 0.02 ppm, if entirely converted to free radicals in the body, would produce about 4,000 times more free radicals than are produced by the natural background radiation levels of about 0.1 rad per year.[2,3] Ozone contents of 0.02 to 0.2 ppm are not uncommon in the Los Angeles basin, and the *"alert level"* of ozone in smog in Los Angeles is 0.50 ppm. Not only ozone, but also oxygen, is converted in the body into free radicals by normal metabolic processes. Thus the action of radiation is not qualitatively different from that of other environmental agents, and the risk of increasing radiation levels by the operation of nuclear power stations must be weighed against the qualitatively similar risk of increasing the ozone and other pollutants in the atmosphere by the operation of fossil-fueled power plants.

At the molecular level, mutations can result from the reaction of a single molecule with a molecule of DNA. Therefore, single ionizations can produce mutations or activate latentviruses in living cells. Similarly, carcinogens (benzo(a)pyrene, for example, which is found in cigarette smoke and is produced in the burning of oil and other fossil fuels) can induce cancer when bound to DNA in ratios of one molecule or less of carcinogen to one molecule of DNA.[4] From this viewpoint the notion of a threshold, a level of radiation or ozone, or benzo(a)pyrene, or other of the innumerable carcinogens, below which there is absolutely no risk to the population, is illusory. Thus there is a potential hazard from the emissions of nuclear power stations-fission or fusion–or from conventional power stations–oil, coal, or gas. This is also true of every natural and manmade physical or chemical agent in the environment. The important question is, *"How great is the hazard associated with a given level of each emission?"*

A general statement that can be made about the magnitude of the hazards associated with environmental agents is that the hazards increase with the level of the agent and the duration of exposure of the population. A more specific statement must be based on detailed data about the action of each agent. Even closely related chemical agents, for example, when tested at equal concentrations on isolated mammalian cells, differ by several orders of magnitude in their ability to bind to DNA or cause mutations in the DNA.[5] Interactions among agents further complicate the picture. Radiation, for example, can increase the efficiency of oncogenic viruses in transforming normal mammalian cells to

malignant cells. This complexity increases greatly going from isolated cells to laboratory animals, and increases enormously in the human population. Therefore, to the extent possible, estimates of the magnitude of the risks associated with the exposure of human populations to various environmental agents must be based on data accumulated from observation of human populations that have been exposed to these agents.

Respiratory effects

The effluents of fossil-fueled plants are comprised of a wide variety of materials including sulfur dioxide, nitrogen dioxide, hydrocarbons, carbon monoxide, heavy metals, particulate matter, radioactive radon and daughter products. Some of these substances take part in photochemical reactions leading to other species of concern–e.g., ozone.

From this variety of materials there is a spectrum of physiological effects. Deleterious effects on the respiratory system caused by sulfur dioxide and nitrogen dioxide acting in concert with suspended particulate matter are generally assumed to be the primary areas of public health concern. This assumption will be adopted for this study only because more quantitative health effects data are available for these materials. In particular, for chronic exposure of populations to low levels of episodic exposure to high levels of sulfur dioxide and particulate matter, an estimate of the correlation of mortality risk can be made from available data. Nevertheless, there is an additional unquantified risk from the other components of fossil fuel emissions.

Ranges of concentrations of sulfur dioxide and exposure times for significant health effects and mortality rates in excess of normal expectation are summarized in Figure 2. Particulates are not taken into account in this figure, but they must be present for sulfur dioxide to be effective as indicated.

Detailed analytic studies of several types of populations in Chicago indicate a significant incremental point for the occurrence of increased death rates, increased symptoms in bronchitis and increased occurrence of respiratory infections. This point occurs between sulfur dioxide levels of 0.19 ppm and 0.29 ppm (12-hour average), associated with the other usual urban pollutants. Considering the federal 24-hour standard (0.14 ppm), these data indicate an inadequate margin of safety for the populations studies. Indeed, these investigators, extrapolating mortality figures, suggest that for some segments of the population (susceptibles) no threshold for health effects or mortality effects can safely be assumed.

Study of pulmonary function measurements in healthy human subjects indicates a significant effect on airway resistance and mid expiratory flow rates after 15-minute challenges with sulfur dioxide at 0.5 ppm, when administered with distilled water or saline aerosols. Heightening of this physiologic response, persistence of it, and provocation of attacks might well be expected in susceptibles such as asthmatics, severe bronchitis, or individuals with genetic susceptibility to respiratory disease.

Air concentration data reported only from locations remote from major point sources of sulfur dioxide and particulate effluents may significantly underestimate the level of challenge experienced by a general population in the immediate downwind catchment. In a general population up to 10 to 20 per cent may be expected to exhibit more lung functional changes or more episodes of respiratory disease symptoms on experiencing intermittent high-level pollution episodes (SO_2 approaching 0.5 ppm) than their average normal neighbors. In the downwind conurbation of the Los Angeles power generating belt, a population of upwards of 530,000 individuals would thus offer some 53,000 susceptibles whose illness responses to as few as four high sulfur dioxide episodes per year could cost them between $10 million and $20 million.

No standards are published for SO_3 or its hydrated form despite the potential for oxidation of sulfur dioxide to this form in the humidified air of coastal population centers. This substance is of concern because of its magnified (three-to-fourfold) effect on respiratory mechanics when compared with sulfur dioxide.

Risks from steady-state effluents

For a given basin with a fixed volume of the question of relative public health risk attributed to various types of power plants can be posed as follows: How many plants of a given type can be operated without reaching a pollutant concentration level having public health significance? Table II presents quantitative answers to this question.

A simplified approach has been taken to arrive at the numbers shown in the table. This approach was meant to eliminate as many complexities as possible, while maintaining a valid comparison of different types of power plants. For this purpose, meteorological considerations have been precluded by assuming the pollutants are released into a large mixing chamber. Each power plant operates at full capacity for one day, and no natural removal mechanisms such as washout by rain or impaction on obstacles have been allowed to deplete the gaseous effluents from the plants. Although inclusion of these mechanisms might be expected to permit operation of more plants, they are irrelevant for the purposes of this comparison. Many more hazardous meteorological conditions can be postulated than the one-day ventilation rate used here. In the table *"tolerable"* is used to mean the maximum number of 1,000 MWe plants that could operate for one day without exceeding an average concentration in the air basin volume corresponding to legislated limits. The limits used were:

145

Air Quality Standards and Regulations for Radioactive Effluent

SO_2 (24-hour average, federal)		0.14 ppm
NO_2 (1-hour average, State of California)		0.225 ppm
Radioactivity	(federal) 2×10^{-19}	Ci/cm^3

The assumption made here is that these legislated limits are related to prevention of health effects. As mentioned earlier, there is in fact a very large (orders of magnitude) safety factor built into the concentration limit for radioactive releases. In contrast, the margin between health effects and air quality standards is quite narrow, especially for SO_2. This can readily be seen by referring back to Figure 1. As pointed out earlier, there is sufficient evidence to connect a substantial cost with increased illness responses in an area subjected to as few as four high sulfur dioxide episodes per year in a setting such as the Los Angeles basin.

This comparison is based on a different approach than the continuous exposure column of Table 1. In the table the public health risks associated with the exposure of large populations to regulated limits is compared. In Table II the degree to which plants contribute towards using up the regulated limit is compared.

Meterological stagnation of several days duration is not an uncommon event in several areas of California. It is an historical fact that the AQS are exceeded regularly in some areas and that these occurrences coincide with meteorological stagnation. Increased mortality data for these occurrences is impossible to glean from the public health data, unless the meterological conditions are extremely adverse and of long duration resulting in substantial mortality and morbidity, such as the New York, Donorra, or London episodes. Nevertheless, lesser occurrences should not be assumed to have no impact.

Transient releases

If the public health risk of any technological system is to be determined, the frequency and consequences of accidents must be considered. For a well-established system, such as a fossil-fueled power plant, the frequency and magnitude of public-risk accidents can be estimated from historical records where they are available. In the case of nuclear power plants, their history is short and their number is relatively small. Hence, more than their record is needed to estimate the frequency and magnitude of their releases.

A deductive approach for making this estimate for nuclear plants has been developed and applied to reactors for a number of years. It consists of determining how an accident can occur by assuming failure of one or more elements in the plant and the probability of such failure. Once the plant has been studied by analyzing all the *"credible"* paths leading to accidents, the question of other accidents that might occur but have not been thought of must be faced. It is assumed that the accidents that have been analyzed represent a sample of a complete spectrum of possible accidents and hence can be used to establish the entire spectrum.

This probabilistic approach to quantifying risk has not been the historical approach to power plant safety—either fossil-fueled or nuclear. Three basic approaches to safety analysis can be identified. The most common is the empirical (or inductive) study of actual performance history to estimate the level of risk of various events. The second is the judgmental (or intuitive) review by experienced professionals to determine if adequate design precautions have been taken. The third is the estimation of system risk as derived from the reliability of individual components and their interaction—a deductive process. Only the first (empirical) and the third (deductive) provide a quantitative result. In the absence of a substantial operative history, nuclear plants have typically been studies by the second (or judgmental) approach. However, in order to make a meaningful comparison between oil-fired and nuclear plants, this report uses the third (deductive) method based on recent studies.

An illustration of the outcome of this approach is presented in Figure 3 for a 1,000 MWe pressurized water reactor (as studied by Otway and Erdmann). The validity of such an accident sequence analysis depends on reliability of the plant safety devices, their ability to function in sequence as expected, and on the inherent dynamic characteristics of the plant type. Because of the very low probability of large releases, the over-all public health risk calculation is not sensitive to the accuracy of the accident sequence analysis. The study presented in Figure 3 should be representative of a modern PWR plant and has therefore been used in this report. A liquid-metal-cooled fast breeder reactor was analyzed in an analogous manner as part of the present study, and the over-all risks due to accidents was found to be not significantly different than those from the PWR.

[illegible] maximum-consequence accidents for both the PWR and the LMFBR are consistent with a frequently cited early study of catastrophic reactor accidents. In the sequel it will be seen that the mortality risks from a nuclear plant are no worse than for a [illegible] fossil-fueled plant.

[illegible] the amount of radioactive mate[illegible] public (in equivalant curies of iodine [illegible] small releases from the more frequent [illegible] large ones, from the low probability [illegible] The small circles represent analyzed accidents [illegible] the smooth curves are based. The two cu[illegible]sent a distinction in character of the accident [illegible] which results from a deficiency in the rea[illegible] cooling system or in the reactivity control system. Both are considered

together in some situations. Others may be explored in a specific plant study. In addition to the accidents forming these curves, a cluster of accidents of higher probability (10^{-2} to 10^{-4} per year) were also included. These were such things as fuel handling mishaps and are shown as a dotted extension in the figure.

For a 1,000-MWe oil-fired plant, there is an associated storage capacity of the order of 2 million barrels. Although some of this storage may not be on the plant site, it is never far removed. Conflagration of some fraction or all of these fuel supplies is a possibility and as such must be considered in estimating the over-all risks of oil-fired plants. As in the case of nuclear reactors, the public health risk due to accidents associated with an oil-fired plant is greater from the released pollutants than from the direct effects of an explosive fire. Hence, an estimate of the frequency of occurrence and the amount of oil burned is needed to assess the risk from released pollutants.

No data specifically for power plants has come to light, but the American Petroleum Institute (API) has tabulated data for fire losses occurring at various types of properties over a number of years. During the past five years (1966 through 1970), API has tabulated data that categorize the magnitudes of the fires into four size groups. After examination of the tabulations for these five years, two classes of properties were selected as being representative of the sizes and types of oil products associated with oil-fired power plants. They were bulk terminals and pipeline stations. These data, after conversion to quantities of oil lost in pounds, and with normalization to the unit of property-year, are presented in Figure 4.

From this graph, the probability of releasing quantities of sulfur dioxide, oxides of nitrogen, hydrocarbons, precursors of oxidants and heavy metals can be estimated. This was carried through only for SO_2 by assuming the values $3 and 331 pounds per barrel of oil containing 0.5 per cent by weight of sulfur. The pounds of SO_2 emitted with varying frequency are also given in the figure.

Figure 4 for an oil-fired plant is then the analogue of Figure 3 for the nuclear plant. They are presented together on a common probability scale in Figure 5. For the oil-fired plant the entire release-probability distribution falls within the regime of high-frequency, small-release accidents of nuclear plants. Another way of contrasting the two graphs is that the least probable, maximum release (a 2-million-barrel fire) of an oil-fired plant is more likely to occur than any of the releases from the nuclear plants, which could be considered more severe than a minor mishap.

Assuming the oil-fired plant and nuclear plant are located at the same site, atmospheric dispersion of the pollutants from an accident and fumigation of the surrounding population can be handled identically in either case. This comparison was based on a stable meteorological condition (Pasquill F category) with a wind velocity of 2 meters per second blowing constantly into a 30-degree sector.

In order to correlate mortality with prevailing pollutant concentrations, the following correlations were used:

1×10^{-6} per person per rem is the mortality risk from thyroid irradiation with no available data demonstrating a risk below 1 rem

30×10^{-6} mortality risk per person per rem for whole-body irradiation down to the background level of 100 mrem

4×10^{-5} $X(SPt)^{1/2}$ mortality risk (death due to respiratory cause only) per person exposed to S(ppm) of SO_2, P(gm/m^3) of particulate matter for 5 (years) down to 10^{-4} (ppm-(gm/m^3)-year) which is a routine urban exposure

Although these correlations, which are based on statistical analyses of epidemiological data, are far from proven physical laws, they are in keeping with the state of knowledge at present.

A comparison of the cumulative mortality risks with distance from the two types of plants is shown in Figure 6. These results suggest the accidental releases from the two types of plants are not substantially different in their over-all mortality effect during the life of the plants. The relatively greater likelihood of occurrences at an oil-fired plant is offset by the greater lethality but less likely radioactive releases from a nuclear plant.

Another important perspective to be gained from this analytic approach is that the occurrence of a large oil fire is a rare event in our conscious experience, but relatively commonplace when compared with significant reactor releases. In other words, events that occur with frequencies of less than once in a million years approach the meaning of *"never"* in everyday language.

The public reaction (or social trauma) that might result from the very rarest and most extreme accidents is difficult to gauge, but is not likely to be large in either case. In the case of an oil-fired plant, the combination of the most adverse meteorological conditions and largest fire might be expected once in a million years and could cause about 70 respiratory deaths per million population (about one-half of the normal annual rate). Because the incremental mortality (and morbidity) would occur in a short time interval, the impact of such an accident probably would be publicly noticeable.

In the case of an extreme nuclear accident, a probability can be assigned to a maximum impact

of about 500 cancer deaths per million population (about one-third of the normal annual cancer rate), estimated to occur less than once in 100 million years. Because most of the fatalities resulting from such radiation exposure would be spread over very many years, the public impact of such a nuclear plant accident is unlikely to have much general visibility. It would be possible to measure the full impact only by maintaining lifetime statistics of the exposed population.

Consequences of accidents are graphed with their corresponding probabilities in Figure 7. For the oil-fired plant, there is not enough known to estimate the worst hypothetical case. It is generally known that respiratory ailments can be increased by the synergistic interaction of various *"insults"* to the system. An extraordinarily rare hypothetical combination of a variety of airborne pollutants, respiratory epidemics (such as influenza), and chronic irritants (including asthmogenic allergens) might substantially increase regional fatalities. It is quite possible that because of the focusing of all these impacts on the respiratory system, the oil-fired plant maximum hypothetical accident could cause as many fatalities as the maximum hypothetical nuclear plant accident—with a probability of occurrence equally low. Also omitted from this estimate is the synergistic effect of other polluting effluents from the oil-fired plant—such as nitrogen oxides, heavy metals (lead, mercury, cadmium, nickel), radioactive elements, carbon monoxide, and carcinogenic compounds. Nitrogen oxides, in particular, may be a serious hazard, but little is known about their quantitative health effects as yet. Insufficient data on respiratory effects are available to evaluate the full impact of all the multiple synergistic combinations that might possibly occur.

Transportation of nuclear fuels

For a thermal power plant to operate on a continuing basis, fuel transportation is a necessary adjunct. For oil- or natural-gas-fueled plants this takes the form of pipelines, while for nuclear plants, trucks, rail cars, or barges are used. Public health risks from pipeline rupture accompanied by fuel burning exist but are not analyzed in this report. Because of public concern regarding radiation, the shipment of spent nuclear fuel elements has been examined. Additionally, the location of a reprocessing plant for nuclear fuel might be contingent on the degree of risk involved in transportation.

There has never been a recorded major accident that has killed, injured or overexposed people as a result of the transportation of radioactive fuel materials. The accumulated experience of such shipping is relatively small. However, accident rates can be estimated if the assumption is made that spent fuel shipments will suffer at the same rate as shipments of explosives and other dangerous materials. This assumption is supported by the fact that the standards in the U.S. (10CFR71, 49CFR171-178 and 46CFR146) place primary reliance for safety on packaging rather than mode of transportation of radioactive material. Hence, commercial carriers can be used. A survey of transportation accident data suggests a reasonable expectation to be 2.5 accidents per million vehicle miles for either rail or truck modes of transportation.

Because of the stringent requirements on spent fuel packaging, most accidents will not result in a release of radioactive material to the environment. The AEC operational experience from 1949 through 1967 has been used to estimate that in 2.5 per cent of the accidents, some fraction of the radioactive material being transported will be released to the environment. In order to estimate the distances to be covered, three potential reprocessing plant locations were considered. They included both an optimally located plant in the state (California) and an inexpediently (with respect to distance) located plant out of the state. The average distance from power plants in the state to the latter location was 2.4 times greater than the former.

Choosing the greatest average transportation distance and assuming every accident which leads to a radioactive release to the environment is a maximum credible accident (all fission gases in the shipping container plenum are released), a conservative projection can be made for the year 2000. The number of serious injuries in the state was found to be less than one in 1,000 years for the projected fuel logistics requirements. This conclusion was based on an average population density and would change in proportion to the actual population density on any chosen route. Two conclusions are derived from this result:

.Transportation of spent nuclear fuel does not measurably add to the public health risks of the power plant.

.Siting of nuclear power plants does not depend on the location of reprocessing plants because the two can be decoupled with little or no change in the total risk.

These conclusions are not meant to imply that the public health risks associated with the siting of facilities for either chemical reprocessing of fuel or waste disposal can be neglected. However, it is expected that future AEC regulations governing releases from any new chemical reprocessing plant or waste disposal facility will be as stringent as those presently applicable to nuclear power plants.

How safe is safe enough?

In comparing the public risk from fossil-fueled and nuclear power stations, it is important to understand what is really meant by risk. The public is confused and misled when leaders and experts make statements with qualitative comparisons such as *"safe"* versus *"unsafe"*, *"credible"* versus

"incredible," *"cautious"* versus *"incautious,"* *"reasonable"* versus *"unreasonable"*–in reference to the risk of injury to the individual. These terms imply absolute boundaries of risk that do not really exist.

Therefore we must ask the question, *"How safe is safe enough?"* and provide quantitative guidelines which will make possible a rational approach towards defining acceptable levels of public risk.

Risk in this study has been used to mean the quantitative probability of injury–i.e., the predictable chance of some specified personal damage occurring in a specified time interval. Public risk is the averaging of individual risks over a large population. The injuries involved may vary from minor annoyances and discomfort (not enough to prevent normal activities), to disabilities that cause reduction in normal productivity (morbidity rate) to loss of life (mortality rate). Because of the dramatically visible nature of death, public risk is usually conceived of in terms of fatalities or mortality rate. However, the importance of the public welfare of the less visible morbidity rate (disabilities) may be much greater in terms of humanistic, economic, and social values. For example, the annual number of deaths in the United States due to automobile accidents is often quoted with alarm, but one rarely hears of the disabling injuries which number hundreds of times as many, and may have an equal or greater social importance.

The same situation has existed in environmental pollution issues. Most public discussions relate almost exclusively to short-term episodes of extreme pollution–either real or projected. In fact, most professional concern has been focused on these infrequent extreme situations. However, from the viewpoint of social costs or of the public health burden, it is important to consider long-term effects of low pollution levels as well as the short-term effects of the more visible episodic high levels-and, in addition, morbidity as well as mortality.

Averaged over a large population and a long time period (man's lifetime), there exist two continuous ranges of events. The first of these is the range of accident magnitudes or public exposure. The second of these is the end result of such exposures, ranging from discomfort to disability to death. It is interesting that an approximate relationship of frequency varying inversely with magnitude appears to apply to most public exposures to risk, (either man-made or natural)[7] and very probably to the pollution effects from both fossil-fueled and nuclear power plants. A statistical and theoretical basis for these relationships can be suggested, but the inadequacy of epidemiological data makes it difficult to verify its generality.

Because mortality data is most readily available, the foregoing quantitative power plant comparisons have dealt with the public risk of fatalities, recognizing that this is only indicative of the total risk, and that the social cost should include a multiplier that accounts for associated disabilities. Similarly, a usually neglected but important factor from low-level exposures is the time required for physiologic impairment to develop. If the time for the effects of exposure to develop is long, then only the younger members of the population may have their later life affected (as with smoking). These factors of degree of morbidity, age, and duration of exposure, changing social value as a function of age, and other similar public health parameters theoretically should be included in any complete study. Unfortunately, basic physiologic and technical data in the air pollution field are generally so uncertain quantitatively that such a refined analysis is only occasionally justified. *"Order of magnitude"* answers are usually all that can be expected in such areas of public risk.

A study of the public acceptance or mortality risk arising from involuntary exposure to socio-technical systems such as motor vehicle transportation indicates that our society has accepted a range of risk exposures as a normal aspect of our life.[7] Figure 8 shows the relation between the per capita benefits of a system and the acceptable risk as expressed in deaths per exposure year (i.e., time of exposure in units of a year). The highest level of acceptable risks that may be regarded as a reference level is determined by the normal U.S. death rate from disease (about one death per year per 100 people). The lowest level for reference is set by the risk of death from natural events–lightning, floods, earthquakes, insect and snake bites, etc. (1 death per year per million people).

In between these two bounds, the public is apparently willing to accept *"involuntary"* exposures-i.e., risks imposed by societal systems and not easily modified by the individual–in relation to the benefits derived from the operations of such societal systems. Although an individual often *"voluntarily"* exposes himself to much higher risks, the public nevertheless expects the regulatory institutions of our society to maintain a consistently cautious approach to its hazards. The principal point of the relationship in Figure 8 is that society does pragmatically accept in existing systems a level of risk related to the benefits it derives.

In commonly familiar terms, an average involuntary risk may be considered *"excessive"* if it exceeds the incidence rate of disease, *"high"* if it approaches it, *"moderate"* if the risk is about 10-100 times less, *"low"* if it approaches the level of natural hazards, and *"negligible"* if it is below this. Events in these last two levels of risk have historically been treated as *"acts of God"* by the public generally-in recognition of their relatively minor impact on our societal welfare as compared to the effort required to avoid the risk.

Thus, any risk created by a new socio-technical system is acceptable *"safe enough"* if the risk level is below the curve of Figure 8. More accurately, when the increment of additional risk added by the new system is associated with an incremental benefit equal

to or greater than that indicated by the curve, the system is "*safe enough*." If, as is usually the case, a new system has a range of uncertainty in its risks, a design target may be set below the curve by an equivalent amount—possibly as much as a factor of 10 or 100.

The position of electric power plants in this benefit-risk relationship is shown in Figure 8. The risk calculation based on regulatory limits has been described earlier—with oil-fired plants setting the upper value and nuclear the lower value. As previously noted, actual risks may be very much less because such plants will operate at less than regulatory limits. The benefits of electricity includes an estimate of both the incremental contribution to industrial output and to other social needs. It is evident that both types of power plants are well within the acceptable risk range.

To summarize, death, disability, and discomfort have always been a normal part of life. Society has historically adjusted its acceptance of these so that changes in societal systems are associated with adequate benefits and also do not substantially or drastically alter the public's involuntary exposure to risk. None of this means that efforts to reduce the risk of death, disability and discomfort should not be made. However, in the application of our resources to reducing public risks, the economic principle of marginal utility should be used—i.e., the resources should be applied where they will do the most good. There is little point in spending effort on improving the safety of a system that is already in the category of "*negligible risk.*" The effort would be better applied, to the higher risk systems that will substantially influence our public health statistics.

The evident fact that the risk perspective of an individual may differ from that of a social sector creates a problem in a democratic political system. Rational decision-making on a societal level may thus require an intensive public education and public discussion of the issues and trade-offs. This is particularly difficult in emotion-laden areas, and perhaps especially so when death, disability and discomfort of human beings are involved.

References

1. H. J. Muller, "Our Load of Mutations," *American Journal of Human Genetics*, Vol. 2, pp. 111-176 (1950).
2. W. A. Prysor, "Free Radical Pathology," *Chemical and Engineering News*, June 7, 1971, pp. 34-51.
3. D. B. Menzel, "Toxicity of Ozone, Oxygen and Radiation," *Annual Review of Pharmacology*, pp. 379-394 (1970).
4. P. Brookes, "Quantitative Aspects of the Reaction of Some Carcinogens with Nucleic Acids and the Possible Significance of Such Reactions in the Process of Carcinogenesis," *Cancer Research*, Vol. 26, pp. 1,994-2,003 (1966).
5. F. Kao and T. T. Puch, "Genetics of Somatic Mammalian Cells XII: Mutagenesic by Carcinogenic Nitro Compoundi," *Journal of Cellular Physiology*, Vol. 78, pp. 139-144 (1971).
6. WASH-740, "Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants," *U.S. Atomic Energy Commission*, March 1957.
7. C. Starr, "Benefit-Cost Studies in Socio-Technical Systems," presented at the Colloquium of Benefit-Risk Relationships for Decision-Making Washington, D.C., April 26, 1971.

TABLE I

PUBLIC RISK COMPARISON

Plant Type	Expected Annual Averages (Deaths per 10 million population per 1,000-MWe plant per year)	
	Continuous Operation at Regulated Exposure Limits	Total Risk from Accidents
Nuclear reactor (cancer deaths)	1	Negligible (0.00006)
Oil-fired plant (respiratory deaths)	60	Negligible (0.0002)

TABLE II.

TOLERABLE NUMBERS OF POWER PLANTS AS IMPLIED BY CURRENT PRACTICES IN LOS ANGELES COUNTY*

Plant Type	Critical Pollutant	Tolerable Number of 1,000-MWe Plants (Exclusive of Pollutants from Other Sources)
Oil	SO_2	10
Natural gas	NO_2	23
Nuclear reactor (LWR)	Radioactive gases	160,000

*Based on the following assumptions:

1. Unspecified mixture of radioactive isotopes released from nuclear plant (Most restrictive assumption based on 1 mrem).
2. Compliance with 0.5 percent by weight sulfur content for oil.
3. Air volume of Los Angeles County was assumed to be 3,165 km^3 which implies a mean inversion height of 300 m.
4. Ventilation of this volume requires one day.
5. Effluent volume rate for 1,000-MWe reactor is taken as 0.5×10^6 cfm which is an estimated upper limit.

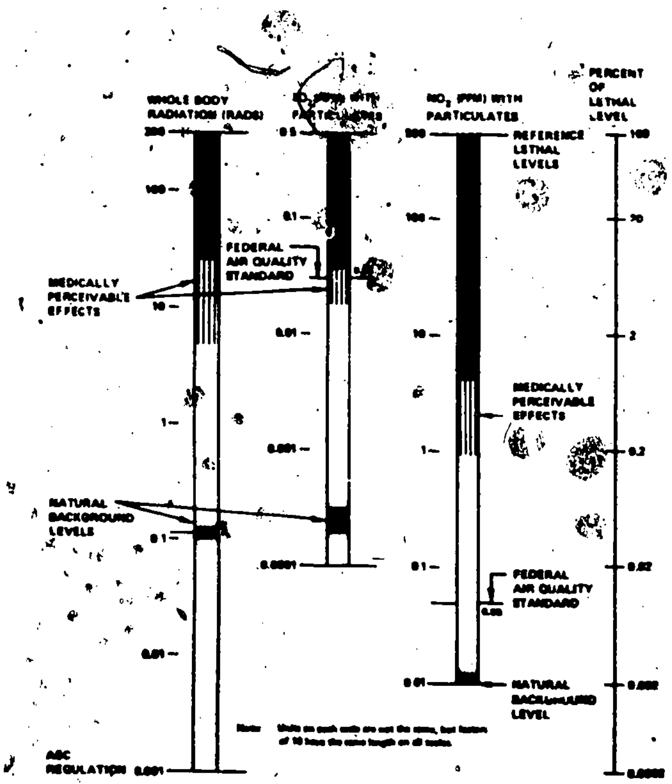


Fig. 1. Observed effects on physiological function of humans

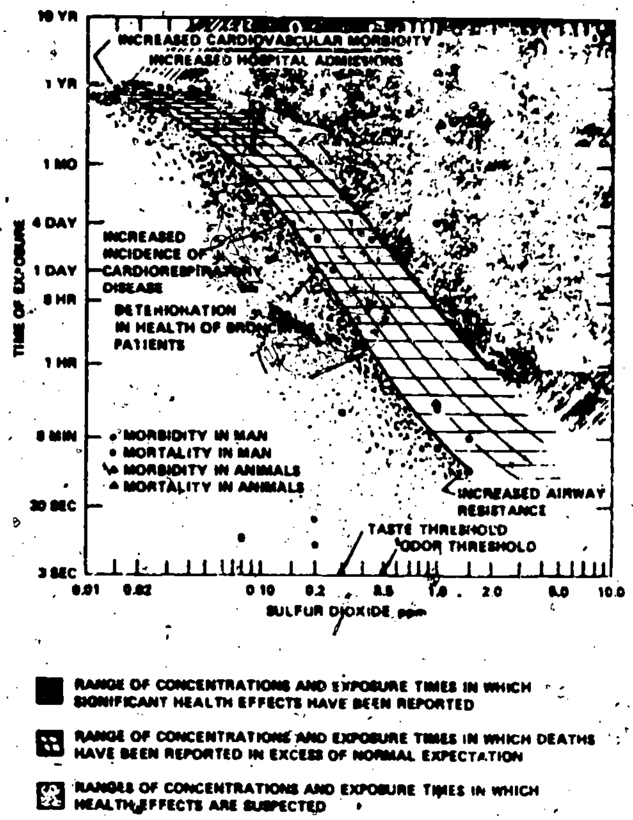


Fig. 2. Effects of sulfur dioxide pollution on health ("Air Quality Criteria for Sulfur Dioxides," a talk by Bernard E. Conley, chief, Air Quality Criteria, National Center for Air Pollution Control)

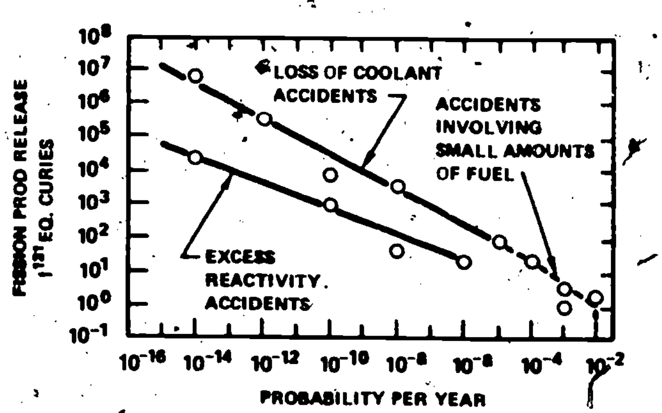


Fig. 3. Fission product release versus accident probability for a 1,000-MWe PWR. Taken from "Reactor Siting and Design from a Risk Viewpoint," H. J. Otway and R. C. Erdmann, Nuclear Engineering and Design, Vol. 13, pp. 365-376 (1970).

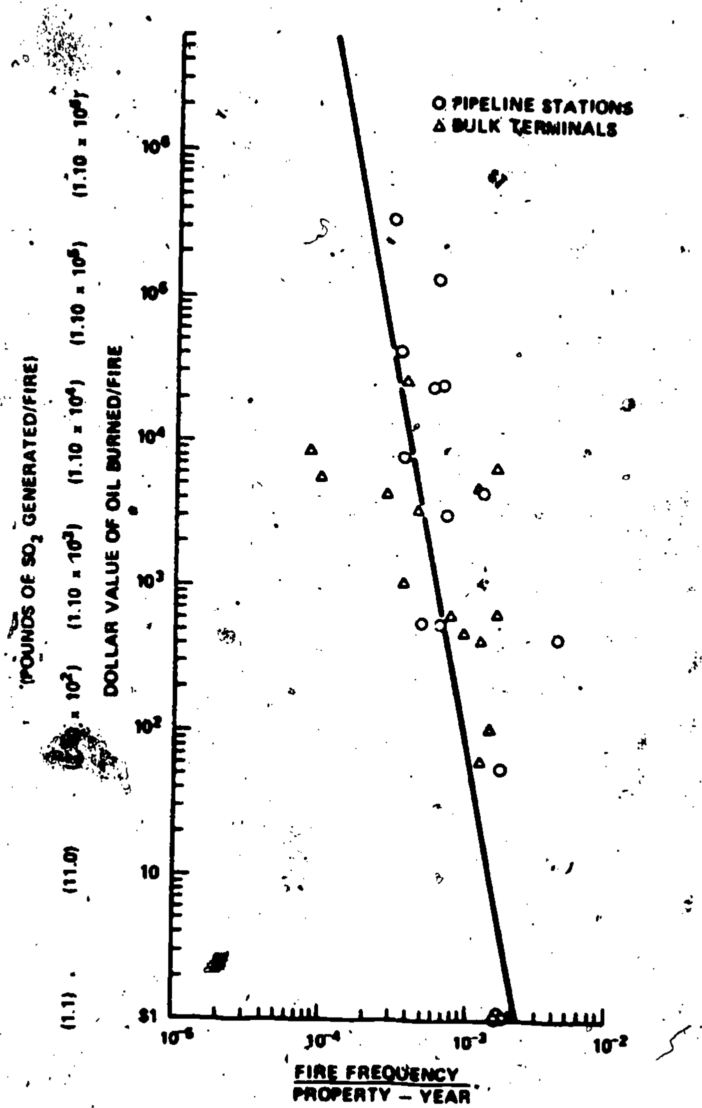


Fig. 4. Size of oil fire vs frequency of occurrence

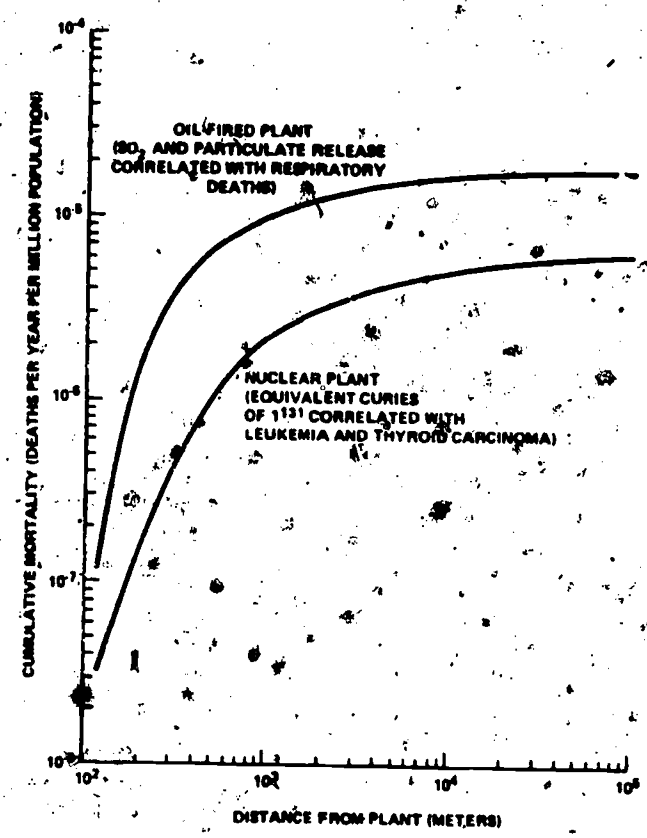


Fig. 6. Cumulative accident mortality with distance

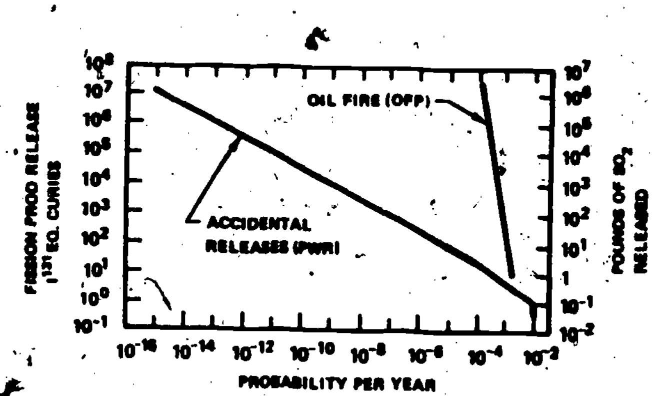
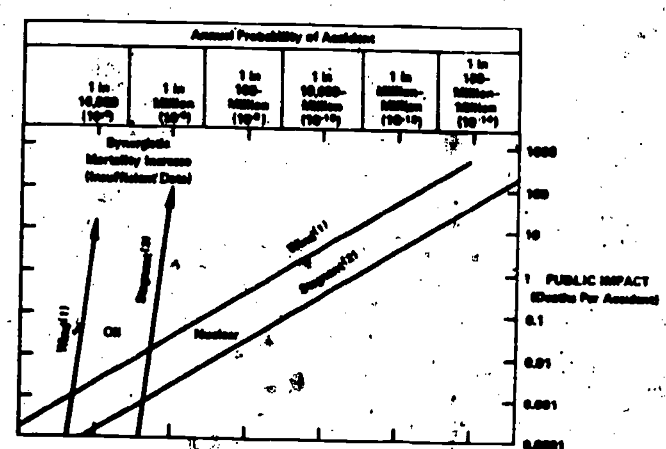


Fig. 5. Comparison of release magnitudes on a common probability scale



(1) The prevailing wind blows into a 30° sector at 2 meters per second under stable meteorological conditions (Pasquill F condition).
(2) The stagnant meteorological condition was assumed to prevail for 4 days with an inversion height of 300 meters.

Fig. 7. Comparison of public risk from individual accidents

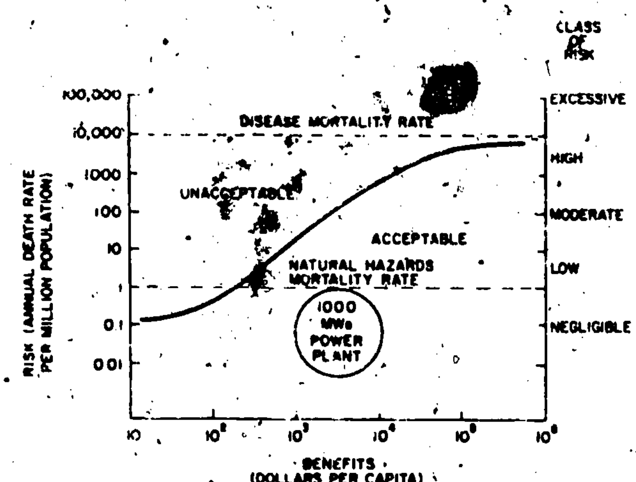


Fig. 8. Benefit-risk pattern for involuntary exposure

SOCIAL BENEFIT VERSUS TECHNOLOGICAL RISK

What is our society willing to pay for safety? by: Chauncey Starr, *Science*, Sept. 19, 1969.

The evolution of technical approaches to solving societal problems customarily involves consideration of the relationship between potential technical performance and the required investment of societal resources. Although such performance-versus-cost relationships are clearly useful for choosing between alternative solutions, they do not by themselves determine how much technology a society can justifiably purchase. This latter determination requires, additionally, knowledge of the relationship between social benefit and justified social cost. The two relationships may then be used jointly to determine the optimum investment of societal resources in a technological approach to a social need.

Technological analyses for disclosing the relationship between expected performance and monetary costs are a traditional part of all engineering planning and design. The inclusion in such studies of *all* societal costs (indirect as well as direct) is less customary, and obviously makes the analysis more difficult and less definitive. Analyses of social value as a function of technical performance are not only uncommon but are rarely quantitative. Yet we know that implicit in every nonarbitrary national decision on the use of technology is a trade-off of societal benefits and societal costs.

In this article, I offer an approach for establishing a quantitative measure of benefit relative to cost for an important element in our spectrum of social values–specifically, for accidental deaths arising from technological developments in public use. The analysis is based on two assumptions. The first is that historical national accident records are adequate for revealing consistent patterns of fatalities in the public use of technology. (That this may not always be so is evidenced by the paucity of data relating to the effects of environmental pollution.) The second assumption is that such historically revealed social preferences and costs are sufficiently enduring to permit their use for predictive purposes.

In the absence of economic or sociological theory which might give better results, this empirical approach provides some interesting insights into accepted social values relative to personal risk. Because this methodology is based on historical data, it does not serve to distinguish what is *"best"* for society from what is *"traditionally acceptable."*

Maximum Benefit at Minimum Cost

The broad societal benefits of advances in technology exceed the associated costs sufficiently to make technological growth inexorable. Shef's socieconomic study (1) has indicated that technological growth has been generally exponential in this century, doubling every 20 years in nations having advanced technology. Such technological growth has apparently stimulated a parallel growth in socioeconomic benefits and a slower associated growth in social costs.

The conventional socioeconomic benefits-health education income–are presumably indicative of an improvement in the *"quality of life."* The cost of this socioeconomic progress shows up in all the negative indicators of our society–urban and environmental problems, technolocigal unemployment, poor physical and mental health, and so on. If we understood quantitatively the casual relationships between specific technological developments and societal values, both positive and negative, we might deliberately guide and regulate technological developments so as to achieve maximum social benefit at minimum social cost. Unfortunately, we have not as yet developed such a predictive system analysis. As a result, our society historically has arrived at acceptable balances of technological benefit and social cost empirically–by trial, error, and subsequent corrective steps.

In advanced societies today, this historical empirical approach creates an increasingly critical situation, for two basic reasons. The first is the well-known difficulty in changing a technical subsystem of our society once it has been woven into the economic, political and cultural structures. For example, many of our environmental-pollution problems have known engineering solutions, but the problems of economic readjustment, political jurisdiction, and social behavior loom very large. It will take many decades to put into effect the technical solutions we know today. To give a specific illustration, the pollution of our water resources could be completely avoided by means of engineering systems now available, but public interest in making the economic and political adjustments needed for applying these techniques is very limited. It has been facetiously suggested that, as a means of motivating the public, every community and industry should be required to place its water intake downstream from its outfall.

In order to minimize these difficulties, it would be desirable to try out new developments in the smallest social groups that would permit adequate assessment. This is a common practice in market-testing a new product or in field-testing a new drug. In both these cases, however, the experiment is completely under the control of a single company or agency, and the test information can be fed back to the controlling group in a time that is short relative to the anticipated commercial lifetime of the product. This makes it possible to achieve essentially optimum use of the product in an acceptably short time. Unfortunately, this is rarely the case with new

technologies. Engineering developments involving new technology are likely to appear in many places simultaneously and to become deeply integrated into the systems of our society before their impact is evident or measurable.

This brings us to the second reason for the increasing severity of the problem of obtaining maximum benefits at minimum costs. It has often been stated that the time required from the conception of a technical idea to its first application in society has been drastically shortened by modern engineering organization and management. In fact, the history of technology does not support this conclusion. The bulk of the evidence indicates that the time from conception to first application (or demonstration) has been roughly unchanged by modern management, and depends chiefly on the complexity of the development.

However, what has been reduced substantially in the past century is the time from first use to widespread integration into our social system. The techniques for *societal diffusion* of a new technology and its subsequent exploitation are now highly developed.

Our ability to organize resources of money, men, and materials to focus on new technological programs has reduced the diffusion-exploitation time by roughly an order of magnitude in the past century.

Thus, we now face a general situation in which widespread use of a new technological development may occur before its social impact can be properly assessed, and before any empirical adjustment of the benefit-versus-cost relation is obvioulsy indicated.

It has been clear for some time that predictive technological assessments are a pressing societal need. However, even if such assessments become available, obtaining maximum social benefit at minimum cost also requires the establishment of a relative value system for the basic parameters in our objective of improved *"quality of life."* The empirical approach implicitly involved an intuitive societal balancing of such values. A predictive analytical approach will require an explicit scale of relative social values.

For example, if technological assessment of a new development predicts an increased per capita annual income of x per cent but also predicts an associated accident probability of y fatalities annually per million population, then how are these to be compared in their effect on the *"quality of life?"* Because the penalties or risks to the public arising from a new development can be reduced by applying constraints, there will usually be a functional relationship (or trade-off) between utility and risk, the x and y of our example.

There are many historical illustrations of such trade-off relationships that were empirically determined. For example, automobile and airplane safety have been continuously weighed by society against economic costs and operating performance. In these and other cases, the real trade-off process is actually one of dynamic adjustment, with the behavior of many portions of our social systems out of phase, due to the many separate *"time constants"* involved. Readily available historical data on accidents and health, for a variety of public activities, provide an enticing stepping-stone to quantitative evaluation of this particular type of social cost. The social benefits arising from some of these activities can be roughly determined. On the assumption that in such historical situations a socially acceptable and essentially optimum trade-off of values has been from disease, their inclusion is not significant.

Several major features of the benefit-risk relations are apparent, the most obvious being the difference by several orders of magnitude in society's willingness to accept *"voluntary"* and *"involuntary"* risk. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis. The risk of death in most sporting activities is surprisingly close to the risk of death from disease–almost as though, in sports, the individual's subconscious computer adjusted his courage and made him take risks associated with a fatality level equaling but not exceeding the statistical mortality due to involuntary exposure to disease. Perhaps this defines the demarcation between boldness and foolhardiness.

In Figure 2 the statistic for the Vietnam war is shown because it raises an interesting point. It is only slightly above the average for risk of death from disease. Assuming that some long-range societal benefit was anticipated from this war, we find that the related risk, as seen by society as a whole, is not substantially different from the average nonmilitary risk from disease. However, for individuals in the military-service age group (age 20 to 30), the risk of death in Vietnam is about ten times the normal mortality rate (death from accident or disease). Hence, the population as a whole and those directly exposed see this matter from different perspectives. The disease risk pertinent to the average age of the involved group probably would provide the basis for a more meaningful comparison than the risk pertinent to the national average age does. Use of the figure for the single group would complicate these simple comparisons, but that figure might be more significant as a yardstick.

The risks associated with general aviation, commercial aviation, and travel by motor vehicle deserve special comment. The latter originated as a *"voluntary"* sport, but in the past half-century the motor vehicle has become an essential utility. General aviation is still a highly voluntary activity. Commercial aviation is partly voluntary and partly essential and, additionally, is subject to government administration as a transportation utility.

Travel by motor vehicle has now reached a benefit-risk balance, as shown in Figure 3. It is interesting to note that the present risk level is only slightly below the basic level of risk from disease. In view of the high percentage of the population involved, this probably represents a true societal judgment on the acceptability of risk in relation to benefit. It also appears from Figure 3 that future reductions in the risk level will be slow in coming, even if the historical trend of improvement can be maintained (4).

Commerical aviation has barely approached a risk level comparable to that set by disease. The trend is similar to that for motor vehicles, as shown in Figure 4. However, the percentage of the population participating is now only 1/20 that for motor vehicles. Increased public participation in commercial aviation will undoubtedly increase the pressure to reduce the risk, because, for the general population, the benefits are much less than those associated with motor vehicles. Commercial aviation has not yet reached the point of optimum benefit-risk trade-off (5).

For general aviation the trends are similar, as shown in Figure 5. Here the risk levels are so high (20 times the risk for disease) that this activity must properly be considered to be in the category of adventuresome sport. However, the rate of risk is decreasing so rapidly that eventually the risk for general aviation may be little higher than that for commerical aviation. Since the percentage of the population involved is very small, it appears that the present average risk levels are acceptable to only a limited group (6).

The similarity of the trends in Figures 3-5 may be the basis for another hypothesis, as follows: the acceptable risk is inversely related to the number of people participating in an activity.

The product of the risk and the percentage of the population involved in each of the activities of Figures 3-5 are plotted in Figure 6. This graph represents the historical trend of total fatalities per hour of exposure of the population involved (7). The leveling off of motor-vehicle risk at about 100 fatalities per hour of exposure of the participating population may be significant. Because most of the U.S. population is involved, this rate of fatalities may have sufficient public visibility to set a level of social acceptability. It is interesting, and disconcerting, to note that the trend of fatalities in aviation, both commercial and general, is uniformly upward.

The hour-of-exposure unit was chosen because it was deemed more closely related to the individual's intuitive process in choosing an activity than a year of exposure would be, and gave substantially similar results. Another possible alternative, the risk per activity, involved a comparison of too many dissimilar units of measure; thus, in comparing the risk for various modes of transportation, one could use risk per hour, per mile, or per trip. As this study was directed toward exploring a methodology for determining social acceptance of risk, rather than the safest mode of transportation for a particular trip the simplest common unit–that of risk per exposure hour–was chosen.

The social benefit derived from each activity was converted into a dollar equivalent, as a measure of integrated value to the individual. This is perhaps the most uncertain aspect of the correlations because it reduced the *"quality-of-life"* benefits of an activity to an overly simplistic measure. Nevertheless, the correlations seemed useful, and no better measure was available. In the case of the *"voluntary"* activities, the amount of money spent on the activity by the average involved individual was assumed proportional to its benefit to him. In the case of the *"involuntary"* activities, the contribution of the activity to the individual's annual income (or the equivalent) was assumed proportional to its benefit. This assumption of roughly constant relationship between benefits and monies, for each class of activities, is clearly an approximation. However, because we are dealing in orders of magnitude, the distortions likely to be introduced by this approximation are relatively small.

In the case of transportation modes, the benefits were equated with the sum of the monetary cost to the passenger and the value of the time saved by that particular mode relative to a slower, competitive mode. Thus, airplanes were compared with automobiles, and automobiles were compared with public transportation or walking. Benefits of public transportation were equated with their cost. In all cases, the benefits were assessed on an annual dollar basis because this seemed to be most relevant to the individual's intuitive process. For example, most luxury sports require an investment and upkeep only partially dependent upon usage. The associated risks, of course, exist only during the hours of exposure.

Probably the use of electricity provides the best example of the analysis of an *"involuntary"* activity. In this case, the fatalities include those arising from electrocution, electrically caused fires, the operation of power plants and the mining of the required fossil fuel. The benefits were estimated from a United Nations study of the relationship between energy consumption and national income; the energy fraction associated with electric power was used. The contributions of the home use of electric power to our *"quality of life"* –more subtle than the contributions of electricity in industry–are omitted. The availability of refrigeration has certainly improved our national health and the quality of dining. The electric light has certainly provided great flexibility in patterns of living, and television is a positive element. Perhaps, however, the gross income measure used in the study is sufficient for present purposes.

Information on acceptance of *"voluntary"* risk

by individuals as a function of income benefits is not easily available, although we know that such a relationship must exist. Of particular interest, therefore, is the special case of miners exposed to high occupational risks. In Figure 1, the accident rate and the severity rate of mining injuries are plotted against the hourly wage (2, 3). The acceptance of the activity to the individual risk is an exponential function of the wage, and can be roughly approximated by a third-power relationship in this range. If this relationship has validity, it may mean that several *"quality of life"* parameters (perhaps health, living essentials, and recreation) are each partly influenced by any increase in available personal resources, and that thus the increased acceptance of risk is exponentially motivated. The extent to which this relationship is *"voluntary"* for the miners is not obvious, but the subject is interesting nevertheless.

Risk Comparisons

The results of the societal activities studied, both *"voluntary"* and *"involuntary,"* are assembled in Figure 2. (For details of the risk-benefit analysis, see the appendix). Also shown in Figure 2 is the third-power relationship between risk and benefit characteristic of Figure 1. For comparison, the average risk of death for accident and from disease is shown. Because the average number of fatalities from accidents is only about one-tenth the number achieved, we could say that any generalizations developed might then be used for predictive purposes. This approach could give a rough answer to the seemingly simple question *"How safe is safe enough?"*

The pertinence of this question to all of us, and particularly to governmental regulatory agencies, is obvious. Hopefully, a functional answer might provide a basis for establishing performance *"design objectives"* for the safety of the public.

Voluntary and Involuntary Activities

Societal activities fall into two general categories–those in which the individual participates on a *"voluntary"* basis and those in which the participation is *"involuntary,"* imposed by the society in which the individual lives. The process of empirical optimization of benefits and costs is fundamentally similar in the two cases–namely, a reversible exploration of available options–but the time required for empirical adjustments (the time constants of the system) and the criteria for optimization are quite different in the two situations.

In the case of *"voluntary"* activities, the individual uses his own value system to evaluate his experiences. Although his eventual trade-off may not be consciously or analytically determined, or based upon objective knowledge, it nevertheless is likely to represent, for that individual, a crude optimization appropriate to his value system. For example, an urban dweller may move to the suburbs because of a lower crime rate and better schools, at the cost of more time spent traveling on highways and a higher probability of accidents. If, subsequently, the traffic density increases, he may decide that the penalties are too great and move back to the city. Such an individual optimization process can be comparatively rapid (because the feedback of experience to the individual is rapid), so the statistical pattern for a large social group may be an important *"realtime"* indicator of societal trade-offs and values.

"Involuntary" activities differ in that the criteria and options are determined not by the individuals affected but by a controlling body. Such control may be in the hands of a government agency, a political entity, a leadership group, an assembly of authorities or *"opinion-makers,"* or a combination of such bodies. Because of the complexity of large societies, only the control group is likely to be fully aware of all the criteria and options involved in their decision process. Further, the time required for feedback of the experience that results from the controlling decisions is likely to be very long. The feedback of cumulative individual experiences into societal communication channels (usually political or economic) is a slow process, as is the process of altering the planning of a control group. We have many examples of such *"involuntary"* activities, war being perhaps the most extreme case of the operational separation of the decision-making group from those most affected. Thus, the real-time pattern of societal trade-offs on *"involuntary"* activities must be considered in terms of the particular dynamics of approach to an acceptable balance of social values and costs. The historical trends in such activities may therefore be more significant indicators of social acceptability than the existent trade-offs are.

In examining the historical benefit-risk relationships for *"involuntary"* activities, it is important to recognize the perturbing role of public psychological acceptance of risk arising from the influence of authorities or dogma. Because in this situation the decision-making is separated from the affected individual, society has generally clothed many of its controlling groups in an almost impenetrable mantle of authority and of imputed wisdom. The public generally assumes that the decision-making process is based on a rational analysis of social benefit and social risk. While it often is, we have all seen after-the-fact examples of irrationality. It is important to omit such *"witchdoctor"* situations in selecting examples of optimized *"involuntary"* activities, because in fact these situations typify only the initial stages of exploration of options.

Quantitative Correlations

With this description of the problem, and the associated caveats, we are in a position to discuss the quantitative correlations. For the sake of simplicity in this initial study, I have taken as a measure of the physical risk to the individual the fatalities

(deaths) associated with each activity. Although it might be useful to include all injuries (which are 100 to 1,000 times as numerous as deaths), the difficulty in obtaining data and the unequal significance of varying disabilities would introduce inconvenient complexity for this study. So the risk measure used here is the statistical probability of fatalities per hour of exposure of the individual to the activity considered.

Public Awareness

Finally, I attempted to relate these risk data to a crude measure of public awareness of the associated social benefits (see Fig. 7). The *"benefit awareness"* was arbitrarily defined as the product of the relative level of advertising, the square of the percentage of population involved in the activity, and the relative usefulness (or importance) of the activity to the individual (8). Perhaps these assumptions are too crude, but Figure 7 does support the reasonable position that advertising the benefits of an activity increases public acceptance of a greater level of risk. This, of course, could subtly produce a fictitious benefit-risk ration–as may be the case for smoking.

Atomic Power Plant Safety

I recognize the uncertainty inherent in the quantitative approach discussed here, but the trends and magnitudes may, nevertheless be of sufficient validity to warrant their use in determining national *"design objectives"* for technological activities. How would this be done?

Let us consider as an example the introduction of nuclear power plants as a principal source of electric power. This is an especially good example because the technology has been primarily nutured, guided and regulated by the government, with industry undertaking the engineering development and the diffusion into public use. The government specifically maintains responsibility for public safety. Further, the engineering of nuclear plants permits continuous reduction of the probability of accidents, at a substantial increase in cost. Thus, the trade-off of utility and potential risk can be made quantitative.

Moreover, in the case of the nuclear power plant the historical empirical approach to achieving an optimum benefit-risk trade-off is not pragmatically feasible. All such plants are now so safe that it may be 30 years or longer before meaningful risk experience will be accumulated. By that time, many plants of varied design will be in existence, and the empirical accident data may not be applicable to those being built. So a very real need exists now to establish *"design objectives"* on a predictive-performance basis.

Let us first arbitrarily assume that nuclear power plants should be as safe as coal-burning plants, so as not to increase public risk. Figure 2 indicates that the total risk to society for electric power is about 2×10^{-9} fatality per person per hour for exposure. Fossil fuel plants contribute about 1/5 of this risk, or about 4 deaths per million population per year. In a modern society, a million people may require a million kilowatts of power, and this is about the size of most new power stations. So, we now have a target risk limit of 4 deaths per year per million-kilowatt power station (9).

Technical studies of the consequences of hypothetical extreme (and unlikely) nuclear power plant catastrophies, which would disperse radioactivity into populated areas, have indicated that about 10 lethal cancers per million population might result (10). On this basis, we calculate that such a power plant might statistically have one such accident every 3 years and still meet the risk limit set. However, such a catastrophe would completely destroy a major portion of the nuclear section of the plant and either require complete dismantling or years of costly reconstruction. Because power companies expect plants to last about 30 years, the economic consequences of a catastrophe every few years would be completely unacceptable. In fact, the operating companies would not accept one such failure, on a statistical basis, during the normal lifetime of the plant.

It is likely that, in order to meet the economic performance requirements of the power companies, a catastrophe rate of less than 1 in about 100 plant-years would be needed. This would be a public risk of 10 deaths per 100 plant-years, or 0.1 death per year per million population. So the economic investment criteria of the nuclear plant user–the power company–would probably set a risk level 1/200 the present socially accepted risk associated with electric power, or 1/40 the present risk associated with coal-burning plants.

An obvious design question is this: Can a nuclear power plant be engineered with a predicted performance of less than 1 catastrophic failure in 100 plant-years of operation? I believe the answer is yes, but that is a subject for a different occasion. The principal point is that the issue of public safety can be focused on a tangible, quantitative, engineering design objective.

The example reveals a public safety consideration which may apply to many other activities: the economic requirement for the protection of major capital investments may often be a more demanding safety constraint than social acceptability.

Conclusion

The application of this approach to other areas of public responsibility is self-evident. It provides a useful methodology for answering the question *"How safe is safe enough?"* Further, although this study is only exploratory, it reveals several interesting points. (i) the indications are that the public is willing

to accept *"voluntary"* risks roughly 1,000 times greater than *"involuntary"* risks. (ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined). (iv) The social acceptance of risk is directly influenced by public awareness of the benefits of an activity, as determined by advertising, usefulness, and the number of people participating. (v) In a sample application of these criteria to atomic power plant safety, it appears that an engineering design objective determined by economic criteria would result in a design-target risk level very much lower than the present socially accepted risk for electric power plants.

Perhaps of greatest interest is the fact that this methodology for revealing existing social preferences and values may be a means of providing the insight on social benefit relative to cost that is so necessary for judicious national decisions on new technological developments.

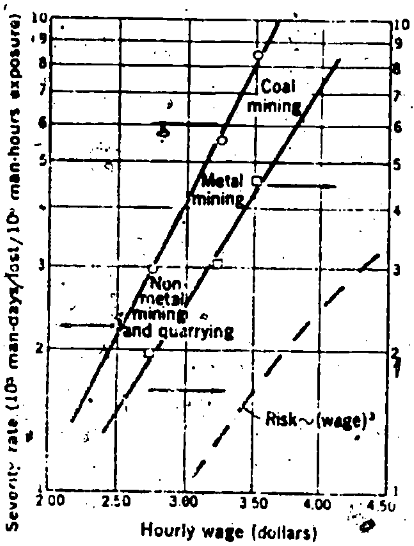


Fig. 1. Mining accident rates plotted relative to incentive.

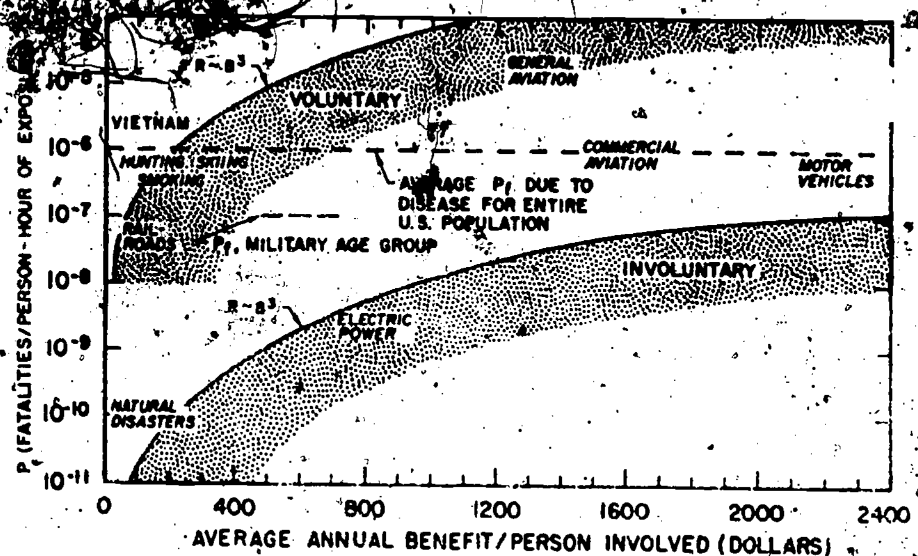
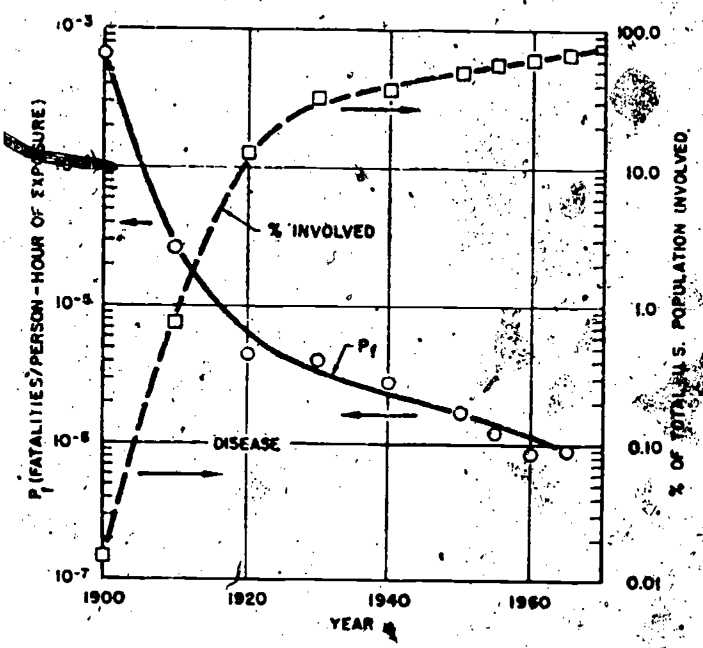


Fig. 2. Risk (R) plotted relative to benefit (B) for various kinds of voluntary and involuntary exposure.



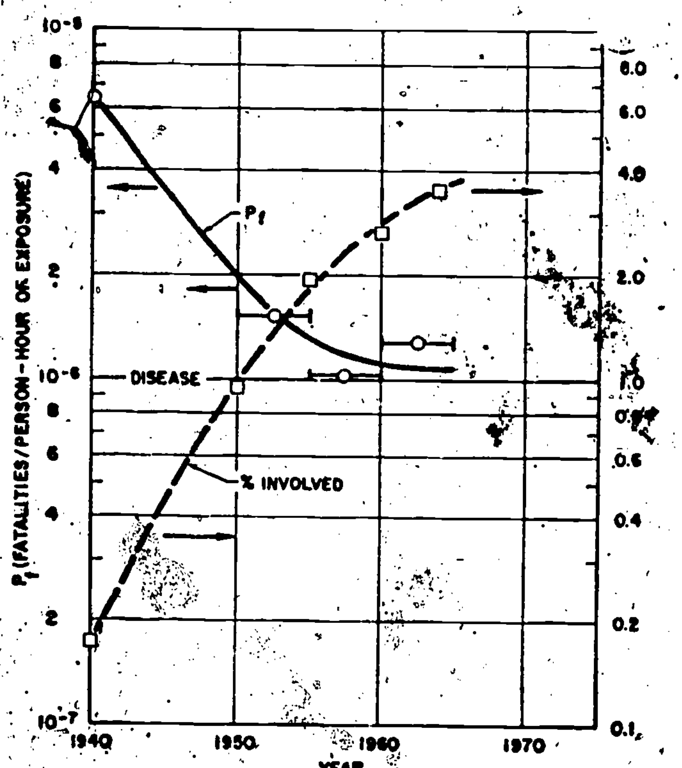
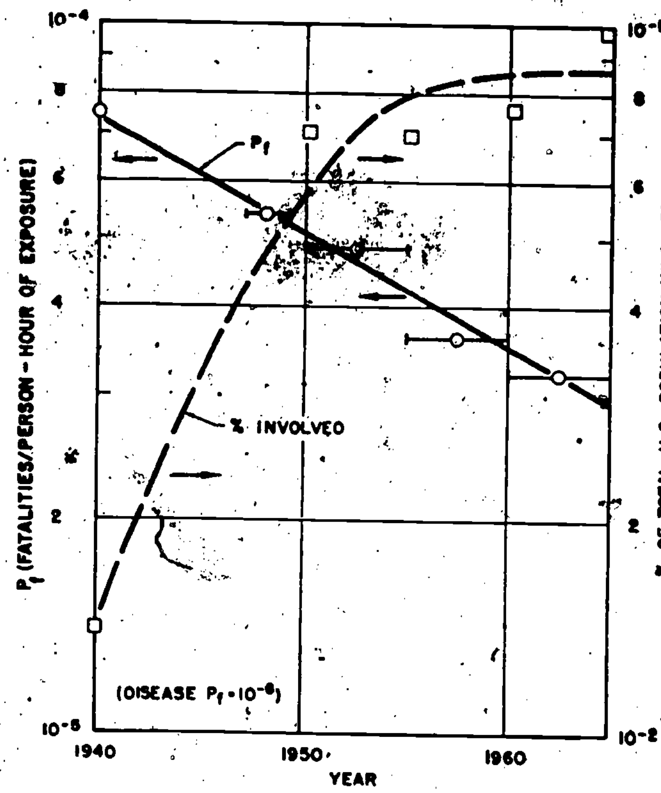


Fig. 3 (above). Risk and participation trends for motor vehicles.

Fig. 4 (right). Risk and participation trends for certified air carriers.



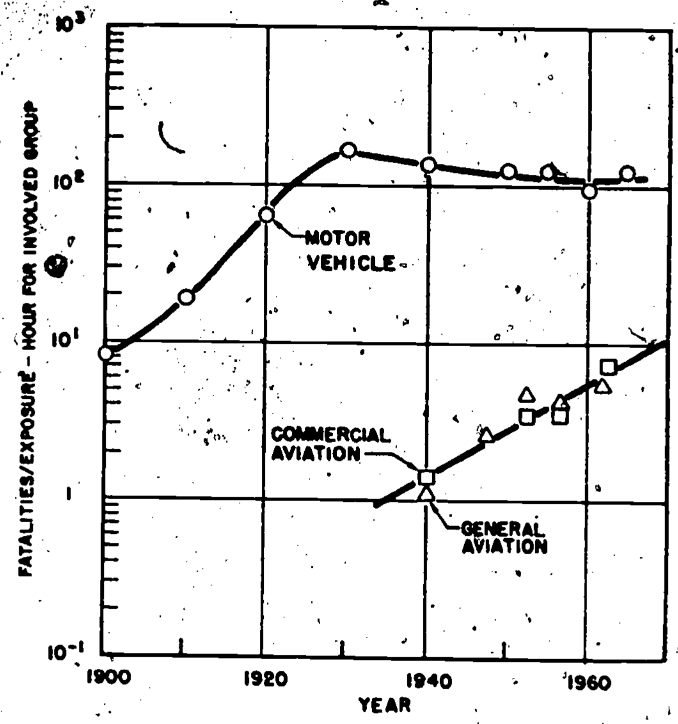


Fig. 5 (left). Risk and participation trends for general aviation. Fig. 6 (above). Group risk plotted relative to year.[9]

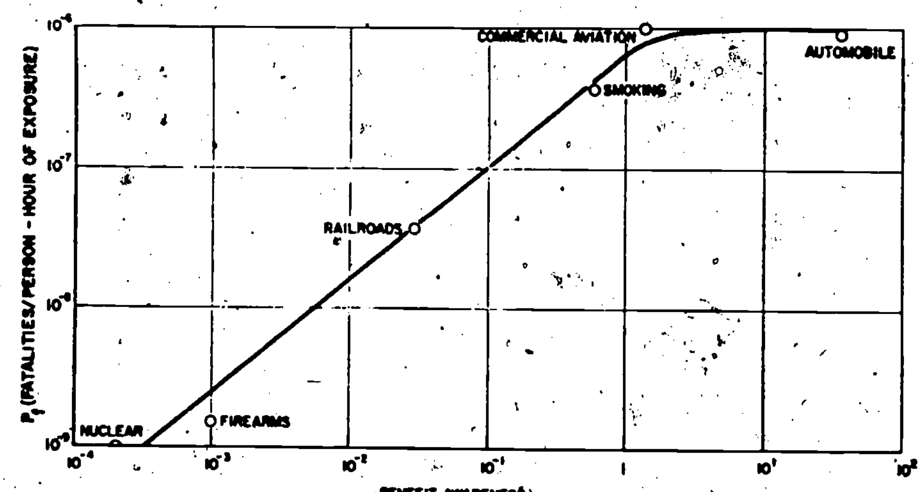


Fig. 7. Accepted risk plotted relative to benefit awareness (see text).

Details of Risk-Benefit Analysis

Motor-vehicle travel. The calculation of motor-vehicle fatalities per exposure hour per year is based on the number of registered cars, an assumed 1 1/2 persons per car, and an assumed 400 hours per year of average car use (data from 3 and 11). The figure for annual benefit for motor-vehicle travel is based on the sum of costs for gasoline, maintenance, insurance, and car pyaments and on the value of the time savings per person. It is assumed that use of an automobile allows a person to save 1 hour per working day and that a person's time is worth $5 per hour.

Travel by air route carrier. The estimate of passenger fatalities per passenger-hour of exposure for certified air route carriers is based on the annual number of passenger fatalities listed in the FAA Statistical Handbook of Aviation (see 12) and the number of passenger-hours per year. The latter number is estimated from the average number of seats per plane, the seat load factor, the number of revenue miles flown per year, and the average plane speed (data from 3). The benefit for travel by certified air route carrier is based on the average annual air fare per passenger-mile and on the value of the time saved as a result of air travel. The cost per passenger is estimated from the average rate per passenger-mile (data from 3), the revenue miles flown per year (data from 12), the annual number of passenger boardings for 1967 (1.32×10^6, according to the United Air Lines News Bureau), and the assumption of 12 boardings per passenger.

General aviation. The number of fatalities per passenger-hour for general aviation is a function of the number of annual fatalities, the number of plane hours flown per year, and the average number of passengers per plane (estimated from the ratio of fatalities to fatal crashes) (data from 12). It is assumed that in 1967 the cash outlay for initial expenditures and maintenance costs for general aviation was $\$1.5 \times 10^9$. The benefit is expressed in terms of annual cash outlay per person, and the estimate is based on the number of passenger-hours per year and the assumption that the average person flies 20 hours, or 4,000 miles, annually. The value of the time saved is based on the assumption that a person's time is worth $10 per hour and that he saves 60 hours per year through traveling the 4,000 miles by air instead of by automobile at 50 miles per hour.

Railroad travel. The estimate of railroad passenger fatalities per exposure hour per year is based on annual passenger fatalities and passenger-miles and an assumed average train speed of 50 miles per hour (data from 11). The passenger benefit for railroads is based on figures for revenue and passenger-miles for commuters and noncommuters given in *The Yearbook of Railroad Facts* (Association of American Railroads, 1968). It is assumed that the average commuter travels 20 miles per workday by rail and that the average noncommuter travels 1,000 miles per year by rail.

Skiing. The estimate for skiing fatalities per exposure hour is based on information obtained from the National Ski Patrol for the 1967-68 southern California ski season: 1 fatality, 17 days of skiing, 16,500 skiers per day, and 5 hours of skiing per skier per day. The estimate of benefit for skiing is based on the average number of days of skiing per year per person and the average cost of a typical ski trip (data from *"The Skier Market in Northeast North America,"* U.S. Dept. Commerce Publ. (1965)). In addition, it assumed that a skier spends an average of $25 per year on equipment.

Hunting. The estimate of the risk in hunting is based on an assumed value of 10 hours' exposure per hunting day, the annual number of hunting fatalities, the number of hunters, and the average number of hunting days per year (data from 11 and from *"National Survey of Fishing and Hunting,"* U.S. Fish Wildlife Serv. Publ. (1965).) The average annual expenditure per hunter was $82.54 in 1965 (data from 3).

Smoking. The estimate of the risk from smoking is based on the ratio for the mortality of smokers relative to nonsmokers, the rates of fatalities from heart disease and cancer for the general population, and the assumption that the risk is continuous (data from the *Summary of the Report of the Surgeon General's Advisory Committee on Smoking and Health* (Government Printing Office, Washington, D.C., 1964)). The annual intangible benefit to the cigarette smoker is calculated from the American Cancer Society's estimate that 30 per cent of the population smokes cigaretts, from the number of cigaretts smoked per year (see 3), and from the assumed retail cost of $0.015 per cigarette.

Vietnam. The estimate of the risk associated with the Vietnam war is based on the assumption that 500,000 men are exposed there annually to the risk of death and that the fatality rate is 10,000 men per year. The benefit for Vietnam is calculated on the assumption that the entire U.S. population benefits intangibly from the annual Vietnam expenditure of $\$30 \times 10^9$.

Electric power. The estimate of the risk associated with the use of electric power is based on the number of deaths from electric current: the number of deaths from fires caused by electricity; the number of deaths that occur in coal mining, weighted by the percentage of total coal production used to produce electricity; and the number of deaths attributable to air pollution from fossil fuel stations (data from 3 and 11 and from *Nuclear Safety* 5,325 (1964)). It is assumed that the entire U.S. population is exposed for 8,760 hours per year to the risk associated with electric power. The estimate for the benefit is based on the assumption that there is a direct correlation between per capita gross national product and commercial energy consumption for the nations of the world (data from Briggs, *Technology and Economic Development* (Knopf, New York, 1963)). It is further assumed that 35 per cent of the energy consumed in the U.S. is used to produce electricity.

Natural disasters. The risk associated with natural disasters was computed for U.S. floods (2.5×10^{-10} fatality per person-hour of exposure), tornadoes in the Mid-west (2.46×10^{-10} fatality), major U.S. storms (0.8×10^{-10} fatality), and California eathrquakes (1.9×10^{-10} fatality) (data from 11). The value for flood risk is based on the assumption that everyone in the U.S. is exposed to the danger 24 hours per day. No benefit figure was assigned in the case of natural disasters.

Disease and accidents. The average risk in the U.S. due to disease and accidents is computed from data given in *Vital Statistics of the U.S.* (Government Printing Office, Washington, D.C., 1967).

REFERENCES AND NOTES

A. L. Shef, *"Socio-economic attributes of our technological society,"* paper presented before the IEEE (Institute of Electrical and Electronics Engineers) Wescon Conference, Los Angeles, August 1968.

Minerals Yearbook (Government Printing Office, Washington, D.C., 1966).

U.S. Statistical Abstract (Government Printing Office, Washington, D.C., 1967).

The procedure outlined in the appendix was used in calculating the risk associated with motor-vehicle travel. In order to calculate exposure hours for various years, it was assumed that the average annual driving time per car increased linearly from 50 hours in 1900 to 400 hours in 1960 and thereafter. The percentage of people involved is based on the U.S. population, the number of registered cars, and the assumed value of 1.5 people per car.

The procedure outlined in the appendix was used in calculating the risk associated with, and the number of people who fly in, certified air route carriers for 1967. For a given year, the number of people who fly is estimated from the total number of passenger boardings and the assumption that the average passenger makes six round trips per year (data from 3).

The method of calculating risk for general aviation is outlined in the appendix. For a given year, the percentage of people involved is defined by the number of active aircraft (see 3); the number of people per plane, as defined by the ratio of fatalities to fatal crashes; and the population of the U.S.

Group risk per exposure hour for the involved group is defined as the number of fatalities per person-hour of exposure multiplied by the number of people who participate in the activity. The group population and the risk for motor vehicles, certified air route carriers, and general aviation can be obtained from Figs. 3-5.

In calculating *"benefit awareness"*, it is assumed that the public's awareness of an activity is a function of A, the amount of money spent on advertising; P, the number of people who take part in the activity; and U, the utility value of the activity to the person involved. A is based on the amount of money spent by a particular industry in advertising its product, normalized with respect to the food and food products industry, which is the leading advertiser in the U.S.

In comparing nuclear and fossil fuel power stations, the risks associated with the plant effluents and mining of the fuel should be included in each case. The fatalities associated with coal mining are about 1/4 the total attributable to fossil fuel plants. As the tonnage of uranium ore required for an equivalent nuclear plant is less than the coal tonnage by more than an order of magnitude, the nuclear plant problem primarily involves hazard from effluent.

This number is my estimate for maximum fatalities from an extreme catastrophe resulting from malfunction of a typical power reactor. For a methodology for making this calculation, see F. R. Farmer, *"Siting criteria--a new approach,"* paper presented at the International Atomic Energy Agency Symposium in Vienna, April 1967. Application of Farmer's method to a fast breeder power plant in a modern building gives a prediction of fatalities less than this assumed limit by one or two orders of magnitude.

Accident Facts, *Nat. Safety Counc. Publ. (1967).*

FAA Statistical Handbook of Aviation (Government Printing Office, Washington, D.C., 1965).

EARTH AND MINERAL SCIENCES
a publication of the Pennsylvania
State University (1974)

Air Pollution from Combustion Sources

Robert H. Essenhigh, Professor of Fuel Science
The Pennsylvania State University

Introduction

The majority of the man-made pollutants present in the air today originate from combustion sources. Table 1 illustrates this with a breakdown of data for 1966 and 1968 published recently by the National Air Pollution Control Administration. Five types of pollutants from five categories of sources are identified, and, of the five source types, the first four and a substantial fraction of the fifth originate in combustion chambers. The quantities listed account for more than 90 per cent of the problem. in the United States. The total weight of all emissions is, perhaps, the most startling figure of all. At 200 million tons or more, this is greater than one-third of the annual coal tonnage used as primary energy source, yet it is made up of components measured in the parts per million range. On the breakdown, certain category types of pollutants stand out–notably, carbon monoxide from transportation alone provides roughly 30 per cent of the total, mostly representing inefficiency of automobile engines; next is SO_X from stationary combustion sources-mostly power stations–at 10 to 11 per cent; hydrocarbons, i.e., unburned or part burned fuel from transportation, and carbon monoxide from miscellaneous sources tie for third place at about 8 per cent each. These four account for over 50 per cent of the total. The type totals amplify this in another way. Carbon monoxide from all sources provides about half the overall total; the remaining types each provide only about 8 to 16 per cent.

These figures underline the serious need for abatement; unfortunately, however, the necessary technology has not always been able to keep abreast of desirable legislative requirements. The purpose of this article is to point out some of the problems and difficulties of reducing pollution from combustion sources.

Health Hazards

Quantity alone, however, is not necessarily the sole criterion of significance in assessing the impact of pollutants. Their physiological effect is what is at issue, and this is generally a function of exposure and concentration. The longer the exposure time the lower the concentration that can be permitted if ill effects are to be avoided. This is illustrated in Figures 1 and 2 for sulfur dioxide and carbon monoxide, respectively.

Figure 1 shows the exposure time required to produce stated physiological effects at a given concentration. Points of interest in this graph are the taste and ~~odor~~ thresholds (0.3 and 0.5 p. p.m.). These would seem to be good danger signals. Evidently, half-a-day to a day's exposure at these levels should cause discomfort, and a week to a month's exposure could be expected to produce adverse effects even in a healthy man. For comparison, average concentrations in cities in the United States have been reported to range from near zero up to 0.16p.p.m., but significantly higher values are occasionally reported. In London in December 1952, sulfur dioxide concentrations averaged 0.57 p.p.m. over a four-day period, during which time 4000 *"excess"* deaths occurred.

Figure 2 provides somewhat similar information for the effects of carbon monoxide. Hemoglobin has a greater affinity for CO than it has for oxygen (by a factor of 200), and the toxic effects follow from the reduced oxygen circulated by the hemoglobin. The percentage of hemoglobin saturation by CO (which fortunately in reversible) is a good indicator of the toxicity level. While Figure 2 also shows the saturation level achieved in a given time at a given CO percentage, it gives no information on the longer term exposures. If this should last for a day or more, physical sickness becomes evident at 25 to 50 p.p.m., and for longer terms (a week or more) human performance is probably impaired at anything above 10 p.p.m. This is possibly achieved by one-pack-a-day cigarette smokers.

Comparable graphs for NO_X do not seem to have been constructed. Of the six most commonly encountered nitrogen oxides, NO_2 is evidently the most important since all the others tend to form it given time (from minutes to hours), although NO is the principal product in flames. At sufficient concentrations, NO_2 is toxic and can cause severe damage, leading to death. The odor threshold is just over 1 p.p.m., and irritation starts in excess of 10 p.p.m. By contrast, an otherwise clear sky would just show slight discoloration at something under 1 p.p.m. The toxic levels, lying between 10 and 100 p.p.m., are not generally reached. However, at the lower levels, NO_2 participates in the photochemical reactions leading to oxidant smog. This smog formation also involves hydrocarbons; hence the concern is reducing both NO_2 and hydrocarbons.

Solid particulates usually have more of a smothering effect than a directly toxic effect, as most are biologically inert, particularly fly-ash and carbon, although they evidently play some part in coating the lungs and reducing the oxygen transfer surface which can be important in bronchial patients. This is usually accepted as having been a factor aggravating the SO_2 effect during the London smog of 1952 when many of the *"excess"* deaths were among those with bronchial difficulties.

Processes of Pollutant Generation from Combustion

The gross processes generating the pollutants by combustion are quite simple, although their detailed mechanisms may be exceedingly complex.

The inorganic particulates are inert materials that enter the flame as minerals and emerge as fly-ash after partial alteration.

Organic particulates are carbon or carbonaceous solids formed by cracking the fuel (coal, oil, or gas) in the flame. Their emissions represents poor combustion control; at the higher concentrations, they are apparent in the combustor exhaust as *"smoke."* It is then common to find CO also present; and if a sample of the exhaust is cooled, condensible hydrocarbons may be found. Control of these pollutants obviously depends on good combustion.

By contrast, NO_X and SO_X are almost indicative of too good combustion. SO_2 results, of course, from sulfur in the fuel, and a substantial fraction usually oxidizes further to SO_3. The SO_3 conversion increases with excess air, so this can be controlled to a considerable extent by firing any furnace or combustor as near to stoichiometric conditions as possible.

Low to zero excess air also reduces the NO_X problem. The nitrogen oxides are formed primarily by reaction of oxygen with atmospheric nitrogen, although nitrogen in the fuel can also participate. In the initial flame reaction, NO predominates, being formed by what is known as the Zeldovich mechanism. The NO formation rate is approximately proportional to the square root of the oxygen concentration, so it is reduced by low excess air. The conversion of NO to NO_2 then depends on relatively slow reaction in the atmosphere, at near ambient temperature, in a large excess of oxygen after escape of the effluent from the stack.

Flame Control of Pollutants

Although the potential for flame control of pollutants is obvious, the details of any procedure are less so. The reduction of excess-air-to control SO_3 formation and reduce NO_X–is only permissible when the combustion system is under such good control that there are no significant unburned combustibles in the effluent gas (CO, hydrocarbons, organic particulates) either before or after the excess air reduction. Table 1 shows that, as a generality, this is hardly the case.

The problem centers on the speed of mixing in the combustion chamber related both to the time required for reaction and to the average residence time of the reactants in the chamber. The mixing aspects may include mixing of the fuel and oxidant in the chamber, which are frequently supplied separately for safety or other reasons. The dominant mixing behavior in most cases, however, is between the fresh, incoming reactants and the part-burned combustion gases already in the combustor. This requires a *"backmix"* flow, in contrast, for example, with the bunsen burner, where the gas and air mix in the burner tube and then carry straight on through the flame and out into the surroundings without any feedback to the burner tube.

In most practical situations, however, the mixing is produced by a combination of turbulence and backmix. In general, there are locally identifiable streams, some moving in the same direction and some in the opposite direction to the main flow. These *"forward"* and *"backmix"* streams move gross quantities of reactants and products around in the mixing region of the combustor, and turbulence promotes cross-mix between the streams. Turbulence is frequently pictured as motion of small volume elements of fluid, or eddies formed by shear flow, with a finite but decaying eddy size. The eddies ultimately dissipate to purely molecular motion, finally representing absolute mixing, but during the eddy lifetime there are local inhomogeneities in concentration, and it is these that are likely to be important in pollutant formation.

If the backmix streams are large and few in number, the turbulence eddies must be correspondingly large with correspondingly long lifetimes so that they can survive for the necessary penetration distance into the backmix streams. In the limit of marginal backmix, with stirring dominated by turbulence, the mixing distance must be of the order of the combustor dimensions, and the eddy lifetimes must be comparable with the residence times in the chamber. However, since the lifetimes have distributions, there is, then, a finite probability that a significant proportion of eddies can escape from the chamber before final decay. If the eddy is almost pure fuel, it can emerge almost intact, or as a range of cracked fuel products, carbon monoxide, hydrocarbon intermediates, and carbon, depending on its temperature history. If the eddy is fuel and oxygen, the volume element might react explosively, and this may possibly be a source of combustion noise. Such localized *"hot spots"* can also contribute to NO formation because of the locally higher temperature.

Even if there is sufficient time for the eddies to decay, final burn-up may still not be complete. Intermediates formed (particularly carbon) may be so much less reactive that the reaction time is increased and exceeds the chamber residence time. This is further aggravated if the products are then quite rapidly cooled. In a small coal-fired boiler (of about 100,000 lb. steam/hr.), cooling of gases through the tube banks can approach 10^4 deg./sec., which is a rate found from post-flame studies that would effectively quench the CO conversion to CO_2. In reciprocating engines, the reaction time is substantially shorter, and the rate of cooling even faster. In consequence, the high level of CO and hydrocarbon emissions from transportation power units is almost inevitable (aggravated in many instances by bad maintenance).

This argument suggests that the objective should be to increase backmix while reducing the turbulence. The possible limit of this is mixing without turbulence–a process known as *"blending."* At the present time, however, the tendency seems to be to go in the opposite direction.

Abatement

In principle, something can be done about potential contaminants by treatment before and after the flame. Five ways can be suggested, although not all are suitable for each of the five principal pollutant types.

(1) *Pretreatment* – Cleaning of the fuel would be aimed at removing mineral matter and sulfur. Removing mineral matter to cut down fly-ash applies only to coal. Cleaning coal is a well-developed technique, but for use in power stations it is usually omitted because of cost, particularly in mine mouth operations where the mined coal goes straight to the crushers. In this case; the inorganics are then removed from the stack gases as fly-ash.

If pretreatment of coal to remove sulfur is ever practiced (as it is on occasion for oil), simultaneous removal of mineral matter might be practicable. Desulfurization by hydrogenation is also potentially possible, with sulfur conversion to H_2S, and has the advantage over post-combustion cleaning in that the weights or volumes of gas to be handled are substantially smaller, with proportionately higher component concentrations. A possible reactor scheme to achieve this was published recently, but only the first steps have so far been taken to implement the proposal.

(2) *Flame Control* – This is altogether more promising, in spite of the problems outlined above (Sec. *"Flame Control of Pollutants"*), by the recycling of flue gas and staged air addition. These do not overcome the turbulence problems already mentioned, but are aimed rather at reducing overall temperature levels, and particularly temperature peaks, either by direct dilution (flue gas recycling) or by delaying the total air addition by staging. This staging is aimed particularly at the NO_x formation, although the staged air addition will reduce the local oxygen concentrations through the flame, which will also help to reduce the SO_3 formation.

Flue gas recycling in sufficient quantities can also cut down smoke formation by a mechanism that has not yet been elucidated. Experiments some years ago showed that smoke from combustion of No. 2 oil could be eliminated by firing a 50 per cent excess air, or at zero excess air but with 50 per cent flue gas recirculation (and in a little more than direct proportion between these limits). Even more surprising was the discovery that when the flue gas recirculation was increased still further, the yellow flame turned blue. This behavior is now the basis for a number of attempts to commercialize a blue flame oil burner for the domestic market with prospects for reduced noise and emissions.

(3) *Exhaust Effluent Treatment* – This has traditionally been practiced to cut down fly-ash and particulate emissions, particularly in power stations generally using cyclomes and electrostatic precipitators. Additional treatment to include removal of sulfur and nitrogen oxides has been attempted more recently, particularly for SO_x, but success has not been widespread. Strauss[1] describes several liquid absorption methods for SO_2, with three applied to power stations, but he also states that no really satisfactory solution of general applicability has been found. The alternative to liquid absorption is solid absorption with calcium oxide or calciumed dolomite, as possible choices. Activated carbon is a further possibility.

Treatment of automobile exhaust with its high level of CO and hydrocarbons has centered on catalysts to burn up both, but again these are still in the development stage.

(4) *Dilution* – If the exhaust effluent from a stack cannot be cleaned by existing techniques, the final resort is dilution. This is achieved by building stacks so high that when the plume reaches the ground the contaminants have been reduced, under most conditions, to below the statutory limit. The atmosphere has, of course, been the traditional sink for most effluents in any case, but the very high stack is the logical outcome of arguments that the atmosphere is still semi-infinite so far as current levels of contaminant generation are concerned. If, for example, it is true that the SO_2 average concentration as it exists naturally in the atmosphere would only double in 15 years at the present rates of SO_2 generation (and disregarding washout), then it would seem reasonable only to make sure that it was well dispersed by a high stack.

Such an operation would be satisfactory for most of the time although lower sulfur fuels would have to be available for use under special atmospheric conditions such as inversions, or those allowing fumigation. It has been estimated that this would occur only about 2 per cent of the time in England, but in some parts of the United States it could be a good deal more. The maritime climate of England would account for the relatively low figure of 2 per cent but the continental climate of the United States could easily be responsible for a single pollution alert lasting a week or more.

(5) *Thermal Efficiency* -- This is one final possibility for pollution abatement that deserves some attention. The rate of production of contaminants will be roughly proportional to the total fuel consumption, so reduction of this total by using the fuel more efficiently must reduce the rate of generation of pollutants. A breakdown of the energy market into four groups of users gives the following: (1) electricity generation and transmission – 15 per cent; (2) residential and commersial – 20 per cent; (3) transportation – 25 per cent; and (4) industrial - 40 per cent. There is not now too much scope for improvement in thermal efficiency in the electricity generation area without radical modification of existing methods, so this will leave the largest SO_x and NO_x sources as they are, with

1 Strauss, W., Industrial Gas Cleaning, Pergamon Press, 1966.

abatement based on other factors. There should, however, be room for improvement in the other three areas, and particularly in industry, which uses the largest fraction of energy and where there is considerable scope for additon of heat recovery equipment.

There has not usually been too much incentive to do this in the past because of the difficulty of justifying such equipment on the basis of recovery of costs. The fraction of manufacturing costs that is due to energy or fuel is only 3.5 per cent for all manufacturing, although it is rather higher in heavy industry (ferroous and nonferrous metals, refractories, chemicals, etc.), where it ranges from 10 to 25 per cent. The cost recovery situation might be improved, however, if manufacturers were to pay for the air they use directly or indirectly (traditionally regarded as free) by a tax on their fuel and electricity consumption.

Judging by Table 1, efficiency improvements would have only a small impact on the pollutant emissions since industry evidently generates only about 15 per cent of the total–a surprisingly low figure-but it would provide a lead and would also contribute to alleviation of the power shortage.

Conclusions

Air pollution from combustion sources is a problem, and in some areas of the country a serious one, but it has still not yet reached the uniformly catastrophic proportions that some of the self-appointed priests and policemen moralizing over the sins of industry would have us believe. However, such catastrophic proportions could well be achieved within a generation if effective uniform action is not taken very shortly. Unfortunately, what can be done is still somewhat limited as much of the needed technology is still undeveloped.

Of the five pollutant types listed in Table 1, particulates are the easiest to live with without further action, although here the removal techniques are also the most advanced; indeed, in a number of instances they depend only on payment for installation costs. The easiest to eliminate on the basis of current knowledge ought to be the combustibles (CO, hydrocarbons, and sometimes organic particulates) emanating from all sources except transportation, although extensive supplementary development research may still be necessary in some cases, particularly in incineration. Knowledge of the basis for controlling NO_X is gaining ground, although again extensive development research will probably be needed in a number of cases to apply the results. The biggest problems still seem to be: CO emissions, particularly from transportation, and SO_X emissions, particularly from power stations. Elimination of CO by catalytic after-burning outside the engine is a stopgap answer at best. The problem really stems from the nature of the reciprocating engine, which cannot really be regarded as an example of elegant engineering design. Can a better unit be produced to displace it? And will society pay the cost in view of the immense capital investment already involved in reciprocating engines? Finally, SO_X emissions still seem to be currently the most intractable. A number of promising possibilities exist, but there is still no commercial process that is simple, cheap, effective, and reliable. It is, perhaps, fortunate that the tall stack solution is available as a stopgap, as long as local ordinances are not unimaginatively rigid and as long as sufficient low-sulfur, stand-by fuel is available for periods when meterorological conditions are adverse.

Prodded by environmentalists, the research is slowly moving toward solutions, aided by much verbal encouragement from bystanders and occasional financial assistance from appropriate funding agencies. The problem exists, of course, very largely because of too little rather than too much science, although some of the more excitable members of the community advise a return to the primitive to eliminate both science and pollution. Such suggestions, however, miss the point. Man, like all living things, generates wastes. This he must live with. It is not the waste of itself that constitutes pollution but the generation of so much waste that adversely affects the environment. This is not unique to man. Even animals can so adversely affect their environment that they suffer for it; for example, by overbreeding when food is plentiful, they overgraze when it is not and may die. Man can do this, too, but he has also learned how to avoid it. Measures to control wastes are not new. One of the most significant steps in waste control ever taken was the production of cheap steel pipe, in quantity, that enabled the separation of drinking water from sewage, and it probably did as much for the general health and reduction of mortality as all medical research to date.

There is no reason to suppose that the current problem of air pollution cannot be solved, given the will and the means. Curiously, one of the big difficulties at present–in addition to the invariable shortage of research funds–is availability of trained manpower to undertake the necessary research. Preaching and legislation are useless without the technology. If those who are so vocal in criticizing the shortcomings of science, industry and the universities in solving *"relevant"* problems were to take a hand in developing the necessary technical solutions, even if it means getting their hands dirty, we should get there a good deal faster.

References

Air Quality Criteria for Sulfur Oxides, U.S. Department of Health, Education and Welfare, National Center for Air Pollution Control, Publications NOs. 1619, March 1967; AP50, January 1969.

Gilpin, A., *Control of Air Pollution*, Butterworths, London, 1963.

Goldsmith, J. R., and Landaw, S. A., *Carbon Monoxide and Human Health*, Science 162, 1352 (1968).

Magill, P. L., Holden, F. R., and Ackley, C. (eds.), *Air Pollution Handbook*, McGraw-Hill, New York, 1956.

Stern, A. C. (ed.), *Air Pollution*, Vols. I and II, Academic Press, 1968.

Strauss, W., *Industrial Gas Cleaning*, Pergamon Press, 1966.

Effects of Sulfur Oxides on Human Beings

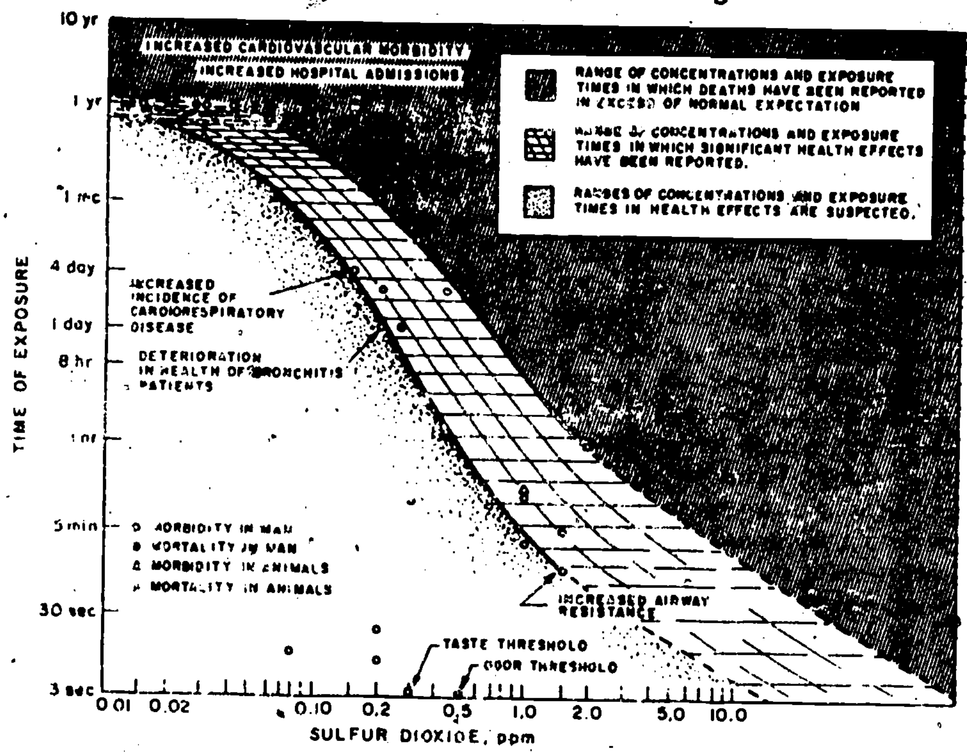


Fig. 1. Variation of health response with SO₂ concentration and exposure time. (From U.S. Department of Health, Education, and Welfare Publication No. 1619.)

Table 1

Emission Rates of Dominant Pollutant Types and Sources for 1966 and 1968

Millions of Short Tons per Year

These data account for more than 90 percent of all emissions in the United States

Pollutant Source	CO	Hydro-carbons	NO_x	SO_x	Partic-ulates	Total by Source	Year
Transportation	63.8	16.6	8.1	0.8	1.2	90.5	1968
	64.5	17.6	7.6	0.4	1.2	91.3	1966
Stationary Combustion Sources	1.9	0.7	10.0	24.4	8.9	45.9	1968
	1.9	0.7	6.7	22.9	9.2	41.4	1966
Industrial Processes	9.7	4.6	0.2	7.3	7.5	29.3	1968
	10.7	3.5	0.2	7.2	7.6	29.2	1966
Refuse Incineration	7.8	1.6	[illegible]	0.1	1.1	11.2	1968
	7.6	1.5	0.5	0.1	1.0	10.7	1966
Miscellaneous*	16.9	8.5	1.7	0.6	9.6	37.3	1968
	16.9	8.2	1.7	0.6	9.6	37.2	1966
Total by Type	101.1	32.0	20.6	33.2	28.3	214.2	1968
	101.6	31.5	16.7	31.2	28.6	209.8	1966

*Includes such sources as forest fires, structural fires, coal refuse, agriculture, organic solvent evaporation, and gasoline marketing

Data Source: National Air Pollution Control Administration

CHAPTER 8

PLANT SITING AND ENVIRONMENTAL IMPACT

1. Siting Criteria

When the public demand for electricity dictates the building of a new generating plant, the utility company involved must make a careful study to determine its best site. It takes into consideration the power network in the region, the type and availability of fuel and the impact that the plant will have on the environment. Traditionally, power plants have been located on the surface of the ground, either near the source of the fuel or near the urban market and major transmission lines. Such sites were selected for economic reasons, without deference to environmental concerns. Today there is greater awareness of the need for increased care in this selection process, and a utility company must make a careful assessment of the impacts that a proposed plant will have on the environment. The utility must file with appropriate government agencies an environmental impact statement which describes these impacts.

The following paragraphs describe important criteria for plant site selection.

A. Power Network Considerations

The service area of an individual utility should be determined. The location of major urban areas should be considered. The location of existing generating plants within the region should be noted. In some instances, it may be desirable to site a new plant next to an existing one. The concept of an *energy park* has recently emerged. It may be advantageous to locate several power plants in the same vicinity. An example of a map of major urban areas and generating plants is shown in Figure 24. The location of transmission lines and interconnections with other power suppliers should be considered. If a plant is built far from existing transmission lines, there will be additional environmental impact from establishing new lines and rights of way.

B. Energy Type and Fuel Source Considerations

The availability of fuels (other than nuclear) varies greatly for different geographic locations. Oil or coal may be available in many areas, but transportation costs or high sulfur content limit their use. Hydroelectric and geothermal sources are extremely limited in occurrence and location.

C. Environmental Considerations

(1) Site Access

It must be possible and economically feasible to transport construction equipment and power plant machinery to the proposed site through the use of existing facilities as much as possible. If major new roads, rail lines or canals must be constructed, their environmental impact has to be considered. Some of the equipment that must be brought in is very large, such as the massive generators, and, in the case of a nuclear plant, the reactor pressure vessel. Ready access to the site is highly important and one of the first factors to be considered.

(2) Geology

The best sites for power plants are in areas that are relatively flat and have adequate drainage. The stability of slopes should be high. Mountains, foothills, marshes and flood plains are considered unfavorable. Rock formations with excessive areas of weakness, such as faults, should be avoided unless adequate engineering compensates for the geologic hazard. Areas that have had, or are prone to, earthquakes, volcanoes, landslides, floods and tidal waves should be excluded from consideration. Areas with underground mines, sinkholes, and caves might prove hazardous due to sudden surface collapse.

(3) Hydrology

Today's massive nuclear and fossil-fueled plants need large quantities of water for cooling. It is, therefore, necessary for a plant to be near a suitable sou[illegible]ater. A detailed study of the surface and gr[illegible]ust accompany any site evaluation. In [illegible] utilities must also consider limitations im[illegible]xisting laws or policies. For example, [illegible]a, surface and ground water rights [illegible] with land rights, and upstream [illegible]ave precedence in water use. However, [illegible]downers must respect downstream [illegible]he water. If a downstream owner uses [illegible] irrigation, a reduction in the flow [illegible] power plant upstream could have an [illegible]ct.

(4) Meterology

Because of their weather [illegible] certain areas should be avoided as power p[illegible]es. However, if a site is otherwise [illegible] may be possible to eliminate the weather-related problems by special engineering of the plant. The ideal power plant site would have we[illegible] conditions that allow sufficient dispersal of wa[illegible] and stack gases to the atmosphere, thereby preventing detrimental effects to the surrounding environment. Also, areas which are prone to waterspouts, tornados or unusually high winds present special engineering problems. Power plants having cooling towers or ponds should not be located where extreme fogging or icing would be hazardous to land, sea or air transportation.

171

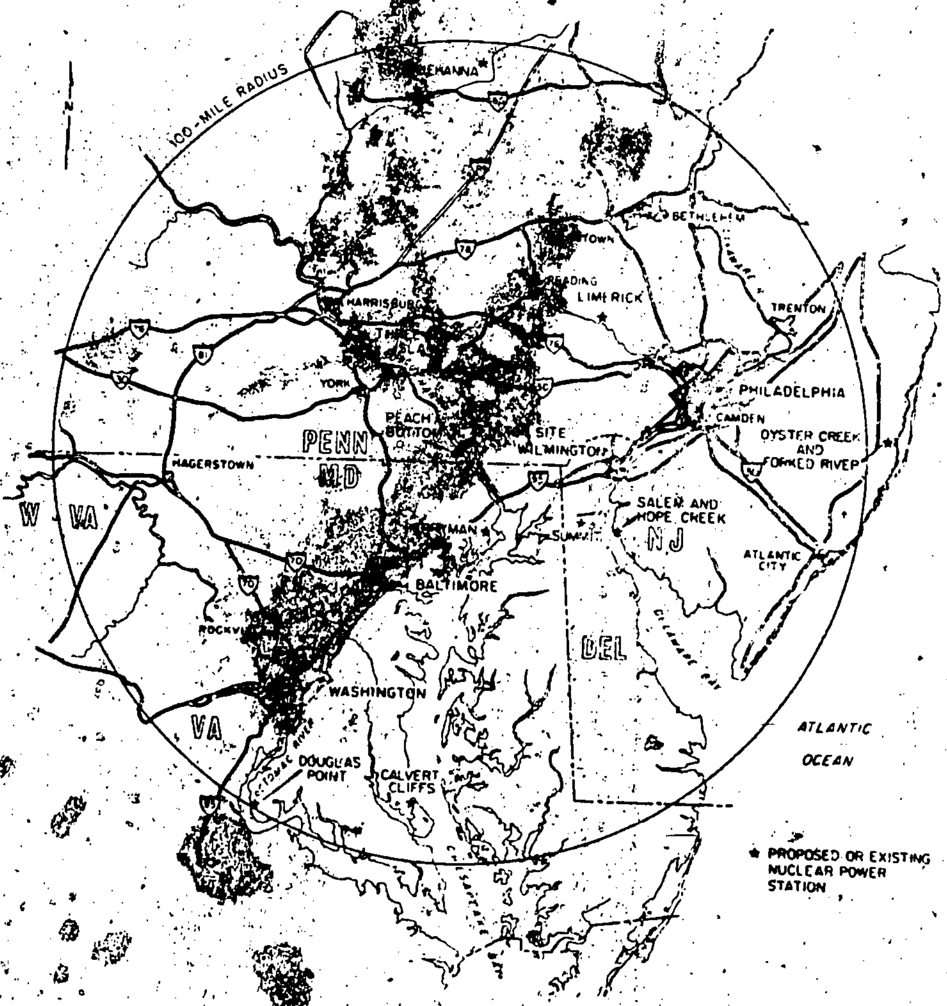

100-MILE RADIUS
BETHLEHEM
LIMERICK
TRENTON
PHILADELPHIA
CAMDEN
OYSTER CREEK AND FORKED RIVER
PENN
MD
HAGERSTOWN
YORK
PEACH BOTTOM
SITE
SALEM AND HOPE CREEK
NJ
ATLANTIC CITY
W VA
BALTIMORE
DEL
WASHINGTON
VA
DOUGLAS POINT
CALVERT CLIFFS
ATLANTIC OCEAN
PROPOSED OR EXISTING NUCLEAR POWER STATION

FIGURE 24

(5) *Ecology*

Some aquatic species, such as salmon and lobster, must live in water temperatures of a narrow range. Water bodies containing such species should generally be avoided as a plant site. This is especially applicable in the extreme southern or northern parts of the United States, where the water temperature is naturally very warm or very cold. Nesting, spawning and nursery areas of important species of wildlife, fish or shellfish should not be considered as a power plant site. Furthermore, a site should not be located where it could adversely interfere with the migration of important animals or where rare or endangered species of wildlife live. In some cases, however, the development of a site may actually benefit some rare or endangered species by serving as a wildlife sanctuary.

(6) *Land Use*

A power plant site should be compatible with other existing uses of the area. Local zoning rules may have to be considered. The amount of land required for a power plant will depend on the fuel used (See Table 9). As mentioned, a coal-fired station requires much space for its coal supply and waste storage. The relatively large area required by a nuclear plant is necessary to provide distance between the reactor and people. This distance, called an exclusion distance, is required by federal law. There must also be a low population zone surrounding the exclusion area. This is discussed in the next section.

(7) *Human Factors*

In the case of nuclear plants, sites must meet federal requirements that protect the general public from radiation exposure. Thus, nuclear plant sites are situated away from densely populated areas.

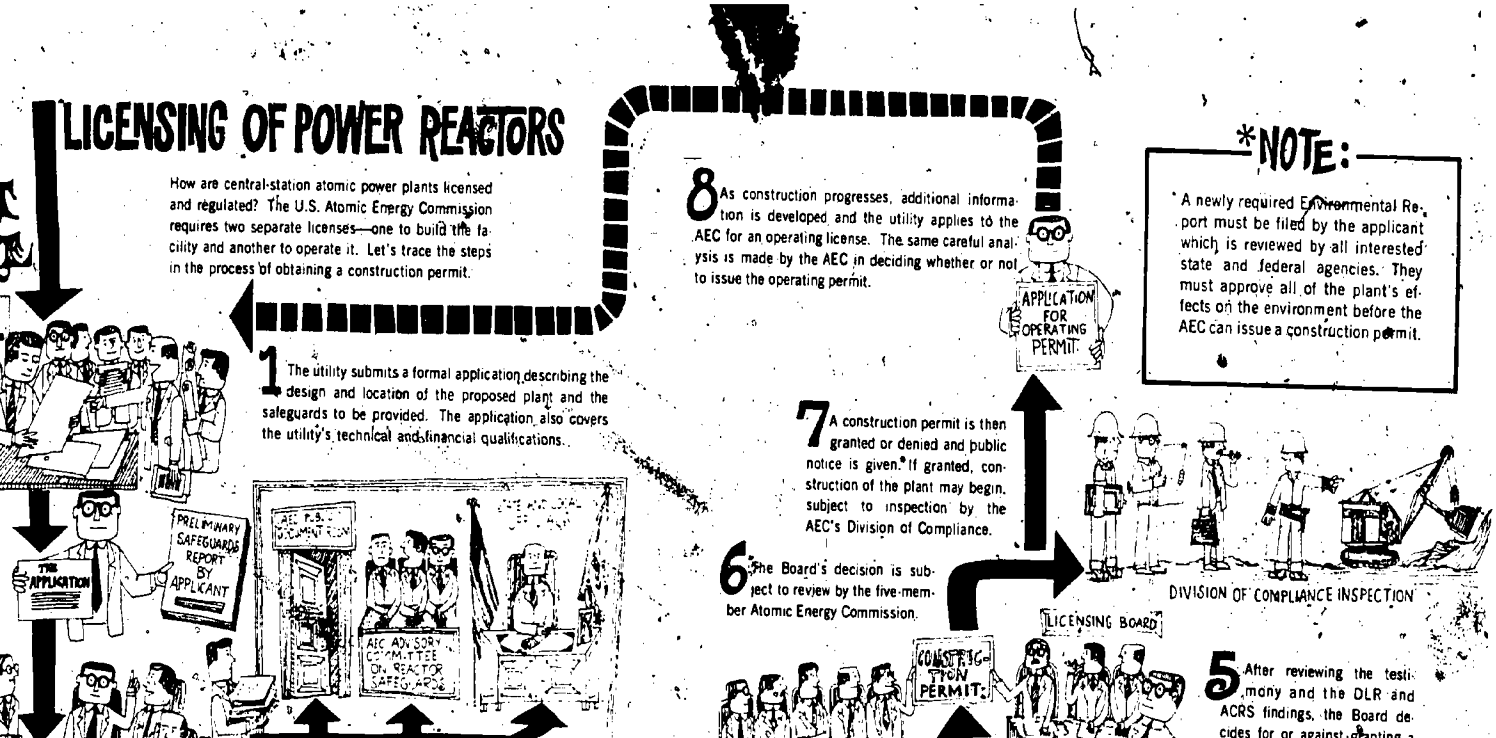
No power plant should be located in, or next to, unique natural resources or scenic attractions, such as national and state parks and wilderness areas. Similarly, a power plant should not be located in or adjacent to historically significant and archaeologically significant areas. Finally, public opinion should be sampled and should play a part in the siting decision.

TABLE 9

Land Area for Power Plants

Plant Fuel	Average Acres Required
Coal	1050
Oil	250
Gas	150
Nuclear	1160

SUPPLEMENTARY
MATERIALS
FOR
CHAPTER 8


LICENSING OF POWER REACTORS
How are central-station atomic power plants licensed and regulated? The U.S. Atomic Energy Commission requires two separate licenses—one to build the facility and another to operate it. Let's trace the steps in the process of obtaining a construction permit.
1 The utility submits a formal application describing the design and location of the proposed plant and the safeguards to be provided. The application also covers the utility's technical and financial qualifications.
PRELIMINARY SAFEGUARDS REPORT BY APPLICANT
THE APPLICATION
TECHNICAL EXPERTS OF COMMISSION REGULATORY STAFF
...e AEC's Division of Licensing & Regulation makes ... of the application available ... the public and ACRS. ...chnical experts study the ...tion, review it with the applicant and prepare an analysis.
...analysis is submitted to the AEC's statutory Committee on Reactor Safeguards, ... of independent experts. ACRS studies ...on in detail and holds conferences with ... and DLR staff. The ACRS findings are ...e AEC and made public.
AEC ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
AEC PRESS RELEASE
NOTICE OF APPLICATION
RELATED INFORMATION
AND CORRESPONDENCE
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS (ACRS)
ANALYSIS
REPORT TO AEC COMMISSIONERS
PRESS RELEASE ACRS REPORT
ATOMIC SAFETY AND LICENSING BOARD
4 A public hearing is held, usually near the proposed site, by an AEC appointed Atomic Safety & Licensing Board. Private citizens, State & local officials, and community groups may attend and give testimony.
5 After reviewing the testimony and the DLR and ACRS findings, the Board decides for or against granting a construction permit.
LICENSING BOARD
CONSTRUCTION PERMIT
REVIEW BY THE COMMISSION
6 The Board's decision is subject to review by the five-member Atomic Energy Commission.
7 A construction permit is then granted or denied and public notice is given.* If granted, construction of the plant may begin, subject to inspection by the AEC's Division of Compliance.
DIVISION OF COMPLIANCE INSPECTION
8 As construction progresses, additional information is developed and the utility applies to the AEC for an operating license. The same careful analysis is made by the AEC in deciding whether or not to issue the operating permit.
APPLICATION FOR OPERATING PERMIT
*NOTE:
A newly required Environmental Report must be filed by the applicant which is reviewed by all interested state and federal agencies. They must approve all of the plant's effects on the environment before the AEC can issue a construction permit.

BACKGROUND INFORMATION

POWER PLANT SITING ACT OF 1971 DRAFT OF PROPOSED FEDERAL GUIDELINES

SECTION 1 - SCOPE

These proposed guidelines are intended to serve as the basis for meeting the requirements set out in the Power Plant Siting Act of 1971, legislation submitted to the Congress by the President on February 10, 1971, and designated H.R. 5277 and S. 1684 (hereinafter *"the Act"*).

SECTION 2 - PURPOSE

The purpose of these guidelines is to assure the establishment of State or regional certifying agencies capable of providing the judgments required under the Act. To this end, these guidelines provide the basis for the establishment of a decision-making process and timely and effective procedures within each certifying agency to assure competent, prompt determination and resolution of environmental and power issues within its jurisdiction. Additionally, these guidelines are designed (i) to integrate to the extent possible, any associated review, licensing, and permit granting activities of the Federal Government with the State or regional procedures, so as to achieve as close to a complete one-stop certification procedure as is possible; and (ii) to provide guidance for the certification procedure of the Federal certifying agency.

SECTION 3 - POLICY

The policy intended to be carried out by these guidelines is to allow the States (or groups of States which elect to act as a regional certifying agency) maximum flexibility within the requirements of this Act to experiment and to develop those procedures for the certification of sites, routes, and facilities which best fit the particular conditions and requirements of each jurisdiction. The primary requirement is that the certifying agency be capable of professionally evaluating and balancing both the need for electric power facilities and the need to protect environmental values.

SECTION 4 - COMPOSITION OF THE STATE OR REGIONAL CERTIFYING AGENCY

a. *Type of Agency* - These guidelines seek to provide the framework for a broad variety of options to State governments in the formation of State and regional certifying agencies. These decision-making bodies may be existing agencies, newly created agencies, or boards consisting of members from an appropriate spectrum of existing State agencies. The decision-making authority may be located with the State Public Utilities Commission, although in such cases care must be taken to insure adequate consideration of environmental aspects through the requirements for participation discussed hereafter and in the manner discussed in Sections 7 and 8 of the Act. It may be located within a State environmental protection agency, although in such cases care must be taken to insure adequate consideration of the need for facilities through participation requirements hereafter. Other possibilities with perhaps greater potential for balancing power and environmental needs would be the State land-use planning agency, the State natural resources agency, or a State siting agency with representatives from the interested existing State agencies. In some cases, States may wish to place final authority with the Governor. To the extent possible, the Federal certifying agency shall allow each State to adopt a State body that best serves the purposes of the Act within its jurisdiction.

In some cases, a pre-existing agency of the State government may be qualified as the State certifying agency, or may serve as the basic agency to which a new office is attached to carry out the functions assigned under the Act. Where the pre-existing agency has a clear identification with either aspect of the power-environment equation, extreme care must be taken to insure that the criteria set out in this section are fully met. It is the intention of this section to encourage the formation of a State or regional certifying agency meriting the confidence of the public as to its competence and objectivity with respect to both electric power needs and environmental protection.

b. *Participation* - Section 5(a) of the Act requires participation in the decision-making process of the certifying agency by environmental protection, natural resources, planning, and electric power regulatory agencies of the State government and authorizes participation by members of the public.

"Participation" by components of State government means either taking part as a voting member of the decision-making body of the certifying agency or acting in an advisory capacity to that agency with respect to the aspect of its decision within the participant's area of competence. Where such participation is limited to an advisory capacity in the participant's area of special competence such advice shall be submitted in writing and made public and the certifying agency may depart from such advice only if it determines and can demonstrate that departure is necessary to accomplish the overall objectives of the certification process. In any event, certifying agencies must ascertain that all applicable Federal standards, permits, or licenses for the project have been satisfied or obtained as required by Section 7 of the Act. In the case of Federal water and air quality standards, the satisfaction shall be determined by the duly authorized State water and air pollution control agencies. *"Federal standards"* means standards established or approved by a Federal agency.

177

"*Participation*" with respect to the public means by making comments or being permitted to become a party to proceedings involving applications in which such person has an interest.

c. *Staff* - the State or regional certifying agency must have a competent and interdisciplinary professional and technical staff capable of dealing with those environmental and power issues which come before it. The Governor, in his request for a Certificate of Qualification from the Federal certifying agency shall describe the composition of the staff. In some cases, the State or regional certifying agency may find that employment of such a staff on a full-time basis would not be justified based on the anticipated work-load. Where this occurs, the Governor shall specify the manner in which the State or regional certifying agency will call upon consultants or experts from other agencies of Government to assure a balanced determination of issues.

d. *Finance* - The State or regional certifying agency shall be authorized to assess and collect fees from electric entities within its jurisdiction to cover the cost of administration of its functions under the Act. The application for a Certificate of Qualification must show to the satisfaction of the Federal certifying agency how the State or regional certifying agency will be financed in a manner adequate to carry out the purposes of the Act.

SECTION 5 - REVIEW AND COMMENT ON LONG-RANGE PLANS

Section 8(a) of the Act sets out the responsibilities of the certifying agencies to review and comment upon the long-range plans prepared and filed pursuant to Secton 4 thereof. Each electric entity operating within the jurisdiction of a certifying agency shall file with it the annual long-range planning document by April 1 of each year. Electric entities will be encouraged to combine plans into a single regional plan in coordination with the procedures outlined in Order 383-2 of the Federal Power Commission, authorizing voluntary annual reports from electric reliability councils covering the continental United States. The Act, however, requires the provision of information not now requested under the FPC procedures, including the preliminary identification of sites and routes planned for use within the next five years, an analysis of efforts to meet environmental protection goals, and other requirements outlined in Section 4 of the Act.

Each certifying agency shall compile and publish by September 1 of each year its review and comments on the annual plans filed with it by the preceding April 1. The intent of this publication is to summarize the long-range plans of electric entities operating within its jurisdiction, their relation to adjoining jurisdictions, and to evaluate the adequacy of these plans from the point of view of providing adequate electric power while maintaining environmental values. The publication and distribution of this report by the certifying agency shall be according to the requirements set forth in Section 8(a) of the Act.

SECTION 6 - PRELIMINARY REVIEW AND HEARINGS ON PROPOSED SITES

As part of its September 1 report on long-range planning by the electric entities within its jurisdiction, the certifying agency shall also publish the compilation of proposed power plant sites and general locations of transmission lines as required in Section 4(a) (2) and Section 8(b) of the Act for all facilities, construction of which is planned to commence within five years. With respect to proposed power plant sites, public hearings shall be held during the period September 1 to December 15 of each year on each newly-identified site, and the certifying agency shall determine whether or not such site is to be placed on the list of approved sites by February 15 of the next year, less than one year after such appeared on the plans of the electric entity. The decision of the certifying agency shall be according to the standards set out in Section 8(c) of the Act. Each site shall receive either:

(1) preliminary approval as a site, subject to review at the time of application for certification only with respect to changed conditions (other factors not considered in this preliminary review such as the facility design would, of course, be reviewed during the certification procedure); or

(2) preliminary conditional approval as a site, subject to review at the time of application for certification with respect to changed conditions, and with respect to conditions placed on the nature or extent of the facilities to be placed thereon. (Approval here would be the same as (1) except that site may be conditioned for a nuclear or fossil fueled plant only, for example); or

(3) suspension pending further study, because the construction of any bulk power facility on the site might unduly impair important environmental values. Such suspension may extend for no more than three years during which time the electric entity together with appropriate environmental agencies must actively seek to determine whether important environmental values would be impaired. Following the period of suspension, the site may be resubmitted and the certifying agency must give preliminary approval, preliminary conditional approval, or disapproval of the site; or

(4) disapproval as a site because the construction of any bulk power facility on the site would unduly impair important environmental values. Such disapproval shall be final and not subject to resubmission for consideration as a site unless there is clear evidence of changed conditions.

SECTION 7 - CERTIFICATION OF FACILITIES

For all bulk power facilities covered by this Act, the appropriate electric entity shall apply for certification of site and facility at least two years prior to planned commencement of construction, as provided for in Sections 6 and 7 of the Act. In addition to any other such information which the certifying agency may require, the electric entity shall provide with its application a detailed statement on:

i. The environmental impact of the proposed facility.

ii. Any adverse environmental effect which cannot be avoided if the facility is constructed and operated as proposed.

iii. Alternative locations, measures, or other actions.

iv. The relationship between the short-term environmental impact of the proposed facility and the maintenance and enhancement of long-term productivity.

v. Any irreversible and irretrievable commitments of resources if the proposed facility is constructed.

Notice of receipt of such application shall be made as provided in Section 8(d) of the Act, and the two-year period shall be considered to begin to run from the time of first publication, which shall in all cases occur within 30 days of the actual receipt of a valid application. Hearings to consider the proposed certification shall commence within 6 months of publication and to the extent possible a decision of the certifying agency shall be reached and published within one year. Failure to reach such conclusion or to indicate that a decision is imminent after a one-year period has passed from date of publication shall be grounds for the electric entity to petition the Federal certifying agency under Section 6(d) of the Act. Except where, for good cause shown, the site has not been drawn from the list of approved sites as provided for under Section 6(b) of the Act, the review of the power plant site shall be limited as described above in Section 6 of these Guidelines.

SECTION 8 - ONE-STOP PROCEDURE

a. *State or Regional CertifyingAgency* - The Act is intended to provide in a single procedure final decisions on all State and local government approvals required for the construction and operation of bulk power supply facilities. It also attempts to coordinate and integrate all necessary reviews of environmental concerns by Federal agencies so as to achieve as close to a complete one-stop procedure as is possible.

Section 7(a) of the Act states that the judgment of the appropriate certifying body shall be conclusive on all questions of siting, land use, state air and water quality standards, public convenience and necessity, aesthetics, and any other State or local requirement. *"Judgment ...shall be conclusive"* means that the State has provided through appropriate use of its legislative and/or executive authority for the issuance of a Certificate of Site and Facility by a qualified State or regional certifying agency which shall certify that all Federal permits, licenses, or standards have been satisfied or obtained and which shall incorporate or supersede any requirements for the issuance of any permit, license, or certificate for the facility involving environmental and power supply concerns required under a State or local statute such that:

(1). the requirements of such State or local permit, license, or certificate are specifically considered in the application for and the issuance of the Certificate of Site and Facility:

(2) the state or local agency responsible for issuing any such permit, license, or certificate participates in the decision-making process as defined in Section 4(b) of these Guidelines, and

(3) the facility is designed, built, and operated in accordance with the specifications provided by the applicant as modified by any further conditions imposed by the certifying agency in the Certificate of Site and Facility.

Where standards of air or water quality established or approved by a Federal agency are to be applied, the determination of whether or not a proposed facility will meet such standards shall be with the duly authorized State air or water pollution control agency. In cases whereby under Federal or State laws or regulations a permit, license, or certificate is dependent upon the granting of another such permit, license, or certificate, the State certifying agency shall provide for any necessary flow of information to assure an orderly and timely certification process.

In order to facilitate efficient consideration of applications for certification, each State or regional certifying agency shall develop a consolidated application form which shall be the sole application necessary for all approvals of state and local governments. All requests for further information and all other correspondences related to the certification shall be made only by or through or with the prior approval of the authorized ceritfying agency.

All Federal agencies with statutory authority for granting licenses, certificates, or permits prior to the construction or operation of a bulk power facility shall, to the fullest extent possible, coordinate their activities, including the time and place of any public hearings and related reviews, with the appropriate State or regional certifying agency. Federal agencies with advisory authority shall supply such advice directly to the certifying agency in compliance with its timetable. Federal agencies shall reduce to an absolute minimum the information required of

applicant above that already presented in the consolidated application to the certifying agency. Such agencies are not required to prepare the detailed statements of environmental impact contemplated in Section 102 (2)(C) of the National Environmental Policy Act of 1969 where the certifying agency has followed a substantially comparable procedure.

b. *Federal Certifying Agency* - In those cases in which the Federal certifying agency exercises jurisdiction either because of the absence of a qualified State certifying agency or upon appeal pursuant to Section 6(d) of the Act, the Federal certifying agency shall provide a one-stop procedure except for license applications before the Atomic Energy Commission which shall be coordinated with the review of the Federal certifying agency. Any other Federal licenses or permits or approvals which may be required shall be considered and decided as an integral part of the review by the Federal certifying agency. The Federal certifying agency, the Environmental Protection Agency, the U.S. Army Corps of Engineers, and any affected Federal land management agencies shall hold any hearings on each application jointly and shall fully coordinate reviews and approvals required by their respective responsibilites under Federal law. Other Federal agencies shall render written advice in their areas of special competence with respect to environmental or power supply aspects of the project and the Federal certifying agency may depart from such advice in its decision only if it determines and can demonstrate that departure is necessary to accomplish the overall objectives of the certification process.

The Federal certifying agency shall operate under these Guidelines except where they are inapplicable and shall develop a consolidated application form, except for the AEC license application, to cover all Federal statutory requirements. The decision of the Federal certifying agency shall be rendered within the one-year period after receipt of an application and, if not, the agency will be required to issue a statement explaining why it has failed to act. The Federal certifying agency shall promulgate procedures and schedule hearings to assure time for a final decision within the two-year period contemplated in the Act. The Federal certifying agency shall have exclusive jurisdiction over the application applying Federal standards only, as provided in Section 5(c) of the Act and such certificate shall supersede any requirements of State or local law with respect to permits, licenses, or standards applicable to the project but such certificate shall be issued only if the Federal certifying agency has ascertained that all Federal permits, licenses, or standards have been satisfied or obtained as required by Section 7 of the Act. Federal standards mean standards established by or approved by a Federal agency.

SECTION 9 - EVALUATIVE CRITERIA

In evaluating long-range plans, conducting preliminary site reviews, and evaluating the application for certification of bulk power supply facilities, the certifying agency shall give consideration to the following factors where applicable:

a. *Electric Energy Needs*
(major emphasis of long-range plan reviews)

(1) Growth in demand and projection of need.

(2) Availability and desirability of non-electric alternative sources of energy.

(3) Availability and desirability of alternative sources of electric power to this facility or to this type of facility.

(4) Promotional activities of the electric entity which may have given rise to the need for this facility.

(5) Socially beneficial uses of the output of this facility, including its use to protect or enhance environmental quality.

(6) Conservation activities which could minimize the need for more power.

(7) Research activities of the electric entity or new technology available to it which might minimize environmental impact.

b. *Land Use Impacts*
(major emphasis of preliminary site reviews)

(1) Area of land required and ultimate use.

(2) Consistency with any State and regional land use plans.

(3) Consistency with existing and projected area land use.

(4) Alternative uses of the site.

(5) Impact on population already in the area: population attracted by construction or operation of the facility itself; impact of availbility of power from this facility on growth patterns and population dispersal.

(6) Geologic suitability of the site or route.

(7) Seismologic characteristics.

(8) Construction practices.

(9) Extent of erosion, scouring, wasting of land–both at site and as a result of fossil fuel demands of the facility.

(10) Corridor design and construction precautions for transmission lines.

(11) Scenic impacts.

(12) Effects on natural systems, wildlife, plant life.

(13) Impacts on important historic, architectural, archeological, and cultural areas and features.

(14) Extent of recreation opportunities and related compatible uses.

(15) Public recreation plan for the project.

(16) Public facilities and accommodation.

c. *Water Resources Impacts*
(major emphasis during preliminary site reviews and facility certification)

(1) Hydrologic studies of adequacy of water supply and impact of facility on stream flow, estuarine and coastal waters, and lakes and reservoirs.

(2) Hydrologic studies of impact of facilities on ground water.

(3) Cooling system evaluation including consideration of alternatives.

(4) Inventory of effluents including physical, chemical, biological, and radiological characteristics.

(5) Hydrologic studies of effects of effluents on receiving waters, including mixing characteristics of receiving waters, changed evaporation due to temperature differentials, and effect of discharge on bottom sediments.

(6) Relationship to water quality standards.

(7) Effects of changes in quantity and quality on water use by others, including both withdrawal and in situ uses; relationshp to projected uses; relationship to water rights.

(8) Effects on plant and animal life, including algae, macroinvertebrates, and fish population.

(9) Effects on unique or otherwise significant ecosystems; e.g., wetlands.

(10) Monitoring programs.

d. *Air Quality Impacts*
(major emphasis during preliminary site reviews and facility certification)

(1) Meterology–wind direction and velocity, ambient temperature ranges, precipitation values, inversion occurrence, other effects on dispersion.

(2) Topography–factors effecting dispersion.

(3) Standards in effect and projected for emissions, design capability to meet standards.

(4) Emissions and controls

a. Stack design
b. Particulates
c. SO_x
d. NO_x

(5) Relationship to present and projected air quality of the area.

(6) Monitoring program.

e. *Solid Wastes Impact*
(major emphasis during facility certification)

(1) Solid waste inventory.

(2) Disposal program.

(3) Relationship of disposal practices to environmental quality standards.

(4) Capability of disposal sites to accept projected waste loadings.

f. *Radiation Impacts*
(major emphasis during preliminary site review and facility certification)

(1) Land use controls over development and population.

(2) Wastes and associated disposal program for solid liquid and gaseous wastes–criteria set by AEC and EPA.

(3) Analyses and studies of the adequacy of engineering safeguards and operating procedures—determined by AEC.

(4) Monitoring—adequacy of devices and sampling techniques.

g. *Noise Impacts*
(major emphasis during facility certification)

(1) Construction period levels.

(2) Operational levels.

(3) Relationship of present and projected noise levels to existing and potential stricter noise standards.

(4) Monitoring—adequacy of devices and methods.

SECTION 10 - EVALUATION OF RELATIVE ENVIRONMENTAL EFFECTS OF ALTERNATIVE SITES AND ROUTES

To the extent possible, only those sites and routes meeting acceptable standards in relation to the criteria outlined in Section 9 of these Guidelines should receive certification from the appropriate certifying agency. Regularly, however, it will be necessary in order to meet recognized electric power needs that a site or route be chosen from a set of alternatives, all of which will present some adverse environmental effects. In such cases it will be necessary for the certifying agency to establish priorities among the evaluative criteria employed. For example, in the case of transmission lines, the priority might be assigned to the land use criteria outlined in Section 9 above; in the case of fossil-fueled power plants the air quality criteria might prevail; and the water quality criteria might prevail for nuclear plants. Assignment of such priorities is not intended to eliminate full consideration of other criteria listed in Section 9, but merely provides guidance for the resolution of difficult cases where a choice among alternatives would otherwise be impossible.

SECTION 11 - FORMATION OF REGIONAL CERTIFYING AGENCY

At any time during the period that this Act is in force, including the two-year period during which programs are being established under it, two or more States may join together and apply for a Certificate of Qualification for a regional certifying agency. Such a regional agency shall be subject to all provisions of these guidelines, except that in the case of facilities located entirely within one State and with no impacts on other member States, the participation required under Section 5(a) of the Act may be limited to governmental components of that one State. It is the intention of this Section to provide maximum flexibility to States in the formation of multi-State certifying agencies under the Act.

SECTION 12 - MULTI-STATE IMPACTS

In those cases where the certifying agency authorized to operate in a State or region believes that an application under consideration by the certifying agency of an adjacent State or region will have potentially harmful effects on the environment within its jurisdiction if granted, or potentially harmful effects on the power needs within its jurisdiction if denied, it may in its own judgment choose one of the following means of involvement:

(1) Where it considers the harm to be of a major nature or conditional upon the occurrence of events considered unlikely, the certifying agency which believes its jurisdiction affected may send a letter of comment to the reviewing certifying agency of the adjacent jurisdiction.

(2) Where it considers the harm to be considerable and likely to occur, the certifying agency may enter as an intervenor the proceedings of the reviewing certifying agency of the adjacent jurisdiction.

NUCLEAR POWER PLANT LICENSING REGULATIONS PERTAINING TO ENVIRONMENTAL RADIOACTIVITY

THE CALVERT CLIFFS DECISION

On July 23, 1970 the U.S. Court of Appeals for the District of Columbia Circuit ruled on the case of the Calvert Cliffs Coordinating Committee, Inc., et al., petitioners, vs the United States Atomic Energy Commission and the United States of America, respondents. This appeal concerned an alleged failure of the AEC to implement the National Environmental Protection Act. The court found fault with the Atomic Energy Commission on four counts:

1. The procedural rules of the Atomic Energy Commission prohibit the raising of non-radiological environmental issues at any hearing if the hearing notice appeared in the Federal Register before March 4, 1971.
2. The Atomic Safety and Licensing Board is prohibited from conducting an independent evaluation and balancing of certain environmental factors if other responsible agencies have already certified that their own environmental standards are satisfied.
3. That the Atomic Safety and Licensing Board hearing need not cover environmental issues unless specifically raised by outside parties or the Atomic Energy Commission.
4. That the AEC rules provide that when a construction permit has been issued prior to January 1, 1970, but an operating license has yet to be issued, the AEC will not formally consider environmental factors or require modifications in the proposed facility until the time of issuance of the operating license.

The Court held that:

1. Environmental issues must be considered at every stage of decision making, including ASLB Hearings.
2. The AEC must consider environmental issues in connection with all licensing actions that took place after January 2, 1970.
3. The AEC must evaluate and balance environmental standards even if other federal or state agencies have certified that their own standards are satisfied.
4. The AEC must conduct a National Environmental Protection Act review and take appropriate action for cases in which construction permits have been issued before January 1, 1970, but for which operating licenses have not yet been issued.

The Atomic Energy Commission did not appeal the Court decision and, in the Federal Register of September 9, 1971, issued new guidelines and regulations to meet all the demands of the court.

For your general background information concerning licensing of nuclear power plants, the following section of the *Federal Register* is suggested:

FEDERAL REGISTER, Vol. 36, No. 35-Saturday, February 20, 1971.

TITLE 10 -- ATOMIC ENERGY

Chapter 1–Atomic Energy Commission

PART 50--LICENSING OF PRODUCTION AND UTILIZATION FACILITIES

General Design Criteria for Nuclear Power Plants

The Atomic Energy Commission has adopted an amendment to its regulations, 10 CFR Part 50, *"Licensing of Production and Utilization Facilities,"* which adds an Appendix A, *"General Design Criteria for Nuclear Power Plants."*

Section 50.34(a) of Part 50 requires that each application for a construction permit include the preliminary design of the facility. The following information is specified for inclusion as part of the preliminary design of the facility:

i. The principal design criteria for the facility.
ii. The design bases and the relation of the design bases to the principal design criteria.
iii. Information relative to materials of construction, general arrangement, and the approximate dimensions sufficient to provide [illegible] assurance that the final design [illegible] conform to the design bases with [illegible] margin for safety.

The *"General Design C[illegible] Nuclear Power Plants"* added as Appe[illegible] 50 establish the minimum requirem[illegible] design criteria for water-cooled [illegible] similar [illegible] design and location, [illegible]

(Continued on the next page)

for which construction permits have been issued by the Commission. They also provide guidance in establishing the principal design criteria for other types of nuclear power plants. Principal design criteria established by an applicant and accepted by the Commission will be incorporated by reference in the construction permit. In considering the issuance of an operating license under Part 50, the Commission will require assurance that these criteria have been satisfied in the detailed design and construction of the facility and that any changes in such criteria are justified.

A proposed Appendix A, "General Design Criteria for Nuclear Power Plant Construction Permits" to 10 CFR Part 50 was published in the FEDERAL REGISTER (32 F.R. 10213) on July 11, 1967. The comments and suggestions received in response to the notice of proposed rule making and subsequent developments in the technology and in the licensing process have been considered in developing the revised criteria which follow.

The revised criteria establish minimum requirements for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission, whereas the previously proposed criteria would have provided guidance for applicants for construction permits for all types of nuclear power plants. The revised criteria have been reduced to 55 in number, include definitions of important terms, and have been rearranged to increase their usefulness in the licensing process. Additional criteria describing specific requirements on matters covered in more general terms in the previously proposed criteria have been added to the criteria. The Categories A and B used to characterize the amount of information needed in Safety Analysis Reports concerning each criterion have been deleted since additional guidance on the amount and detail of information required to be submitted by applicants for facility licenses at the construction permit stage is now included in § 50.34 of Part 50. The term "engineered safety features" has been eliminated from the revised criteria and the requirements for "engineered safety features" incorporated in the criteria for individual systems.

Further revisions of these General Design Criteria are to be expected. In the course of the development of the revised criteria, important safety considerations were identified, but specific requirements related to some of these considerations have not as yet been sufficiently developed and uniformly applied in the licensing process to warrant their inclusion in the criteria at this time. Their omission does not relieve any applicant from considering these matters in the design of a specific facility and satisfying the necessary safety requirements. These matters include:

(i) Consideration of the need to design against single failures of passive components in fluid systems important to safety.

(ii) Consideration of redundancy and diversity requirements for fluid systems important to safety. A "system" could consist of a number of subsystems each of which is separately capable of performing the specified system safety function. The minimum acceptable redundancy and diversity of subsystems and components within a subsystem and the required interconnection and independence of the subsystems have not yet been developed or defined.

(iii) Consideration of the type, size, and orientation of possible breaks in the components of the reactor coolant pressure boundary in determining design requirements to suitably protect against postulated loss of coolant accidents.

(iv) Consideration of the possibility of systematic, nonrandom, concurrent failures of redundant elements in the design of the protection systems and reactivity control systems.

In addition, the Commission is giving consideration to the need for development of criteria relating to protection against industrial sabotage and protection against common mode failures in systems, other than the protection and reactivity control systems, that are important to safety and have extremely high reliability requirements.

It is expected that these criteria will be augmented or changed when specific requirements related to these and other considerations are suitably identified and developed.

Pursuant to the Atomic Energy Act of 1954, as amended, and sections 552 and 553 of title 5 of the United States Code, the following amendment to 10 CFR Part 50 is published as a document subject to codification to be effective 90 days after publication in the FEDERAL REGISTER. The Commission invites all interested persons who desire to submit written comments or suggestions in connection with the amendment to send them to the Secretary, U.S. Atomic Energy Commission, Washington, D.C. 20545, Attention: Chief, Public Proceedings Branch, within 45 days after publication of this notice in the FEDERAL REGISTER. Such submissions will be given consideration with the view to possible further amendments. Copies of comments may be examined in the Commission's Public Document Room at 1717 H Street NW., Washington, DC.

1. Section 50.34(a)(3)(i) is amended to read as follows:

§ 50.34 Contents of applications; technical information.

(a) *Preliminary safety analysis report.* Each application for a construction permit shall include a preliminary safety analysis report. The minimum information to be included shall consist of the following:

* * * * *

(3) The preliminary design of the facility including:

(i) The principal design criteria for the facility.* Appendix A, General Design Criteria for Nuclear Power Plants, establishes minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have previously been issued by the Commission and provides guidance to applicants for construction permits in establishing principal design criteria for other types of nuclear power units;

* * * * *

2. A new Appendix A is added to read as follows:

APPENDIX A—GENERAL DESIGN CRITERIA FOR NUCLEAR POWER PLANTS

Table of Contents

* General design criteria for chemical processing facilities are being developed.

36 FR 3255

INTRODUCTION

Pursuant to the provisions of § 50.34, an application for a construction permit must include the principal design criteria for a proposed facility. The principal design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public.

These General Design Criteria establish minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission. The General Design Criteria are also considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the principal design criteria for such other units.

The development of these General Design Criteria is not yet complete. For example, some of the definitions need further amplification. Also, some of the specific design requirements for structures, systems, and components important to safety have not as yet been suitably defined. Their omission does not relieve any applicant from considering these matters in the design of a specific facility and satisfying the necessary safety requirements. These matters include:

(1) Consideration of the need to design against single failures of passive components in fluid systems important to safety. (See Definition of Single Failure.)

(2) Consideration of redundancy and diversity requirements for fluid systems important to safety. A "system" could consist of a number of subsystems each of which is separately capable of performing the specified system safety function. The minimum acceptable redundancy and diversity of subsystems and components within a subsystem, and the required interconnection and independence of the subsystems have not yet been developed or defined. (See Criteria 34, 35, 38, 41, and 44.)

(3) Consideration of the type, size, and orientation of possible breaks in components of the reactor coolant pressure boundary in determining design requirements to suitably protect against postulated loss-of-coolant accidents. (See Definition of Loss of Coolant Accidents.)

(4) Consideration of the possibility of systematic, nonrandom, concurrent failures of redundant elements in the design of protection systems and reactivity control systems. (See Criteria 22, 24, 26, and 29.)

It is expected that the criteria will be augmented and changed from time to time as important new requirements for these and other features are developed.

There will be some water-cooled nuclear power plants for which the General Design Criteria are not sufficient and for which additional criteria must be identified and satisfied in the interest of public safety. In particular, it is expected that additional or different criteria will be needed to take into account unusual sites and environmental conditions, and for water-cooled nuclear power units of advanced design. Also, there may be water-cooled nuclear power units for which fulfillment of some of the General Design Criteria may not be necessary or appropriate. For plants such as these, departures from the General Design Criteria must be identified and justified.

DEFINITIONS AND EXPLANATIONS

Nuclear power unit. A nuclear power unit means a nuclear power reactor and associated equipment necessary for electric power generation and includes those structures, systems, and components required to provide reasonable assurance the facility can be operated without undue risk to the health and safety of the public.

Loss of coolant accidents. Loss of coolant accidents mean those postulated accidents that result from the loss of reactor coolant at a rate in excess of the capability of the reactor coolant makeup system from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.[1]

Single failure. A single failure means an occurrence which results in the loss of capability of a component to perform its intended safety functions. Multiple failures resulting from a single occurrence are considered to be a single failure. Fluid and electric systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor (2) a single failure of a passive component (assuming active components function properly), results in a loss of the capability of the system to perform its safety functions.[2]

Anticipated operational occurrences. Anticipated operational occurrences mean those conditions of normal operation which are expected to occur one or more times during the life of the nuclear power unit and include but are not limited to loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power.

[1] Further details relating to the type, size, and orientation of postulated breaks in specific components of the reactor coolant pressure boundary are under development.

[2] Single failures of passive components in electric systems should be assumed in designing against a single failure. The conditions under which a single failure of a passive component in a fluid system should be considered in designing the system against a single failure are under development.

CRITERIA

I. Overall Requirements

Criterion 1—Quality standards and records. Structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

Criterion 2—Design bases for protection against natural phenomena. Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

Criterion 3—Fire protection. Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

Criterion 4—Environmental and missile design bases. Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the environmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

ENVIRONMENTAL IMPACT EVALUATION OF THE PLANT SITE

All power plants will have some effects upon the environment. These effects may be both positive and negative.

In order to evaluate this impact a new plant would have on the immediate environment, both short-term and long-term, monitoring programs should precede construction by several years and continue through site preparation, plant construction and operation. These monitoring programs can be divided into the following categories:

A. MEASUREMENT OF THE EXISTING CHARACTERISTICS (PRE-CONSTRUCTION)

This program will establish a reference framework (base-line) for assessing subsequent environmental effects on each activity.

1. Surface Waters
   a. physical and chemical parameter sampling
   b. ecological parameter sampling
2. Ground Water
   a. physical and chemical parameter sampling
   b. ground water modeling
3. Air
   a. dispersion of water vapor data
   b. type and amount of dissolved solids and particulates carried by droplets
   c. general meteorologic data
   d. meteorological modeling
4. Land
   a. geologic data collection
   b. soil data collection
   c. land use and demographic surveys
   d. ecological surveys
5. Radiological Surveys

B. OPERATIONAL MONITORING PROGRAMS

1. Radiological monitoring
   a. in-plant monitoring system
   b. environment monitoring
2. Chemical effluent monitoring
3. Thermal effluent monitoring
4. Meteorological monitoring
5. Ecological monitoring

The initial monitoring programs provide the base-line data needed to prepare an *"environmental report"* required from any company proposing a new plant. This requirement may be both federal or state or both. Within the federal government, the basic legislation is in the National Environmental Policy Act of 1969. Today, many interstate basin commissions and individual states also have laws and regulations that demand environmental reports from companies planning any new facility that may have an adverse effect on the quality of the environment.

In Pennsylvania, for example, it would be virtually impossible for a new electrical generating plant to be built without the preparation of such an environmental report and subsequent environmental impact statement.

After a company submits its environmental report, the requesting authority prepares an environmental impact statement. In the case of nuclear power plants, this statement is prepared by the Directorate of Licensing of the U.S. Atomic Energy Commission, whereas for other types of power plants, the statement is written by the appropriate basin commission or, in some cases, by the company itself.

The following subjects are always addressed in an environmental report and evaluated in the *"Environmental Impact Statement (EIS)."*

Existing Site Environment

Site Location

A detailed contour map showing state, county, and smaller political subdivisions; plant perimeter; exclusion area boundary (nuclear plants); utility property; service area; water bodies; all towns and cities and size; public facilities; and transportation networks.

Regional Historic and Natural Landmarks

This should include a brief discussion of any historic or natural significance of the site and surrounding area. This would include any that are mentioned in the *"National Register of Historic Places" and the "National Registry of Natural Landmarks"* as well as all state and local historical societies. All archaeologically significant areas would also be included.

Geology

Major geological aspects of the site and vicinity should be described; should include: soil, rock types, faults, seismic history, regional radiological data.

Hydrology

Physical, chemical, and hydrological characteristics of surface and ground waters; field tests on an adjacent area to the site; monthly and daily summaries of important parameters such as temperature, flow rate, water table height, chemical stratification, and circulation patterns.

Meterology

Data on site must include: diurnal and monthly averages and extremes of temperature and humidity, wind characteristics, precipitation data, frequency and effects of high velocity wind storms.

Ecology

Identify important local flora and fauna, their habitats and distribution, and relationship between species. Pre-existing environmental stresses should be defined.

The Plant

External Appearance

The buildings profile should be illustrated. Efforts should be made to make the structures and grounds aesthetically pleasing. The location and elevation of release points for liquid and gaseous wastes should be indicated.

Plant Water Use

A quantitative water-use diagram should be presented. Total consumtive use should be shown.

Radwaste, Sanitary, and Other Waste Systems

Include flow diagram of waste systems showing origin, treatment, and disposal of all solid, liquid, and gaseous wastes generated.

Chemical and Biocide Systems

Describe chemical additives, corrosion products, waste streams or discharges from chemical processing and water treatment that may enter the local environment as a result of plant operation.

Transmission Facilities

A contour map or aerial photos should show proposed rights-of-way and existing substations, lengths and widths should be specified, access roads, land-use adjacent to right-of-way, construction changes to land needed, underground construction if any, and the type, color, and visibility of transmission structures from frequently traveled public roads.

Environmental Effects of Site Preparation and Plant Construction

The construction of a power plant and related facilities will inevitably effect the environment. Some of these effects will be adverse. This part of the *"Environmental Report"* would include a description of the anticipated effects.

Effects of Site Prep and Construction on Land Use

This would include a description of how construction activities may disturb the existing terrain and wildlife habitats. Also included are those effects that would be beneficial, as, for example, the use of excess soil to create playgrounds and other recreational facilities.

Effects of Site Prep and Construction on Water Use

This should be a description of the impingement of site preparation and construction activities on lakes, rivers, and/or ground water.

Transmission Facilities Construction

Includes the effects of construction and installation of transmission line towers and facilities on the land and on the people.

Resources Committed

A discussion of any irreversible and irretrievable commitments of land, flora and fauna which are expected if construction and operation of the plant should become a reality.

CHAPTER 9

ENERGY CONSERVATION

Until recent years, energy was cheap and abundant in the United States and there seemed no need for conservation. But matters have changed drastically, particularly since the Near East embargo on oil exports. Conservation of energy resources, which means making the best and wisest use of these resources, was forced on the American public. We are urged to conserve gasoline, natural gas, fuel oil and electricity.

Increases in the price of these products have helped promote conservation, and there have been some short-term savings in energy. Obvious measures, such as cutting down on display lighting, reducing thermostat settings in winter and reducing driving, have helped cut energy use.

We can consider two major thrusts in the area of energy conservation. One is the research and development programs being carried out by government agencies, utilities, and industries in an effort to make better use of energy resources. The other is the awareness that each of us as consumers should have of ways in which we can conserve energy.

A major example of research in conservation technology is that being carried out through the National Conservation Research, Development and Demonstration Programs funded through ERDA. Some of the aims of these programs are as follows: improving reliability and cutting energy losses in electrical distribution systems; developing methods for energy storage; assisting industry in becoming more efficient in their use of energy; developing uses for waste heat; developing economically feasible methods of decreasing energy loss from existing buildings; developing improved designs for new buildings to reduce energy consumption; disseminating information on the energy efficiency of appliances; and encouraging industry to develop more energy-efficient products.

There are many things we can do in our homes each day to reduce the use of energy. Heating and cooling systems are the greatest energy users in our homes. There are many ways to save on energy in this area. The first is adequate insulation. Since the greatest amount of heat loss or gain is usually through the roof, proper attic insulation is a must. So is insulation in outside walls and in floors covering unheated areas. Weatherstripping, caulking and storm doors and windows also help to keep heat loss at a minimum in winter. During winter, a maximum daytime temperature of 68 degrees is recommended. This should be several degrees lower at night and when you are away for a while. During the summer, 78 degrees is a comfortable temperature. Since high humidity makes us feel warmer, a humidifier in the winter and a dehumidifer in the summer may help save energy in the long run. In the winter, the air from an electric clothes dryer can be vented into the house to add warmth and moisture. The proper use of lined or insulated drapes can help control a home's temperature. On sunny winter days, they should be opened to let the sun help warm the house. Otherwide, they should be closed in winter. On sunny summer days, the drapes should be closed to keep the sun out. If possible, unused rooms of a home should not be heated or cooled. Air conditioner and heater vents or outlets should not be obstructed by furniture or drapes. Heating and cooling equipment should be kept clean and properly adjusted to operate more efficiently.

Heating water usually consumes the second largest amount of energy in our homes. There are several ways to reduce energy requirements in this area. In buying a water heater, choose one with high efficiency and good insulation. Get only the size needed, since too large a tank wastes energy. Try to place the water heater as near as possible to the major areas of hot water use to minimize heat loss in the pipes. Do not set the thermostat higher than necessary and use hot water only when necessary for laundry and dishwashing-cool or warm water can often be substituted. Eliminate leaks in faucets, particularly hot water leaks.

Proper use of home appliances can further cut energy use. For example, open and close refrigerator and freezer doors only when necessary. Use the smaller burner and smaller oven in the kitchen range whenever possible. Wash only full loads in dishwashers and clothes washers. It may be possible to eliminate the drying cycle on the dishwasher by simply opening the door when the wash cycle is finished and letting the hot dishes air dry. Save energy by always turning off lights shen leaving a room-even if only for a few minutes. Use fluorescent lamps wherever possible, since they use much less energy than incandescent bulbs for the same amount of light.

As we have seen, electricity cannot be efficiently stored, but must be generated as needed. Thus, utilities must be equipped to generate enough electricity to meet peak demands, even though much of the equipment is not needed at other times. So, it is helpful to use electrical power when demand is low. The peak times are between 5 p.m. and 8 p.m. in winter and between 1 p.m. and 5 p.m. in summer. There is even talk of charging less for electricity used during nonpeak hours, as is now the case with long-distance phone calls.

Various consumer groups have calculated that home consumption of energy could be reduced by 15 per cent by common-sense avoidance of waste.

There is simply not enough energy to go around at the rate we are now using it. We must find ways to reduce consumption and make the best use of the resources we have. In doing this, we must remember that we are not the last generation of people on earth.

SUPPLEMENTARY
MATERIALS
FOR
CHAPTER 9

EFFICIENCY OF ENERGY USE IN THE UNITED STATES, Eric Hirst and John Meyers, *Science*, March 30, 1973.

Conflicts between the demand for energy and environmental quality goals can be resolved in several ways. The two most important are (i) development and use of pollution control technologies and of improved energy-conversion technologies, and (ii) the improvement in efficiency of energy use. Increased efficiency of energy use would help to slow energy growth rates, thereby relieving pressure on scarce energy resources and reducing environmental problems associated with energy production, conversion, and use.

Between 1950 and 1970, U.S. consumption of energy resources (coal, oil, natural gas, falling water, and uranium) doubled (1), with a average annual growth rate of 3.5 per cent–more than twice the population growth rate.

Energy resources are used for many purposes in the United States (2) (Table 1). In 1970, transportation of people and freight consumed 25 per cent of total energy, primarily as petroleum. Space heating of homes and commercial establishments was the second largest end-use, consuming an additional 18 per cent. Industrial uses of energy (process steam, direct heat, electric drive, fuels used as raw materials (3), and electrolytic processes) accounted for 42 per cent. The remaining 15 per cent was used by the commerical and residential sectors for water heating, air conditioning, refrigeration, cooking, lighting, operation of small appliances and other miscellaneous purposes.

During the 1960's, the percentage of energy consumed for electric drive, raw materials, air conditioning, refrigeration and electrolytic processes increased relative to the total. Air conditioning showed the largest relative growth, increasing its share of total energy use by 81 per cent, while the other uses noted increased their shares of the total by less than 10 per cent in this period.

The growth in energy consumption by air conditioners, refrigerators, electric drive, and electrolytic processes–coupled with the substitution of electricity for direct fossil fuel combustion for some space and water heating, cooking, and industrial heat–accounts for the rapid growth in electricity consumption. Between 1960 and 1970, while consumption of primary energy (1) grew by 51 per cent, the use of electricity (4) grew by 104 per cent. The increasing use of electricity relative to the primary fuels is an important factor accounting for energy growth rates because of the inherently low efficiency of electricity generation, transmission, and distribution which averaged 30 per cent during this decade (1,4). In 1970, electrical generation (4) accounted for 24 per cent of energy resource consumption as compared to 19 per cent in 1960.

Industry, the largest energy user, includes manufacturing; mining; and agriculture, forestry, and fisheries. Six manufacturers–of primary metals; of chemicals; of petroleum and coal; of stone, clay, and glass; of paper; and of food–account for half of industrial energy consumption (5), equivalent to 20 per cent of the total energy budget.

Energy consumption is determined by at least three factors: population, affluence, and efficiency of use. In this article we describe three areas in which energy-efficiency improvements (the third factor) might be particularly important: (i) transportation of people and freight, (ii) space heating, and (iii) space cooling (air conditioning).

Energy efficiency varies considerably among the different passenger and freight transport modes. Shifts from energy-intensive modes (airplanes, trucks, automobiles) to energy-efficient modes (boats, pipelines, trains, buses) could significantly reduce energy consumption. Increasing the amount of building insulation could reduce both space-heating and air-conditioning energy consumption in homes and save money for the homeowner. Energy consumption of air conditioning could be greatly reduced through the use of units that are more energy efficient.

Transportation

Transportation of people and goods consumed 16,500 trillion British thermal units (6) in 1970 (25 per cent of total energy consumption) (1). Energy requirements for transportation increased by 89 per cent between 1950 and 1970, an average annual growth rate of 3.2 per cent.

Increases in transportation energy consumption (7) are due to (i) growth in traffic levels, (ii) shifts toward the use of less energy-efficient transport modes, and (iii) declines in energy efficiency for individual modes. Energy intensiveness, the inverse of energy efficiency, is expressed here as British thermal units per ton-mile for freight and as British thermal units per passenger-mile for passenger traffic.

Table 2 shows approximate values (8) for energy consumption and average revenue in 1970 for intercity freight modes; the large range in energy efficiency among modes is noteworthy. Pipelines and waterways (barges and boats) are very efficient; however, they are limited in the kinds of materials they can transport and in the flexibility of their pickup and delivery points. Railroads are slightly less efficient than pipelines. Trucks, which are faster and more flexible than the preceding three modes, are, with respect to energy, only one-fourth as efficient as railroads. Airplanes, the fastest mode, are only 1/60 as efficient as trains.

The variation in freight prices shown in Table 2 closely parallels the variation in energy

intensiveness. The increased prices of the less efficient modes reflect their greater speed, flexibility, and reliability.

Table 3 gives approximate 1970 energy and price data for various passenger modes (8). For intercity passenger traffic, trains and buses are the most efficient modes. Cars are less than one-half as efficient as buses, and airplanes are only one-fifth as efficient as buses.

For urban passenger traffic, mass transit systems (of which about 60 per cent are bus systems) are more than twice as energy efficient as automobiles. Walking and bicycling are an order of magnitude more efficient than autos, on the basis of energy consumption to produce food. Urban values of efficiency for cars and buses are much lower than intercity values because of poorer vehicle performance (fewer miles per gallon) and poorer utilization (fewer passengers per vehicle).

Passenger transport prices are also shown in Table 3. The correlation between energy intensiveness and price, while positive, is not as strong as for freight transport. Again, the differences in price reflect the increased values of the more energy-intensive modes.

The transportation scenario for 1970 shown in Table 4 gives energy savings that may be possible through increased use of more efficient modes. The first calculation uses the actual 1970 transportation patterns. The scenario—entirely speculative—indicates the potential energy savings that could have occurred through shifts to more efficient transport modes. In this hypothetical scenario, half the freight traffic carried by truck and by airplane is assumed to have been carried by rail; half the intercity passenger traffic carried by airplane and one-third the traffic carried by car are assumed to have been carried by bus and train; and half the urban automobile traffic is assumed to have been carried by bus. The load factors (percentage of transport capacity utilized) and prices are assumed to be the same for both calculations. The scenario ignores several factors that might inhibit shifts to energy-efficient transport modes, such as existing land-use patterns, capital costs, changes in energy efficiency within a given mode, substitutability among modes, new technologies, transportation ownership patterns, and other institutional arrangements.

The hypothetical scenario requires only 78 per cent as much energy to move the same traffic as does the actual calculation. This savings of 2800 trillion Btu is equal to 4 per cent of the total 1970 energy budget. The scenario also results in a total transportation cost that is $19 billion less than the actual 1970 cost (a 12 per cent reduction). The dollar savings (which includes the energy saved) must be balanced against any losses in speed, comfort, and flexibility resulting from a shift to energy-efficient modes.

To some extent, the current mix of transport modes is optimal, chosen in response to a variety of factors. However, noninternalized social costs, such as noise and air pollution and various government activities (regulations, subsidization, research), may tend to distort the mix, and, therefore, present modal patterns may not be socially optimal.

Present trends in modal mix are determined by personal preference, private economics, convenience, speed, reliability, and government policy. Emerging factors such as fuel scarcities, rising energy prices, dependence on petroleum imports, urban land-use problems, and environmental quality considerations may provide incentives to shift transportation patterns toward greater energy efficiency.

Space Heating

The largest single energy consuming function in the home is space heating. In an average all-electric home in a moderate climate, space heating uses over half the energy delivered to the home; in gas- or oil-heated homes, the fraction is probably larger because the importance of thermal insulation has not been stressed where these fuels are used.

The nearest approach to a national standard for thermal insulation in residential construction is *"Minimum Property Standards (MPS) for One and Two Living Units"* issued by the Federal Housing Administration (FHA). In June 1971, FHA revised the MPS to require more insulation, with the stated objectives of reducing air pollution and fuel consumption.

A recent study (9) estimated the value of different amounts of thermal insulation in terms both of dollar savings to the homeowner and of reduction in energy consumption. Hypothetical model homes (1800 square feet) were placed in three climatic regions, each representing one-third of the U.S. population. The three regions were represented by Atlanta, New York and Minneapolis.

As an example of the findings of the study, Table 5 presents the results applicable to a New York residence, including the insulation requirements of the unrevised and the revised MPS, the insulation that yields the maximum economic benefit to the homeowner, and the monetary and energy savings that result in each case. The net monetary savings are given after recovery of the cost of the insulation installation, and would be realized each year of the lifetime of the home. A mortgage interest rate of 7 per cent was assumed.

The revised MPS provide appreciable savings in energy consumption and in the cost of heating a residence, although more insulation is needed to minimize the long-term cost to the homeowner. A further increase in insulation requirements would increase both dollar and energy savings.

The total energy consumption of the United States (1) in 1970 was 67,000 trillion Btu, and about 11 per cent was devoted to residential space heating and 7 per cent to commercial space heating (2). Table 5 shows reductions in energy required for space heating of 49 per cent for gas-heated homes and 47 per cent for electric-heated homes in the New York area by going from the MPS-required insulation in 1970 to the economically optimum amount of insulation. The nationwide average reductions are 43 per cent for gas-heated homes and 41 per cent for electric-heated homes. An average savings of 42 per cent, applied to the space heating energy requirements for all residential units (single family and apartment, gas and electric), would have amounted to 3,100 trillion Btu in 1970 (4.6 per cent of total energy consumption). The energy savings are somewhat understated—as insulation is added, the heat from lights, stoves, refrigerators, and other appliances becomes a significant part of the total heat required. The use of additional insulation also reduces the energy consumption for air conditioning as discussed later.

Electrical resistance heating is more wasteful of primary energy than is direct combustion heating. The average efficiency for electric power plants (1) in the United States is about 33 per cent, and the efficiency (4) of transmitting and distributing the power to the customer is about 91 per cent. The end-use efficiency of electrical resistance heating is 100 per cent; so the overall efficiency is approximately 30 per cent. Thus, for every unit of heat delivered in the home, 3.3 units of heat must be extracted from the fuel at the power plant. Conversely, the end-use efficiency of gas- or oil-burning home heating systems is about 60 per cent (claimed values range from 40 to 80 per cent), meaning that 1.70 units of heat must be extracted from the fuel for each unit delivered to the living area of the home. Therefore, the electrically heated home requires about twice as much fuel per unit of heat as the gas- or oil-heated home, assuming equivalent insulation.

The debate about whether gas, oil, or electric-resistance space heating is better from a conservation point of view may soon be moot because of the shortage of natural gas and petroleum. The use of electricity generated by nuclear plants for this purpose can be argued to be a more prudent use of resources than is the combustion of natural gas or oil for its energy content. Heating by coal-generated electricity may also be preferable to heating by gas or oil in that a plentiful resource is used and dwindling resources are conserved.

The use of electrical heat pumps could equalize the positions of electric-, oil-, and gas-heating systems from a fuel conservation standpoint. The heat pump delivers about 2 units of heat energy for each unit of electric energy that it consumes. Therefore, only 1.7 units of fuel energy would be required at the power plant for each unit of delivered heat, essentially the same as that required for fueling a home furnace.

Heat pumps are not initially expensive when installed in conjunction with central air conditioning; the basic equipment and air handling systems are the same for both heating and cooling. A major impediment to their widespread use has been high maintenance cost associated with equipment failure. Several manufacturers of heat pumps have carried out extensive programs to improve component reliability that, if successful, should improve acceptance by homeowners.

Space Cooling

In all-electric homes, air conditioning ranks third as a major energy-consuming function, behind space heating and water heating. Air conditioning is particularly important because it contributes to or is the cause of the annual peak load that occurs in the summertime for many utility systems.

In addition to reducing the energy required for space heating, the ample use of thermal insulation reduces the energy required for air conditioning. In the New York case, use of the economically optimum amount of insulation results in a reduction of the electricity consumed for air conditioning of 26 per cent for the gas home or 18 per cent for the electric home, compared to the 1970 MPS-compliance homes.

The popularity of room air conditioners is evidenced by an exponential sales growth with a doubling time of 5 years over the past decade; almost 6 million were sold in 1970. The strong growth in sales is expected to continue since industry statistics show a market saturation of only about 40 per cent.

There are about 1,400 models of room air conditioners available on the market today, sold under 52 different brand names (10). A characteristic of the machines that varies widely but is not normally advertised is the efficiency with which energy is converted to cooling. Efficiency ranges from 4.7 to 12.2 Btu per watt-hour. Thus the least efficient machine consumes 2.6 times as much electricity per unit of cooling as the most efficient one. Figure 1 shows the efficiencies of all units having ratings up to 24,000 Btu per hour, as listed in (10).

From an economic point of view, the purchaser should select the particular model of air conditioner that provides the needed cooling capacity and the lowest total cost (capital, maintenance, operation) over the unit's lifetime. Because of the large number of models available and the general ignorance of the fact that such a range of efficiencies exists, the most economical choice is not likely to be made. An industry-sponsored certification program requires that the cooling rating and wattage input be listed on the nameplate of each unit, providing the basic information required for determining efficiency. However, the nameplate is often hard to locate and does not state the efficiency explicitly.

The magnitude of possible savings that would result from buying a more efficient unit is illustrated by the following case. Of the 90 models with a

capacity of 10,000 Btu per hour, the lowest efficiency model draws 2100 watts and the highest efficiency model draws 880 watts. In Washington, D.C., the average room air conditioner operates about 800 hours per year. The low-efficiency unit would use 976 kilowatt-hours more electricity each year than the high-efficiency unit. At 1.8 cents per killowatt-hour, the operating cost would increase by $17.57 per year. The air conditioner could be expected to have a life of 10 years. If the purchaser operates on a credit card economy with an 18 per cent interest rate, he would be economically justified in paying up to $79 more for the high-efficiency unit. If his interest rate were 6 per cent, an additional purchase price of $130 would be justified.

In the above example, the two units were assumed to operate the same number of hours per year. However, many of the low-priced, low-efficiency units are not equipped with thermostats. As a result, they may operate almost continuously, with a lower-than-desired room temperature. This compounds the inefficiency and, in addition, shortens the lifetime of the units.

In addition to the probable economic advantage to the consumer, an improvement in the average efficiency of room air conditioners would result in appreciable reductions in the nation's energy consumption and required generating capacity. If the size distribution of all existing room units is that for the 1970 sales, the average efficiency (10) is 6 Btu per watt-hour, and the average annual operating time is 886 hours per year, then the nation's room air conditioners consumed 39.4 billion kilowatt-hours during 1970. On the same basis, the connected load was 44,500 megawatts, and the annual equivalent coal consumption was 18.9 million tons. If the assumed efficiency is changed to 10 Btu per watt-hour, the annual power consumption would have been 23.6 billion kilowatt hours, a reduction of 15.8 billion kilowatt-hours. The connected load would have decreased to 26,700 megawatts, a reduction of 17,800 megawatts. The annual coal consumption for room air conditioners would have been 11.3 million tons, a reduction of 7.6 million tons, or at a typical strip mine yield of 5000 tons per acre, a reduction in stripped area of 1500 acres in 1970.

Other Potential Energy Savings

Energy-efficiency improvements can be effected for other end uses of energy besides the three considered here. Improved appliance design could increase the energy efficiency of hot-water heaters, stoves, and refrigerators. The use of solar energy for residential space and water heating is technologically feasible and might some day be economically feasible. Alternatively, waste heat from air conditioners could be used for water heating. Improved design or elimination of gas pilot lights and elimination of gas yard lights would also provide energy savings (11). Increased energy efficiency within homes would tend to reduce summer air-conditioning loads.

In the commercial sector, energy savings in space heating and cooling such as those described earlier are possible. In addition, the use of total energy systems (on-site generation of electricity and the use of waste heat for space and water heating and absorption air conditioning) would increase the overall energy efficiency of commercial operations.

Commercial lighting accounts for about 10 per cent of total electricity consumption (12). Some architects claim that currently recommended lighting levels can be reduced without danger to eyesight or worker performance (13). Such reduction would save energy directly and by reducing air-conditioning loads. Alternatively, waste heat from lighting can be circulated in winter for space heating and shunted outdoors in summer to reduce air-conditioning loads.

Changes in building design practices might effect energy savings (13). Such changes could include use of less glass and of windows that open for circulation of outside air.

Waste heat and low temperature steam from electric power plants may be useful for certain industries and for space heating in urban districts (14). This thermal energy (about 8 per cent of energy consumption in 1970) (15) could be used for industrial process steam, space heating, water heating, and air conditioning in a carefully planned urban complex.

The manufacture of a few basic materials accounts for a large fraction of industrial energy consumption. Increased recycle of energy-intensive materials such as aluminum, steel, and paper would save energy. Saving could also come from lower production of certain materials. For example, the production of packaging materials (paper, metal, glass, plastic, wood) requires about 4 per cent of the total energy budget. In general, it may be possible to design products and choose materials to decrease the use of packaging and to reduce energy costs per unit of production.

Implementation

Changes in *energy prices*, both levels and rate structures, would influence decisions concerning capital versus life costs, and this would affect the use of energy-conserving technologies. *Public education* to increase awareness of energy problems might heighten consumer sensitivity toward personal energy consumption. Various local, state, and federal *government policies* exist that, directly and indirectly, influence the efficiency of energy use. These three routes are not independent; in particular, government policies could affect prices or public education (or both) on energy use.

One major factor that promotes energy consumption is the low price of energy. A typical family in the United States spends about 5 per cent of its annual budget on electricity, gas, and gasoline. The cost of fuels and electricity to manufacturers is about 1.5 per cent of the value of their total

shipments. Because the price of energy is low relative to other costs, efficient use of energy has not been of great importance in the economy. Not only are fuel prices low, but historically they have declined relative to other prices.

The downward trend in the relative price of energy has begun to reverse because of the growing scarcity of fuels, increasing costs of both money and energy-conversion facilities (power plants, petroleum refineries), and the need to internalize social costs of energy production and use. The impact of rising energy prices on demand is difficult to assess.

The factors cited above (fuel scarcity, rising costs, environmental constraints) are likely to influence energy price structures as well as levels. If these factors tend to increase energy prices uniformly (per Btu delivered), then energy price structures will become flatter; that is, the percentage difference in price between the first and last unit purchased by a customer will be less than that under existing rate structures. The impact of such rate structure changes on the demand for energy is unknown, and research is needed.

Increases in the price of energy should decrease the quantity demanded and this is likely to encourage more efficient use of energy. For example, if the price of gasoline rises, there will probably be a shift to the use of smaller cars and perhaps to the use of public transportation systems.

Public education programs may slow energy demand. As Americans understand better the environmental problems associated with energy production and use, they may voluntarily decrease their personal energy-consumption growth rates. Experiences in New York City and in Sweden with energy-conservation advertising programs showed that the public is willing and able to conserve energy, at least during short-term emergencies.

Consumers can be educated about the energy consumption of various appliances. The energy-efficiency data for air conditioners presented here are probably not familiar to most prospective buyers of air conditioners. If consumers understood energy and dollar costs of low-efficiency units, perhaps they would opt for more expensive, high-efficiency units to save money over the lifetime of the unit and also to reduce environmental impacts. Recently, at least two air-conditioner manufacturers began marketing campaigns that stress energy efficiency. Some electric utilities have also begun to urge their customers to use electricity conservatively and efficiently.

Public education can be achieved through government publications or government regulations, for example, by requiring labels on appliances which state the energy efficiency and provide estimates of operating costs. Advertisements for energy-consuming equipment might be required to state the energy efficiency.

Federal policies, reflected in research expenditures, construction of facilities, taxes and subsidies, influence energy consumption. For example, the federal government spends several billion dollars annually on highway, airway, and airport construction, but nothing is spent for railway and railroad construction. Until recently, federal transportation research and development funds were allocated almost exclusively to air and highway travel. Passage of the Urban Mass Transportation Act, establishment of the National Railroad Passenger Corporation (AMTRAK), plus increases in research funds for rail and mass transport may increase the use of these energy-efficient travel modes.

Similarly, through agencies such as the Tennessee Valley Authority, the federal government subsidizes the cost of electricity. The reduced price for public power customers increases electricity consumption over what it would otherwise be.

Governments also influence energy consumption directly and indirectly through allowances for depletion of resources, purchase specifications (to require recycled paper, for example), management of public energy holdings, regulation of gas and electric utility rate levels and structures, restrictions on energy promotion, and establishment of minimum energy performance standards for appliances and housing.

The federal government spends about $0.5 billion a year on research and development for civilian energy, of which the vast majority is devoted to energy supply technologies (16):

...Until recently only severely limited funds were available for developing a detailed understanding of the ways in which the nation uses energy...The recently instituted Research Applied to National Needs (RANN) Directorate for the National Science Foundation...has been supporting research directed toward developing a detailed understanding of the way in which the country utilizes energy. ...This program also seeks to examine the options for meeting the needs of society at reduced energy and environmental costs.

Perhaps new research on energy use will reveal additional ways to reduce energy growth rates.

Summary

We described three uses of energy for which greater efficiency is feasible: transportation, space heating, and air conditioning. Shifts to less energy-intensive transportation modes could substantially reduce energy consumption; the magnitude of such savings would, of course, depend on the extent of such shifts and possible load factor changes. The hypothetical transportation scenario described here results in a 22 per cent savings in

energy for transportation in 1970, a savings of 2800 trillion Btu.

To the homeowner, increasing the amount of building insulation and, in some cases, adding storm windows would reduce energy consumption and provide monetary savings. If all homes in 1970 had the "*economic optimum*" amount of insulation, energy consumption for residential heating would have been 42 per cent less than if the homes were insulated to meet the pre-1971 FHA standards, a savings of 3100 trillion Btu.

Increased utilization of energy-efficient air conditioners and of building insulation would provide significant energy savings and help to reduce peak power demands during the summer. A 67 per cent increase in energy efficiency for room air conditioners would have saved 15.8 billion kilowatt-hours in 1970.

In conclusion, it is possible from an engineering point of view to effect considerable energy savings in the United States. Increases in the efficiency of energy use would provide desired end results with smaller energy inputs. Such measures will not reduce the *level* of energy consumption, but they could slow energy growth *rates*.

References and Notes

1. Bureau of Mines, *U.S. Energy Use at New High in 1971* (News Release, 31 March 1972).
2. Stanford Research Institute, *Patterns of Energy Consumption in the United States* Menlo Park, Calif., November 1971).
3. In this article all fuels used as raw materials are charged to the industrial sector, although fuels are also used as feedstocks by the commercial and transportation sectors.
4. Edison Electric Institute, *Statistical Yearbook of the Electric Utility Industry for 1970* (Edison Electric Institute, New York, 1971).
5. U.S. Bureau of the Census, 1967 *Census of Manufacturers, Fuels and Electric Energy Consumed* (MC67 (S)-4. Government Printing Office, Washington, D.C. 1971).
6. Conversion factors are: from British thermal units to joules (1055), from miles to meters (1609), from inches to meters (0.0254), from acres to square meters (4047), and from tons to kilograms (907).
7. E. Hirst, *Energy Consumption for Transportation in the U.S., (Oak Ridge National Laboratory Report ORNL-NSF-EP-15, Oak Ridge, Tenn. 1972);* R. A. Rice, "System energy as a factor in considering future transportation," presented at American Society of Mechanical Engineers annual meeting, December 1970).
8. Energy efficiency and unit revenue values for 1970 are computed in E. Hirst, *Energy Intensiveness of Passenger and Freight Transport Modes: 1950-1970* (Oak Ridge National Laboratory Report ORNL-NSF-EP 44. Oak Ridge, Tenn., 1973).
9. J. C. Moyers, *The Value of Thermal Insulation in Residential Construction Economics and the Conservation of Energy* (Oak Ridge National Laboratory Report ORNL-NSF-EP-9. Oak Ridge, Tenn., December 1971).
10. Association of Home Appliance Manufacturers, 1971 *Directory of Certified Room Air Conditioners,* 15 June 1971.
11. Hittman Associates, *Residential Energy Consumption--Phase I Report,* No. HUD-HAI-1, (Columbia, Md., March 1972).
12. C. M. Cryler, General Electric Company, private communication.
13. R. G. Stein, "*Architecture and Energy,*" presented at the annual meeting of the American Association for the Advancement of Science, Philadelphia, 29 December 1971.
14. A. J. Miller, et al., *Use of Steam-Electric Power Plants to Provide Thermal Energy to Urban Areas* (Oak Ridge National Laboratory Report ORNL-HUD-14, Oak Ridge, Tenn. 1971).
15. R. M. Jimeson and G. G. Adkins, "*Factors in waste heat disposal associated with power generation,*" presented at the American Institute of Chemical Engineers national meeting, Houston, texas, March 1971).
16. National Science Foundation RANN *Program, Summary Report of the Cornell Workshop on Energy and the Environment, 22 to 24 February 1972,* Senate Committee on Interior and Insular Affairs, No. 92-23, May 1972 (Government Printing Office, Washington, D.C. 1972).

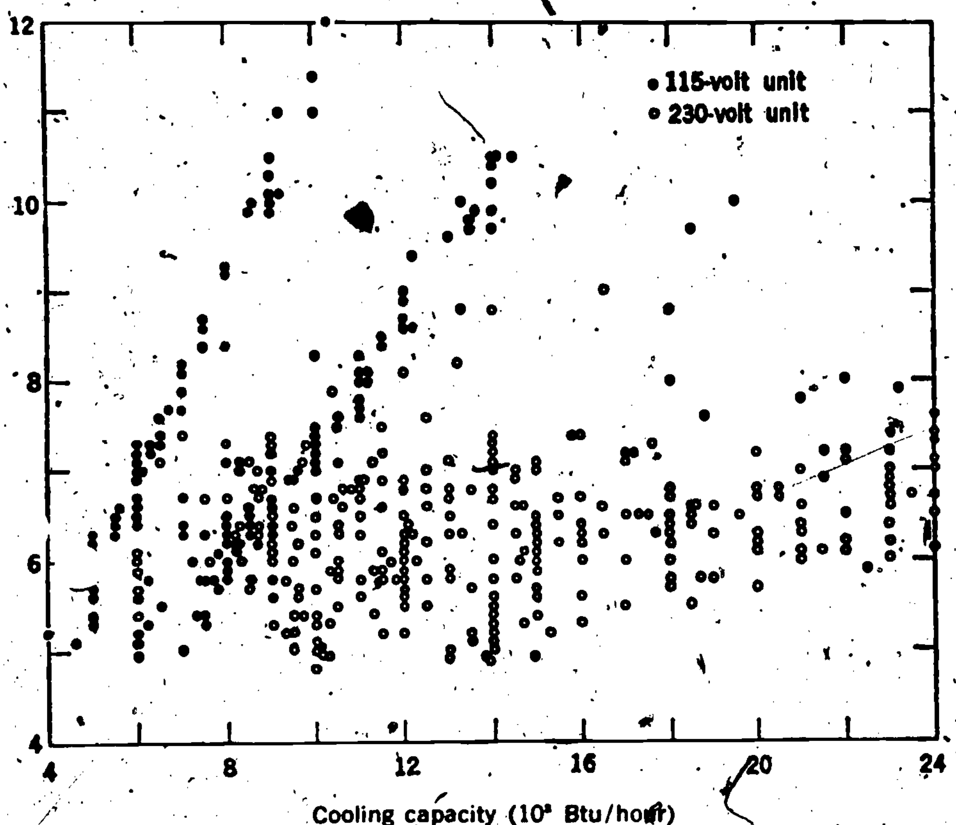


Fig. 1. Efficiency of room air conditioners as a function of unit size.

Table 1. End-uses of energy in the United States.

Item	1960* (%)	1970† (%)
Transportation	25.2	24.7
Space heating	18.5	17.7
Process steam	17.8	16.4
Direct heat	12.9	11.0
Electric drive	7.4	8.1
Raw materials	5.2	5.6
Water heating	4.0	4.0
Air conditioning	1.6	2.9
Refrigeration	2.1	2.3
Cooking	1.5	1.2
Electrolytic processes	1.1	1.2
Other‡	2.7	4.9

* Data for 1960 obtained from Stanford Research Institute (SRI) (2). † Estimates for 1970 obtained by extrapolating changes in energy-use patterns from SRI data. ‡ Includes clothes drying, small appliances, lighting, and other miscellaneous energy uses.

Table 2. Energy and price data for intercity freight transport.

Mode	Energy (Btu/ton-mile)	Price (cents/ton-mile)
Pipeline	450	0.27
Railroad	670	1.4
Waterway	680	0.30
Truck	2,800	7.5
Airplane	42,000	21.9

Table 3. Energy and price data for passenger transport.

Mode	Energy (Btu/passenger-mile)	Price (cents/passenger-mile)
	*Intercity**	
Bus	1600	3.6
Railroad	2900	4.0
Automobile	3400	4.0
Airplane	8400	6.0
	Urban†	
Mass transit	3800	8.3
Automobile	8100	9.6

* Load factors (percentage of transport capacity utilized) for intercity travel are about: bus, 45 percent; railroad, 35 percent; automobile, 48 percent; and airplane, 50 percent. † Load factors for urban travel are about: mass transit, 20 percent; and automobile, 28 percent.

Table 4. Actual and hypothetical energy consumption patterns for transportation in 1970.

	Total traffic	Percentage of total traffic						Total energy (10^{12} Btu)	Total cost (10^{9} $)
		Air	Truck	Rail	Waterway and pipeline	Auto	Bus*		
				Intercity freight traffic					
Actual	2210†	0.2	19	35	46			2400	45
Hypothetical	2210	0.1	9	44	46			1900	33
				Intercity passenger traffic					
Actual	1120‡	10		1		87	2	4300	47
Hypothetical	1120	5		12		58	25	3500	45
				Urban passenger traffic					
Actual	710‡					97	3	5700	68
Hypothetical	710					49	51	4200	63
				Totals					
Actual								12,400	160
Hypothetical								9600	141

* Intercity bus or urban mass transit. † Billion ton-miles. ‡ Billion passenger-miles.

Table 5. Comparison of insulation requirements and monetary and energy savings for a New York residence.

Insulation specification	Unrevised MPS*		Revised MPS*		Economic optimum	
	Gas	Electric	Gas	Electric	Gas	Electric
Wall insulation thickness (inches)	0	1⅞	1⅞	1⅞	3½	3½
Ceiling insulation thickness (inches)	1⅞	1⅞	3½	3½	3½	6
Floor insulation	No	No	Yes	Yes	Yes	Yes
Storm windows	No	No	No	No	Yes	Yes
Monetary savings ($/yr)	0	0	28	75	32	155
Reduction of energy consumption (%)	0	0	29	19	49	47

* Minimum property standards (MPS) for one and two living units.

200

ENERGY CONSERVATION PUT IN PERSPECTIVE

by: R. L. Dunning, Manager, Energy Utilization Project, Power Systems Planning Dept., Westinghouse Electric Corp., Pittsburgh, Pa.

In order to make energy conservation meaningful, the various choices open to the public must be pinpointed, along with their contribution toward a goal. Only in this way can intelligent choices be made.

The energy crisis has generated a great deal of information on how to save energy. Some of these suggestions are good; others are almost worthless. And none of this information puts into perspective the amont of energy actually saved. For efforts to be meaningful, however, it is important to know not only how great a given energy saving is, but its overall contribution in terms of the job that has to be done. It makes no sense to expend a great deal of effort for an insignificant return, while at the same time overlooking a potentially large area of savings.

With the lifting of the oil embargo, the immediate pressures to conserve energy are also lifted. But this does not mean that the need to conserve energy in all segments of the economy–especially oil and gas–has been eliminated. Indeed, if we are to follow-through on President Nixon's call for energy independence for the United States in the 1980s, conservation must be a continuing effort for many years to come. Certainly, the pressures for conservation next winter will be as severe as this past winter, if not more so.

Because energy comes in several forms–oil, natural gas, coal, nuclear–energy discussions usually contain a variety of terms and abbreviations, such as Btu, Mw, kwhr, therm, and bbl/day of oil. It is, therefore, helpful to put the various forms of energy in common units. This is easily done by using the equivalents: 1 gal of fuel oil contains 140,000 Btu. This same heat content is contained in 140 cu ft of natural gas, 11 lb of coal, or 41 kwhr of electricity at the point of use. These Btu equivalents are the energy units available to the consumer. They do not include allowance for the energy used in the refining and distribution of oil, the distribution of gas, or the generation and transmission of electricity.

Since conservation of oil is of most immediate concern, all references to energy forms will be in terms of barrels or gallons of oil (42 gal/bbl).

Since 1.9-million bbl of crude oil must be saved altogether by the 65-million households in the U.S., 1.23 gal/day, or 450 gal/year, must be saved by each family if the U.S. is to meet the federal objective. To Mr. and Mrs. Average American, that 450 gal of crude oil works out to be 12% of present energy consumption–3,812 gal/year (2,297 for household uses and 1,515 for autos).

Generally, saving energy in any form can help solve the oil shortage because, in most areas of the country, oil or gas is used to generate at least a part of the electricity produced. So with the objective in mind of saving 450 gal/year of oil per household, an examination of some of the alternates available and the kind of savings that result in terms of gallons of oil are in order.

At this point, the average citizen should be prepared for a few disappointments-as well as for some pleasant surprises. Some of the energy-conservation practices he may be following so religiously do not contribute much toward his 450-gal goal. Switching to other alternatives would net much greater savings. Some of the things that have been suggested as measures of seemingly equal magnitude may actually differ by a factor of 10.

Areas of savings

As a general rule, the most significant sources of savings are the automobile, home heating, and the personal use of hot water. Of these, the biggest energy economies can be realized by changing the utilization pattern of the family car. To demonstrate, data from the U.S. Statistical Abstract for 1971 show that (1) car use averages 9,900 miles/year or 27 miles/day; (2) in 1971, cars averaged 13.7 miles/gal of gasoline; (3) total gasoline use in 1971 was 723 gal/car, or 2 gal/day; (4) in 1973, cars used 20% more fuel than in 1971, because of air-pollution controls; and (5) compact cars use only two-thirds as much fuel as regular-size cars.

With these assumptions, and the fact that one gal of gasoline is equivalent to 1.24 gal of crude oil after allowances for transportation and refinery losses, it is easy to see how a big portion of the 450-gal saving can be realized by changing automobile use patterns.

By reducing speed from 65 to 55 mph, a full-size 1971-model car will save 30.6 gal of crude-oil equivalent in a year. If it's a 1973 model, the saving will be greater–36.9 gal.

With a 1971 compact car, the saving due to reduced speed will be 20.5 gal, and for a 1973 compact, the saving is 24.5 gal. By not driving the family car one day a week, the following annual savings can be realized:

1971 big car	145.0 gal
1973 big car	174.5 gal
1971 compact	96.5 gal
1973 compact	116.5 gal

If a commuter who normally drives to work five days a week joins a three-person car pool, and drives his car only once every three days, the saving is remarkable in both dollars and gallons of crude oil. Exactly how big it is varies widely, depending on the size and model of car and the daily commuting distance. But examination of the chart will show that a commuter driving a 1971 compact 10 miles a day

201

would save $40 and 100 gal/year of crude oil equivalent. At the other extreme, a full-size 1972 model commuting 30 miles would save $216 and 590 gal of crude oil. Any commuter can estimate his own personal savings by using the chart.

The chart can also be used to estimate potential savings in cost of commuting by switching to a different model or size of car. For example, if a commuter who travels 20 miles a day using a 1973 full-size car switches to a 1973 compact, he would save 130 gal of oil and $48/year in his commuting. For all driving, the saving would be twice as much.

Coincidentally, savings realized by switching from a personal automobile to mass transit are identical to those gained by joining a three-person car pool. In the case of mass transit, savings stem from its greater energy efficiency (3,800 Btu per passenger-mile) compared to the automobile (11,340 Btu per passenger mile for an average 1971 car). Thus, a commuter trying to be more energy-efficient has an equal choice of mass transit or a car pool.

Savings in the home

Around the house, there are even more choices for savings, to help add up to those 450 gal/year. For example, lowering the thermostat by four degrees results in saving anywhere from 82 to 158 gal, depending on the type of heating system (see Table 1). The reason for the wide variation between types of heating systems is the difference in their overall energy efficiency. Electric-space-heating efficiency is about 32%, oil heating 36%, gas 41%, and the electric heat pump 64% (EW, Feb. 1, 1974, p.60).

Adding storm windows produces savings of 185 gal/year for a gas-heated home, and 209 gal for an oil-heated home. Adding insulation to the attic floor to retain heat saves 217 gal/year for a gas-heated home and 244 gal for an oil-heated home.

Electrically heated homes are presumed to be adequately insulated, and provided with dual-pane or storm windows, at the time of construction.

Turning off a gas yard-light that consumes 18,000 cu ft/year of gas will save 159 gal/year of crude-oil equivalent. But replacing that gas light with a 30-w electric bulb will save 148 gal/year of oil, while providing the same amount of illumination with no sacrifice in safety or aesthetics.

One means of energy conservation available to most Americans, which hasn't received the attention it perhaps deserves, is the daily bath. If the published statistics on the highly personal act of bathing are accepted, it can be seen that a normal tub bath requires 23 gal of water at 110F. A normal shower of three or four minutes requires 12 gal of 100F. (This is not to be confused with the 10-to-15-minute therapeutic showers taken by some teenagers.) Assuming one bath or shower a day per person, the family can save 39 gal/year of oil equivalent per person–156 gal for a family of four–simply by taking showers instead of baths–if the house is heated by resistance heating.

If it is heated by a heat pump and uses resistance heating elements in the hot water tank, the saving by showering compared to tubbing is 40 gal of oil per person. With a gas or oil furnace and water heater, the saving is 17 gal of oil per person.

One unique conservation measure–and certainly one of the simplest–is the act of putting the stopper in the wash-basin while shaving with lather and blades, or while shampooing. This saves between 2.4 and 5.7 gal/year of oil per year for water heating when compared to letting the hot water run. But switching to an electric shaver accomplishes even more–it uses only as much energy in a year as the hot water for the lather-and-blade shaving routine uses in two or three days.

One way or another, the average American should have no trouble saving 450 gal/year of oil–but it will pay him to find out what he's gaining in return for what he's sacrificing. In energy conservation, as in many of the developments of our times, things are not always what they seem.

Other areas of savings

Based on what is gleaned from the newspaper, television, and radio, it is possible to gain a false sense of accomplishment from rigid adherence to what are presented as worthwhile conservation measures. Things like turning off lights, cutting down on the use of appliances and TV, the extension of Daylight Saving Time, etc., would not, by themselves, even come close to the kind of savings our society must achieve. In fact, many are practically negligible when compared to the potential energy savings discussed so far.

For example, one conservation practice that has been recommended, and is being followed in many homes, is turning off electric lights to save energy and money. If enough lights are turned off to achieve a reduction of 10% of the average winter consumption for lighting, the net saving in oil equivalent is disappointing. The reason is that lighting simply doesn't use that much energy–and 100% of what it does use is converted to heat.

If the home has an electric-resistance heating system, there is no gain at all, since the heat that was supplied by the now-extinguished lights must be made up by the heating system, and both operate at the same 100% efficiency. In the case of incandescent lamps, 10% is radiated in the visible spectrum, and 90% in the invisible infrared spectrum; for fluorescent, 21% is visible and 79% in the nonvisible spectrum. But for either type, whether the radiation is visible or not, it all ends up as heat.

If the home is heated by heat pump, the 10%

reduction in lighting will save the equivalent of 2.3 gal of oil during the six winter months (see Table II). If the home has a gas furnace, the saving will be about 1 gal of oil for the same period. If the heating system is oil-fired, the saving will be only about 1/2 gal of oil. The differences are due to the variation in heating-system efficiencies (for calculation, see box).

In terms of money saved, 10% fewer lights will not reduce the electric bill at all with resistance heating; it will reduce it by 41¢ for the whole winter with a heat pump; by 85¢ with a gas furnace, and by only 1¢ with an oil furnace. These figures are based on oil at 39¢/gal, gas at $1.16/Mcf, and electricity at 1 1/2¢/kwhr.

Thus, not more than 2.3 gal of oil are saved by turning off 10% of the lights in winter. But, turning off lights in summer, in an air-conditioned home, is slightly more important. Under these conditions, the air conditioner does not have to work so hard.

Nevertheless, the difference is still very little—because the air conditioner is quite an efficient machine. In a home that is not air-conditioned, the saving from turning off 10% of the lights for the summer months is 2.2 gal of oil equivalent. If the home is air-conditioned, the saving is 3.1 gal.

A total of about 5 gal of oil saved in a year by turning off 10% of the lighting seems like the hard way to build toward that 450-gal goal.

Continuing the analysis, what is the effect of cutting down on the use of toasters, mixers, blenders, and other portable appliances—all by 10%? In the summer months, the payoff is 4.7 gal from not using the appliances, plus 1.5 gal from not forcing the air-conditioning system to remove the heat given off by the appliances.

In winter the payoff is smaller because, again, the heating system must make up for the heat the appliances formerly supplied; as with lighting, all the electric energy going into the appliance ends up as heat. So, with electric-resistance heat, there's again no saving. With a heat pump, the saving is 2.3 gal of oil. With a gas furnace, the saving is 1.1 gal, and with an oil heating system, the saving drops to 0.6 gal.

The potential saving by cutting back on watching color television, or by switching from color to your old black-and-white set, is of the same order of magnitude, and for the same reasons.

Equally disappointing when it comes to saving energy is the switch to year-round Daylight Saving Time. Despite what may have appeared in some media, the heating requirements are not affected at all by the shift in hours. There is some saving in lighting, by going to bed earlier and getting up earlier, even if some lights are still required in the morning hours during winter. If we assume that lighting used in the added morning hour is half the amount saved because of the extra hour of daylight in the evening, we find that the average home produces oil-equivalent savings of 0.6 gal for a resistance-heated home, 2.7 gal for a home with a heat pump, 1.3 gal for a gas-heated home, and 1.4 gal for an oil-heated home. Here the question arises: Is it worth it; in view of the inconvenience and dislocation created for families and businesses?

And to compound the problem of Daylight Saving Time and the danger of sending children to school in the dark, it is being suggested that we eliminate half of the energy used for street and highway lighting. In return for this sacrifice of safety and security, we will save 20,000 bbl/day of oil. While this may sound like a lot, it only adds up to 5 gal/year per family—not very much toward our 450-gal goal.

Nonoil energy sources

In many areas of the country—wherever the electricity is generated from coal, hydro, or nuclear sources—saving electricity will not result in any saving of oil at all. As a matter of fact, over 60% of our electricity is made from nonoil or gas sources, and a distinction should be drawn between electric energy sources. Right now, the problem is a shortage of oil, not a shortage of coal, nuclear, or hydro energy. If our real objective is to save oil, then some of our conservation practices can even backfire in these areas.

For example, in an area using coal for generation, turning out 10% of the lights in the winter in an oil-heated home will save 52 lb of coal, but will require an extra 4.1 gal of oil in the home to supply the added heat load.

In summary, many conservation measures provide minimal savings in energy, and at the same time may even be counterproductive when it comes to saving oil. Fortunately, there are several measures available that are far more significant, almost all of which pertain either to reducing home-heating requirements, to cutting consumption of hot water, or to changes in patterns of personal transportation.

Table I: Potential yearly savings from major conservation measures, gallons of crude-oil equivalent

Conservation measure	Electric resistance	Electric heat pump	Gas furnace	Oil furnace
	Type of heating system			
Lower thermostat 4F	158	82	130	147
Add 6-in. insulation in attic	N.A.	N.A.	217	244
Add storm windows	N.A.	N.A.	185	209
Turn off gas yard light	N.A.	N.A.	159	N.A.
Replace gas yard light with 30-w lamp	N.A.	N.A.	148	N.A.
Shower vs tub bath				
1 Person	39	40	17	17
Family of 4	156	160	68	68
Lather & blade shave with stopper in lavatory, vs running water	5.4	5.7	2.4	2.4
Electric shaver	0.05	0.05	0.05	0.05

Table II: Potential yearly savings from minor conservation measures, gallons of crude-oil equivalent

Conservation measure	Electric resistance	Electric heat pump	Gas furnace	Oil furnace
	Type of heating system			
Reduce lighting 10%				
Winter	0	2.3	1.1	0.6
Summer no A/C	2.2	N.A.	2.2	2.2
Summer with A/C	3.1	3.1	3.1	3.1
Extend daylight saving time to full year	0.6	2.7	1.3	1.4
Reduce use of portable appliances by 10%	6.2	8.5	7.3	6.8
Reduce color-TV use by 10%	[illegible]	3.3	2.8	2.3
Replace color TV with black & white	4.9	8.5	6.5	5.6

Energy savings calculation, lighting reduced 10%

The mathematics by which energy equivalents are determined is illustrated by an analysis of the oil equivalent saved by reducing home lighting by 10%. Starting with the assumption that average annual consumption for lighting is 816 kwhr, of which 544 kwhr are used during winter months and 272 kwhr during summer months, the saving from a 10% reduction in winter is equal to one-tenth of the winter kwhr consumption, minus the heat provided previously by the lighting system.

Mathematically, this can be represented by the equation:

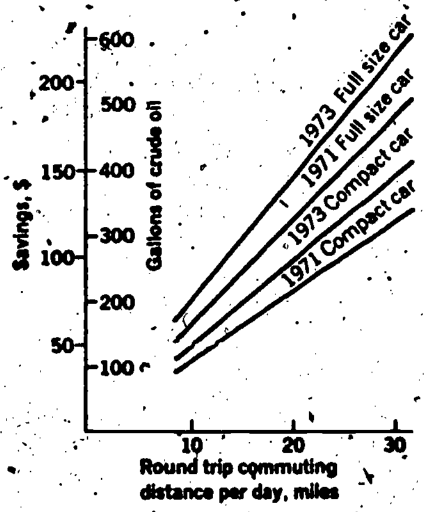
$$= \frac{0.1 \times \text{kwhr} \times 3{,}412\ \text{Btu/kwhr}}{\text{Electric utility system efficiency} \times 140{,}000\ \text{Btu/gal}} - \frac{0.1 \times \text{kwhr} \times 3{,}412\ \text{Btu/kwhr}}{\text{Furnace efficiency} \times \text{Fuel distribution efficiency} \times 140{,}000\ \text{Btu/gal}}$$

For a gas-heated home this is illustrated by:

$$= \frac{0.1 \times 544 \times 3{,}412}{0.313 \times 140{,}000} - \frac{0.1 \times 544 \times 3{,}412}{0.45 \times 0.9 \times 140{,}000} = 1.0 \text{ gal of heating oil}$$

In the process of refining heating oil, 11% of the crude oil is lost. Thus, to get 100 gal of heating oil would require 112⅓ gal of crude oil. For this example, 1 gal of heating oil requires 1.12 gal of crude oil plus transportation losses.

For summer months, the formula is similar. In a house without air conditioning, electricity consumption is reduced to 272 kwhr, and only the first half of the equation is used. For a house with air conditioning, the whole equation is used, but electricity consumption reduces to 272 kwhr; furnace efficiency is replaced with an air-conditioner efficiency (COP) of 3, fuel-distribution efficiency is replaced by the electric-utility-system efficiency of 0.313, and the minus sign changes to a plus.



204

CHAPTER 10

SUMMARY

We must keep before us the fact that all energy sources have some impact on the environment. Table 10 summarizes the effects discussed in the preceding chapters. It also summarizes fuel supplies.

To quote S. David Freeman, former Director of the Energy Policy Staff of the President's Office of Science and Technology: *"After man's long struggle for bare survival and simple comforts, the stage has been reached where most people in this country are trained and paid for thinking. An abundant supply of low-cost energy is essential to continue this trend, freeing man from burdensome chores and enabling him to spend more and more of his time enjoying the pleasures of affluence, leisure, and education. It is for these reasons that national policy has long been to assure an abundant supply of low cost energy."*

To supply these needs, we must be prepared to make several vital decisions in the near future:

1. How can we best produce electrical energy to meet increasing needs to maintain our quality of life and still maintain a quality environment? We want both.

2. What energy source, or combination of energy sources, will produce the least detrimental effects on the environment?

These are decisions which the American public must make. They are extremely important decisions that will affect the lives of unborn generations. We must weigh the availability and importance of fuels, the impact on the environment and human needs, keeping in mind that pollution is more a by-product of affluence than of poverty.

Whether the energy comes from fossil fuels, nuclear reactors or a variety of sources is a decision which must be made after a careful weighing of the facts. In the words of Craig Hosner, formerly on the Joint Committee on Atomic Energy, *"Society must balance risk against potential benefits to the people; the ultimate decision should be that which is the greatest good for the greatest number."*

The decision is yours.

TABLE 10

Environmental Effects of Electrical Power Generation

	Effects on Land	Effects on Water	Effects on Air	Biological Effects	Supply
	Disturbed land Large amounts of solid waste Mine tailings	Chemical mine drainage Increased water temperature	Sulfur oxides Nitrogen oxides Particulates Some radioactive gases	Respiratory problems from air pollutants	Large reserves
	Wastes in the form of brine Pipeline construction	Increased water temperature Oil spills	Nitrogen oxides Some sulfur oxides	Respiratory problems from air pollutants	Limited domestic reserves
	Pipeline construction	Increased water temperature	Some oxides of nitrogen	None detectable	Extremely limited domestic reserves
n	Disposal of radioactive wastes Mine tailings	Increased water temperature Some radioactive liquids	Some release of radioactive gases	None detectable in normal operation	Large reserves if breeders are developed

APPENDIX I

GLOSSARY OF TERMS

The following terms are included to aid you in your understanding of the material included in the text and of the terms you will encounter as you investigate the effects of power generation. Many of the nuclear terms are excerpted from the U.S. Atomic Energy Commission booklet *Nuclear Terms: A Brief Glossary*. Many other terms have been added by the committee in order to increase your understanding of the specific words relating to power production.

absorbed dose — When ionizing radiation passes through matter, some of its energy is imparted to the matter. The amount absorbed per unit mass of irradiated material is called the absorbed dose, and is measured in rems and rads.

absorber — Any material that absorbs or diminishes the intensity of ionizing radiation. Neutron absorbers, like boron, hafnium and cadmium are used in control rods for reactors. Concrete and steel absorb gamma rays and neutrons in reactor shields. A thin sheet of paper or metal will absorb or attenuate alpha particles and all except the most energetic beta particles.

absorption — The process by which the number of particles or photons entering a body of matter is reduced by interaction of the particles or radiation with the matter; similarly, the reduction of the energy or particles or photons while traversing a body of matter.

activation — The process of making a material radioactive by bombardment with neutrons, protons, or other nuclear particles or photons.

acute radiation sickness syndrome — An acute organic disorder that follows exposure to relatively severe doses of ionizing radiation. It is characterized by nausea, vomiting, diarrhea, blood cell changes, and in later stages of hemorrhage and loss of hair.

air sampling — The collection and analysis of samples of air to measure its radioactivity or to detect the presence of radioactive substances, particulate matter or chemical pollutants.

alpha particle — (Symbol α) A positively charged particle emitted by certain radioactive materials. It is made up of two neutrons and two protons bound together. Hence, it is identical with the nucleus of a helium atom. It is the least penetrating of the three common types of decay radiation.

atom — A particle of matter whose nucleus is indivisible by chemical means. It is the fundamental building block of the chemical elements.

atomic bomb — A bomb whose energy comes from the fission of heavy elements such as uranium-235 and plutonium-239.

Atomic Energy Commission — (Abbreviation AEC) The federal agency which previously had statuatory responsibilities for atomic energy matters. Functions taken over in 1974 by Energy Research and Development Administration and Nuclear Regulatory Commission.

atomic mass — (see atomic weight, mass)

atomic mass unit — (Abbreviation amu) One-twelfth the mass of a neutral atom of the most abundant isotope of carbon, carbon-12.

atomic number — (Symbol Z) The number of protons in the nucleus of an atom, and also its positive charge. Each chemical has its characteristic atomic number, and the numbers of the known elements form a complete series from 1 (hydrogen) to 105.

atomic reactor — A nuclear reactor.

atomic weight — The mass of an atom relative to other atoms. The present-day basis of the scale of atomic weights is carbon; the most common isotope of this element has

arbitrarily been assigned an atomic weight of 12. The unit of the scale is one-twelfth the weight of the carbon-12 atom, or roughly the mass of one proton or one neutron. The atomic weight of any element is approximately equal to the total number of protons and neutrons in its nucleus.

autoradiograph — A photographic record of radiation from radioactive material in an object, made by placing the object very close to a photographic film or emulsion. The process is called autoradiography. It is used, for instance, to locate radioactive atoms or tracers in metallic or biological samples.

background radiation — The radiation in man's natural environment, including cosmic rays and radiation from the naturally radioactive elements, both outside, and inside the bodies of humans and animals. It is also called natural radiation. The term may also mean radiation that is unrelated to a specific experiment.

backscatter — When radiation of any kind strikes matter (gaseous, solid or liquid), some of it may be reflected or scatter back in the general direction of the source. An understanding or exact measurement of the amount of backscatter is important when beta particles are being counted in an ionization chamber, in medical treatment with radiation, or in the use of industrial radioisotopic thickness gauges.

barrier shield — A wall or enclosure shielding the operator from an area where radioactive material is being used or processed by remote control equipment.

beta particle — (Symbol β) An elementary particle emitted from a nucleus during radioactive decay, with a single electrical charge and a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Beta radiation may cause skin burns, and beta-emitters are harmful if they enter the body. Beta particles are easily stopped by a thin sheet of metal.

BeV — Symbol for a billion (10^9) electron volts. (See electron volt.)

binding energy — The binding energy of a nucleus is the minimum energy required to dissociate it into its component neutrons and protons.

biological dose — The radiation dose absorbed in biological material. Measured in rems.

biological half life — The time required for a biological system, such as a human or animal, to eliminate by natural processes half the amount of a substance (such as a radioactive material) that has entered it.

biological shield — A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level safe for humans.

body burden — The amount of radioactive material present in the body of a human or an animal.

boiling water reactor — A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine.

bone seeker — A radioisotope that tends to accumulate in the bones when it is introduced into the body. An example is strontium-90, which behaves chemically like calcium.

breeder reactor — A reactor that produces more fissionable fuel than it consumes. The new fissionable material is created by capture in fertile materials of neutrons from fission. The process by which this occurs is known as breeding.

BTU — British Thermal Unit. The amount of heat required to change the temperature of one pound of water one degree Fahrenheit.

by-product material — Any radioactive material (except source material for fissionable material) obtained during the production or use of source material or fissionable material. It includes fission products and many other radioisotopes produced in nuclear reactors.

calorie (large calorie)	The amount of heat required to change the temperature of one kilogram of water one degree Centigrade.
carbon oxides	Compounds of carbon and oxygen produced when the carbon of fossil fuels combines with oxygen during burning. The two most common such oxides are carbon monoxide, a very poisonous gas, and carbon dioxide.
cask	A heavily shielded container used to store and/or ship radioactive materials.
cathode rays	A stream of electrons emitted by the cathode, or negative electrode, of a gas-discharge tube or by a hot filament in a vacuum tube, such as a television tube.
chain reaction	A reaction that stimulates its own repetition. In a fission chain reaction, a fissionable nucleus absorbs a neutron and fissions, releasing additional neutrons. These in turn can be absorbed by other fissionable nuclei, releasing still more neutrons. A fission chain reaction is self-sustaining when the number of neutrons released in a given time equals or exceeds the number of neutrons lost by absorption in nonfissioning material or by escape from the system.
charged particle	An ion; an elementary particle that carries a positive or negative electric charge.
chromosome	The determiner of heredity within a cell.
cladding	The outer jacket of nuclear fuel elements. It prevents corrosion of the fuel by the coolant and the release of fission products into the coolant. Aluminum or its alloys, stainless steel and zirconium alloys are common cladding materials.
closed-cycle reactor system	A reactor design in which the primary heat of fission is transferred outside the reactor core to do useful work by means of a coolant circulating in a completely closed system that includes a heat exchanger.
coal gasification	The process of obtaining methane and other combustible gases from coal, using the heat of the gas to generate electricity, then burning the gases to operate a steam cycle.
community	All the plant and animal species that live and interact in a particular environment.
containment	The provision of a gas-tight shell or other enclosure around a reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident.
containment vessel	A gas-tight shell or other enclosure around a reactor.
control rod	A rod, plate or tube containing a material such as hafnium, boron, etc. used to control the power of a nuclear reactor. By absorbing neutrons, a control rod prevents the neutrons from causing further fission.
coolant	A substance circulated through a nuclear reactor to remove or transfer heat. Common coolants are water, heavy water, air, carbon dioxide, liquid sodium and sodium-potassium alloy.
cooling tower	A tower designed to aid in the cooling of water that was used to condense the steam after it left the turbines of a power plant.
core	The central portion of a nuclear reactor containing the fuel elements and usually the moderator, but not the reflector.
counter	A general designation applied to radiation detection instruments or survey meters that detect and measure radiation.
critical mass	The smallest mass of fissionable material that will support a self-sustaining chain reaction under stated conditions.

criticality — The state of a nuclear reactor when it is just sustaining a chain reaction.

curie — (Abbreviation Ci) The basic unit to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion disintegrations per second, which is approximately the rate of decay of 1 gram of radium. A curie is also a quantity of any nuclide having 1 curie of radioactivity. Named by Marie and Pierre Curie, who discovered radium in 1898.

daughter — A nuclide formed by the radioactive decay of another nuclide, which in this context is called the parent. (See radioactive series.)

decay chain — A radioactive series.

decay heat — The heat produced by the decay of radioactive nuclides.

decay, radioactive — The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide. The process results in a decrease, with time, of the number of the original radioactive atoms in a sample. It involves the emission from the nucleus of alpha particles, beta particles (or electrons), or gamma rays; or the nuclear capture or ejection of orbital electrons; or fission. Also called radioactive disintegration.

decontamination — The removal of radioactive contaminents from surfaces or equipment, as by cleaning or washing with chemicals.

detector — Material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument.

deuterium — (Symbol ^2H or D) An isotope of hydrogen whose nucleus contains one neutron and one proton and is therefore about twice as heavy as the nucleus of normal hydrogen, which is only a single proton. Deuterium is often referred to as heavy hydrogen; it occurs in nature as 1 atom to 6500 atoms of normal hydrogen. It is nonradioactive. (See heavy water.)

deuteron — The nucleus of deuterium. It contains one proton and one neutron.

dose — (See absorbed dose, biological dose, maximum permissible dose, threshold dose.)

dose equivalent — A term used to express the amount of effective radiation when modifying [illegible] have been considered. The product of absorbed dose multiplied by [illegible] multiplied by a distribution factor. It is expressed numerically [illegible]

dose rate — The radiation dose delivered per unit time: Measured, for instance, in [illegible] per hour.

dosimeter — A device that measures radiation dose, such as a film badge or ionization chamber.

doubling dose — Radiation dose which would eventually cause a doubling of gene mutations.

ecology — The science dealing with the relationship of all living things with each other and with their environment.

ecosystem — A complex of the community of living things and the environment forming a functioning whole in nature.

efficiency — That percentage of the total energy content of a power plant's fuel which is converted into electricity. The remaining energy is lost to the environment as heat.

electron — (Symbol) An elementary particle with a unit negative charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom. Positive electrons, or positrons, also exist for brief periods of time as the result of positron decay.

electron volt	(Abbreviation ev or eV) The amount of kinetic energy gained by an electron when it is accelerated through an electric potential of 1 volt. It is equivalent to 1.603 x 10^{-12} erg. It is a unit of energy, or work, not of voltage.
element	One of the 105 known chemical substances that cannot be divided into simpler substances by chemical means. A substance whose atoms all have the same atomic number. Examples are hydrogen, lead, and uranium. Not to be confused with fuel element.
energy	The ability to do work.
Energy Research and Development Administration	(Abbreviation ERDA) The independent executive agency of the federal government with responsibility for management of research and development in all energy matters.
enrichment	(See isotopic enrichment)
environment	The total surroundings of an organism which act upon it.
exclusion area	An area immediately surrounding a nuclear reactor where human habitation is prohibited to assure safety in the event of an accident.
excursion	A sudden, very rapid rise in the power level of a reactor caused by supercriticality. Excursions are usually quickly suppressed by the negative temperature coefficient of the reactor and/or by automatic control rods.
fast breeder reactor	A reactor that operates with fast neutrons and produces more fissionable material than it consumes.
fast neutron	A neutron with kinetic energy greater than approximately 1,000,000 electron volts.
fast reactor	A reactor in which the fission chain reaction is sustained primarily by fast neutrons rather than by slow-moving neutrons. Fast reactors contain little or no moderator to slow down the neutrons from the speeds at which they are ejected from fissioning nuclei.
fertile material	A material, not itself fissionable by thermal neutrons, which can be converted into a fissionable material by irradiation in a reactor. There are two basic fertile materials, uranium-238 and thorium-232. When these fertile materials capture neutrons, they are partially converted into fissionable plutonium-239 and uranium-233, respectively.
film badge	A light-tight package of photographic film worn like a badge by workers in nuclear industry or research, used to measure exposure to ionizing radiation. The absorbed dose can be calculated by the degree of film darkening caused by the irradiation.
fissile material	While sometimes used as a synonym for fissionable material, this term has also acquired a more restricted meaning; namely, any material fissionable by neutrons of all energies, including thermal (slow) neutrons as well as fast neutrons. The three primarily fissile materials are uranium-233, uranium-235 and plutonium-239.
fission	The splitting of a heavy nucleus into two approximately equal parts (which are nuclei of lighter elements), accompained by the release of a relatively large amount of energy and generally one of more neutrons. Fission can occur spontaneously, but usually is caused by nuclear absorption of gamma rays, neutrons or other particles.
fission fragments	The two or more nuclei which are formed by the fission of a nucleus. Also referred to as primary fission products. They are of medium atomic weight, and are radioactive.
fission products	The nuclei (fission fragments) formed by the fission of heavy elements, plus the nuclides formed by the fission fragments' radioactive decay.

fissionable material	Commonly used as a synonym for fissile material. The meaning of this term has also been extended to include material that can be fissioned by fast neutrons only, such as uranium-238. Used in reactor operations to mean fuel.
flux (neutron)	A measure of the intensity of neutron radiation. It is the number of neutrons passing through one square centimeter of a given target in one second. Expressed as n x v, where n = the number of neutrons per cubic centimet and v = their velocity in centimeters per second.
fly ash	Small particles of ash produced by the burning of fuels. They are dispersed up the smoke stack and may be carried some distance before they settle to the earth.
food chain	The pathways by which any material (such as radioactive material from fallout) passes from the first absorbing organism through plants and animals to humans.
fossil fuel	Naturally occurring substances derived from plants and animals which lived in ages past. The bodies of these long-dead organisms have become our recoverable fuels which can be burned, such as lignite, coal, oil and gas.
fuel (nuclear)	Fissionable material used or usable to produce energy in a reactor. Also applied to a mixture, such as natural uranium, in which only part of the atoms are readily fissionable, if the mixture can be made to sustain a chain reaction.
fuel cycle	The series of steps involved in supplying fuel for nuclear power reactors. It includes mining, refining, the original fabrication of fuel elements, their use in a reactor, chemical processing to recover the fissionable material remaining in the spent fuel, reenrichment of the fuel material, and refabrication into new fuel elements.
fuel element	A rod, tube, plate or other mechanical shape or form into which nuclear fuel is fabricated for use in a reactor. (Not to be confused with element.)
fuel reprocessing	The processing of reactor fuel to recover the unused fissionable material.
fusion	The formation of a heavier nucleus from two lighter ones (such as hydrogen isotopes), with the attendant release of energy.
gamma rays	(Symbol γ) High energy, short wave length electromagnetic radiation originating in the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded against by dense materials, such as lead or depleted uranium. Gamma rays are essentially similar to x-rays, but are usually more energetic.
gas cooled reactor	A nuclear reactor in which a gas is the coolant.
gaseous diffusion (plant)	A method of isotopic separation based on the fact that gas atoms or molecules with different masses will diffuse through a porous barrier (or membrane) at different rates. The method is used by the AEC to separate uranium-235 from uranium-238; it requires large gaseous diffusion plants and enormous amounts of electric power.
Geiger-Muller counter	A radiation detection and measuring instrument. It consists of a gas-filled Geiger-Muller tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation. It was named for Hans Geiger and W. Muller who invented it in the 1920s. It is sometimes called simply a Geiger counter, or a G-M counter.
genetic effects of radiation	Radiation effects that can be transferred from parent to offspring. Any radiation-caused changes in the genetic material of sex cells.
genetically significant dose	A population-averaged dose which estimates the potential genetic effects of radiation on future generations. It takes into consideration the number of people in various age groups, the average dose to the reproductive organs to which people in these groups are exposed, and their expected number of future children.

graphite (reactor grade) — A very pure form of carbon used as a moderator in nuclear reactors.

half life — The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half lives vary from millionths of a second to billions of years. Also called physical half life. (See decay, radioactive)

half life, biological — (See biological half life.)

half life, effective — The time required for a radionuclide contained in a biological system, such as a human or an animal, to reduce its activity by half as a combined result of radioactive decay and biological elimination. (Compare biological half life and half life.)

half-thickness — The thickness of any given absorber that will reduce the intensity of a beam of radiation to one-half its initial value.

health physics — The science concerned with recognition, evaluation and control of health hazards from ionizing radiation.

heat exchanger — Any device that transfers heat from one fluid (liquid or gas) to another or to the environment.

heat sink — Anything that absorbs heat; usually part of the environment, such as the air, a river or outer space.

heavy water — (Symbol D_2O) Water containing significantly more than the natural proportions (one in 6500) of heavy hydrogen (deuterium) atoms to ordinary hydrogen atoms. Heavy water is used as a moderator in some reactors because it slows down neutrons effectively and also has a low cross section for absorption of neutrons.

heavy water moderated reactor — A reactor that uses heavy water as its moderator. Heavy water is an excellent moderator and thus permits the use of inexpensive (unenriched) uranium as a fuel.

hydrocarbons — Compounds composed of hydrogen and carbon. These occur in petroleum, natural gas and coal.

hydroelectricity — Electricity produced from the energy of falling water. Dammed water is used to turn turbines located below the dam.

induced radioactivity — Radioactivity that is created when substances are bombarded with neutrons as from a nuclear explosion or in a reactor, or with charged particles and photons produced by accelerators.

intensity — The energy or the number of photons or particles of any radiation incident upon a unit area or flowing through a unit of solid material per unit of time. In connection with radioactivity, the number of atoms disintegrating per unit of time.

ion — An atom or molecule that has lost or gained one or more electrons. By this ionization it becomes electrically charged. Examples: an alpha particle, which is a helium atom minus two electrons; a proton, which is hydrogen atom minus its electron.

ionization — The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

ionization chamber — An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of the electricity.

ionization event — An occurrence in which an ion or group of ions is produced; for example, by passage of a charged particle through matter.

ionizing radiation Any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Examples: alpha, beta, gamma radiation, short-wave ultraviolet light. Ionizing radiation may produce severe skin or tissue damage.

irradiation Exposure to radiation, as in a nuclear reactor.

isotope One of two or more atoms with the same atomic number (the same chemical element) but with different atomic weights. An equivalent statement is that the nuclei of isotopes have the same number of protons, but different numbers of neutrons. Thus carbon-12, carbon-13 and carbon-14 are isotopes of the element carbon, the numbers denoting the approximate atomic weights. Isotopes usually have very nearly the same chemical properties, but somewhat different physical properties.

isotope separation The process of separating isotopes from one another, or changing their relative abundances, as by gaseous diffusion or electromagnetic separation. Isotope separation is a step in the isotopic enrichment process.

isotopic enrichment A process by which the relative abundances of the isotopes of a given element are altered, thus producing a form of the element which has been enriched in one particular isotope and depleted in its other isotopic forms.

kilowatt hour One kilowatt of electricity expended for one hour.

kilo- A prefix that multiplies a basic unit by 1000.

lethal dose A dose of ionizing radiation sufficient to cause death. Median lethal dose (MLD or LD-50) is the dose required to kill within a specific period of time (usually 30 days) half of the individuals in a large group of organisms similarly exposed. The LD-50/30 for man is about 400,000 to 450,000 mrem.

low population zone An area of low population density sometimes required around a nuclear installation. The number and density of residents is of concern in providing, with reasonable probability, that effective protection measures can be taken if a serious accident should occur.

magnetic bottle A magnetic field used to confine or contain a plasma in controlled fusion (thermonuclear) experiments.

magnetic mirror A magnetic field used in controlled fusion experiments to reflect charged particles back into the central region of a magnetic bottle.

mass The quantity of matter in a body. Often used as a synonym for weight, which, strictly speaking, is the force exerted on a body by the earth.

mass-energy equation The statement developed by Albert Einstein, German-born American physicist, that the mass of a body is a measure of its energy content, as an extension of his 1905 special theory of relativity. The statement was subsequently verified experimentally by measurements of mass and energy in nuclear reactions. The equation, usually given is $E = mc^2$, shows that when the energy of a body changes by an amount E (no matter what form the energy takes), the mass, m, of the body will change by an amount equal to E/c^2. The factor c^2, the square of the speed of light in a vacuum, may be regarded as the conversion factor relating units of mass and energy. The equation predicted the possibility of releasing enormous amounts of energy by the conversion of mass to energy. It is also called the Einstein equation.

matter The substance of which a physical object is composed. All materials in the universe have the same inner nature, that is, they are composed of atoms, arranged in different (and often complex) ways; the specific atoms and the specific arrangements identify the various materials.

maximum credible accident The most serious reactor accident that can reasonably be imagined from any adverse combination of equipment malfunction, operating errors and other foreseeable causes. The term is used to analyze the safety characteristics of a reactor. Reactors are designed to be safe even if a maximum credible accident should occur.

maximum permissible dose	That dose of ionizing radiation established by competent authorities as an amount below which there is no reasonable expectation of risk to human health, and which at the same time is somewhat below the lowest level at which a definite hazard is believed to exist. (See radiation protection guide).
mean life	The average time during which an atom, an excited nucleus, a radionuclide or a particle exists in a particular form.
median lethal dose	(See lethal dose.)
mega-	A prefix that multiplies a basic unit by 1,000,000.
Mev	One million (10^6) electron volts. Also written as MeV.
milli-	A prefix that multiplies a basic unit by 1/1000.
moderator	A material, such as ordinary water, heavy water, or graphite, used in a reactor to slow down high velocity neutrons, thus increasing the likelihood of further fission.
molecule	A group of atoms held together by chemical forces. The atoms in the molecule may be identical, as in H_2, S_2, and S_8, or different, as in H_2O and CO_2. A molecule is the smallest unit of a compound which can exist by itself and retain all its chemical properties. (Compare atom, ion.)
mutation	A permanent transmissible change in the characteristics of an offspring from those of its parents.
natural radiation or natural radioactivity	Background radiation.
natural uranium	Uranium as found in nature. It contains 0.7 per cent of uranium-235, 99.3 per cent of uranium-238 and a trace of uranium-234. It is also called normal uranium.
neutron	(Symbol n) An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen-1. A free neutron is unstable and decays with a half life of about 13 minutes into an electron, proton and neutron. Neutrons sustain the fission chain reaction in a nuclear reactor.
neutron capture	The process in which an atomic nucleus absorbs or captures a neutron.
nitrogen oxides	Compounds of nitrogen and oxygen which may be produced by the burning of fossil fuels. Very harmful to health, and may be important in the formation of smogs.
nuclear energy	The energy liberated by a nuclear reaction (fission of fusion) or by radioactive decay.
nuclear power plant	Any device, machine or assembly that converts nuclear energy into some form of useful power, such as mechanical or electrical power. In a nuclear electric power plant, heat produced by a reactor is generally used to make steam to drive a turbine that in turn drives an electric generator.
nuclear reaction	A reaction involving a change in an atomic nucleus, such as fission, fusion, neutron capture, or radioactive decay, as distinct from a chemical reaction, which is limited to changes in the electron structure surrounding the nucleus.
nuclear reactor	A devise in which a fission chain reaction can be initiated, maintained and controlled. Its essential component is a core with fissionable fuel. It usually has a moderator, a reflector, shielding, coolant and control mechanisms. Sometimes called an atomic furnace, it is the basic machine of nuclear energy.

Nuclear Regulatory Commission
(Abbreviation NRC) The independent federal commission which licenses and regulates nuclear facilities.

nuclear super-heating
Superheating the steam produced in a reactor by using additional heat from a reactor. Two methods are commonly employed: recirculating the steam through the same core in which it is first produced (integral superheating) or passing the steam through a second and separate reactor.

nucleon
A constituent of an atomic nucleus, that is, a proton or a neutron.

nucleonics
The science and technology of nuclear energy and its applications.

nucleus
The small, positively charged core of an atom. It is only about 1/10,000 the diameter of the atom, but contains nearly all the atom's mass. All nuclei contain both protons and neutrons, except the nucleus of ordinary hydrogen, which consists of a single proton.

nuclide
A general term applicable to all atomic forms of the elements. The term is often erroneously used as a synonym for isotope, which properly has a more limited definition. Whereas isotopes are the various forms of a single element (hence are a family of nuclides) and all have the same atomic number and number of protons, nuclides comprise all the isotopic forms of all the elements. Nuclides are distinguished by their atomic number, atomic mass, and energy state.

parent
A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter), either directly or as a later member of a radioactive series.

particulates
Small particles of solid material produced by burning of fuels.

permissible dose
(See maximum permissible dose.)

personnel monitoring
Determination by either physical or biological measurement of the amount of ionizing radiation to which an individual has been exposed, such as by measuring the darkening of a film badge or performing a radon breath analysis.

photon
Electromagnetic radiation.

physical half life
(See half life.)

pig
A heavy shielding container (usually lead) used to ship or store radioactive materials.

pile
Old term for nuclear reactor. This name was used because the first reactor was built by piling up graphite blocks and natural uranium.

Plowshare
The Atomic Energy Commission program of research and development on peaceful uses of nuclear explosives. The possible uses include large-scale excavation, such as for canals and harbors, crushing ore bodies and producing heavy transuranic isotopes. The term is based on a Biblical reference, Isaiah 2:4.

plutonium
(Symbol Pu) A heavy, radioactive, man-made metallic element with atomic number 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238. It is used for reactor fuel and in weapons.

pollution
The addition of any undesirable agent to an ecosystem.

pool reactor
A reactor in which the fuel elements are suspended in a pool of water that serves as the reflector, moderator and coolant. Popularly called a swimming pool reactor, it is usually used for research and training.

population density
The number of persons per unit area (usually per square mile) who inhabit an area.

positron
A subatomic particle with the mass of an electron but having a positive charge of the same magnitude as the electron's negative charge.

power reactor	A reactor designed to produce useful nuclear power, as distinguished from reactors used primarily for research, for producing radiation or fissionable materials or for reactor component testing.
pressure vessel	A strong-walled container housing the core of most types of power reactors; it usually also contains moderator, reflector, thermal shield and control rods.
pressurized water reactor	A power reactor in which heat is transferred from the core to a heat exchanger by water kept under high pressure to achieve high temperature without boiling in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.
primary fission products	Fission fragments.
protection	Provisions to reduce exposure of persons to radiation. For example, protective barriers to reduce external radiation or measures to prevent inhalation of radioactive materials.
Q	A billion billion Btu's of energy (10^{18} Btu).
quality factor	The factor by which absorbed dose is to be multiplied to obtain a quantity that expresses, on a common scale of all ionizing radiations, the irradiation incurred by exposed persons. It is used because some types of radiation such as alpha particles are more biologically damaging than other types.
rad	(Acronym for radiation absorbed dose) The basic unit of absorbed dose of radiation. A dose of one rad means the absorption of 100 ergs of radiation energy per gram of absorbing material.
radiation	The emission and propagation of energy through matter or space by means of electromagnetic disturbances which display both wave-like and particle-like behavior; in this context the particles are known as photons. Also, the energy so propagated. The term has been extended to include streams of fast-moving particles (alpha and beta particles, free neutrons, cosmic radiation, etc.). Nuclear radiation is that emitted from atomic nuclei in various nuclear reactors, including alpha, beta and gamma radiation and neutrons.
radiation area	Any accessible area in which the level of radiation is such that a major portion of an individual's body could receive in any one hour a dose in excess of 5 millirem, or in any five consecutive days a dose in excess of 150 millirem.
radiation burn	Radiation damage to the skin.
radiation damage	A general term for the harmful effects of radiation on matter.
radiation detection instrument	Devices that detect and record the characteristics of ionizing radiation.
radiation monitoring	Continuous or periodic determination of the amount of radiation present in a given area.
radiation protection	Legislation and regulations to protect the public and laboratory or industrial workers against radiation. Also measures to reduce exposure to radiation.
radiation protection guide	The officially determined radiation doses which should not be exceeded without careful consideration of the reasons for doing so. These are equivalent to the older term maximum permissible dose.
radiation shielding	Reduction of radiation by interposing a shield of absorbing material between any radioactive source and a person, laboratory area or radiation-sensitive device.
radiation source	Usually a man-made sealed source of radioactivity used in teletherapy, radiography, as a power source for batteries, or in various types of industrial gauges. Machines such as accelerators and radioisotopic generators and natural radionuclides may also be considered sources.

radiation standards — Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for industrial control of radiation and control of radiation by legislative means. (See radiation protection, radiation protection guide.)

radiation sterilization — Use of radiation to cause a plant or animal to become sterile, that is, incapable of reproduction. Also the use of radiation to kill all forms of life (especially bacteria) in food, surgical sutures, etc.

radiation warning symbol — An officially prescribed symbol (a magenta trefoil on a yellow background) which should be displayed when a radiation hazard exists.

radioactive — Exhibiting radioactivity or pertaining to radioactivity.

radioactive contamination — Deposition of radioactive material in any place where it may harm persons, spoil experiments or make products or equipment unsuitable or unsafe for some specific use. The presence of unwanted radioactive material found on the walls of vessels in used-fuel processing plants, or radioactive material that has leaked into a reactor coolant. Often referred to only as contamination.

radioactive dating — A technique for measuring the age of an object or sample of material by determining the ratios of various radioisotopes or products of radioactive decay it contains. For example, the ratio of carbon-14 to carbon-12 reveals the approximate age of bones, pieces of wood, or other archaeological specimen that contain carbon extracted from the air at the time of their origin.

radioactive isotope — A radioisotope.

radioactive series — A succession of nuclides, each of which transforms by radioactive disintegration into the next until a stable nuclide results. The first member is called the parent, the intermediate members are called daughters, and the final stable member is called the end product.

radioactive waste — (See waste, radioactive.)

radioactivity — The spontaneous decay or disintegration of an unstable atomic nucleus, usually accompanied by the emission of ionizing radiation. (Often shortened to activity.)

radioecology — The body of knowledge and the study of the effects of radiation on species of plants and animals in natural communities.

radioisotope — A radioactive isotope. An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. More than 1300 natural and artificial radioisotopes have been identified.

radioisotopic generator — A small power generator that converts the heat released during radioactive decay directly into electricity. These generators generally produce only a few watts of electricity and use thermoelectric or thermionic converters. Some also function as electrostatic converters to produce a small voltage. Sometimes called an atomic battery.

radiology — The science which deals with the use of all forms of ionizing radiation in the diagnosis and treatment of disease.

radiomutation — A permanent transmissible change in form, quality or other characteristic of a cell or offspring from the characteristics of its parent, due to radiation exposure. (See genetic effects of radiation, mutation.)

radioresistance — A relative resistance to cells, tissues, organs, or organisms to the injurious action of radiation. (Compare radioresistance.)

radium — (Symbol Ra) A radioactive metallic element with atomic number 88. As found in nature, the most common isotope has an atomic weight of 226. It occurs in minute quantities associated with uranium in pitchblende, carnotite and other minerals.

radiosensitivity — A relative susceptibility of cells, tissues, organs or organisms to the injurious action of radiation. (Compare radioresistance.)

radon — (Symbol Rn) A radioactive element, one of the heaviest gases known. Its atomic number is 86, and its atomic weight is 222. It is a daughter of radium in the uranium radioactive series.

reactor — (See nuclear reactor.)

recycling — The reuse of fissionable material, after it has been recovered by chemical processing from spent or depleted reactor fuel, reenriched and then refabricated into new fuel elements.

reflector — A layer of material immediately surrounding a reactor core which scatters back or reflects into the core many neutrons that would otherwise escape. The returned neutrons can then cause more fissions and improve the neutron economy of the reactor. Common reflector materials are graphite, beryllium and natural uranium.

regulating rod — A reactor control rod used for making frequent fine adjustment in reactivity.

relative biological effectiveness (RBE) — A factor used to compare the biological effectiveness of different types of ionizing radiation. It is the inverse ratio of the amount of absorbed radiation, required to produce a given effect, to a standard or reference radiation required to produce the same effect.

rem — (Acronym of roentgen equivalent man.) The unit of dose of any ionizing radiation which produces the same biological effect as a unit of absorbed dose or ordinary x-rays. The RBE dose (in rems) = RBE x absorbed dose (in rads).

rep — (Acronym for roentgen equivalent physical) An obsolete unit of absorbed dose of any ionizing radiation, with a magnitude of 93 ergs per gram. It has been superseded by the rad.

reprocessing — Fuel reprocessing.

roentgen — (Abbreviation r) A unit of exposure to ionizing radiation. It is that amount of gamma or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge (either positive or negative) in 1 cubic centimeter of dry air under standard conditions. Named after Wilhelm Roentgen, German scientist who discovered x-rays in 1895.

roentgen equivalent, man — (See rem.)

roentgen rays — X-rays.

safety rod — A standby control rod used to shut down a nuclear reactor rapidly in emergencies.

scaler — An electronic instrument for rapid counting of radiation-induced pulses from Geiger counters or other radiation detectors. It permits rapid counting by reducing by a definite scaling factor the number of pulses entering the counter.

scram — The sudden shutdown of a nuclear reactor, usually by rapid insertion of the safety rods. Emergencies or deviations from normal reactor operation cause the reactor operator or automatic control equipment to scram the reactor.

shield (shielding) — A body of material used to reduce the passage of radiation.

smog — A mixture of smoke and fog. A fog made heavier and usually darker by smoke and chemical fumes.

smoke — Suspension of small particles in a gas.

solar energy — The energy produced by the fusion reaction occurring on the sun, which reaches the earth as radiant energy. This energy may be converted into heat or electricity by physical devices.

somatic effects of radiation — Effects of radiation limited to the exposed individual, as distinguished from genetic effects, which also affect subsequent unexposed generations. Large radiation doses

can be fatal. Smaller doses may make the individual noticeably ill, may merely produce temporary changes in blood-cell levels detectable only in the laboratory, or may produce no detectable effects whatever. Also called physiological effects of radiation. (Compare genetic effects of radiation.)

spent (depleted) fuel — Nuclear reactor fuel that has been irradiated (used) to the extent that it can no longer effectively sustain a chain reaction.

spill — The accidental release of radioactive material.

stable — Incapable of spontaneous change. Not radioactive.

stable isotope — An isotope that does not undergo radioactive decay.

subcritical assembly — A reactor consisting of a mass of fissionable material and moderator which cannot sustain a chain reaction. Used primarily for educational purposes.

subcritical mass — An amount of fissionable material insufficient in quantity or of improper geometry to sustain a fission chain reaction.

supercritical reactor — A reactor in which the power level is increasing. If uncontrolled, a supercritical reactor would undergo an excursion.

superheating — The heating of a vapor, particularly steam, to a temperature much higher than the boiling point at the existing pressure. This is done in power plants to improve efficiency and to reduce condensation in the turbines.

survey meter — Any portable radiation detection instrument especially adapted for surveying or inspecting an area to establish the existence and amount of radioactive material present.

sulfur oxides — Compounds composed of sulfur and oxygen produced by the burning of sulfur and its compounds in coal, oil and gas. Harmful to the helath of man, plants and animals, and may cause damage to materials.

thermal breeder reactor — A breeder reactor in which the fission chain reactor is sustained by thermal neutrons.

thermal pollution — Raising the temperature of a body of water such as a lake or stream to an undesirable level by the addition of heat. This heat may change the ecological balance of that body of water, making it impossible for some types of life to survive, or it may favor the survival of other organisms, such as algae.

thermal reactor — A reactor in which the fission chain reaction is sustained primarily by thermal neutrons. Most current reactors are thermal reactors.

thermal shield — A layer or layers of high density material located within a reactor pressure vessel or between the vessel and the biological shield to reduce radiation heating in the vessel and the biological shield.

thermonuclear reaction — A reaction in which very high temperatures allow the fusion of two light nuclei to form the nucleus of a heavier atom, releasing a large amount of energy. In a hydrogen bomb, the high temperature to initiate the thermonuclear reaction is produced by a preliminary fission reaction.

threshold dose — The minimum dose of radiation that will produce a detectable biological effect.

tracer, isotopic — An isotope of an element, a small amount of which may be incorporated into a sample of material (the carrier) in order to follow (trace) the course of that element through a chemical, biological or physical process, and thus also follow the larger sample. The tracer may be radioactive, in which case observations are made by measuring the radioactivity. If the tracer is stable, mass spectrometers or neutrons activation analysis may be employed to determine isotopic composition. Tracers also are called labels or tags, and materials are said to be labeled or tagged when radioactive tracers are incorporated in them.

turbine	A rotary engine made with a series of curved vanes on a rotating spindle. May be actuated by a current of fluid such as water or steam.
unstable isotope	A radioisotope.
uranium	(Symbol U) A radioactive element with the atomic number 92, and as found in natural ores, an average atomic weight of approximately 238. The two principal natural isotopes are uranium-235 (0.7 per cent of natural uranium), which is fissionable, and uranium-238 (99.3 per cent of natural uranium), which is fertile. Natural uranium also includes a minute amount of uranium-234. Uranium is the basic raw material of nuclear energy.
uranium enrichment	(See isotopic enrichment.)
waste, radioactive	Equipment and materials from nuclear operations which are radioactive and for which there is no further use. Wastes are generally classified as high-level (having radioactivity concentrations of hundreds of thousands of curies per gallon or cubic foot), low-level (in the range of 1 microcurie per gallon or cubic foot), or intermediate-level (between these extremes.)
watt	A unit of power equal to one joule per second.
whole body counter	A device used to identify and measure the radiation in the body (body burden) of human beings and animals; it uses heavy shielding to keep out background radiation and ultrasensitive scintillation detectors and electronic equipment.
x-ray	A penetrating form of electromagnetic radiation emitted either when the inner orbital electrons of an excited atom return to their normal state (these are characteristic x-rays), or when a metal target is bombarded with high speed electrons (these are bremsstrahlung). X-rays are always nonnuclear in origin.

APPENDIX II

BIBLIOGRAPHY

GOVERNMENTAL PUBLICATIONS

California Inst. Tech., Environmental Quality Lab Report No. 5, 1971, *Geothermal Resources in California, Potentials and Problems*, M. Goldsmith.

Congressional Record, 117 (190), pp. S. 20766-80, *Clean Energy Via the Wind*, December 7, 1971.

Department of Interior, Geologic Survey, News Release, *U.S. Coal Resources in Ground: 3210 Billion Tons*, April 20, 1968.

International Commission on Radiological Protection, ICRP Publ. No. 8, Permagon Press, 1966, *The Evaluation of Risks from Radiation.*

International Atomic Energy Agency, Kartner Ring II, P. O. Box 590, A-1011, Vienna, Austria, Nuclear Power and the Environment, 85 pp.

Joint Committee on Atomic Energy, U.S. Congress, Selected Materials on Environmental Effects of Producing Electric Power, August, 1969.

Joint Committee on Atomic Energy Hearings on Enrivonmental Effects of Producing Electric Power, Phase I, October 28-31 and November 4-7, 1969, p. 357.

Los Almos Scientific Laboratory, LA-4869-MS, November, 1971, *Goals of Cost-Benefit Analysis in Electric Power Generation*, from Risks vs. Benefit: Solution or Dream, D. E. Watson.

National Council on Radiation Protection and Measurement, Basic Radiation Protection Criteria, Report No. 39, Jan. 15, 1971.

Oak Ridge National Laboratory, ORNL-NSIC-28, *Earthquakes and Nuclear Power Plant Design*, T. F. Lomenick and NSIC Staff, July 1970.

Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, Nuclear Safety Information Center, J. R. Buchanan, Assistant Director, will supply information on breeder reactors, or other aspects of the nuclear energy program.

Office of Science and Technology, Energy Staff, *Electric Power and the Environment*, August 1970.

Staff Report, ORNL 4451, *Siting of Fuel Reprocessing Plants and Waste Management Facilities*, July 1970.

Patterns of Energy Consumption in the United States, prepared for President's Office of Science and Technology by Stanford Research Institute, January 1972.

Sagan, L. A., *Human Radiation Exposures from Nuclear Power Reactors*, Archives of Environmental Health, 22, 487, 1971.

Schneider, K. J. et al., *Status of Solification and Disposal of Highly Radioactive Liquid Wastes from Nuclear Power in the USA*, Symp. Environmental Aspects of Nuclear Power Stations, IAEA-SM-146/22, August 1970.

Testimony of Milton Shaw, Director, Division of Reactor Development and Technology at AEC Rulemaking Hearing, January 27, 1972, *An Interim Criteriae for Emergency Core Cooling Systems in Large Civilian Nuclear Power Plants*, Docket No. RM-50-1.

The National Power Survey, A Report on the Federal Power Commission, October 1964.

U. S. Atomic Energy Commission, Civilian Nuclear Power, A Report to the President, 1962.

U. S. Atomic Energy Commission, Civilian Nuclear Power, 1967 supplement to the 1962 report to the President, February 1967.

U. S. Atomic Energy Commission, Doc. WASH-1082, Current Status and Future Technical and Economic Potential of Light Water Reactors, U. S. Government Printing Office, Washington, D. C., March 1968.

U. S. Atomic Energy Commission, Licensing of Power Reactors, U. S. Government Printing Office, 1967.

U. S. Atomic Energy Commission, Division of Compliance, Report on Releases of Radioactivity from Power Reactors in Effluents During 1970, October 1971.

U. S. Atomic Energy Commission, WASH-740, Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants, March 1957.

U. S. Atomic Energy Commission, TID-25857, 1972, Lauriston S. Taylor, *What We Do Know About Low-Level Radiation*, The Environmental and Ecological Forum 1970-71.

U. S. Atomic Energy Commission, Division of Technical Information, *Radioactive Wastes*, Understanding the Atom Series, C. H. Fox, 1969.

U. S. Atomic Energy Division of Technical Information, *The Natural Radiation Environment*, Understanding the Atom Series, J. Kastner. 1968.

Selected Materials on Environmental Effects of Producing Electric Power, Joint Committee on Atomic Energy, U. S. Congress, *The Need for Advance Planning of Thermal Discharges*, R. T. Jaske, August 1969.

U. S. Congress, Hearing before Subcommittee on Legislation of Joint Committee on Atomic Energy, June 22, 23, July 13, 14, 1971, Part 1.

U. S. Department of Interior, Pacific Northwest Water Laboratory, Corvallis, Oregon, Industrial Waste Guide on Thermal Pollution, Federal Water Pollution Control Administration, September, 1968.

U. S. Environmental Protection Agency, Office of Radiation Programs, August, 1972, ORP/CSD 72-1, Estimates of Ionizing Radiation Doses in the US -- 1960-2000.

U. S. Government Printing Office, Code of Federal Regulations, Title 10.

U. S. Government Printing Office, Considerations Affecting Steam Power Plant Site Selection, Energy Policy Staff, Office of Science and Technology.

U. S. Government Printing Office, *Energy and Environment: Electric Power*, Council on Environmental Quality, August 1973.

U. S. Government Printing Office, Environmental Effects of Producing Electric Power, hearings before the Joint Committee on Atomic Energy, Congress of the United States, 1969-70. Probably the most complete and current collection of data on wastes from fossil fuel and nuclear power plants. Hearing reports published in three phases: Phase I, January 1970, Phase II and III, Spring 1970.

U. S. Government Printing Office, Nuclear Safety, issured quarterly.

U. S. Government Printing Office, The Economy, Energy and the Environment, prepared by the Library of Congress, Legislative Reference Service, for U. S. Congress, Joint Economic Committee, September 1970.

U. S. Senate, 91st Congress, 1st session, November 1969, *Testimony on Underground Uses of Nuclear Energy*, J. Gofman, A. Tamplin, Subcommittee on Air and Water Pollution of Public Works Committee.

PERIODICALS

Barnea, J., *Geothermal Power*, Scientific American, September 1971, pp. 70-77.

Beall, S. E., *Uses of Waste Heat*, Oak Ridge National Laboratory Review, Spring, 1970, pp. 9-14.

Benedict, M., *Electric Power from Nuclear Fission*, Bulletin of the Atomic Scientists, 27 (7), 8, 1971.

Blomeke, J. O. and W. C. McClain, *A Salt Mine Repository for Radioactive Wastes*, Nuclear News, April 1971, page 35.

Bohn, Hinrich L., *A Clean New Gas*, Environment, 13(10) December 1971, pp. 4-9.

Bray, A. P., *Emergency Core Cooling: A Rebuttal*, Nuclear News, November 1971, page 25.

Bruce, A. W., *Engineering Aspects of a Geothermal Power Plant*, U.N. Symp. on Development and Utilization of Geothermal Resources, September 22-October 1, 1970, Pisa, Italy.

Bruces, A. M., *Critique of the Linear Theory of Carcinogensis*, Science, 128, 693, 1958.

Bush, S. H., *The Role of the Advisory Committee on Reactor Safeguards in the Reactor Licensing Process*, Nuclear Safety, 13(1) 1, Jan./Feb. 1972.

Cambel, Ali B., *Impact of Energy Demands*, Physics Today, December 1970, page 38.

Chance for Solar Energy Conversion, Chemical and Engineering News, December 20, 1971, page 39.

Chapman, D. et al., *Electricity Demand Growth and the Energy Crisis*, Science, 178, 703, November 17, 1972.

Commoner, Barry and Richard Daly, *What is the Harm of Nuclear Testing to Human Inheritance?* Scientist and Citizen, 6: Nos. 9-10, September, October 1964.

Conference on the Pediatric Significance of Peacetime Radioactive Fallout, Pediatrics, 41: No. 1, 1968.

Corbit, Carl D., *Reactors, Radiation and Risk*, Power Engineering, July 1971, page 43.

Eisenbud, M. and H. G. Petrow, *Radioactivity in the Atmospheric Effluents of Power Plants that use Fossil Fuels*, Science, 144, 288, April 17, 1964.

Eliassen, R., *Power Generation and the Environment*, Bulletin of the Atomic Scientists, September 1971, page 37.

Emergency Core Cooling, Nuclear Industry, June 1971, page 13.

Energy, Science, 178, 599, 732, 849, 968, 1079, 1273,; 179, 54, 164, 178,, November 1972 - January 1973.

Energy Issue, Scientific American, 225 (3), September 1971.

Environmental Aspects of Nuclear Power, Nuclear Engineering International, October 1970, page 826.

Faltermayer, O. E., *The Energy 'Joyride' is Over*, Fortune, September 1972, page 99.

Fenner, D. and J. Klarmann, *Power from the Earth*, Environment, 13 (10), 19, December 1971. See also J. T. O'Rourke; letter to the Editor, *Clean Steam*, Ibid, 14 (2), March 1972.

Forbes, I. A. et al., *Nuclear Reactor Safety: An Evaluation of New Evidence*, Nuclear News, September 1971, page 32.

Forbes, I. A. et al., *Cooling Water*, Environment, 14(1), 40, Jan./Feb. 1972.

Ford, D. F. et al., *A Critique of the AEC's Interim Criteria for Emergency Core Cooling Systems*, Nuclear News, January 1972, page 28.

Ford, N. C. and J. W. Kane, *Solar Power*, Bulletin of the Atomic Scientists, 27, 52, October 1971.

Freke, A. M., *A Model for the Approximate Calculation of Safe Rates of Discharge of Radioactive Wastes into Marine Environments*, Health Physics, 13, 1967, pp. 743-58.

Fusion Scientists Optimistic Over Progress, Chemical and Engineering News, December 20, 1971, page 32.

Gillette, R., *Nuclear Safety*, Science, 177, 771, 867, 970 and 1080, September 1972.

Gofman, J. W. and A. R. Tamplin, *Radiation, Cancer and Environmental Health*, Hospital Practice, 5, (10), 91, 1970.

Gofman, John, *Nuclear Power and Ecocide: An Adversary View of New Technology*, Bulletin of the Atomic Scientists, 27 (7), 28-32, September 1971.

Green, L. Jr., *Energy Needs Versus Environmental Pollution: A Reconciliation?* Science, 156: 1448-1450.

Hamilton, L. D., *On Radiation Standards*, Bulletin of the Atomic Scientists, March 1972, page 30.

Hammond, A. L., *Geothermal Energy, An Emerging Major Resource*, Science, 177, 978, September 15, 1972.

Hammond, A. L., *The Fast Breeder Reactor: Signal of a Critical Reaction*, Science, 176, 391, April 1972.

Harleman, D. R. F., *Heat, the Ultimate Waste*, Technology Review, Massachusetts Institute of Technology, December 1971, page 44.

Hartley, H. et. al., *Energy for the World's Technology*, New Scientist, November 13, 1969, pp. 1-24.

Hennessey, Joseph F., *Indemnification of USAEC's Contractors Against Liability for Nuclear Incidents*, Progress in Nuclear Energy, Series X, v.3, page 252, Pergamon Press, New York, 1962.

Hogerton, J. F., *The Arrival of Nuclear Power*, Scientific American, February 1968, pp. 1-24.

Holcomb, Robert W., *Radiation Risk: A Scientific Problem*, Science, 167(6), 853-855, February 1970.

Hope, M. and J. Young, *The Great Nuclear Debate: Are Our Babies in Danger?* Redbook Magazine, January 1972, page 16.

Jordan, W. H., *Nuclear Energy: Benefits vs. Risks*, Physics Today, May 1970, p. 32.

Jordan, Walter H., *The Issues Concerning Nuclear Power*, Nuclear News, October 1971, p. 43.

Lapp, Ralph E., *Gaining Safety in Nuclear Power*, Current, March 1971.

Lapp, Ralph E., *The Four Big Fears About Nuclear Power*, New York Times Magazine, February 7, 1971.

Lapp, Ralph E., *The Nuclear Power Controversy: Safety*, The New Republic, January 23, 1971, page 18.

Lapp, Ralph E., *The Nuclear Plant Controversy-II: Power and Hot Water*, The New Republic, February 6, 1971, page 20.

Lapp, Ralph E., *The Nuclear Plant Controversy-III: Radiation Risks*, The New Republic, February 27, 1971, page 17.

Lave, L. B. and L. C. Freeburg, *Health Effects on Electricity Generation from: Coal, Oil and Nuclear Fuel*, Nuclear Safety Journal, 14(5), September-October 1973.

Lear, John, *Radioactive Ashes in the Kansas Salt Cellar*, Saturday Review, February 19, 1972, page 39.

Lidsky, L. M., *The Quest for Fusion Power*, Technology Review, January 1972, page 10.

Lindap, P. J. and J. Rotblat, *Radiation Pollution of the Environment*, Bulletin of the Atomic Scientists, 27(7), 17, September 1971.

Lindap, P. J. and J. Rotblat, *Strontium-90 and Infant Mortality*, Nature, 224, 1257-1260, December 1969.

List, E. J., *Energy and the Environment in Southern California*, California Institute of Technology, Engineering and Science, November 1971, pp. 14-17.

Lohse, G. E., T. K. Thompson and B. R. Wheeler, *In-Bed Combustion Calcination of Radioactive Wastes*, Transactions, 14(2), 495, October 1971.

Los Angeles Times, *The Shortage of Natural Gas*, Thursday, April 13, 1972.

Lyon, R. N., *Earthquakes and Nuclear Power*, Oak Ridge National Laboratory Review, Fall 1968, p. 29.

Main, Jerome, *A Peak Load of Troubles for the Utilities*, Fortune, November 1969, page 116.

Maisel, A. Q., *The Big Push to Atomic Breeder Reactors*, Reader's Digest, April 1972, page 164.

Mann, L. A., *Indemnity for AEC Contractors and Licensees*, Nuclear Safety, 3(1), 7, 1961.

Marrone, J., *Nuclear Liability Insurance-A Brief History Reflecting the Sucess of Nuclear Safety*, Nuclear Safety, 12, 291, 1971.

McCullough, C. R., *Radiation in Perspective*, Nuclear Safety, 6 (1), 31, Fall 1964.

Meinel, A. B. and M. P., *Is it Time for a New Look at Solar Energy?* Physics Today, February 1972, page 32.

Meinel, A. B. and M. P., *Physics Looks at Solar Energy*, Physics Today, February 1972, page 44.

Meleis, M. and R. C. Erdmann, *The Development of Reactor Siting Criteria Based Upon Risk Probability*, Nuclear Safety, 13, (1), 22, 1972.

Miller, J. N., *Just How Safe is a Nuclear Power Plant?* Reader's Digest, June 1972, page 95.

Mills, G. Alex et al., *Fuels Management in an Environmental Age*, Environmental Science and Technology, 5: No. 1, pp. 30-38, January 1971.

Minnesota Committee for Environmental Information, *Cooling it in Minnesota*, Environment, March 1969, pp. 21-25.

Minnick, L. E., *Letter to the Editor*, Look Magazine, comment on the article *The Nuclear Threat Inside America*, Look Magazine, 34(25), 1970.

Morgan, J. G., National Conference on Waste Heat Utilization, Nuclear Safety, 13(3), 216, 1972.

Morison, Robert S., *Dying*, Scientific American, September 1973, pp. 55-60.

Moshe, J. L. and A. P. Frass, *Fusion by Laser*, Scientific American, 224: No. 6, June 1971, pp. 21-33.

Nation's Energy Crisis, The New York Times, July 6, 7, 8, 1971.

Novick, Sheldon, *Toward a Nuclear Power Precipice*, Environment, pp. 32-40, March 1973.

H. Foreman, Ed., *Nuclear Power and the Public*, University of Minnesota Press, 1970.

Olds, F. C., *The End of Decade Doubling*. Power Engineering, April 1972, page 44.

Otway, H. J., et. al., *A Risk Estimate for an Urban-Sited Reactor*, Nuclear Technology, 12, 173, 1971.

Otway, H. J. and R. C. Erdmann, *Reactor Siting and Design from a Risk Viewpoint*, Nuclear Engineering and Design, 13, 365, 1970,

Post, R. F., *Fusion Power*, Bulletin of the Atomic Scientists, October 1971, page 42.

Post, Richard F., *Prospects for Fusion Power*, Physics Today, pp. 31-39, April 1973.

Power from Coal--Part I A Special Report, Power, February 1974, pp. S-1 to S-24.

Power from Coal--Part II A Special Report, Power, March 1974, pp. S-25 to S-48.

Power from Coal--Part III A Special Report. Combustion, Pollution Controls, Power, April 1974.

Rasmussen, N. C., *Nuclear Reactor Safety--An Opinion*, Nuclear News, January 1972, page 35.

Rex, R. W., *Geothermal Energy--The Neglected Energy Option*, Bulletin of the Atomic Scientists, 27, 52, October 1971.

Sagan, L. A., *Human Costs of Nuclear Power*, Science, August 1972, pp. 487-93.

Sagan, Leonard A., *Infant Mortality Controversy: Sternglass and His Critics*, Bulletin of the Atomic Scientists, October 1969, pp. 26-32.

Schneider, K. J., *Solidification and Disposal of High-Level Radioactive Wastes in the U.S.*, Reactor Technology, 13(4), 387, 1970-71.

Shapley, Deborah, *Radioactive Cargoes: Record Good but the Problems Will Multiply*, Science, 172, June 1971, pp. 1318-1322.

Snow, J. A., *Radioactive Waste from Reactors*, Environment, May 1967, page 89.

Starr, Chauncey, *Radiation in Perspective*, Nuclear Safety, 5(4), 1964.

Starr, Chauncey, *Social Benefit vs. Technological Risk*, Science, Vol. 165, September 1969, pp. 1232-1238.

Stein, Jane, *Coal is Cheap, Hated, Abundant, Filthy, Needed*, Smithsonia, February 1973, pp. 19-27.

Steiner, D., *The Radiological Impact of Fusion*, New Scientist, December 16, 1971, page 168.

Stratton, R. C., *Insurance: An Equalizer of Risk*, Nuclear Safety I(3), 1960.

Tamplin, A., Y. Ricker and M. F. Longmate, *A Criticism of the Sternglass Article on Fetal and Infant Mortality*, Bulletin of the Atomic Scientists, December 1969. See also M. Friedlander and J. Klarmann, *How Many Children?* Environment; 11: No. 10, December 1969.

The Electric Power Crisis in America, Look Magazine, August 10, 1971.

The Prophets of Pollution, Nature, 225, 397, 1970.

The Space Available, Environment, 12(2), 2, March 1970.

Trials and Tribulations of Trying to Counter Shoreham Critics at 52-day Proceeding, Nuclear Industry, June 1971, pp. 23-26.

Tsiviglou, Ernest C., *Nuclear Power: The Social Conflict*, Environmental Science and Technology, Vo. 5, pp. 404-410, May 1971.

Van Atta, C. M., *Controlled Thermonuclear Reactors*, Nuclear News, 14(10X), 68, 1971.

Weaver, Kenneth F., *The Search for Tomorrow's Power*, National Geographic, November, 1972, pp. 650-681.

Weinberg, A. M. and R. P. Hammond, *Global Effects of Increased Use of Energy*, Intern Conf. on Peaceful Uses of Atomic Energy, A/Conf. 49/P/033, Geneva, Switzerland, September 1971, *Limits to the Use of Energy*, American Scientists, 58, 412, 1970.

Weinberg, A. M., *The Moral Imperatives of Nuclear Energy*, Nuclear News, December 1971, page 33.

Woodson, Riley T., *Cooling Towers*, Scientific American, May 1971 Vol. 224: No. 5, pp. 70-78.

Wright, James H. and J. A. Nutant, *The Environment and Nuclear Power*, Atomic Power Digest, Westinghouse Nuclear Energy Systems, 1971.

Yadigarozlu, G., A. G. Reinking, V. E. Schrock, *Estimation of Spent Fuel Transportation Risks*, Trans. AM. Nucl. Soc., 15(1), 74, 1972.

Yeates, D. B., A. S. Golden, D. W. Moeller, *Natural Radiation in the Urban Environment*, Nuclear Safety, 13, (4), 275, 1972.

BOOKS AND BOOKLETS

A Compilation of Reviews of the Theories of De. Ernest J. Sternglass: Atomic Industrial Forum, Background Infor. AIF Inc., n.d.

Abrahamson, *Environmental Cost of Electric Power*, Scientists Institute for Public Information.

Ball, Russell H., Nuclear Power and the Environment, A Compilation of Excerpts from Recent Literature, San Diego Section, ANS, August 1970.

Calder, R., Living With the Atom, University of Chicago Press, 1962.

Committee for Nuclear Information, Setting the Balance, Risks and Benefits of Nuclear Energy, September 1965.

Corey, Gordon R., *Electricity in a Changing Environment*, Seminars University of Wisconsin, February 1971, and Massachusetts Institute of Technology, March 1971, available from AIF-Info, August 1971.

Curtis, R. and E. Hogan, Perils of the Peaceful Atom, Ballatine Books, 1970.

Dahlberg, *What Everyone Should Know About Nuclear Energy*, San Diego Section, ANS, March 1971.

Eisenbud, M., Environmental Radioactivity, McGraw-Hill, New York, 1963.

Foreman, Harry, Nuclear Power and the Public, University of Minnesota Press, 1970.

Glasstone, Samuel, Sourcebook on Atomic Energy, D. Van Nostrand Co., Inc., 3rd Edition, 1967.

Gofman and Tamplin, Poisoned Power, Rodale Press.

Grendon, Alexander, Comments to Sternglass, Proceedings of the Sixth Berkeley Symp. on Mathematical Statistics and Probability, University of California, Berkeley, July 1971.

Harvey, R. W. and W. C. Schmidt, *The Management of Radioactive Wastes from Nuclear Fuel Reprocessing at Hanford*, Atlantic Richfield Hanford, Co., March 1971.

Hogerton, John F., Notes on Nuclear Power, Atomic Industrial Forum, Inc., 2nd Edition, 1970.

Honstead, *Quantitive Evaluation of Environmental Factors Affecting Population Exposure Near Hanford*, Battelle Northwest Report BNWL-SA-3203, October 1970.

Hubbert, M. K., Energy Resource, Chapter 8, in Resources and Man, A Study by the Committee on Resources and Man, National Acadmey of Sciences/National Research Council, W. H. Freeman, San Francisco, 1969.

Hull, A. P. and F. J. Shore, *Sternglass: A Case History*, Brookhaven National Laboratory, BNL-16613, March 5, 1972.

International Commission on Radiological Protection Reports, Pergamon Press, 14 publications on various aspects of the evaluation of risks from ionizing radiation and the setting of standards.

Lave, L. B. and E. P. Seskin, Air Pollution and Human Health, John Hopkins University Press, in press 1974.

Martin, J. E., E. D. Howard, D. T. Oakley, Radiation Doses from Fossil-Fuel and Nuclear Power Plants, Power Generation and Environmental Change, Chapter 9, American Association for Advancement of Science, MIT Press, 1971, page 107.

McCloskey, Michael, *An Environmentalist Views the Energy Crisis*, Sierra Club, June 15, 1971.

Meredith, D. L. Nuclear Power Plant Siting: A Handbook for the Layman, Marine Advisory Service Bulletin #6, University of Rhode Island, June 1972.

National Academy of Sciences, The Biological Effects of Atomic Radiation-Summary Reports, Washington, D.C., National Research Council, 1960.

Novick, Sheldon, The Careless Atom, Houghton Mifflin Co., Boston, 1969.

O'Brien, Brice, National Coal Association, *Remarks to San Diego Section NAS*, Jan. 21, 1969.

Olson, D. J., *Semiscale Blowdown and Emergency Core Cooling (ECC) Project, Test Report-Test 845, (ECC Injection)*, Aerojet Nuclear Company, ANCR-1014.

Pennsylvania Power and Light Company, Nuclear Power, in Perspective, 1972.

Public Health Service, Radioactive Waste Discharges to the Environment from Nuclear Power Facilities, Rockville, Md., March 1970.

Remick, Forrest J., Nuclear Power: Threat or Promise, printed by the Pennsylvania Electric Association.

Resources for the Future, 1755 Massachusetts Ave., N.W., Washington, D.C., Patterns of U.S. Energy Use and How They Have Evolved, Annual Report, 1968.

Ridker, R. G., *Economic—Cost of Air Pollution–Studies in Measurement*, F. A. Praeger, N.Y., 1967, pp. 55-56.

Schubert, Jack and Ralph Lapp, Radiation: What it is and How it Effects You, Viking Press, 1968.

Seaborg, Glen T., Fission and Fusion-Developments and Projects, Speech given at Berkely, California, November 20, 1969, U.S. Atomic Energy Commission.

Shone, F. J., Serious Incidents and Major Accidents, Atomic Industrial Forum.

Smith, J. M. Jr., Perspective on Radioactive Effluents from BWR Nuclear Power Plants, and Radioactive Effluents and Standards, Nuclear Information Source Book, General Electric, Nuclear Energy Division, February 1971.

Starr, C. and M. A. Greenfield, Public Health Risks of Thermal Power Plants, a report prepared for the Resources Agency of California, UCLA-ENG-7242, May 1972.

Tamplin, A. R. and J. W. Gofman, Population Control Through Nuclear Pollution, Nelson Hall Company, Chicago, 1970.

Tamplin, Arthur R., *Safety of Nuclear Reactors*, Proc. Northwest Conf. on Nuclear Energy, Portland, Oregon, December 1969, page 166.

The Effects on Populations of Exposure to Low Levels of Ionizing Radiation, Report of the Advisory Committee on the Biological Effects of Ionizing Radiation, Division of Medical Sciences, National Academy of Sciences–National Research Council, Washington, D.C. 1972.

U.N. Publications Office, New York, United Nations Scientific Committee on the Effects of Atomic Radiation, Official records of the General Assembly, 13th Session, Supplement 17 (A/3838) 1958; 17th Session, Supplement 16 (A/5216); 19th Session, Supplement 14 (A/5814) 1964; 21st Session, Supplement 14 (A/6314) 1966.

Watson, D. E., The Risk of Carcinogensis from Long-Term Low Dose Exposure to Pollution Emitted by Fossil Fuel Power Plants, University of California, Lawrence Livermore Laboratory Report, UCRL-50937, October 1970.

Winsor, G. H. and J. R. Roberts, The Management of High Level Radioactive Waste, Nuclear Information Source Book, General Electric Co., Nuclear Energy Division, February 1971.

Wright, James H., Power and the Environment, Westinghouse Electric Corp., Pittsburgh, Pa., 1970.

From Understanding the Atom Series, U.S. Atomic Energy Commission, Division of Technical Information, Washington, D.C., the following titles are pertinent:

a. Atomic Fuel
b. Atomic Power Safety
c. Atoms, Nature and Man
d. Controlled Nuclear Fusion
e. The Creative Scientist, His Training and His Role
f. Direct Conversion of Energy
g. The First Reactor
h. The Genetic Effects of Radiation
i. Microstructure of Matter
j. Neutron Activation Analysis
k. The Natural Radiation Environment
l. Nuclear Clocks
m. Nuclear Energy for Desalting
n. Nuclear Power and the Environment
o. Nuclear Power and Merchant Shipping
p. Nuclear Power Plants
q. Nuclear Projects
r. Nuclear Propulsion for Space
s. Nuclear Reactors
t. Nuclear Terms, A Glossary
u. Our Atomic World
v. Plowshare
w. Plutonium
x. Power from Radioisotopes
y. Radioactive Wastes
z. Radioisotopes and Life Processes
i. Reading Resources in Atomic energy
ii. SNAP: Nuclear Space Reactors
iii. Sources of Nuclear Fuel
iv. Synthetic Transuranium Elements
v. Whole Body Counters
vi. Your Body and Radiation

APPENDIX III

A DECISION MAKING MODEL

The reader has been confronted with numerous issues regarding the conflict between enjoying the supposed benefits of a technological society and reducing the quality of our environment to intolerable levels. Decisions to resolve the conflict must be made; they will be made. If knowledgeable people refuse to make these decisions, less knowledgeable persons will. The attitude of *letting George do it* is a gross shirking of responsibility.

But how does a person with a taste of knowledge about the problem (such as that acquired throught this minicourse) make such decisions? How does he evaluate the available data? How does he know when he has surveyed all the data? How does he test for logical inconsistencies within the reports? The problem of analyzing large sets of information and formulating workable solutions to problems perceived is one of the most mind-boggling and difficult endeavors of the human mind; it is also one of the most rewarding!

A model or guide to this decision-making process is presented in Figure 25. This model is presented in the form of an instructional flowchart and suggests things to do (rectangles) and includes crucial questions (diamonds) which help pinpoint errors in interpretation of the data and conclusions. The rectangles and diamonds are logically interconnected by arrows which suggest which way to proceed.

Each of the main points in the flowchart requires a brief explanation. First, one enters the intellectual process with an awareness of environmental problems of electrical generation and an interest in the identification of solutions to these problems.

Stage 1. Survey your knowledge of power sources and the environment to acquire factual information and the understanding of the basic issues involved. Completion of the minicourse is useful here.

Stage 2. Identify questions you may have about the issues for further refinement and analysis.

Stage 3. Have others raised similar questions? Answering this question can provide access to discussions of the issue which have already been completed and tends to reduce the phenomenon of re-inventing the wheel. In addition, the knowledge that you may be raising a relatively new question can be an enlightening and rewarding experience.

Note: Diamonds represent decision in the form of questions which lend themselves to Yes, No, or ? answers. The path one takes through the flowchart is determined by the answer to the question.

Stage 4. Have solutions been posed? If Stage 3 has been answered in the affirmative, we now begin to investigate the merits of the solutions.

Stage 5. Are solutions based on solid evidence? If Stage 4 has been answered in the affirmative, we can now ask if there is substantial and logical evidence to support the solution under question.

Stages 6-9. A negative response in either Stage 3, 4 or 5 directs the decision-maker into the key branch of the flowchart. Stage 6 directs the learner to survey information related to the problem (or solution), or to examine specific issues which relate to the problem under consideration. Caution must be used here to avoid the temptation of switching to a related problem. Stick to the issue at hand! In stage 7, list alternative solutions to the problem. That is, determine, without excessive evaluation at this point, if there are other possible solutions to the problem. In Stage 8, start the process of evaluating the main and alternative solutions from Stage 7 by listing advantages and disadvantages of each solution.

Now that you have examined the evidence and tabulated the pros and cons of the problem or solution, evaluate each as to its practicability and feasibility. Then rank solutions from best to poorest. (Stage 9) In ranking, one arranges the solutions from the best to the poorest.

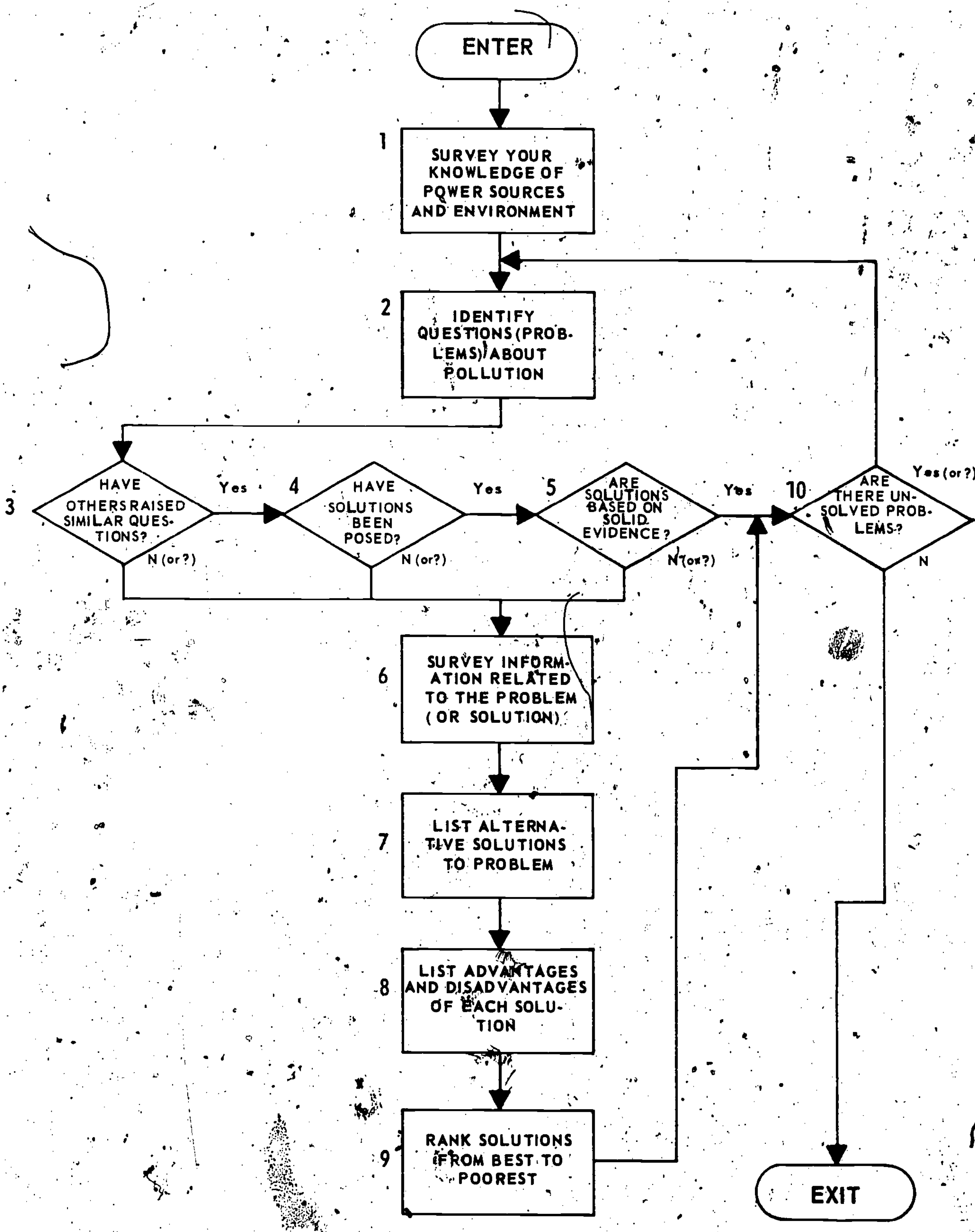
After Stage 9, the flow is cycled back to Stage 10.

Stage 10. Are there unsolved problems? Presuming affirmative answers to Stages 3, 4 and 5, we now are at the point where we see if all important questions have been asked. While it is recognized that the words *important questions* obviously involve value (subjective) judgments, such value judgments in technological applications are unavoidable.

A negative answer to Stage 10 recycles the flow back to Stage 2, and a positive response sends one to the exit of the decision-making program.

Two additional comments regarding this decision-making flowchart are in order. First, it represents a series of intellectual processes and you must try to understand it.

Second, the flowchart is only a first approximation (only representative) of the complex mental process involved in human problem-solving. It is hoped that it will be most valuable when considered in its present form which is neither exceedingly simple nor excessively complicated.



Flowchart of Basic Decision-Making Model for Resolution of Environmental Problems

FIGURE 25

APPENDIX IV

LICENSING OF NUCLEAR POWER PLANTS

The following is a brief outline of the procedures which must be followed by a utility in order to construct and operate a nuclear power plant.

Before formally filing an application for construction and operation of a nuclear reactor, the company must select a site for the planned facility according to the criteria specified by the U.S. Nuclear Regulatory Commission. Then two specific permits must be obtained by the utility company: a construction permit and an operating license.

A. Steps in Obtaining a Construction Permit.

1. The utility company must submit a formal application to the Directorate of Licensing of the U.S. Nuclear Regulatory Commission. The application must contain detailed information concerning:

   a. Design and location of the proposed plant.

   b. Safeguards to be provided.

   c. Comprehensive data on the proposed site and its environment.

2. A review of the application is made by the NRC Directorate of Licensing. An analysis of the application is prepared.

3. Copies of the application are made available to the public and to the NRC Advisory Committee on Reactor Safeguards. This committee reviews the application and holds conferences with the applicant and the Directorate of Licensing staff.

4. A public hearing is held, usually near the proposed site, by an NRC-appointed Atomic Safety and Licensing Board. Testimony may be given by private citizens, state and local officials and community groups.

5. The Atomic Safety and Licensing Board reviews the testimony presented at the public hearing and the findings of the Directorate of Licensing and Advisory Committee on Reactor Safeguards and the decision is made for or against granting a construction permit.

6. The decision of the Atomic Safety and Licensing Board is subject to review by the five-member Nuclear Regulatory Commission.

7. A construction permit is granted or denied, and public notice is given of the action.

8. If a construction permit is granted, construction of the plant may begin, under constant inspection of the NRC Division of Compliance.

9. As construction progresses, the company applies to the NRC for an operating license.

B. Steps in Obtaining an Operating License

1. As construction of the reactor proceeds, NRC inspections assure that the requirements of the construction permit are met.

2. When final design is completed, the applicant submits a final safety analysis report in support of an application for an operating license. The safety analysis report must include:

   a. Plans for operation.

   b. Procedures for coping with emergency situations.

   c. Final details on reactor design such as containment, core design and waste handling systems.

3. The Directorate of Licensing prepares a detailed evaluation of the information submitted and presents this evaluation to the Advisory Committee on Reactor Safeguards.

4. The Advisory Committee on Reactor Safeguards prepares an independent evaluation and reports its opinion to the Commission. This is made public.

5. The NRC may then:

   a. Publish a 30-day public notice of the proposed issuance of a provisional operating license.

   b. Schedule a public hearing on the application.

   c. Normally a hearing will not be held at this stage unless:

      i. There is a difficult safety problem of public importance.

ii. Substantial public interest warrants a hearing.

d. If a public hearing is held, the decision of the licensing board is subject to Commission review.

6. Any operating license may be provisional for an initial period of operation, at the end of which time a review is made to determine conditions for a full term license of not more than 40 years.

a. The license sets forth the particular conditions which are to be met in order to assure protection of the health and safety of the public.

b. Reactor operators must be individually licensed by the Commission.

7. All licensed reactors are inspected periodically by members of the NRC Division of Compliance to assure that they are operated in accordance with the terms of their licenses.

8. An Environmental Report must be submitted as part of the applications for both the Construction Permit and the Operating License.