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ABSTRACT

This course, developed for use in secondary and adult education, is an effort to describe the cost-benefit ratio of the various methods of generation of electrical power in an era when the requirement for additional sources of power is growing at an ever-increasing rate and environmental protection is a major concern. This course was written and compiled by an independent committee drawn from educators, engineers, health physicists, members of industry and conservation groups, and environmental scientists. Among the topics discussed are the increasing need for electrical power and methods for meeting this need, nuclear power and fossil fueled plants, the biological effects of nuclear and fossil fueled plants, wastes in the production of electric power, plant site considerations, energy conservation, and the environmental effects of electrical power generation. The appendixes include a glossary of terms, a bibliography, a decision-making model and a brief outline of the procedures which must be followed by a utility in order to construct and operate a nuclear power plant. (BT)

PDE WORKING PAPER

The Environmental Impact of Electrical Power Generation: Nuclear and Fossil

A Minicourse for Secondary Schools and Adult Education

Division of Science and Technology
Bureau of Curriculum Services
Pennsylvania Department of Education
1973

Commonwealth of Pennsylvania
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PURPOSE OF COURSE

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

The development of this minicourse has been partially supported by the Division of Nuclear Education and Training of the U.S. Atomic Energy Commission and produced under the direction of the Pennsylvania Department of Education. It was written and compiled by an independent committee drawn from educators, engineers, health physicists, members of industry and conservation groups, and environmental scientists.

This course is an effort to describe the cost-benefit ratio of the various methods of generation of electrical power.

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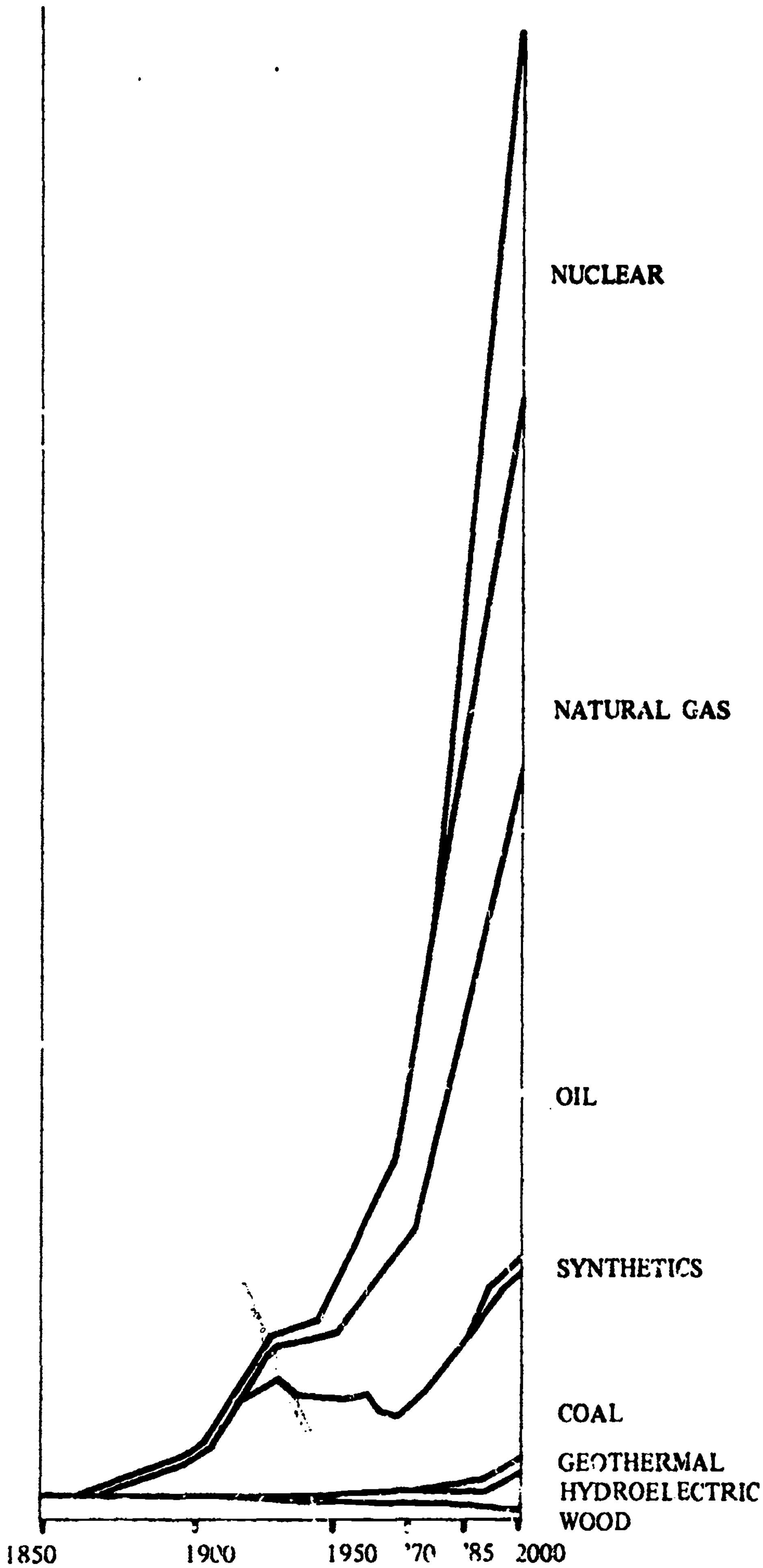
INTRODUCTION

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. But these plants have an impact on our environment. The biological effects of nuclear and fossil fueled plants are discussed in Chapter 5. In addition to having biological effects, these plants produce wastes, including waste heat, that have environmental effects. These wastes are the subject of Chapter 6. Chapter 7 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 8. Finally, a summary of environmental effects is given.

Appendix I is a glossary of useful terms, many of which are used in the text. When one of the words in the glossary is used for the first time in the text, it appears in italics. Appendix II is a bibliography containing many useful references for future study. Appendix III is a decision-making model to help the reader analyze the information he has received. Appendix IV is a brief outline of the procedures which must be followed by a utility in order to constuuct and operate a nuclear power plant.

THE WORLD'S ENERGY PRODUCTION



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Chapter 1

THE DEMAND FOR ELECTRICAL ENERGY

Energy, the power to do work, is the basic building block of civilization. The standard of living of people throughout time has been directly dependent upon their energy resources. Figure 1 shows the relationship between energy consumption and living standards for many different countries.

It becomes obvious from looking at Figure 1 that Americans have a gluttonous appetite for energy. In the past, we have tended to act as though our energy-producing resources such as coal, gas and oil were unlimited. Now, however, we are beginning to realize that they are not. We hear about the shortage of natural gas, fuel oil and gasoline. We hear about or even experience *"black-outs"* or *"brown-outs"* from a shortage of electricty. We are also recognizing the impact on the environment resulting from the large-scale production of energy.

Thus, in the past several years, the words *"energy crisis"* have been increasingly heard. One major thrust of this crisis concerns the conversion of various fuels such as coal, gas, oil or uranium into electrical energy.

The United States, with about six per cent of the world's population, consumes about 35 per cent of the world's yearly electrical energy. According to the *New York Times*, every child born in the United States will use eight times as much of the world's natural resources as a child born in an underdeveloped country.

The demand for electricity in this country has been doubling every 10 years. One reason for this increased demand has been the growing population.

Population growth is not new to American life. Big families are rooted in our frontier tradition--our early years of rapid growth westward--when families of seven or eight children were necessary for some to survive in a harsh and forbidding environment. With the closing of the frontier, American families became smaller, and during the Depression years, the population actually began to decline. Following World War II, the size of the American family again increased significantly. At present, our population is still increasing, but the rate of increase is smaller than in previous years. Population projections estimate that the population of the United States in the mid-1970s will be 206 million and by 2040 will have doubled to 412 million.

Only one-seventh of the projected increase in electrical production in the United States will be due to this population increase. Most of the remainder will be due to new consumer products, industrial processes and improved transportation 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 manufactured items which Americans take for granted, such as plastics, aluminum and glass, are made with the expenditure of electrical energy. 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 purposes related to cleaning up the environment, such as recycling of wastes, mass transit and sewage treatment.

Table 1 presents a breakdown of the uses of electricity.

Table 1

Consumption of Electricity in the United States

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

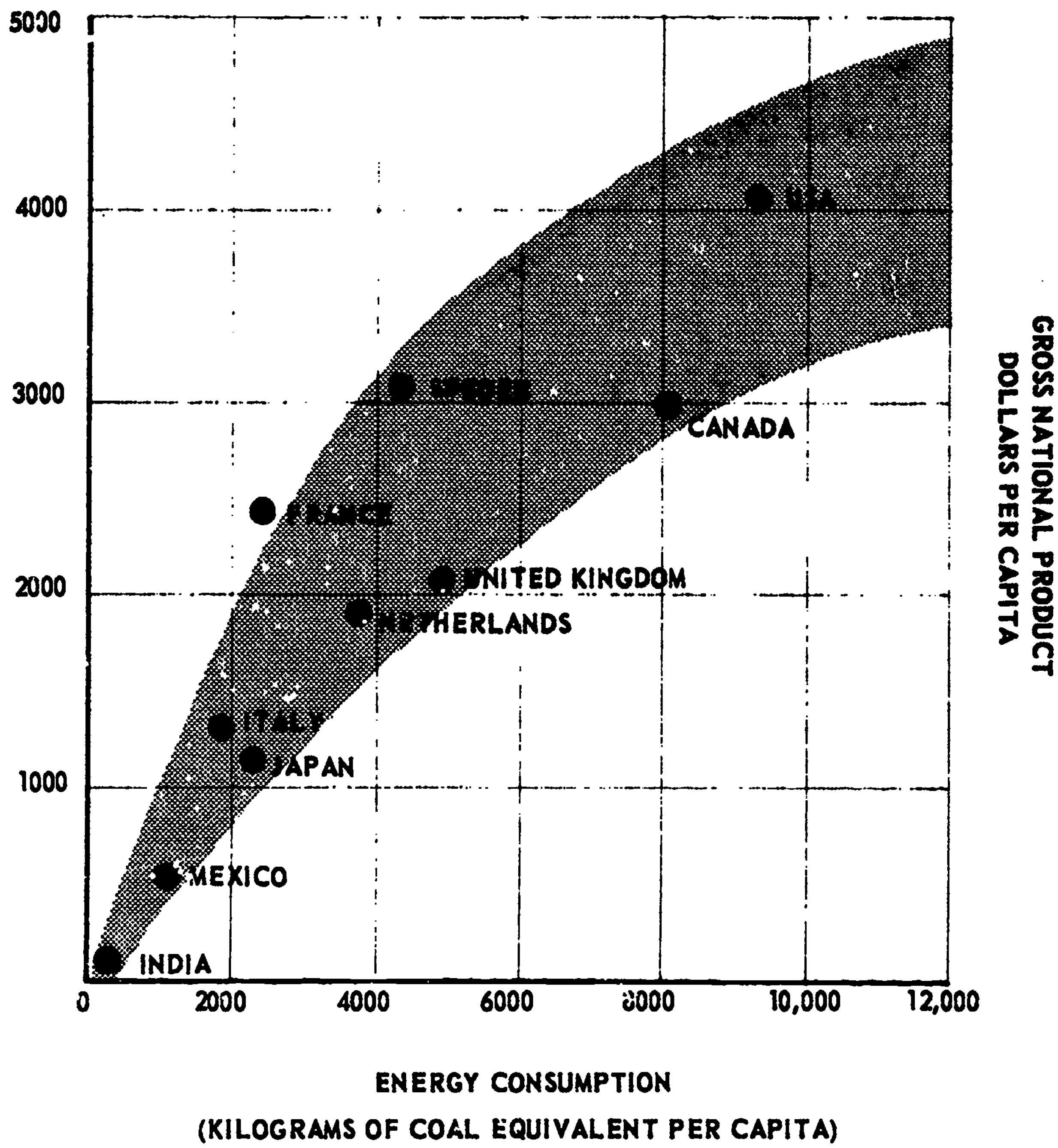


FIGURE I

ENERGY CONSUMPTION AND LIVING STANDARDS

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 Table 2, 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.

Table 2

Electrical Consumption for Some Common Home Appliances

Appliance	Esitmated 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
Refirgerator-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

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

*Use 110 or 220 volts, whichever applies.

Now that you have estimated the annual electrical consumption for your family, keep in mind that this represents only part of your real per capita consumption. Much more electricity is expended to manufacture the goods and services you use each day. The per capita electrical consumption in the United States for the year 1968 was 6500 kilowatt hours, most of it for industrial processes to maintain our high standard of living.

Table 3 gives past data and projections compiled by the electric utility industry for population and power needs.

Table 3

Population Projections and Power Needs

	1950	1970	1980	2000
U.S. Population (millions)	142	200	232	301
Total Power Capacity (millions of kilowatts)	85	340	665	21000
Power Consumed per person per year (kilowatt hours)	2000	7000	13000	33000

The projected growth of generating capacity in 11 Northeastern states illustrates these rapidly mounting electrical power demands. A report to the Federal Power Commission indicates that between 1970 and 1990, the power industry in these 11 states would have to build about four times as much electrical generating capacity as the industry had provided in all its 80-year history. In other words, about four times the 1970 capacity must be built in one-fourth the time to meet the projected needs. Based on 1970 prices, these tremendous undertakings will involve an investment of a staggering $50 billion for generation, transmission, and distribution facilities.

Chapter 2

MEETING THE DEMAND FOR ELECTRICAL ENERGY

THE GENERATION OF ELECTRICAL ENERGY

Our idea of electricity is based largely on what it does, 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 2 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 3) Current produced in this way is called alternating current (a.c.) because the electrons and therefore the current are moving in alternating directions in the conductor. This is the kind of current we use every time 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 used.

The only real 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 so that the turbine spins. 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. The hydroelectric station uses falling water to make the turbine spin. Gas turbines use hot gases to spin the turbine, much like a jet engine.

Figure 4 shows the major United States steam generating centers as of 1970, by size and geographic distribution. Figure 5 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.

CURRENT METHODS OF GENERATING ELECTRICAL ENERGY

The turbines that supply our electrical energy were kept spinning by these sources in 1972.

Table 4

Methods of Electrical Generation in 1972

Coal	47%
Gas	23%
Oil	10%
Hydroelectric	17%
Nuclear (Uranium)	3%

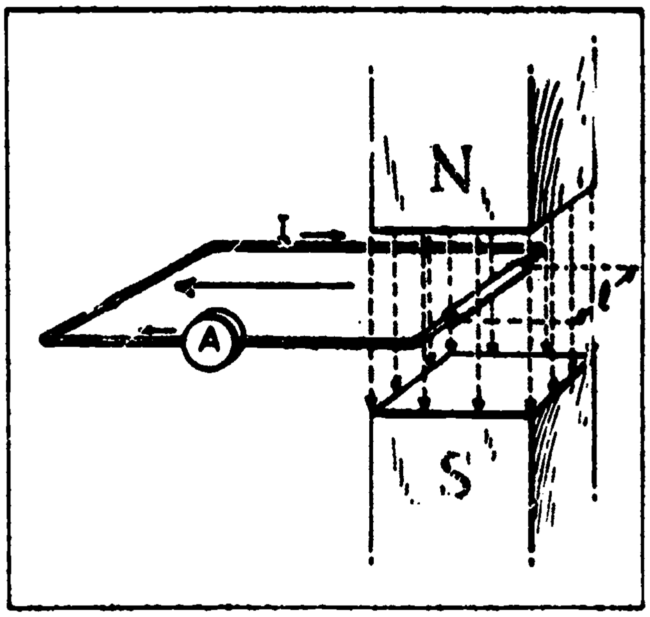


FIGURE 2

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

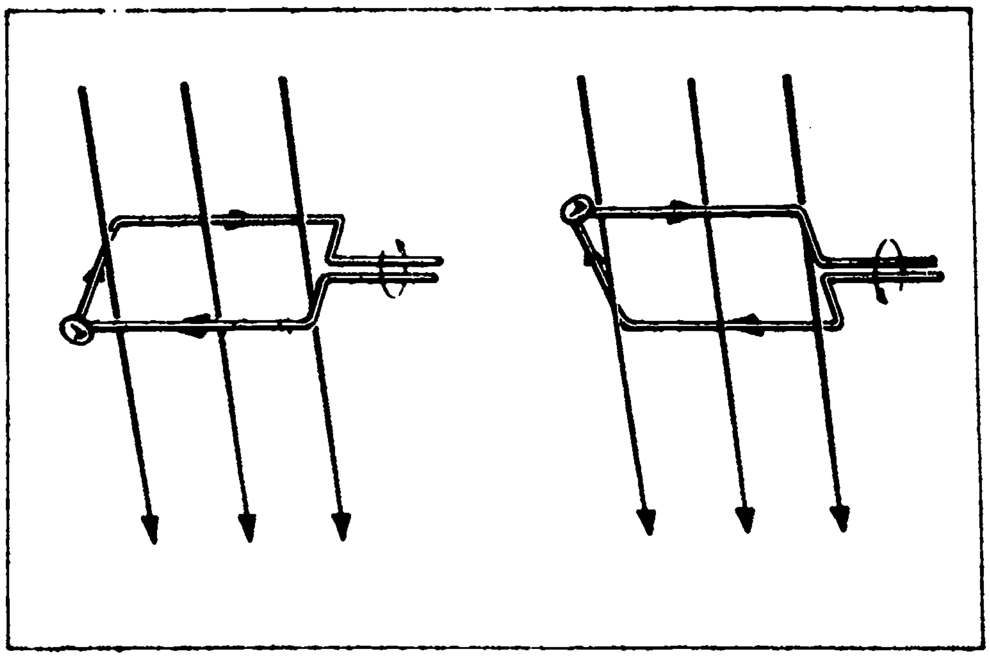


FIGURE 3

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

MAJOR STEAM GENERATING CENTERS 1970

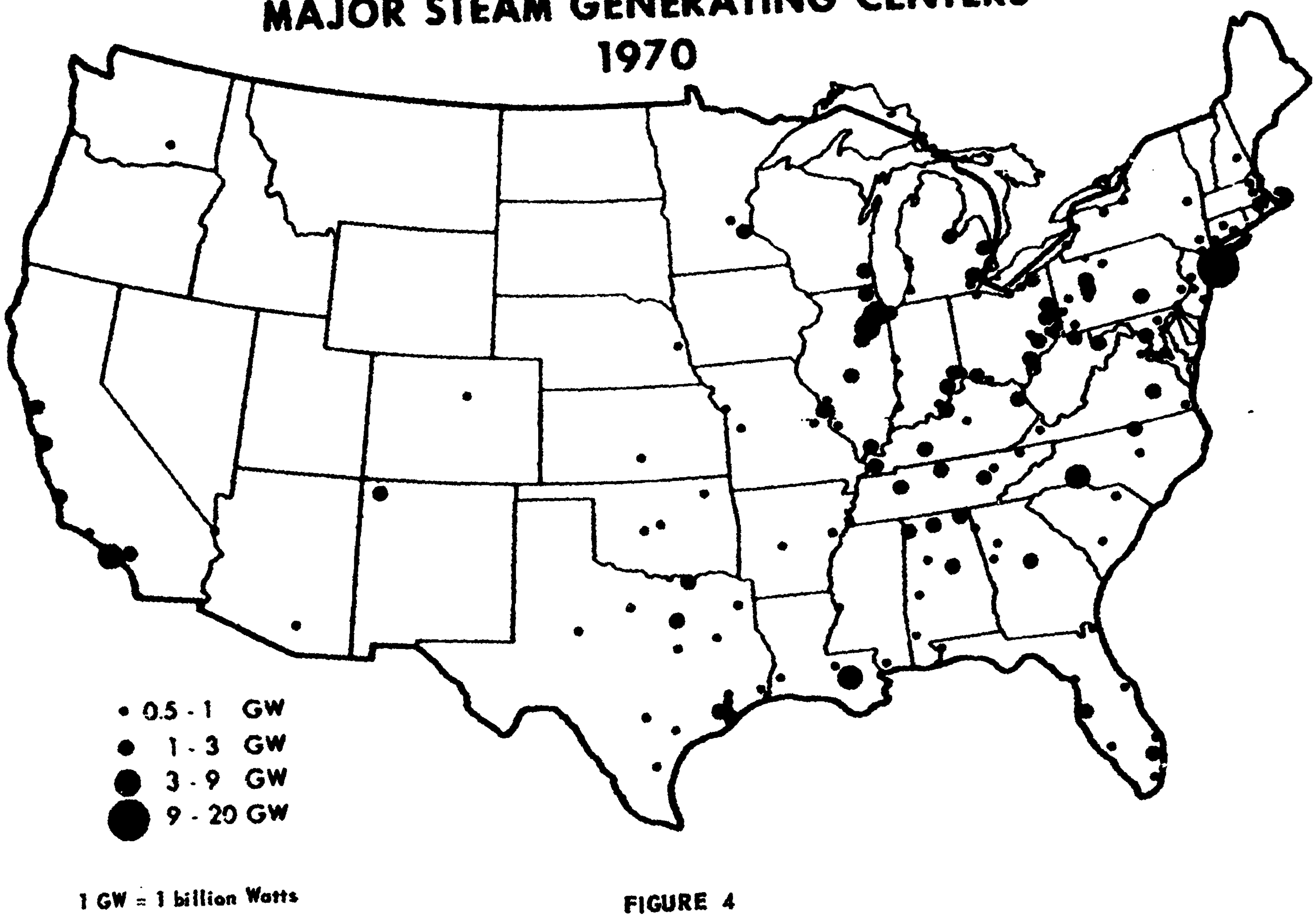


FIGURE 4

MAJOR STEAM GENERATING CENTERS
1990

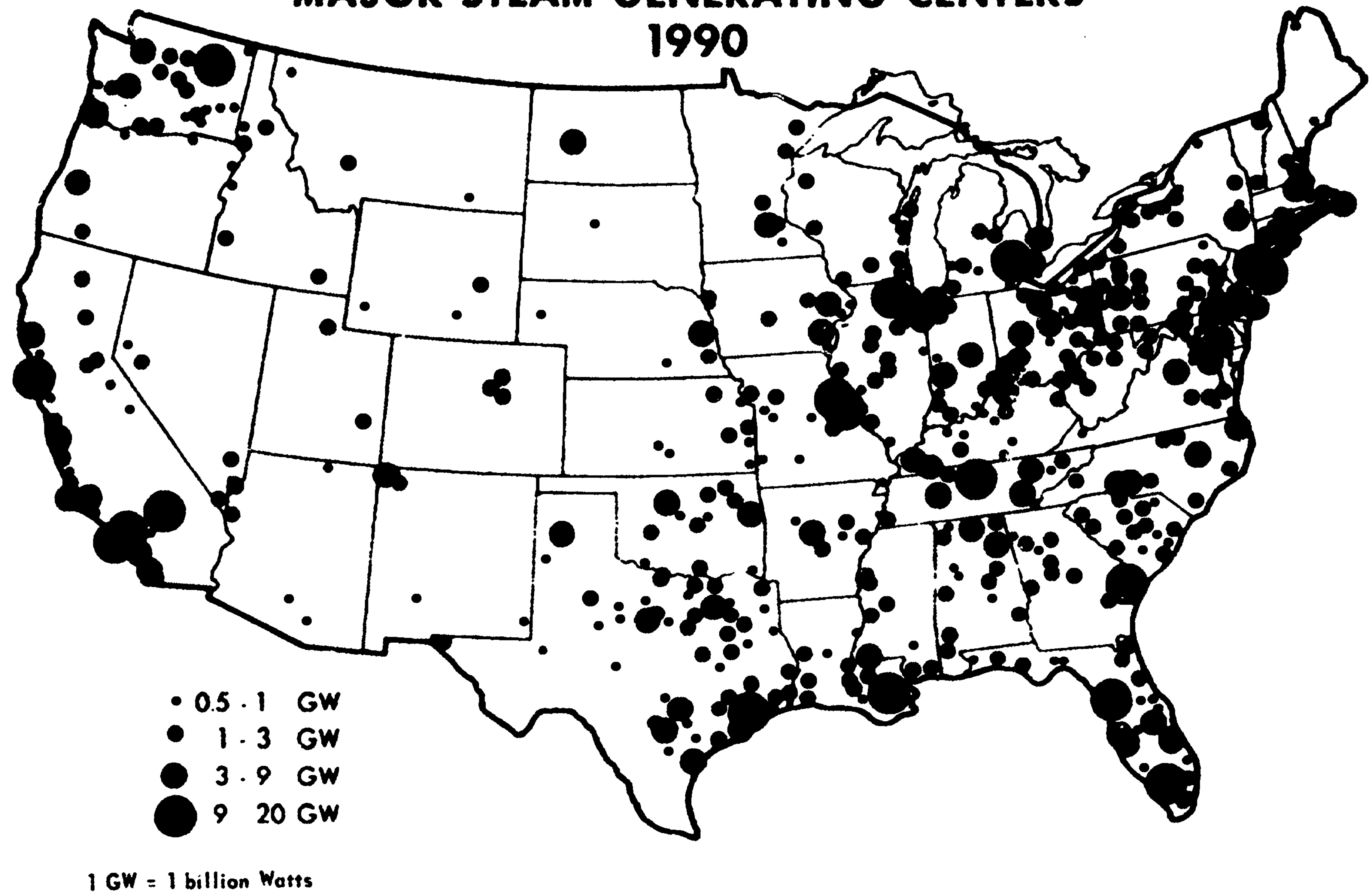


FIGURE 5

Other sources such as solar energy and geothermal energy provide a minute amount of electrical energy.

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 the 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 are the two alternatives presented and compared in detail in subsequent chapters of this text.

Before beginning this comparison, however, a look into various other possibilities for electrical generation is in order. This discussion is included because coal, oil and gas 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 resources. Even our known reserves of high-grade uranium ores are limited. It is expected that breeder reactors. which produce more fissionable material than they consume, will offset any uranium shortage for many hundreds of years. However, the technology to develop efficient breeder reactors is only now reaching the pilot plant stages, and only the first generation of these reactors has been built. *Coal gasification* will someday be used to turn our vast reserves of dirty coal into clean methane gas which will meet much of our future power needs. These future hopes will be covered in more detail in subsequent chapters.

Table 5 gives an estimate of when the different types of fuel will be depleted.

Table 5

Estimated Depletion of Economically Recoverable World Fuel Reserves

Fuel	Year
Mineable Coal	2400
Oil	2030
Gas	2020
Fissionable Uranium-235 (High-grade ore)	2040
Uranium-238 and Thorium-232 for Breeder Reactors	4000

ALTERNATIVE METHODS OF POWER PRODUCTION

The following is a summary of several possible methods of power production under study or in limited use.

Fossil Fuel Sources and Energy Systems

Solvent Refining of Coal

A technique is in the development stage which will 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.

Oil from Coal and Garbage

Processes are being developed which would 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. This process has an important potential for helping cope with municipal and agricultural garbage, since shredded garbage and other biological waste can be substituted for the pulverized coal, producing a 20 to 30 per cent yield of oil, based on the weight of the dried raw material.

Gas from Oil

One way in which natural gas supplies could be relatively rapidly expanded would be its production from naphtha and other petroleum components. This capacity could be developed much more quickly and with less capital expenditures than coal gasification. In this process, the oil is first desulfurized by reacting it with hydrogen gas. It is then reacted with steam under high temperature and pressure conditions to form a gas containing about 80 per cent methane and 20 per cent carbon dioxide. The carbon dioxide is readily removed, leaving synthetic natural gas. The product would cost significantly more than current natural gas, both because of the processing cost and the cost of the oil feed. This approach may be used to fill in the gap until coal gasification can be perfected.

Magnetohydrodynamics (MHD)

The one really 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 electrical 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 system as high as 60 per cent, 1 1/2 times that of a modern fossil fuel plant. Laboratory-scale MHD generators are in operation at the present. However, 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 new concepts of electrical energy currently under study.

Energy from the Sun

Diffused solar radiant energy (sunshine) can be collected and converted to electricity by several methods, including thermal conversion and direct conversion. Solar power plants have been proposed for desert areas having a large number of clear days, tropical oceans and even outer space.

Thermal Conversion Systems

Thermal conversion systems would involve trapping the sun's rays by an extensive array of steel pipes coated with materials which are heated by absorbing the sunlight. 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 1000 degrees F 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 1000 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.

Direct Conversion Systems

Direct conversion devices can convert solar radiant energy directly into electricity. One direct conversion scheme is the launching of a satellite-mounted array of solar cells in synchronous orbit which would permanently locate the cells over a pre-selected position on the earth's surface. Radiant energy would be converted into direct current which in turn would be converted electronically into microwave energy. This energy would be beamed to earth to be collected by 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 current power needs would require a solar collector panel 25 square miles in size in space, with a receiving antenna 36 square miles in size on earth. Obviously, the initial cost of such a solar generating station would be much higher than that of present stations. Operating expenses, however, would be very low, since the *"fuel"* resource is free, and there would be no moving mechanical parts in the system. Over a 40 year life, electricity costs might be lower than that from conventional sources.

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 during hot summer days.

Solar Sea Power

Proposed initially by the French physici Jacques D'Arsonval in 1881, solar sea power h 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 F, 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 killowatt 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.

Power from Other Natural Forces

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.

In a few locations, natural steam is available. In many places, hot water can be tapped as usable energy sources. Also there are areas of intensely hot rock that can be used by fracturing the rock and forcing cold water down where it can be heated. It can be returned to the surface to produce steam power. Where available, this should be clean, cheap and almost pollution-free energy source. For all its seeming simplicity, however, geothermal power is not without its problems. Corrosive hot water must be handled and the 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 source of water pollution, and there is often the liberation of hydrogen sulfide into the atmosphere. There also exists the possibility of land subsidence and an increase in seismic activity.

Total exploitation of all of the country's known geothermal resources could supply less than one per cent of the projected consumption of electricity by the year 2000. So this energy source presents no significant solution to the long-range energy problems.

Tidal Power

Tidal power utilizes the energy of the flowing tides which reverse direction four times a day. Tidal power plants can be located in only a few favorable places 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.

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 out in the oceans or Great Lakes where they could catch the strong prevailing winds. But because the wind is so highly variable, successful wind power generation, like solar power, is dependent upon energy storage, since the energy must be captured as it becomes available in its capricious moments. At best, wind power could supply only a small portion of our future energy needs.

Fusion Power

The most probable long-range resolution to the dilemma of dwindling fuel is the process of fusion, which powers the stars. In fusion, two light nuclei are fused together to form a heavier nucleus, releasing nuclear energy. The fusion reaction will use the heavy isotopes of hydrogen called dueterium and tritium. Deuterium can be economically separated from sea water, and tritium can be obtained in a nuclear reaction involving lithium. The fusion process is expected to result in smaller quantities of radioactive waste than the current fission reactors. So here may be the ultimate fuel–cheap, 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 C, 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 for a fraction of a second until a fusion reaction takes place. No one has yet made controlled fusion produce more energy than it consumes.

In the past, fusion research efforts have been directed to the goal of igniting and containing fusion reactions within magnetic fields. Many scientists now think that a more feasible approach is the use of high-powered lasers to initiate and confine such reactions. This newer concept is to heat in pulses small pellets of deuterium and tritium with many high-powered laser beams coming from different directions, instantaneously heating the pellets to ignite fusion and at the same time containing 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 that yet need to be overcome to be able to build practicable power systems based on either fusion concept are immense, probably putting the time of the first fusion power plants into the next century.

Small Unit Backup Electrical Power Sources

Internal Combustion Engine

One approach which is becoming increasingly useful in helping to solve short-term power shortage problems 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 system. It is expected that 100 megawatt units will be available by 1990. These systems burn expensive high quality fossil fuels, resulting in less environmental pollution. They are primarily used only when the electrical demand exceeds the capacity of the cheaper electricity from turbine generators, or as emergency power sources close to centers of large electrical demand.

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. This is done electrochemically, without having to go through the inefficient combustion steps required by most other fossil fueled electrical generating approaches. This 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 up to several hundred megawatts are envisioned for the future. Such units would not supplant other power generation sources, but would be used as supplemental power systems which would give electric utilities additional flexibility for providing the right amount of power where and when it is needed.

Increasing the Output of Electrical Generating Plants

The demand for electricity varies considerably from season to season, day to day and even hourly throughout the day, but electricity cannot be generated and stored for the peak times. It must be consumed as soon as it is generated. Thus the generating capacity of a system must be geared to meeting the peak load demand and there are large periods of time, especially during the night and weekends, when much of this generating capacity is not being utilized. Methods are being sought which would make greater use of this idle capacity.

Pumped Storage

Hydroelectric plants are useful to complement and supplement base load power, but as mentioned previously, most sites in which hydroelectric plants can be built have already been exploited. The pumped storage concept utilizes the principle of hydroelectric power generation and increases the utilization of existing power generation capacity. During periods of low electrical demand, the electricity is used to pump water to high reservoirs. Then during periods of peak load electrical demand, the process is reversed and the stored water is released to turn hydraulic turbines to produce the additional power needed.

While such systems enable a higher utilization of power plant equipment of the utility system, losses in the process amount to about 25 per cent. That is, for every four kilowatts used to pump the water to the reservoir, only three 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.

Hydrogen Fuel Economy

A proposed approach which is gaining increasing numbers of 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 nonpolluting water vapor, with the only possible pollutant being the nitrogen oxides formed from the components of air. If it is burned in pure oxygen, even this source of pollution is eliminated.

It would be easily transported in existing natural gas piping systems 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 then to transmit electricity over power lines, because of line losses.

It is envisioned that large coastal power plants, such as nuclear or solar sea power plants, would use their excess capacity for the electrolysis of water, producing oxygen and hydorgen gases. The efficiency of these electrolyzers would be 60 to 70 per cent. The large plants could therefore be operated 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 to be stored until needed. They would then be burned in efficient combustion turbines or in even more efficient fuel cells.

The major obstacle for the large-scale future use of hydrogen depends on a large extent on society's overcoming what has been called the *"Hindenburg syndrome."* Most of the older members of our population can still picture in their minds the newsreel film of the hydrogen-filled German zeppelin Hindenburg which crashed in flames and killed several passengers. However, proponents of the use of hydrogen fuel feel that if it is properly handled, it will be as safe as natural gas is today.

Chapter 3

NUCLEAR POWER PLANTS

THE FISSION PROCESS

When *atoms* of certain heavy elements are bombarded by *neutrons*, the nuclei of some of these atoms will capture a neutron and become unstable. Such an atom will then change in one of several ways. One possibility is for the unstable atoms to *fission*, or split into two or more smaller atoms. Together the fission products weigh slightly less than the combined weight of the original atom and the bombarding neutron, and this missing weight or mass has been converted into energy, as described by Einstein's formula: energy equals mass times the velocity of light squared ($E=mc^2$). As the 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. This steam can be used to spin turbines and generate electricity. Thus the only difference between nuclear and fossil fuel 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 6). If the chain reaction is to continue, there must be enough atoms packed close enough together to insure the capture of enough neutrons to keep a constant rate of fission. The amount of material required for this is called the *critical mass*.

Generally, the smaller atoms produced in the fission process, called the *fission fragments*, are unstable. To change to a stable state, they throw off charged subatomic particles and/or electromagnetic waves. This process is called *radioactive decay*. Substances which change in this fashion are called *radioactive*: the products are *radiation*.

During radioactive decay, three principal types of radiation can be emitted from an atom. Heavy nuclei such as the naturally-occurring isotopes of uranium and thorium often decay by the emission of *alpha particles*, which are high energy helium nuclei. Other atoms decay by the emission of *beta particles*, which can be either high energy negatively charged *electrons* (negatrons) or positively charged electrons *(positrons)*. These also originate from the nucleus of the decaying atom. Fission fragments usually decay by the emission of negatively charged electrons. Decay by the emission of these particles is usually followed by the emission of electromagnetic radiation 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 of lower energy and therefore are less penetrating, x-rays and gamma rays are the same.

Loss of this radiation changes the atomic structure of the radioactive substance, a process which continues until a stable (nonradioactive) element is reached. Uranium, for instance, is radioactive, and 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 an element to decay to its *daughter* species of atoms is known as the *half life* of that element. If an atom has a short half life, it will quickly decay away. Half lives vary from minute fractions of a second to millions of years.

Figure 7 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 the half life lengths.

NUCLEAR FUEL

Uranium is the basic nuclear fuel because it contains uranium-235, the only substance found in nature that readily undergoes fission. The natural concentration of uranium-235 in uranium is seven-tenths of one per cent, the balance being 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 of the deposits are shallow and mined by open-pit techniques, but the greater part comes from underground mines.

Uranium mining disturbs land areas, but much smaller areas are involved than in the mining of coal. Around 30,000 tons of uranium ore must be mined and milled 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 in a strip mine to ship the two million tons of coal per year needed for a comparable coal-burning plant.

NUCLEAR FISSION CHAIN REACTION

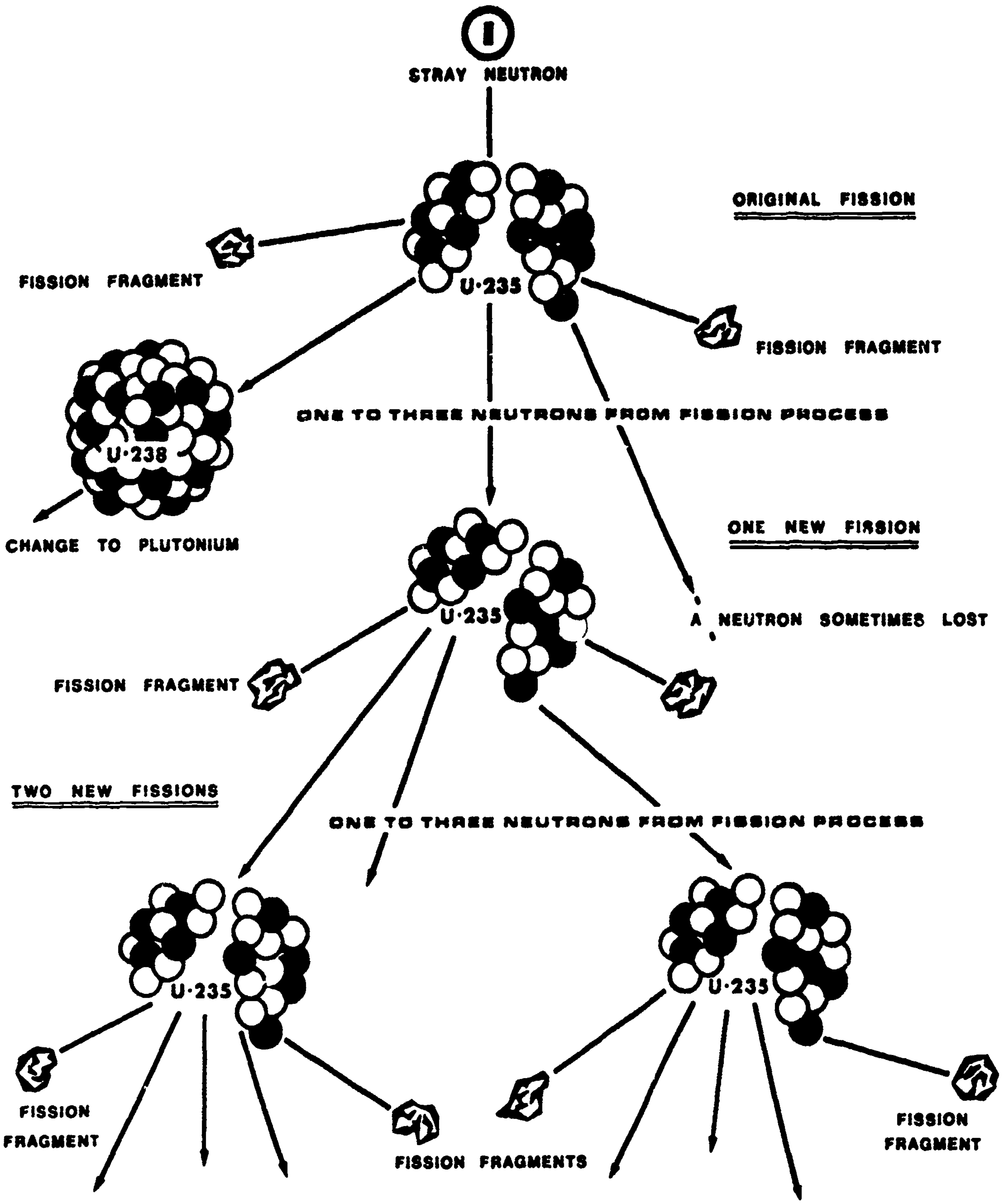


FIGURE 6

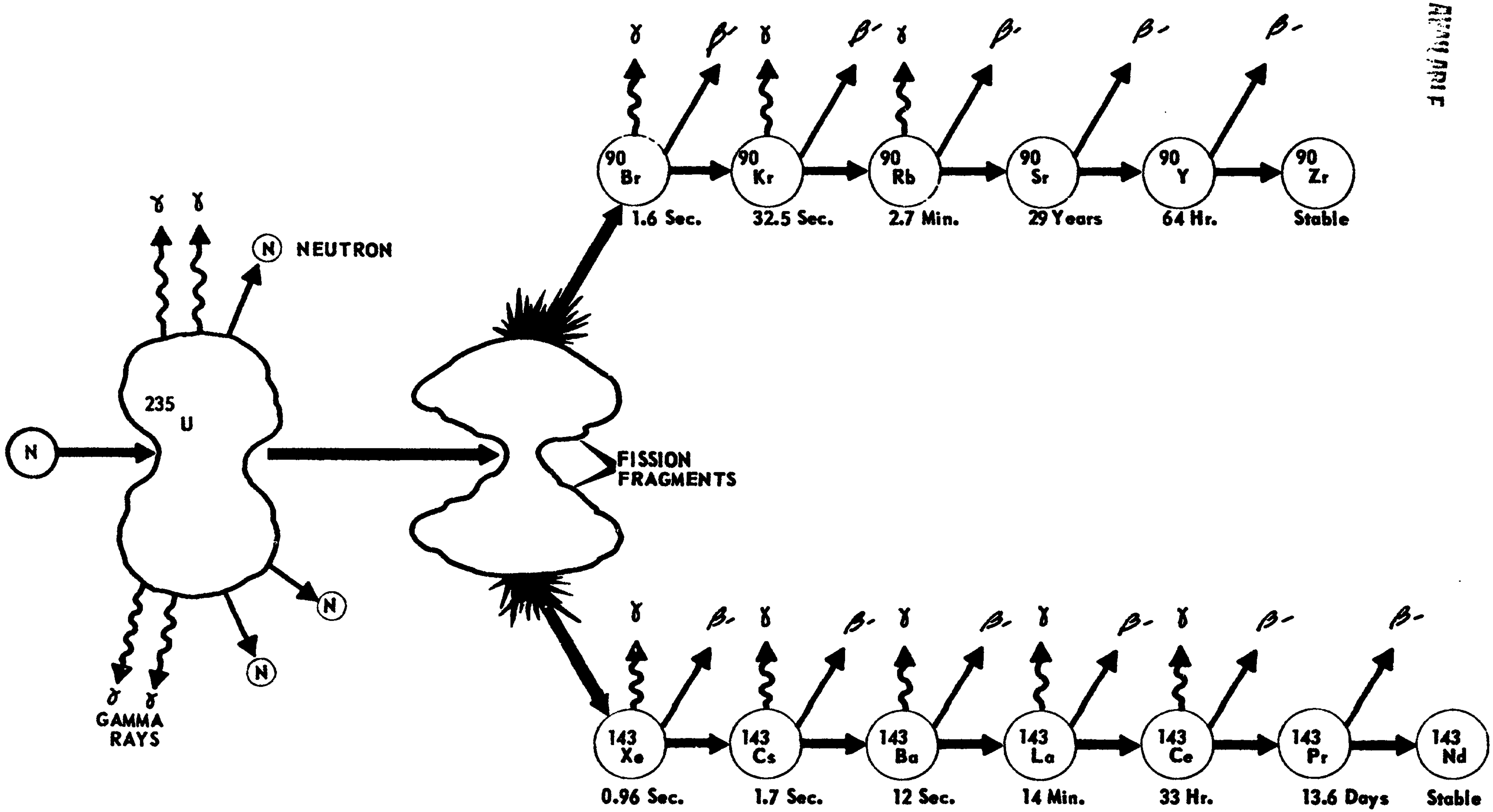


FIGURE 7

URANIUM FISSION AND BETA DECAY CHAINS

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 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 are made of materials that readily absorb neutrons. These rods are usually strips of metal (boron or cadmium), 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 may be stopped completely. This makes it possible to produce heat at a desired rate or to shut down the reactor completely.

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

The shielding consists of components made 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 members from radiation damage. Still other shielding components prevent radiation from escaping and causing biological damage.

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

Major reactor components are shown in Figures 8, 9 and 10. The reactor core which is shown within the reactor vessel of Figure 8 is approximately a right cylinder with a diameter of about 11 feet and a height of 13 feet. The core is made up of 177 fuel assemblies which weigh about 1500 pounds each. The fuel assembly is in turn a vertical stack of 180 fuel rods and 16 guide tubes for the neutron-absorbing control rods (Figure 9). Each fuel rod is a zirconium alloy tube about 0.4 inches in diameter with a wall thickness of about 0.025 inches (Figure 10). Within the zirconium tube, called ***cladding***, is a vertical stack of uranium dioxide fuel pellets containing slightly *enriched* uranium. Enriched uranium contains more of the fissionable uranium-235 than the naturally-occuring percentage. These pellets are about three-eights of an inch in diameter and three-fourths of an inch long. Each fuel rod is held in a lower spacer grid, several intermediate spacer grids and an upper grid and housing.

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. Of all the power reactors ordered for construction in this country as of September 1971, 35 per cent were boiling water reactors, 62 per cent were pressurized water reactors, one per cent was gas cooled and two per cent were other types. A major research program is underway to develop another type, the fast breeder reactor.

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 is brought into the reactor and allowed to boil. It then is taken out of the reactor as pressurized steam. The steam is used to drive a turbine, producing electrical power. Typically, a BWR operates at a pressure of about 1000 pounds per square inch and produces steam at about 550 degrees Farenheit. The BWR has the advantage of simplicity, but suffers

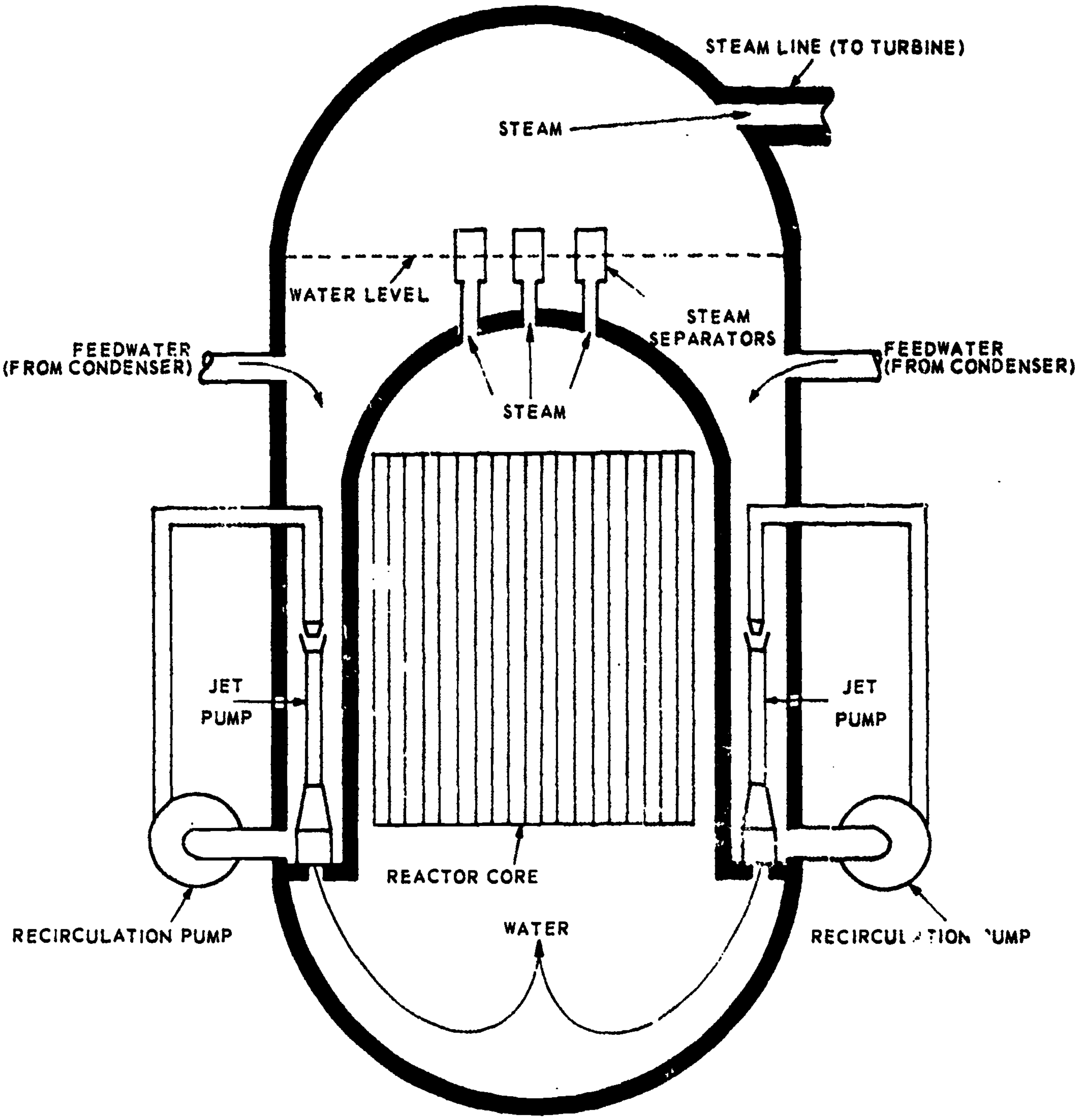
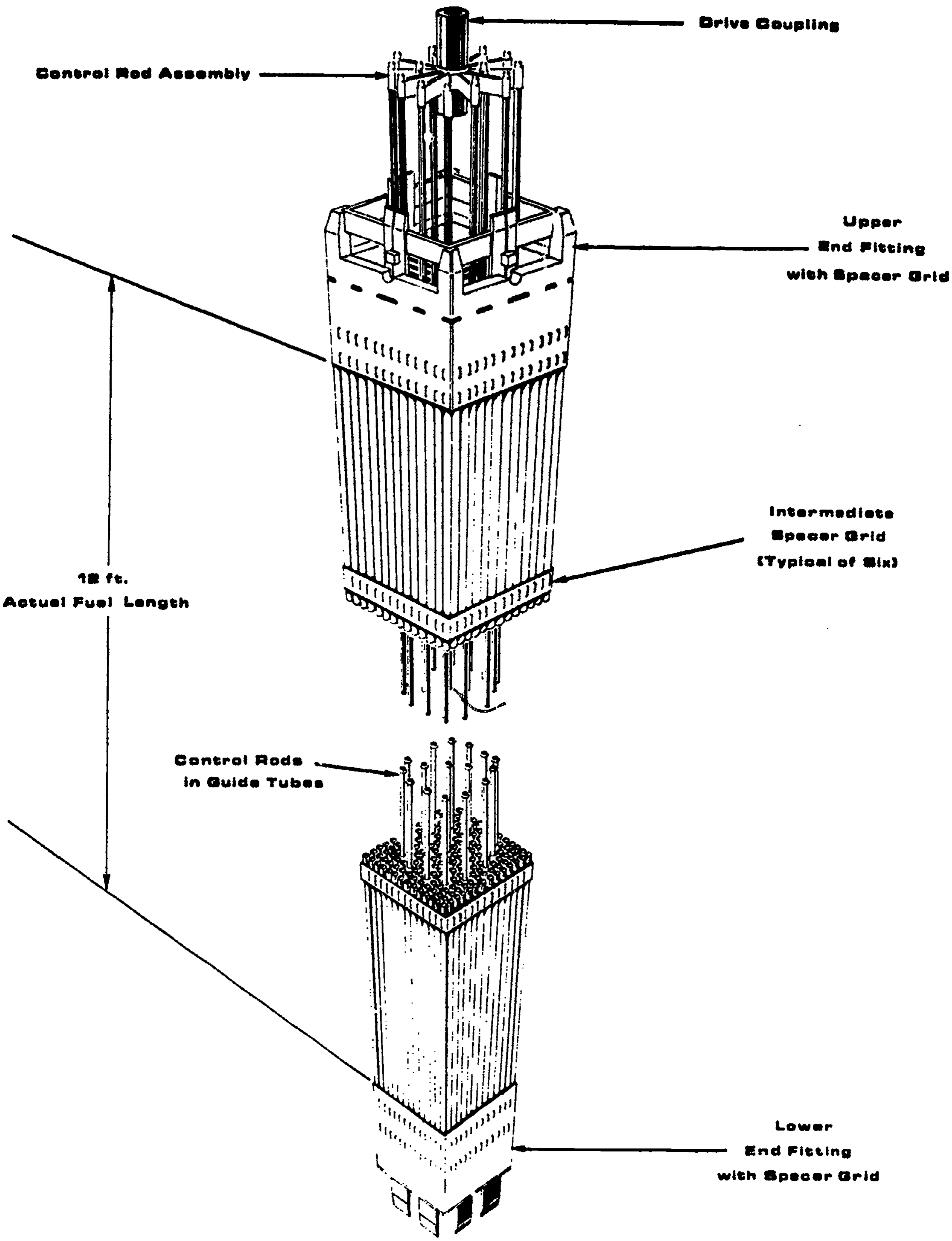


FIGURE 8
SCHEMATIC ARRANGEMENT OF BOILING WATER REACTOR

FUEL ASSEMBLY



FUEL ASSEMBLY - Cutaway Showing Partially Inserted Control Rod Assembly

FIGURE 9

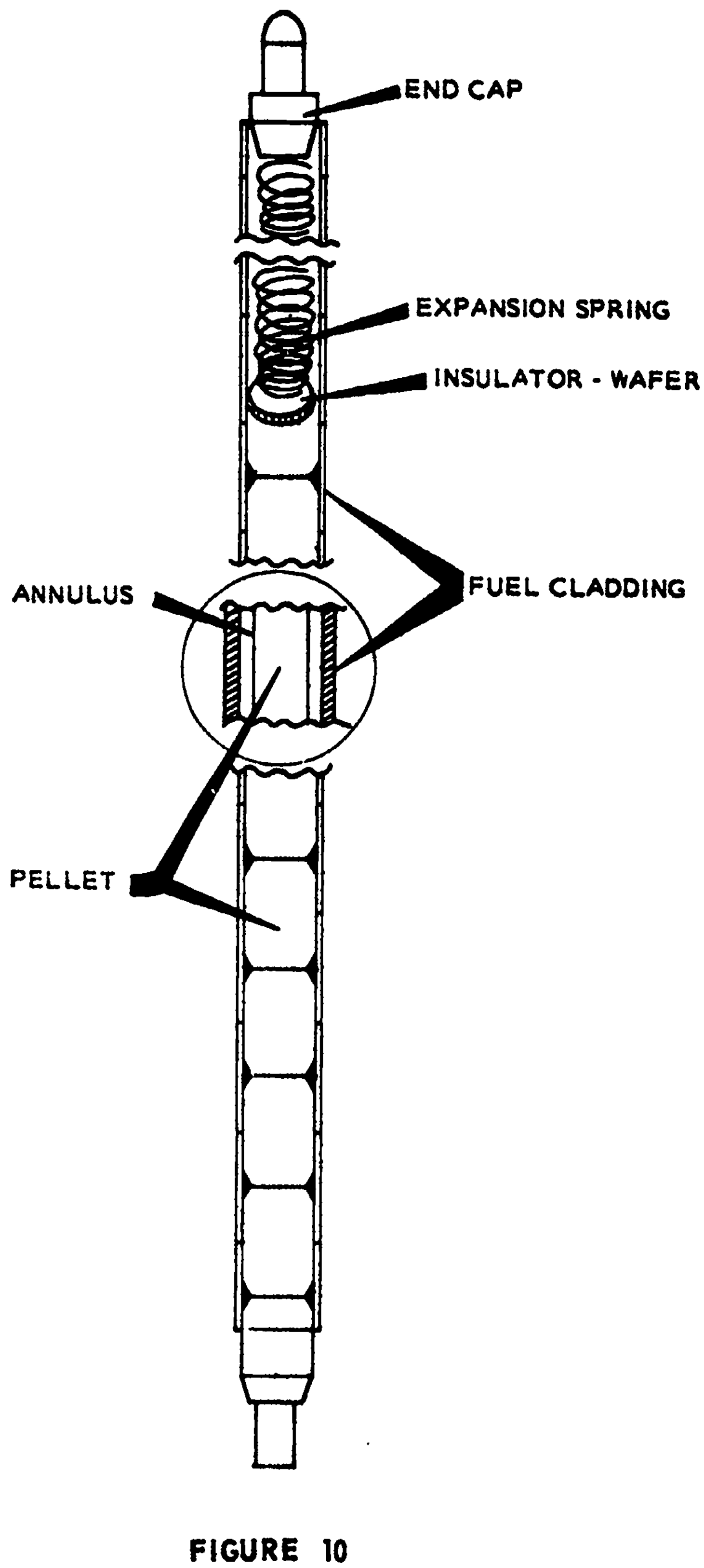


FIGURE 10
CUTAWAY OF FUEL ELEMENT
FOR NUCLEAR REACTOR CONE

BOILING-WATER REACTER

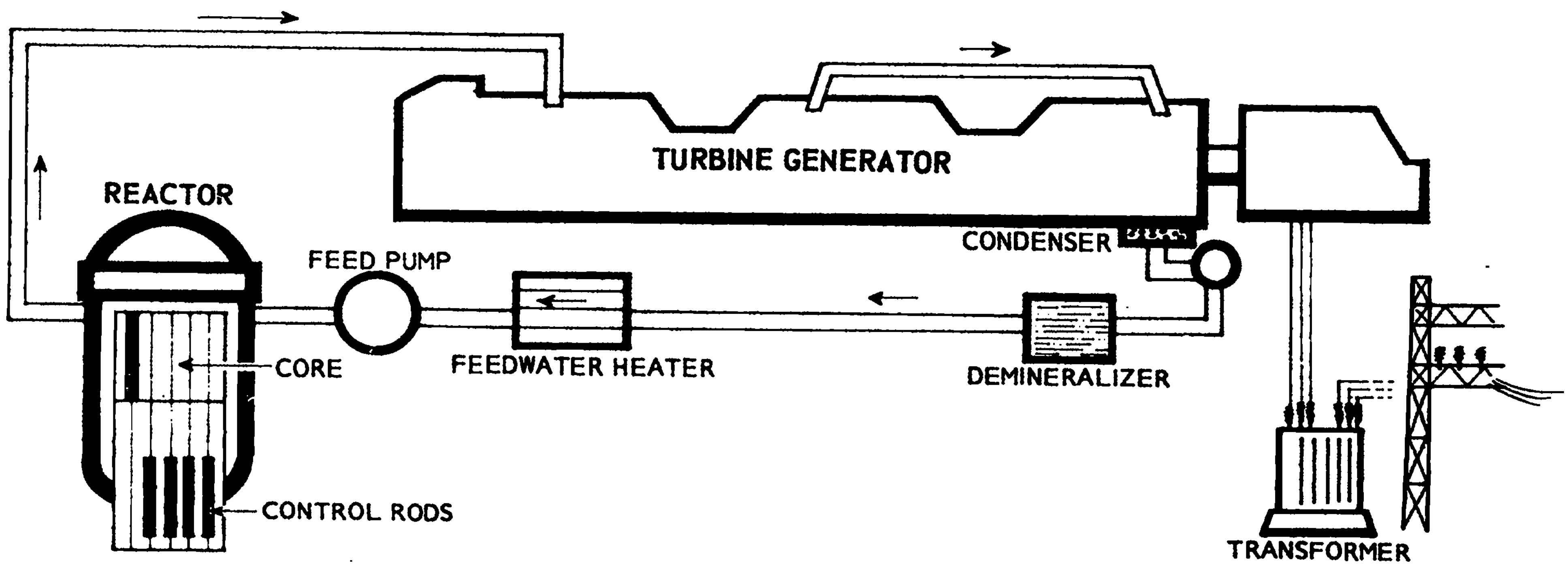


FIGURE 11

from the disadvantage of requiring a large core for cooling purposes. Some of the atoms and materials dissolved in the water may become radioactive and be carried through to the turbine section, increasing the area where radiation exists. The early models of boiling water reactors suffered from a high emission of radioactive gases as compared with other reactors, but this has been significantly reduced in newer models. Boiling water reactors still emit more radioactive gases such as xenon, Krypton, and iodine than contemporary pressurized water reactors.

Pressurized Water Reactors (PWR)

In a *pressurized water reactor* (Figure 12), pressure keeps the water from boiling. Instead, it is pumped through the core and is removed at the top as a heated liquid. The water is then circulated through a heat exchanger in which steam is produced from water in a secondary loop and used to drive a turbine. The cooled water in the primary loop is then returned to the reactor to again cool the core. The PWR normally operates at pressures of 2000 pounds per square inch and about 660 degrees Farenheit. The PWR has several advantages over the boiling water reactors. The coolant used at the reactor core does not directly contact the turbine. Thus 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 PWR, however, requires higher operating pressures and additional heat exchangers, which lowers its efficiency The high temperature increases the corrosion of the fuel rods, the cladding, and the vessel.

High Temperature Gas Cooled Reactors(HTGR)

In the *high temperature gas cooled reactor* (Figure 13), as the name suggests, the core is cooled by passing certain gases over it. Usually purified carbon dioxide or helium is the gas employed as the coolant. This type of reactor has a low fuel consumption rate, because very few neutrons are captured by the coolant, but it has several 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 can water coolant, it can produce steam at much higher temperatures than the 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 an *efficiency* equal to that of the best fossil plants. Current water cooled plants have somewhat lower efficiency than modern fossil fueled plants, and therefore are potentially sources of greater *thermal pollution.*

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 5, that the high grade ores of this material are estimated to be depleted by the the year 2040. *Breeder reactors* are looked upon as a method of extending this limited fuel supply so that it will last hundreds of years beyond the estimated date, because breeder reactors 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. This is also a fertile material, converting under neutron irradiation to fissionable uranium-233. The 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 types of power reactors, but not at such a high rate as in breeders. When an atom of uranium-235 fissions, it produces on the average 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

PRESSURIZED WATER REACTOR

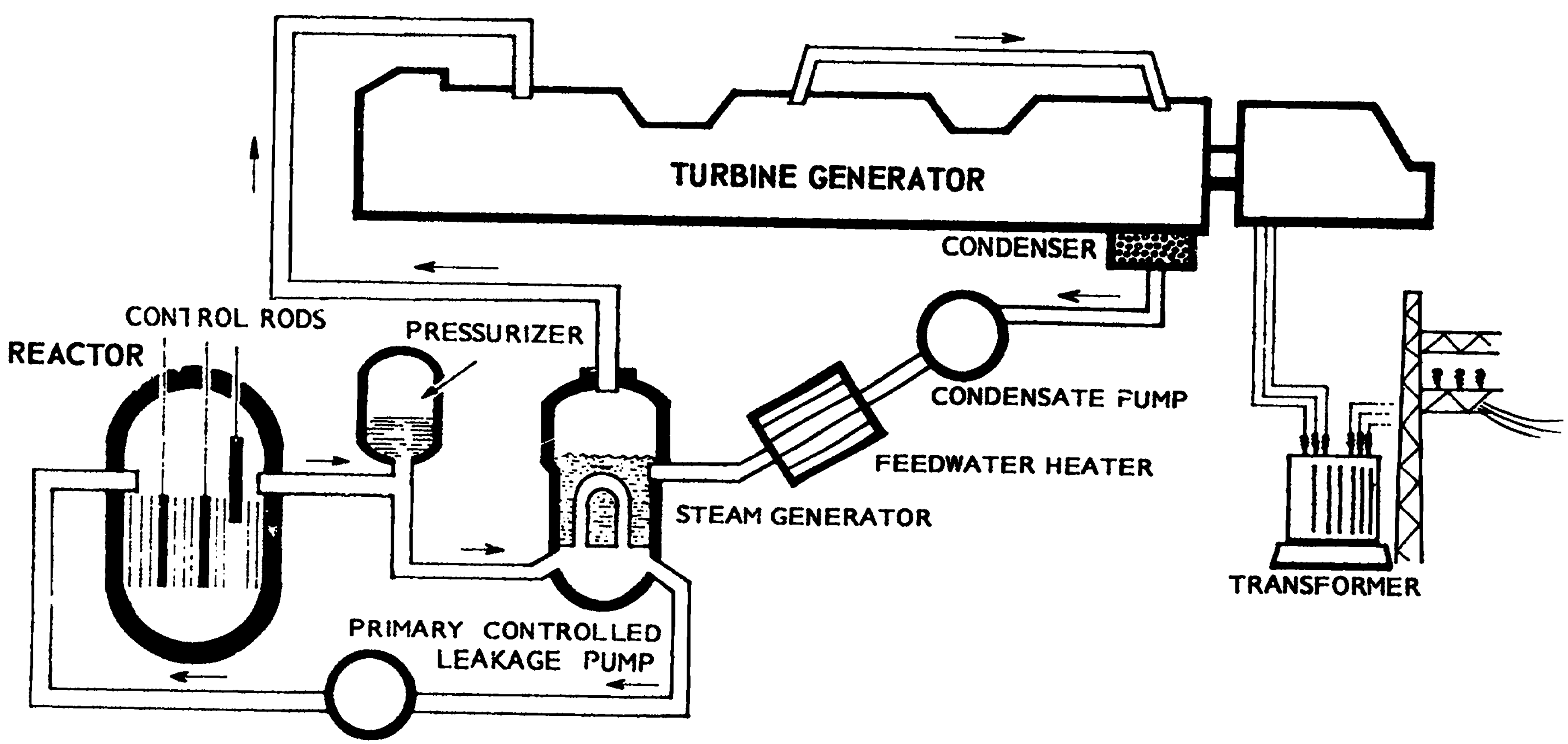


FIGURE 12

HIGH-TEMPERATURE, GAS-COOLED REACTOR

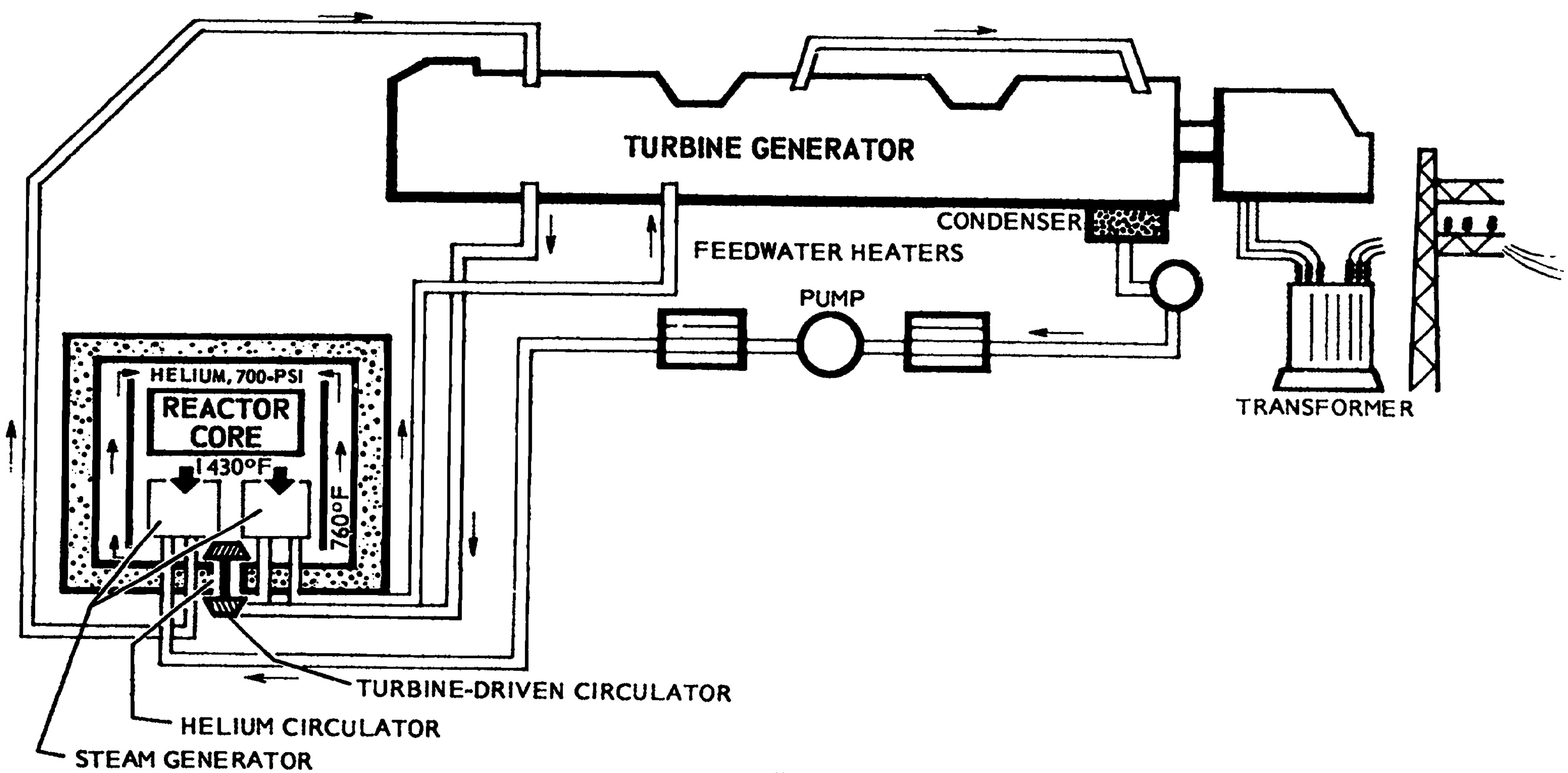


FIGURE 13

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 are consumed.

In 1970, President Richard Nixon said in a message to Congress, *"Our best hope today for meeting the nation's demand for economical clean energy lies with the fast breeder reactor. Because of its highly efficient use of nuclear fuel, the breeder reactor could extend the life of our natural uranium supply from decades to centuries, with far less impact on the environment than the power plants which are operating today."*

President Nixon established as a national goal the successful demonstration of a breeder technology by 1980. By 1972 the federal government had spent some $650 million to develop the liquid metal fast breeder reactor. More will undoubtedly have to be spent before commercial breeders are available. On the other hand, several groups, including the Scientist's Institute for Public Information and Friends of the Earth, have seriously questioned the government's commitment to breeder technology on the grounds of public safety, and recommend that the government spend more money on the development of alternative sources of electrical energy.

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-233-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

Liquid Metal Cooled Fast Breeder Reactors

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 14.

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.

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

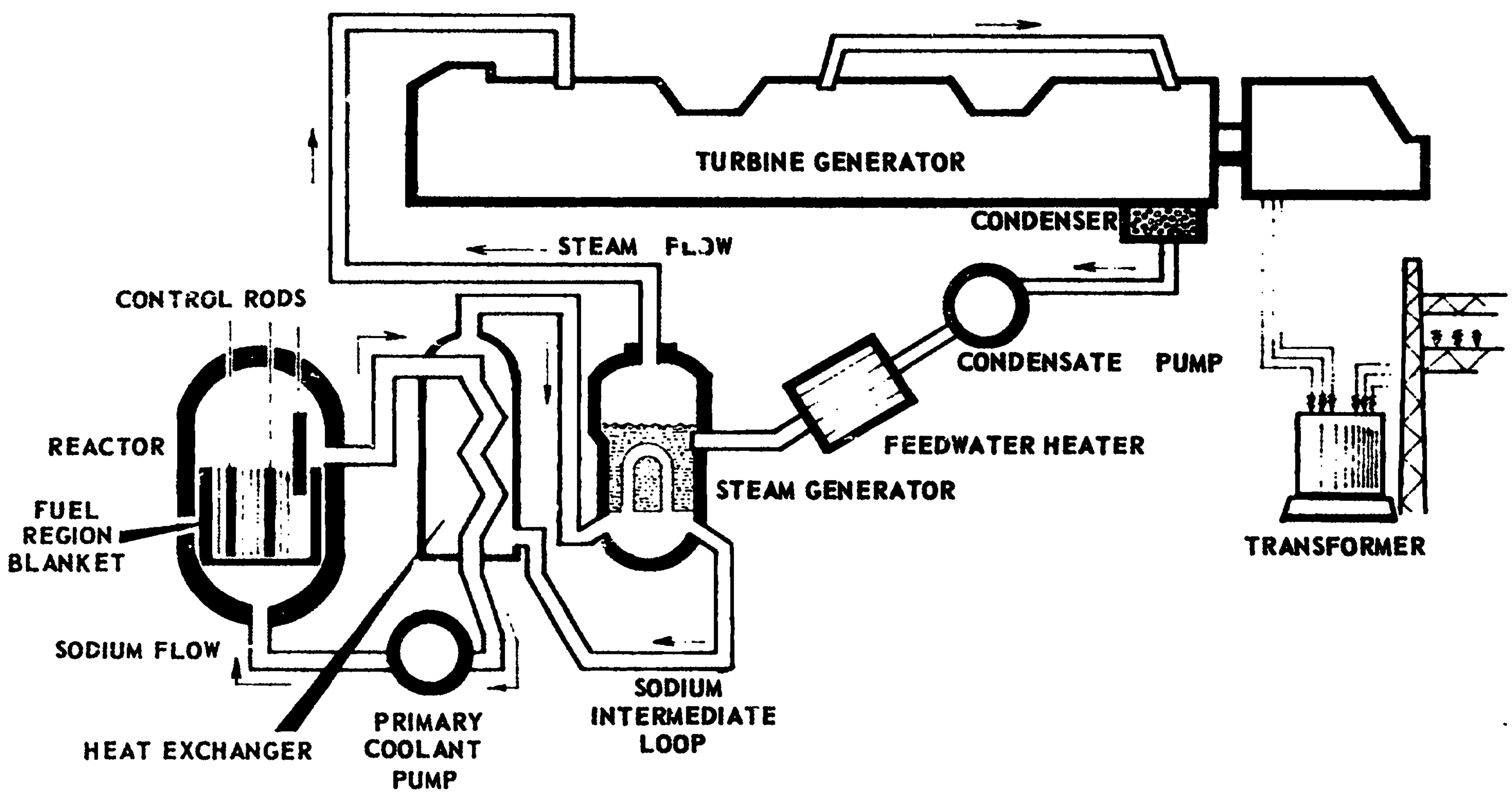
The fuel in such a system would probably be a mixture of oxides of uranium and plutonium.

Liquid metal fast breeder reactors have the potential of greater efficiency 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 efficiency for light water reactors. This means a decrease in waste heat.

The LMFBR has some disadvantages when compared with light water reactors. These disadvantages are due mainly to the sodium coolant. Sodium is a highly chemically reactive metal which will burn if exposed to either water or air. Further,

FIGURE 14

LIQUID METAL FAST BREEDER REACTOR



it is a solid at room temperature and requires a elaborate heating system to assure that it will remain liquid at all times throughout the coolant system. Sodium is not transparent to light, which complicates refueling and maintenance.

The sodium coolant will capture some of the reactor neutrons and become intensely radioactive. Since the main *radioisotope* 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 will 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 results in an increase in reactor power. The opposite effect occurs in light water reactors.

The cost of building a LMFBR will be 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 operating prototype systems. It is the United State's goal to develop two or more prototypes in the 1970s and to have larger plants operational in the 1980s. Some other nations appear to be more advanced in the development of breeder reactors than the United States.

SAFETY SYSTEMS IN NUCLEAR REACTORS

No accident affecting the public health and safety has occurred in a commercial nuclear power plant. Furthermore, no radiation injury to a plant worker has occurred in such a plant. This record is due to stringent safety precautions taken by the builders of nuclear plants. A nuclear power plant cannot be built or operated without a license from the U.S. Atomic Energy Commission, which is charged by law with the responsibility of satisfying itself that the plant will not endanger public health and safety.

Control During Normal Operations

Nuclear power plants form small quantities (on the order of serveral pounds per day) of radioactive substances. In normal operation, more than 99.99 per cent of these substances remain within the fuel assemblies. The small amount that gets out of the fuel enters the reactor coolant system and is removed by purification equipment. An infinitesimally small amount of radiation is released to the environment on a strictly controlled basis, subject to conservative and rigidly enforced Atomic Energy Commission (AEC) health and safety regulations. This is discussed in greater detail in Chapter 5.

Accident Prevention

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 nonfissioning 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 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.

Engineered Safeguards

In addition to the natural safeguards, many safety features are built as an integral part of any reactor facility. These include the following.

1. Monitoring of reactor neutron intensity.

   Since neutrons initiate the 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 the neutron intensity rises above a preselected limit.

2. Reactor control systems

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

3. Reactor safety circuit instrumentation

Instruments constantly monitor what is happening in the core. Improper signals concerning temperature, pressure, or other measurements will cause immediate reactor shutdown. Each safety system has one or more backup systems which operate when there is a failure in the primary system.

4. Electric power requirements

Reactor designers assume that at some time all electric power available to a nuclear plant may be shut off. To allow for this possibility, reactor systems are usually designed so that they require no electric power to achieve safe reactor shutdown. Those which may require power after shutdown, for example, to keep the coolant circulating, are equipped with emergency diesel generators and batteries to supply electricity for the reactor when no outside power is available. These are test run at intervals to insure reliability if and when they are needed.

5. 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 made available to provide emergency core cooling. The network is fully automatic, and does not require operator intervention during the initiation of the emergency core cooling systems. The effectiveness of some of the current emergency core cooling systems has been seriously questioned, so they are now under very close study

Containment in the Event of Accidents

As has been seen, there are multiple physical barriers in reactor systems to guard against the escape of radioactive substances into the environment. This multiple barrier concept recognizes that the radioactive fission products must be contained within the reactor system in order to avoid exposing the public to radiation. There is first of all the ability of the fuel material to retain most of the fission products, even when overheated. Then there is the fuel element cladding through which fission products must pass in order 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 forms a secondary containment system, and may be sealed off as a further safety move. Figure 8 shows some features of a containment system.

NUCLEAR POWER PROBLEMS

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 of difficulty in obtaining the necessary licensing. Hearings for various licenses by the AEC, state agencies and other groups, once nearly routine, have become battlegrounds for environmentalists concerned about radiological safety, plant siting and thermal pollution.

Even though the electrical power industry regards nuclear power plants as the answer for the long term, it is less than happy with nuclear plant performance to date. Many plants are operating at lower than expected efficiencies, and have had problems which have caused them to be shut down for long periods.

Chapter 4

FOSSIL FUELED ELECTRICAL GENERATING STATIONS

THE COMBUSTION PROCESS

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. When these fossil fuels are burned, they release heat energy which can be used to produce electricity. Coal, oil and gas are composed mainly of hydrogen and carbon. In the combustion process, they produce carbon dioxide and water vapor, plus byproducts such as sulfur dioxide, oxides of nitrogen, unburned hydrocarbons, carbon monoxide and ash.

FOSSIL FUELED PLANTS

Most large fossil fuel-burning plants are similar in design. (Figure 15) Fuel in the form of crushed coal, oil or gas is blown under high pressure into large boilers. Flames and hot gases resulting from the burning of the fuel pass over and around thousands of tubes filled with water. The water inside the tubes is converted to steam which collects in steam drums at the top of the boiler. The steam is then used to burn turbine generators to produce electricity.

The most noteworthy developments in fossil fuel generation in recent years has been the increase in plant size from about 700 megawatts to 1300 megawatts. These units have increased their efficiency by going to higher steam pressures and temperatures. Such plants are going to higher stacks for pollution dispersal, electrostatic precipitators for particulate control, and increased use of low sulfur fuel.

Gas

Gas is considered as the cleanest of the fossil fuels, since it is essentially methane which can be readily burned completely 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 pipelines under the ground. They are reasonably safe and have little environmental impact, with the possible exception of the Alaskan pipeline, which will have to be carefully designed to prevent damage to the fragile Arctic environment.

Unfortunately, natural gas is being used up faster than new reserves are being discovered. Electric utilities will probably be among the first to suffer from the gas production deficiency. It is anticipated that by 1990 there will be none available for use as fuel for electric utilities. More and more the natural gas will have to be supplied from oil and coal gasification and from shipment from places as far away as Siberia.

Petroleum companies are starting to make long-term commitments to foreign countries for the purchase of liquified natrual gas. To be economical, this will have to be shipped in large super-sized tankers whose use will require the construction of large ports along our coasts. The proposed construction of such ports is now being attacked by environmentalists because of the environmental implications of their building and operation.

Oil

Because of the lack of economical technology for removing sulfur from coal, utilities and industries are turning to oil to meet the 1970 Clean Air Act requirements, especially in the northeastern United States. The slowdown in building 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. We already import one-fourth of our oil, and the National Petroleum Council estimates that by the early 1980s we may need to bring in half of our oil supply from abroad.

Those responsible for our national security worry about becoming dependent on foreign oil sources, especially those in the oil-rich but politically volatile Middle East. What would happen if the Arab states should cut off our oil shipments?

CONVENTIONAL FOSSIL-FUELED PLANT

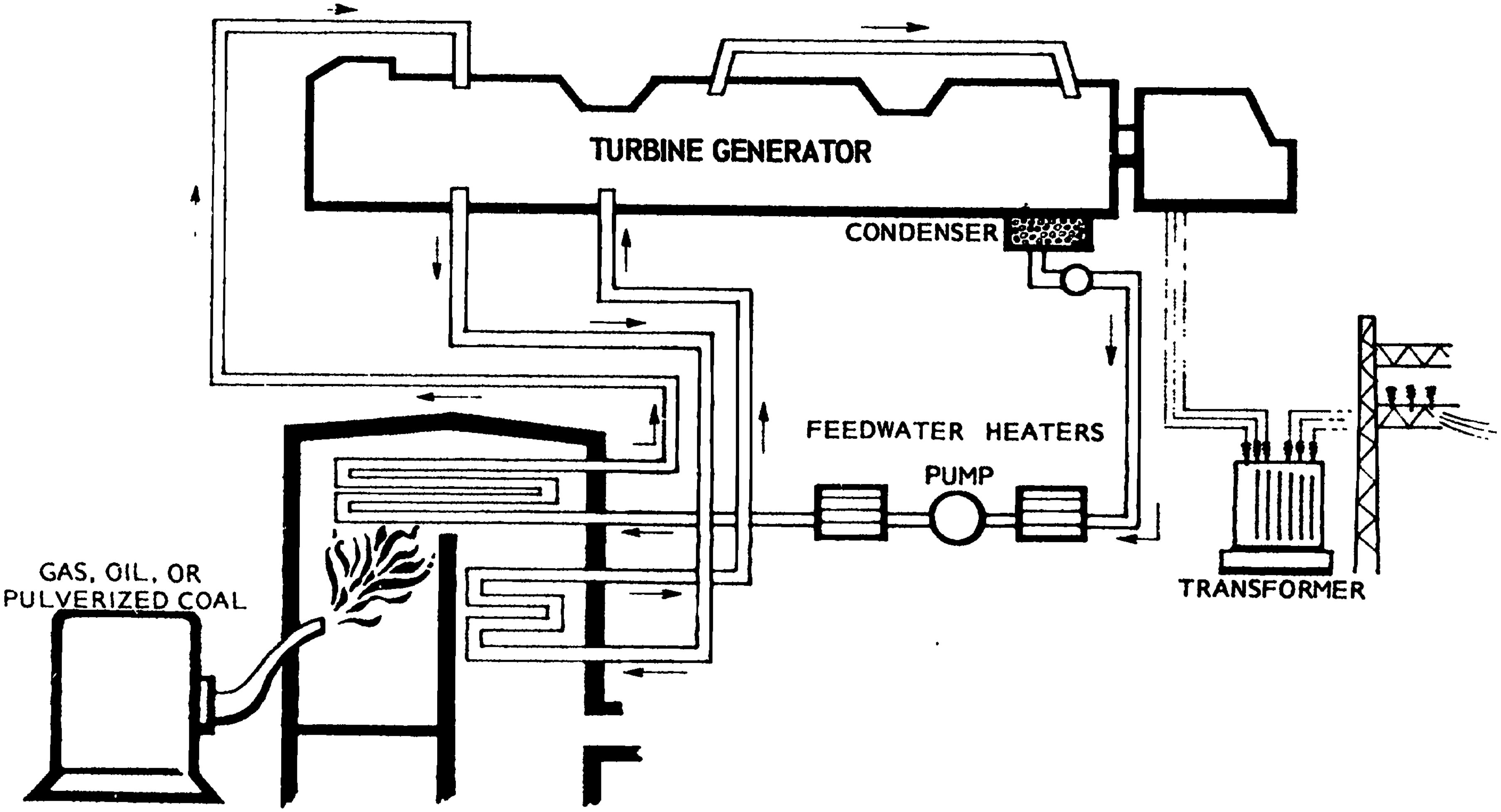


FIGURE 15

Economists are worried about the huge increase in the balance of trade deficit if we turn to foreign supplies of oil. For example, Saudi Arabia has more crude oil reserves than the United States and Latin America combined. It is estimated that by 1980 Saudi Arabia will have the money to purchase one major United States corporation per year from dollars obtained from fuel sales.

In addition to the oil supply problem there is a problem of refinery capacity. Most United States refineries are running at maximum capacity, and no new refineries are slated for completion before 1974. 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 amounts of available oil. For example, an increase in the number of cars, plus engine modifications to reduce emissions and increasing use of air conditioning and power accessories, has increased gasoline consumption and therefore reduced capacity for fuel oil production. Oil and gas are rapidly becoming too valuable to burn directly. We must begin to think in terms of conserving them as raw materials for making chemicals and foodstuffs which will be needed in the more distant future.

Onshore oil production rarely presents any significant pollution problems, although accidental pollution may sometimes occur from blowouts of wells or losses of oil in storage or transportation. Offshore operations present more problems, with oil spills and fires at the wells. Oil spills and discharges from tankers are also important problems to be solved. There is also the problem of contamination of inland waterways and harbors resulting from transfer of oil between or from vessels.

Coal

The fossil fuel use situation is the reverse of the fuel supply. Oil and gas supply three-quarters of U.S. energy needs including transportation, whereas coal, which supplies 20 per cent of the U.S. energy, represents three-quarters of the fossil fuel reserves. Coal is found in 38 states, and there are some 1.5 trillion tons of known reserves (Figure 16). 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 of producing sulfur compounds which are harmful pollutants. This problem is discussed in Chapter 5. Its geographical distribution is not the best. Figure 16 shows that most of the eastern coal is anthracite, which has a high sulfur content, while most of the low sulfur lignite coal is located in the west, far from places where the energy is most needed. Coal is also responsible for large amounts of waste products. These are discussed in Chapter 6.

Furthermore, getting coal out of the ground without major damage to the environment has become a serious problem. Underground coal mines pollute the water table, harbor fires, and have 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 than by deep mine operations. Currently 44 per cent of all coal mined comes from strip mining. But strip mining destroys surface 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 stabilization. Supporters of tough anti-stripping legislation estimate that meaningful reclamation of strip mines would add about 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 problems of mines being closed by strikes.

Since transportation of coal is so expensive, some companies are building power plants atop the coal mine and sending the electricity to market by wire. For example, most Philadelphia-Baltimore-Washington consumers get electricity from a trio of huge mine-mouth plants atop Chestnut Ridge, an immense coal-bearing mountain in western Pennsylvania.

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

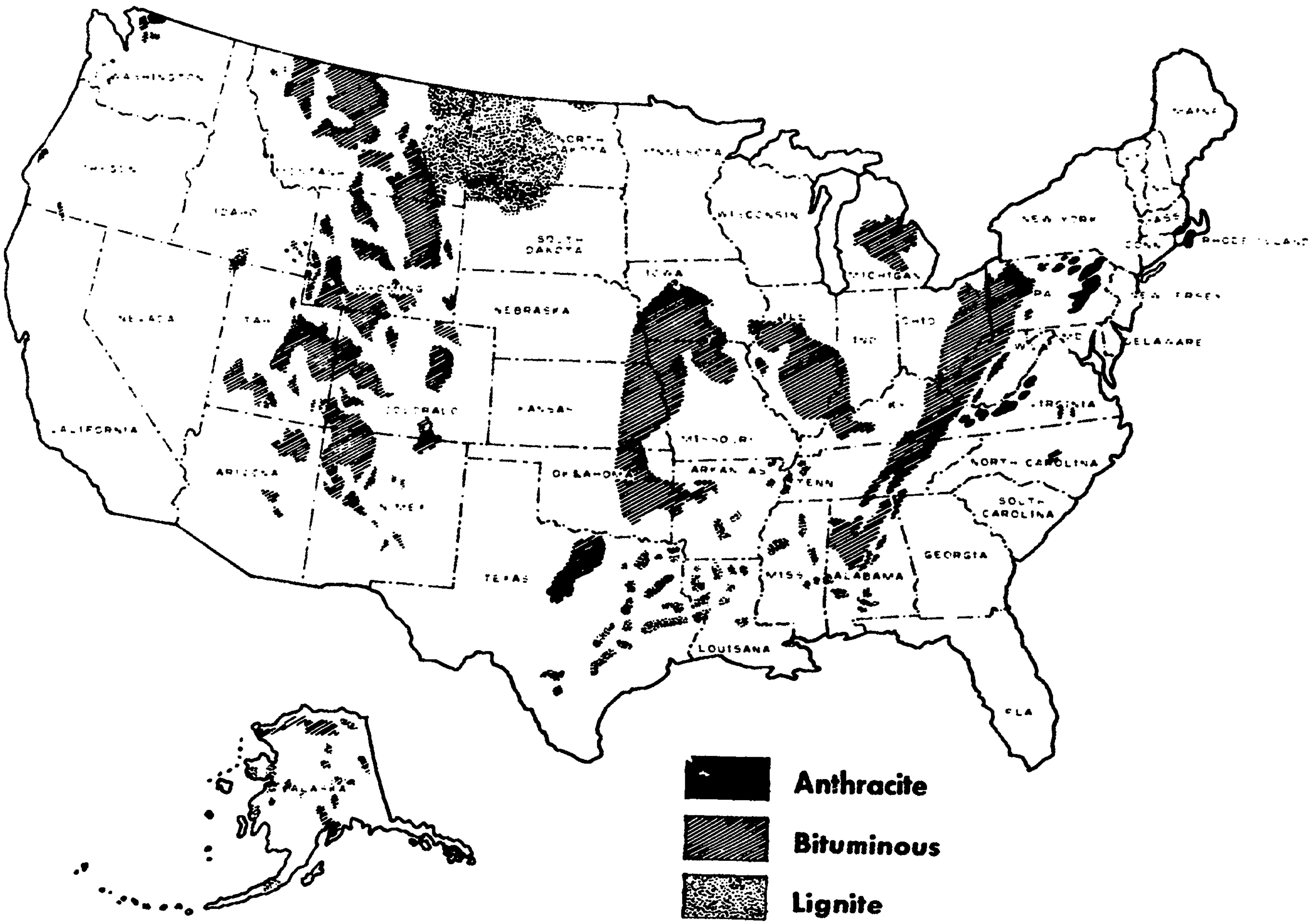


FIGURE 16

Coal Gasification

Coal gasification offers the best long-term solution to the problems of gas supplies and should produce a clean method of utilizing our coal reserves. Domestic gasification would not be subject to foreign controls of fuel, and would not adversely affect the U.S. balance of payments. It would also provide new jobs for the depressed job market in rural coal mining areas of the country.

Coal gasification has top priority among all the Department of Interior programs related to coal conversion. President Nixon has singled out coal gasification along with nuclear breeder reactors for special attention and stepped-up federal funding. Representative Mike McCormack, Chairman of the House Task Force on Energy, has stated, *"Coal gasification is just as important as the breeder reactor."*

In coal gasification, water is heated to steam along with oxygen and reacts with coal to make hydrogen-rich gas containing carbon monoxide, methane, hydrogen sulfide, and ammonia. The gas is cleaned of its unwanted constituents, leaving only carbon monoxide, hydrogen and methane. What is left is combustible, but has a low heat content compared to natural gas. The final step, and the one yet to be proven on a commercial scale, is to upgrade the heat content and cleanliness of this product. In a process called methanization, there is a further reaction of the carbon monoxide and hydrogen to produce more methane. The final product is then about equivalent in heat content to natural gas.

It is expected that about two per cent of the natural gas will be made in this manner by 1985, and about 10 per cent by the year 2000. The gas produced will probably be expensive–about double current gas prices–but competitive with other supplemental sources such as liquified natural gas from the Middle East or Russia.

The process needs large amounts of water to make the steam. Water consumption in the west, where most of the potential coal gasification sites are located, has long been a problem. Future gasification sites will probably be limited by water requirements rather than by coal reserves.

Initially the price of such gas would be too high for use by electric utilities, but it could be used for commercial applications. Coal gasification is expected to double present coal consumption by 1985. Strip mining is expected to be used to a large extent, requiring a large amount of restoration of mined areas.

Thermal pollution by coal gasification plants is expected to be significant, since the conversion to pipeline gas is expected to be only about 65 per cent efficient. Disposal of large amounts of coal ash is also required. Fortunately, coal gasification is carried out in a closed vessel, which should prevent any significant air pollution.

Although the preceeding coal gasification process will not be immediately useful for power generation, a composite process looks very promising. In this process, the gas produced from the reaction of coal, air and steam has the sulfur and ash removed and is burned directly in a gas turbine. Gas turbines have the potential of better efficiency than steam turbines because they can operate at much higher temperatures. The hot exhaust gases from the turbine are run through a recovery boiler to produce steam which is led to a steam turbine to make more electricity. The result is a plant which should be much cleaner and more efficient than conventional coal burning plants.

In summary, despite the various technical problems which must be solved in its use, the extensive wealth that this country has in its coal reserves must be utilized in supplying much of our energy needs for the foreseeable future.

Chapter 5

BIOLOGICAL EFFECTS: A COMPARISON

In this section we will consider the biological effects of radiation, as well as the effects of exposure to the more traditional fossil fuel-generated pollutants: sulfur dioxide, particulates, nitrogen oxides and hydrocarbons. We will also discuss the benefit-risk concept. 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 the other pollutants; and radiation effects are not well understood and are feared by the average person.

In the case of both radiation and traditional air pollutants, most of the reliable data on effects on humans was gained from statistical analysis of cases in which people received large doses. Much less is known about the effect of exposure to very small amounts of these pollutants.

It is only within the last 20 years that one has begun to suspect problems because of air pollutants from use of fossil fuels, and has begun to try to control these problems. This is after thousands of years of burning fuels for the release of energy.

The case of exposure to radiation is similar only in part. Humans have been living with low levels of *background* radiation since the beginning of time on earth. They were unaware of its existence until about 1895, when radioactivity was discovered. The early experiments with x-rays soon produced a number of injuries to the experimenters. Almost immediately the use of this phenomenon began to be controlled. By the time power reactors began to be built in the mid-1950s, the radiation emitted from these plants and the radioactive byproducts produced were under strict regulation. This is in contrast to the case for fossil fuels, where regulation followed long after their development as energy sources.

BIOLOGICAL EFFECTS OF NUCLEAR POWER PLANTS

Fundamental Information

All matter is made up of simple units called atoms. These atoms each have a nucleus which has an electrically positive (+) charge. A cloud of electrically negative (-) electrons orbit around the positive nucleus. Ordinarily the number of negative electrons equals the number of positive charges on 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, and 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.

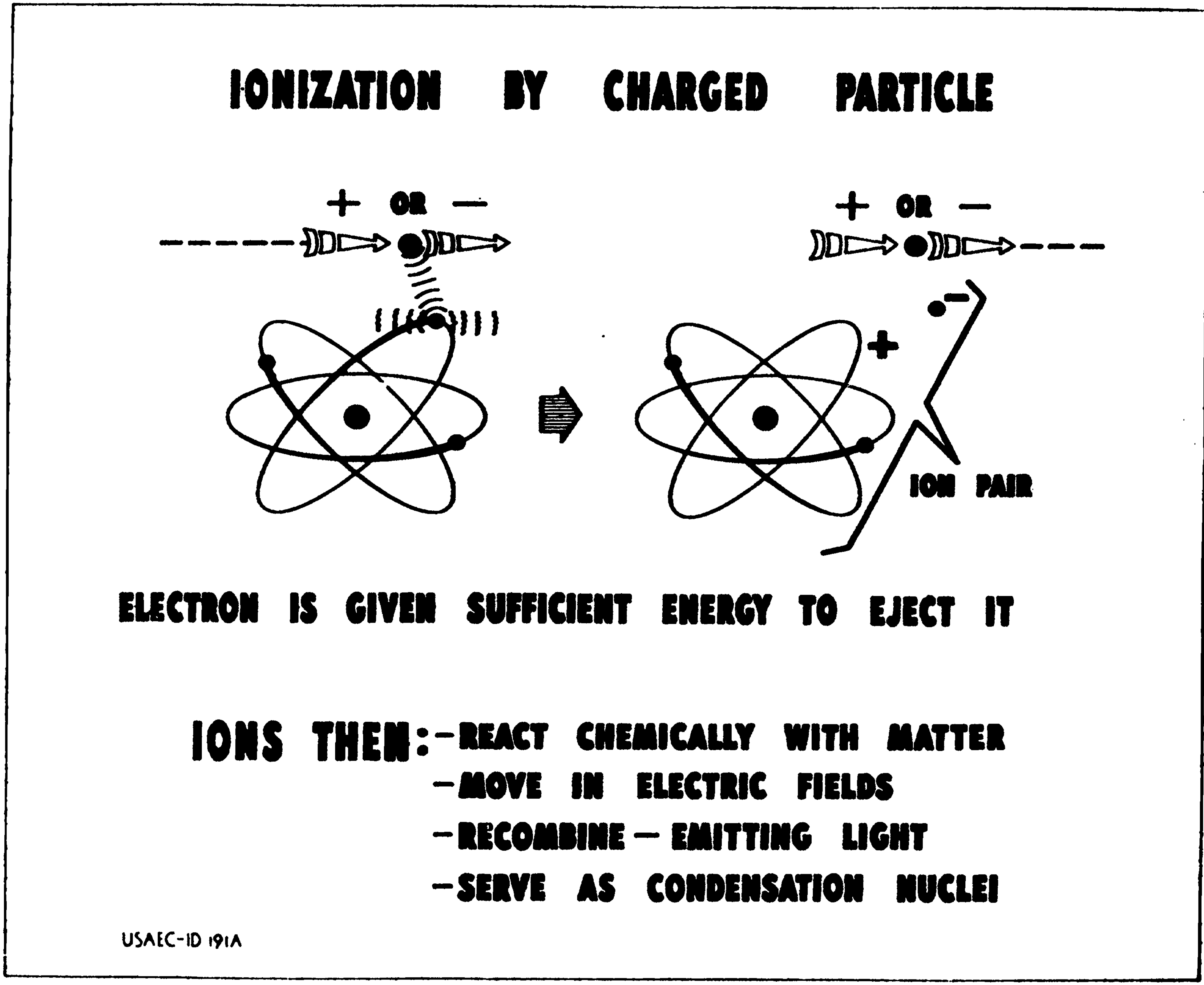
When one or more electrons is separated from the atom, the atom is said to be ionized. The atom has a net positive charge since it is missing an electron. This positive atom taken with its separated negative electron is called an *ion* pair. (See Figure 17).

It was seen in Chapter 3 that some atoms are radioactive, and these atoms emit radiation as they decay to a stable state. Table 6 shows the composition of the various kinds of decay radiation.

Table 6

Definition of Types of Decay Radiation

	Radiation	Protons	Neutrons	Electrons	#Charge
Particulate	Alpha (α)	2	2	0	+2
	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



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 17

When these radiations pass through matter, they interact with the electron clouds of the atoms in the matter. In this process the radiations lose their 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 and steel.

The most penetrating of these radiations are gamma rays. High energy gamma rays can completely penetrate a person or a concrete block or a sheet of lead.

Beta radiations, which are high energy electrons or positrons, are capable of penetrating a piece of aluminum foil or several layers of a person's skin. In air their range may be as much as a yard.

Alpha radiations, which are high energy helium nuclei, can sometimes penetrate a very thin piece of paper, but cannot penetrate conventional aluminum foil. Alpha radiations are not important in terms of external radiation. They are, however, the most hazardous of all types if they are located within the body as a result of swallowing or inhaling an alpha emitter.

The injury-producing potential of 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 electrical charge and energy of the radiation. This energy loss produces chemically reactive species such as ion pairs in the absorbing material, and these species do the damage by disrupting the functions of the cells.

Radiation Detection

The presence of 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 the form of *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.

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 charge in a standard amount of air. The roentgen can be measured directly since the electric current produced can be measured with 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 is equal to the energy required to raise the body temperature by .000002 degrees Farenheit.

The *roentgen equivalent man* (rem) is the unit of *dose equivalent*. It is a measure of not only energy deposited, but also the resulting biological effects.

For instance, suppose 500 rads of gamma rays 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 in causing this change. In other words, the alpha radiation would have a *quality factor* of 10 as compared to the gamma ray.

We can use the formula rems = rads x quality factor to convert to rems. Using 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 protection 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.

Sources of Radiation

As we have mentioned, humans have always been exposed to radiation. This natural or background radiation comes from many sources.

One source of natural radiation is the 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 naturally-occurring radioactive isotopes. For example, natural radioactive materials like uranium and thorium are widely distributed in soil and rocks. The more energetic radiations from these radioisotopes serve to 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. (See Figure 18) This radioisotope is constantly being formed in the upper atmosphere by the interaction of cosmic radiation on atmospheric nitrogen. These naturally-occurring radioisotopes add about 50 mrem/year to our exposure.

The amount of radiation dose received from natural radiation varies according to location. For example, the cosmic radiation dose doubles from about 40 mrem/year to about 80 mrem/year when moving from sea level to 10,000 feet, as when someone moves from Philadelphia to a town high in the Rocky Mountains. This exposure increases by 15 per cent moving 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 rock.

Even the type of house a person lives in affects the amount of background radiation received. The background received by a person living in a wooden house is 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-type building materials.

Several sources of man-made radiation add 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. These are summarized in Table 7. The radiation doses in this table are *genetically significant doses*, which means that they estimate the potential genetic effects of radiation on future generations.

Table 7

Sources of Man-made Radiation

Source	Average Genetically Significant Dose (mrem/year)
Medicine and Dentistry	
Diagnostic (1970)	36
Therapeutic	12
Internal (Radionuclides)	1
Environmental	
Weapons fallout	4
Reactors (Living at site boundary)	5
Reactors (Average person in the population)	.01 to 001

To put this into perspective: if you had to make the choice of the best way or group of ways to reduce radiation exposure, what would you decide?

1. Prohibit people from living in brick and concrete houses. Require everyone to live in wooden houses. This would save 50 to 200 mrem/year for each person now occupying brick and concrete houses.

2. Work to reduce our medical x-ray exposure from the current 36 mrem/year.

3. Prohibit people from living in Manhatten. Require them to move to Queens, at a saving of 15 mrem/year for each person.

4. Require reactors to reduce their radioactive effluents by a factor of ten, saving each of us 0.009 to 0.09 mrem/year.

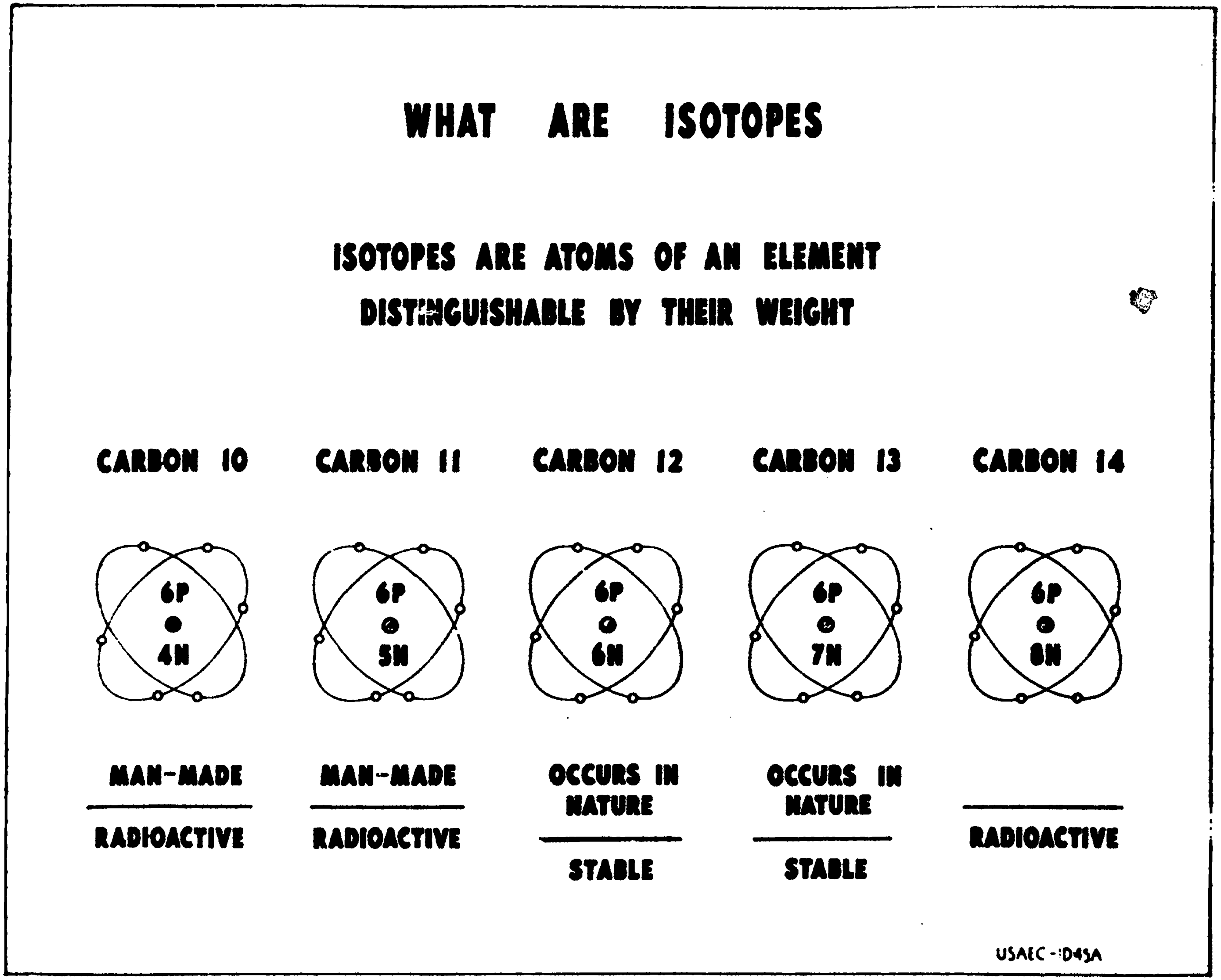

WHAT ARE ISOTOPES
ISOTOPES ARE ATOMS OF AN ELEMENT
DISTINGUISHABLE BY THEIR WEIGHT
CARBON 10
6P
4N
MAN-MADE
RADIOACTIVE
CARBON 11
6P
5N
MAN-MADE
RADIOACTIVE
CARBON 12
6P
6N
OCCURS IN NATURE
STABLE
CARBON 13
6P
7N
OCCURS IN NATURE
STABLE
CARBON 14
6P
8N
RADIOACTIVE
USAEC-1D45A

FIGURE 18

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

Factors Which Influence Radiation Effects

Radiation effects are not dependent solely on the amount of radiation received. Other factors influence the biological effects of radiation.

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 will begin. Thus if a particular dose is delivered over a long period of time, 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, a noticeable reaction may result.

Knowledge of the effects of radiation has generally resulted from data on large doses received in a short time. These sources include Hiroshima survivors, victims of radiation accidents and patients receiving radiation therapy. However, most human exposure is in the form of 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, it has been the general practice 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, it is assumed that some injury results from any exposure to radiation. According to the International Committee on Radiation Protection (IRCP): *"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 is not known to be the case. There are certainly levels of radiation that produce no detectable effects-background radiation and routine diagnosite x-rays, for example. But the most conservative assumptions are used to insure maximum protection for the population.

Age of the Individual

The age of the exposed individual can greatly affect his sensitivity to radiation. When organs are developing before birth, the sensitivity is high, because differentiating cells and cells undergoing rapid division are more easily damaged. Similarly, in the period between birth and 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. This exposure, however, may give rise to genetic effects in children. In a person beyond the reproductive age, these genetic effects are not important. Similarly, for older persons whose life expectancy has decreased, radiation effects which might appear only after a long time (for example tumor induction) would not be as significant as with younger people.

Part of Body Irradiated

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 made recommendations for the general public for dose limits to different parts of the body. These range from a low of 500 mrem/year to the reproductive organs and red bone marrow to a high of 7500 mrem/year for the hands, forearms, feet and ankles.

Extent of Body Irradiated

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 portion of the body can aid in the recovery of the affected portion.

Biological Variation

Although it is possible to determine an average dose which produces certain effects, individual responses will vary from those of the average. For instance, it required a dose of about 600 rads in a single exposure to kill half a group of rats within 30 days. On the other hand, some of these rats died after 400 rads and some were still living after 800 rads. This is biological variation.

Internal Radiation

Most of what has been said so far about radiation effects has been in terms of external dose, that is radiation received from 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 is nuclear medical techniques. These radioactive materials move through the body in the same manner as the nonradioactive materials. They are also eliminated in the same manner, and constantly become weaker through radioactive decay.

With external radiation, the dose to an individual can be reduced with shielding, distance or shortening of the exposure time. When the radioactive source is inside the body, reduction of the dose is not so 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 actually becomes a part of the living tissue.

The effect of internal radiation depends on several factors. One of these is the sensitivity to radiation of the organs or tissue to which the material goes. Another factor is the type of energy of the radiation being emitted. This determines the quality factor. The physical and chemical form of the radioactive material also helps to determine its effects. A major factor in the effect of internal radiation is the *effective half life* (T_E) 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 radioactive material; and the *physical half life* (T_p), which is the half life of the radioactive material as defined in Chapter 3. These three terms are related by the expression

$$1/T_E = 1/T_p + 1/T_B$$

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.

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 offspring of the person who has been irradiated.

Somatic Effects

1. **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 affected. Thus a cell may respond to irradiation by chromosomal changes, cell death before division, failure to specialize, failure to divide completely or slowing of the division rate. In addition, some cells will be unaffected by the radiation.

The cellular response to radiation is determined by a number of factors. Among these are the stage of specialization of the cell, its activity and its division rate. These factors would partially account for the sensitivity to radiation of the embryo as compared to an adult. In the embryo, a small group of cells eventually will 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 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.

2. Organ sensitivity

The radiosensitivity of organs and tissues depends on cell multiplication. In the lining of the gastrointestinal tract, for example, some of the cells are mature. These are continuously 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 cells still living 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 will depend on which organ was 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 severe damage to the blood-making system because the majority of this system was not exposed to the radiation. On the other hand, a moderate dose of only 30,000 mrads to the small reproductive organs can result in temporary sterility.

3. Total body doses

The effects of large sudden whole body doses of radiation are called the *acute radiation sickness syndrome.* This syndrome consists of nausea, vomiting, general aches and pains and possibly a decrease in the number of white cells. Localized phonomena 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 of the eyes may cause cataracts. At still higher dose levels, death will probably occur.

Table 8 shows the probable results of various massive whole body doses of radiation received over a short time period.

Table 8

Effects of Large Whole-Body Doses of Radiation

Dose	Effect
10,000,000 mrem	Death within hours due to damage to central nervous system
1,200,000 mrem	Death within several days due to damage to gastrointestinal system
600,000 mrem	Death within several weeks due to damage to blood-forming organs
450,000 mrem	50-50 chance of death within 30 days
100,000 mrem	Possible temporary impairment, but probable recovery

It has been shown in animals that high radiation doses cause bodily changes that lead to effects similar to the aging process. 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.

The effects of long-term, low dose rate exposure must be predicted, since data on such exposure and its effects are nearly impossible to obtain. The problem is complicated because such low dose effects generally develop years after the exposure. Also, the same effects may be caused by something other than the radiation. For example, cancer and leukemia may be long-delayed consequences of a single large exposure 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 naturally-occurring radioactive gas resulting from the decay of uranium and thorium radioisotopes.

Genetic Effects

The term 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 alternation in the environment. Whatever their origins, most mutations are undesirable. Every individual has some of these undesirable mutations.

Radiation-induced mutations are divided into two classes: gene mutations and chromosomal abnormailities. Most radiation-induced alterations are gene mutations. These 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 the first generation offspring, it makes them slightly less fit.

Chromosomal abnormalities include chromosome loss and chromosome breaks. These effects are more severe, and the result is usually 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 is the dose that would eventually cause a doubling in the rate of gene mutations that occur spontaneously.

In the United States at the present time, about 100 million children are born in a generation. Of these, about two per cent will have genetic defects as a consequence of spontaneous unavoidable genetic changes which were passed on to the individuals from all their ancestors. If a doubling dose of radiation were applied to the population for the present and all future generations, this 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 taken 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 the individuals of the population were 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 man-made source currently in operation. (See Table 7)

Non-Human Biological Effects

In the earthly environment, 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 to protect us, much of the data upon which test 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 are applicable to all other life forms as well. 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 the case of 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 included in the environmental surveillance program. This reconcentration ability makes the shellfish a good monitor for cross-checking radioactive discharges.

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 that we do have 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, accompained 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 on 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.

All available evidience indicates that several of the above assumptions are simply 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* or maximum permissible dose to the general population arrived at as a result of these assumptions is presently set at 170 mrem/year above natural background. This figure does not include an individual's radiation dose from medical procedures. The NCRP does not attempt any regulation or limiting of radiation exposure for necessary diagnostic and therapeutic purposes. They do make recommendations to reduce that part of the exposure which does not contribute to the efficiency of 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 Atomic Energy 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 the federal radiation protection guides for individual members of the public.

BIOLOGICAL EFFECTS OF FOSSIL FUELED POWER PLANTS

Biological effects of fossil fuels come mainly from the air pollution which is a result of the burning of such fuels. Fossil fueled plants produce air pollution in the form of oxides of sulfur and nitrogen, carbon monoxide, unburned hydro-carbons and particulates in the form of fly ash. Table 9 shows typical amounts of pollutants released to the environment by a 1000 megawatt power station.

Table 9

Emissions from Fossil Fueled Generating Stations

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	–

The figures in Table 9 assume 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 ash content for the coal with 97.5 per cent fly ash removal efficiency. No other pollution control equipment is assumed in determining these figures.

When talking about the effects of 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 air pollutant such as sulfur dioxide in another gas, air. One part per million (ppm) means one part of the pollutant in one million parts of air.

Sulfur Dioxide

Sulfur dioxide (SO_2) is an air pollutant of major concern, since 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 transormed to sulfur trioxide or to sulfuric acid and particulate sulfate salts. These conversions depend on the presence of moisture in the air, on the presence of dusts and smokes and on the intensity and duration of sunlight.

The health effects of the oxides of sulfur are related to injury to 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 of the lungs of experimental animals.

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 level of moisture in the air is changing. The intensity of sunlight varies. The temperature rises and falls. 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 the individual pollutants. 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 or vanadium, which may be present in particulate matter, react with the sulfur dioxide to form sulfuric acid. Sulfuric acid is a more severe irritant to the bronchial system, and 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 the science of epidemiology. This science deals with the study of the movement of an injury or disease through a population after the injury or disease begins to be noticed. The epidemiologist must think of all the possible causes for the disease in the group of people and then carefully eliminate all the causes except one. These epidemiological studies lack the controlled conditions of the laboratory, but they are carried out in the real life environment. From these studies, it has been clearly concluded that the oxides of sulfur in the air have an effect on the health of a group of people, and that the severity of the effect is directly related to the degree of pollution.

The results of some epidemiological studies of the effects of sulfur dioxide are listed in Table 10.

Table 10

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	Distrinct 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 respirator 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.

Particulates

Particulates are primarily mineral ash plus 0.5 to 5 per cent unburned fuel.

The effects of particulate air pollution on health are related to injury 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 the particulate from the effects of other known pollutants in the air.

In Table 10 on effects of sulfur dioxide, in most of the studies cited, the particulate load in the air was proportional to the sulfur dioxide concentration.

The 1970 Clean Air Act mandates that standards be enforced on all pollutants by mid-1975, and that the best available means be installed, rather than waiting until ideal processes are available. Today, several different types of systems are being used to control the emission of sulfur dioxide and particulate matter to the atmosphere. One system involves the conversion of sulfur dioxide to sulfur trioxide; the sulfur trioxide reacts with water vapor, and can then be condensed as sulfuric acid. Sale of sulfuric acid can help offset the cost of operating the system.

In this system, 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, preventing their release into the atmosphere. The ash, often referred to as fly ash, can then be collected and transported to a disposal site.

From the precipitator, the hot flue gas flows to the second stage of the cleansing process, the converter. In the converter, a catalyst fosters the chemical change of sulfur dioxide to sulfur trioxide. The flue gas, now rich in sulfur trioxide, next flows through a heat exchange system, where the gas is cooled.

The final stage of the system is that of actual sulfuric acid production. Acid is condensed in the absorbing tower, while the flue gas continues to the mist eliminator, where remaining small amounts of sulfuric acid mist are collected. The flue gas, with virtually all of the fly ash and sulfur dioxide removed, can now be released to the atmosphere.

Oxides of Nitrogen

This class of pollutants includes four different oxides, but most of the studies have been conducted on nitrogen dioxide (NO_2). During combustion, the nitrogen gas 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 is a function of 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 has been significantly correlated with increases in respiratory diseases, at mean daily concentrations between 0.062 and 0.109 ppm 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 removal of the oxides of both nitrogen and sulfur.

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, reducing them to relatively harmless carbon dioxide and water vapor.

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.

Radiation from the Burning of Coal

All coal contains a small amount of naturally-occurring radioactive materials such as potassium, uranium, thorium and their decay products. Assuming five parts per million of radioactive material in coal (0.01 pound per ton), then a 1000 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 is released into the atmosphere as radon gas. 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 has been detected near such plants due to this release of radioactivity, and thus no effort has been made to date to control it.

HOW SAFE IS SAFE ENOUGH? RISK VERSUS BENEFIT

Technological growth has been tremendous in recent years. Following closely behind this growth in the advanced countries of the world has been social and economic benefits. But each advancement has also brought about a cost or risk to the people. Both the benefits and the risks brought about by technological growth 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. The passage by Congress of the National Environmental Policy Act of 1969 is strong evidence that most citizens accept the conservation of the natural environment as an important element of the quality of life. There is also little doubt that relatively full employment and at least modest affluence for most individuals is important to the public. Thirdly, goods and services depending on electric 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 seriously wants lighting, forced-circulation heating, radio and 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.

Chapter 6

WASTES IN THE PRODUCTION OF ELECTRIC POWER

This chapter deals with waste products from the generation of electrical energy, other than those wastes having a direct biological effect, such as the air pollutants discussed in the preceding chapter. The first section deals with the problem of disposing of waste heat, since this is a problem shared by nuclear and fossil fueled plants. The next section discusses the radioactive wastes produced in a nuclear power plant, and the last section deals with wastes from fossil fueled plants.

HEAT AS A WASTE PRODUCT

Most of the energy used by humans is provided through the process of converting heat energy into electrical and/or mechanical energy. The efficiency of this conversion is limited by natural laws. Modern steam turbine equipment provides probably the highest efficiency of all the heat engines in practical use today, but still between 60 to 70 per cent of the total available energy is not used and must be dissipated to the environment as heat.

Several factors make the problem of heat disposal more difficult for nuclear plants than for fossil fueled plants. First, using high temperatures (1000 to 1100 degrees Fahrenheit) and high steam pressures (1800 to 3500 pounds per square inch), today's modern fossil fueled steam-electric plants attain an overall thermal efficiency of 37 to 38 per cent. However, less than half of the presently operating plants attain this thermal efficiency. The average efficiency of all fossil-fueled plants is about 33 per cent. Because of certain design criteria, most current nuclear power plants produce steam at lower temperatures (500 to 600 degrees Fahrenheit)and at lower pressures (800 to 1000 pounds per square inch). Thus their thermal efficiency is somewhat lower, approximately 32 per cent so they must reject more heat. Advanced gas cooled reactors presently in the design and testing stage are expected to equal or exceed the thermal efficiency of the best fossil fueled plants.

Secondly, nuclear power plants are generally built with a larger generating capacity than fossil fueled plants. This means a greater amount of heat to be dissipated at the location of a nuclear power plant.

Finally, nuclear power plants make a greater demand on their supply of cooling water than do fossil fueled plants. This is because fossil plants discharge about 15 per cent of their waste heat into the air with the flue gas, with the remaining 85 per cent being discharged into a cooling stream of water. Since nuclear reactors do not reject heat by way of combustion gases, nearly all of their waste heat is discharged into the cooling stream.

Methods of Heat Disposal

As previously stated, heat from the combustion of fossil fuel in a boiler or from the fission of nuclear fuel in a reactor is used to produce steam which drives a turbine connected to a generator. When the heat energy in the steam has been converted to mechanical energy in the turbine, the *"spent"* steam is converted back into water in a condenser.

Condensation is accomplished by passing large amounts of cooling water through the condenser. In the least costly and most widely used method, the cooling water is taken directly from a nearby river, lake, estuary or ocean. 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 increase is usually less than one degree Fahrenheit at points 1000 feet from the point of discharge. The body of cooling water eventually loses the 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, and may favor the rapid growth of some aquatic plants. If this temperature change in the cooling water is excessive, it may cause critical ecological problems. However, if the volume of cooling water is large enough, the temperature change may be neglibible. In more northern areas, it is possible that increasing the temperature of the water may actually be desirable.

The discharge of heated water into natural water systems has not produced major problems as yet, but continued growth in electrical power production may well cause damaging environmental stresses to occur in some areas unless heat loss is controlled. There are alternatives to the once-through system which cause less of a strain on the natural waterways. Each of them involves environmental effects and economic penalties. The best system for a particular plant must therefore be decided on a case-by-case basis.

Artificial ponds or lakes can be constructed to provide a source of water for circulation through the condensers. These ponds require large land areas for storage and drainage; a 1000 megawatt plant might require as much as 3000 acres for such a pond. These ponds will create some local fogging on cold days due to the evaporation of warm water from their surface.

Waste heat may be transferred to the air through wet or dry *cooling tower* systems. In wet cooling tower systems, 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 1000 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 climatic conditions. In cold or humid weather, the liklihood of fogging and precipitation is increased, and in some cases with cold climates, these towers have created icing problems on nearby plant structures and roads.

In dry cooling tower systems, the cooling water is carried through pipes over which air is passed and the heat is dissiapted by conduction and convection rather than by evaporation. Dry cooling towers avoid the problems of fogging and icing common to wet cooling towers, but they require a larger surface area for heat transfer and the circulation of a larger volume of air. This cuts down the overall power plant efficiency. Dry cooling tower technology has not yet been demonstrated in the United States.

Although these alternatives offer relief from a potential thermal effects problem, they do not constitute a satisfactory answer to the heat problem. The probable answer will be to find a use for the excess heat and to increase the efficiency of electrical generation to decrease the amount of such excess heat.

Research is underway on finding uses for the excess heat from power plants. One study is investigating the beneficial uses of low grade heat in compatable urban systems. An example is the use of discharge heat to increase the rate and effectiveness of secondary sewage treatment processes. Another possibility is that treated sewage effluent may be used in cooling towers, where the nutrients can be substantially concentrated by the process of 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 into the environment. Desalination of sea water might be accomplished in the cooling towers, providing pure water and minerals.

Controlled heated water has been found to be advantageous to a few forms of fish culture, particularly shellfish. Tests demonstrate that it is possible to extend the growing season for crops by utilizing reject heat in agriculture.

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 city of the future, practically all the reject heat would no longer be waste heat to be disposed of, but would be a resource to be used for beneficial purposes.

RADIOACTIVE WASTES

The first point where waste products which contain measurable amounts of radioactivity appear in the nuclear power production cycle is with the mining and milling of the uranium or thorium ores. These materials are brought to the surface of the earth and concentrated. Radioactive materials which are not present in commercially valuable amounts go into tailing piles and milling by-products. In addition to these solid wastes, the mills produce large quantities of liquid wastes containing low levels of radioactivity.

These materials require further processing and often enrichment steps. This results in more wastes containing natural radioisotopes.

Fabrication of the fuel elements produces some liquid waste and scrap with low levels of radioactivity.

Operation of of nuclear power plant produces solid, liquid and gaseous wastes. The fission by-products produced by nuclear fuels in reactors are by far the largest source of these wastes in terms of radioactivity. As we have mentioned, more than 99.99 per cent of these fission products remain confined within the fuel elements. Valuable unused fuel remains in the fuel elements along with these accumulated fission products. When it comes time to refuel the power plant, which is done at intervals of a year or longer, the reactor is shut down and the top of the reactor vessel is removed. The spent fuel elements are moved to a storage vault or pool where they remain for several months until the radioactive materials with short half lives have had a chance to decay. By the end of this time, nearly all of the gaseous fission products have lost their radioactivity. The fuel elements are then loaded into ruggedly-built lead-shielded steel containers for shipment by truck, rail, or barge to a plant where they will be chemically processed to recover the unfissioned uranium and the plutonium formed during reactor operation.

In the repocessing plant, the tubes which make up the fuel assemblies are chopped into small segments, and the fuel pellets are dissolved in strong acid. Then the fuel and fission products are chemically separated. It is at this point that highly radioactive waste is produced. These liquid wastes pose the most severe hazard and the most complex technical problems in radioactive waste management.

Principles of Radioactive Waste Management

There are three basic principles which are broadly applied in waste management.

Delay and Decay

The first of these principles is *"delay and decay."* Radioactive materials with reasonably short half lives are retained at the site where they are generated until their natural decay rate has caused the radioactivity to dissipate. This is generally a period equal to about ten half lives of the particular radioisotope. It would be convenient if there were some method to change long-lived radioisotopes into short-lived radioisotopes or nonradioactive material. But the half lives of radioisotopes are not responsive to outside influences. Each isotope decays at its own particular rate regardless of temperature, pressure or other chemical and physical processes Actually, since allowing radioisotopes to decay naturally is the only currently practical means of eliminating their radioactivity, any other method of waste handling must be considered to be an intermediate step leading finally to disposal by decay.

Dilute and Disperse

The second principle of radioactive waste management is *"dilute and disperse."* Wastes of appropriately low radioactivity may be reduced to permissible levels for release by dilution in air or waterways. Wherever materials are to be released to the environment, the amount of radioactivity that can be safely dispersed is determined separately for each specific radioisotope. Such release is carefully monitored and controlled.

Concentrate and Contain

The third radioactive waste management principle is *"concentrate and contain."* Radioactive wastes can be concentrated and stored in controlled sites. The volume of the stored material would be prohibitively great if it were not first concentrated.

The choice of a disposal technique depends on the nature of the waste: its degree of radioactivity, half life and form.

Gaseous Waste Management

The mining, milling and fabrication of uranium into fuel elements produces airborne radioactivity from natural radioisotopes. This typically occurs in low concentration, and specialized ventilation of the work area gives adequate protection. Air discharged from mine ventilation systems usually contains appreciable amounts of radon-222 and its decay products.

The generation of gaseous radioactive wastes at nuclear power plants varies in composition for each type of reactor, but these wastes can be effectively managed. In general, gaseous wastes are held for an appropriate period of decay, then filtered and released under controlled conditions through a high stack. Since these gases are a great deal more dense than air, high stack discharge is desirable to prevent layering and accumulation at ground level. The filters which are used collect radioactive solid particles. Specially-treated charcoal filters may be used to remove radioactive iodine. The release of radioactive gases from operating nuclear facilities has been substantially below limits prescribed by applicable radiation standards.

Gaseous wastes are produced at fuel reprocessing plants. Various scrubbers, filters and absorption systems are used before these gases are released to the environment through high stacks fitted with monitoring equipment to register level of radioactivity and rate of flow.

The radionuclide krypton-85, with a 10 year half life, has been studied especially in connection with its release in gaseous wastes. The contribution of krypton-85 to radiation doses in the vicinity of a nuclear power plant is negligible, since it is a fission product and is almost totally retained in the fuel elements until their reprocessing. It is a part of the gaseous waste from the reprocessing plant. The radiological effects, both local to the reprocessing site and on a worldwide basis, of the release of krypton-85 have been considered. The conclusion is that it will not pose a significant problem until well into the 21st century. Cryogenic (extremely low temperature) absorption methods to remove krypton-85 are being developed, and should solve the problem before it becomes significant.

Liquid Waste Management

Uranium mines and ore mills produce relatively large quantities of low-level liquid wastes. These require minimal treatment before being released into the environment. Fuel fabrication plants produce small amounts of low-level acid wastes which are diluted, neutralized, stored to permit decay and then discharged to waterways.

In a typical water cooled reactor power plant, there are two sources of liquid waste: the reactor coolant itself and drainage from supporting laboratories and facilities. Often these wastes, which are usually of a low level of radioactivity, are permitted to decay, and then are diluted and discharged to waterways. When necessary, the radioactive liquids undergo treatment by systems such as evaporators or ion exchangers. No liquid wastes are released into the ground at reactor installations, and the amount of radioactivity released to the waterways is carefully monitored and controlled.

Fuel reprocessing plants are the source of highly radioactive liquid wastes. Processing the used fuel leaves a concentrated liquid waste which contains more than 99 per cent of the radioactive substances from the spent fuel elements. Currently this residue is being stored in underground steel tanks at the reprocessing sites. Nearly 25 years of experience, primarily with wastes from the nuclear weapons program, has demonstrated that this tank storage is safe and practical. But technology for solidifying these liquids has been developed, and the AEC now requires that they be converted to a more stable solid form. Under this procedure, the highly radioactive liquid wastes are stored in carefully built double-walled tanks at the reprocessing plant for a maximum of five years to allow many of the heat-generating isotopes to decay and make further processing easier. The liquid waste must be solidified, and then the solid material encapsulated in sealed, manageably-sized stainless steel containers for shipment to a federal repository. This shipment must be accomplished within ten years from the processing of the fuel. The most promising long-term control method for these solidified wastes seems to be storage deep underground in stable geological formations such as salt mines or granitic bedrock. Pending a full safety evaluation and acceptance of such a geological repository, extended storage will be provided in a surface repository. All necessary technology is available for constructing, maintaining and monitoring these shielded storage facilities, and this is the approach that the AEC will follow to accept and manage the high level radioactive wastes to be delivered in the early eighties.

It has been estimated that by the year 2000, 77 million gallons of high-level liquid wastes would have been generated by the civilian nuclear power program if it had not been for the regulatory requirement on solidification. Solidification will reduce this volume, and the total amount of solidified high level waste accumulated by the end of the century is expected to be about 500,000 cubic feet. This volume would cover one football field to a height of just over 10 feet.

There is growing interest in international cooperation in high-level radioactive waste management. In 1972 the United States participated in meetings of the Nuclear Energy Agency (formerly European Nuclear Energy Agency) and the International Atomic Energy Agency on high-level waste management. It appears that the first order of business is to agree on the degree of protection needed for these wastes, and then to evaluate the various storage concepts. The operation of international high-level waste repositories would be the next logical subject of discussion.

Solid Waste Management

Solid refuse from mining operations has such a low level of radioactivity that it is usually piled near mine portals. Solid refuse from ore refining mills, called tailings, are usually held in controlled areas to prevent dispersal to the environment.

Solid wastes from nuclear power plants are only moderately radioactive. They consist mostly of residues from filtering systems and evaporators and of contaminated equipment and materials. These materials are packaged as required by transportation safety regulations, and shipped to special burial grounds. These burial grounds are on state- or federally-owned land, and are subject to either federal or state regulations. The solid wastes are generally buried in unlined pits and trenches. Several feet of earth are placed over these pits or trenches so that radiation exposure to workers at the burial site, or to the public at the nearest possible point of approach, are well within the applicable regulatory limits.

No high-level solid wastes can be sent to such burial grounds. High-level solid waste, after a limited period of storage at a fuel reprocessing site, must be sent to a federal repository.

Waste Management for Breeder Reactors

Since 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 reprocessing plant wastes may 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 and not in kind of waste, so that new basic technology will not be required. The use of metallic sodium as a reactor coolant will require the expansion of presently existing sodium safety technology to the handling of contaminated solid wastes generated during breeder reactor repairs and maintenance. 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 can be stabilized to preclude air and water pollution by methods in use today.

WASTES FROM FOSSIL FUELED PLANTS

Other than a small amount of air pollution and the thermal effects which have already been discussed, gas fueled electrical generating stations produce little in the way of waste products.

In onshore oil production, nearly three barrels of brine, which is pumped out of the ground with the oil, must be disposed of for every barrel of oil produced.

Coal is responsible for large amounts of waste products. Mention has already been made of the large land 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 is washed, producing 90 million tons of waste annually. These unsightly piles of waste sometimes ignite and burn for long periods, creating air pollution. Rainwater leaches salts and acid from the piles and can 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 in addition to that discharged into the atmosphere. Over the 35 year life of a 1000 megawatt coal-burning power station, it 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 blocks, but other uses need to be found for these vast amounts of waste which are being generated.

Chapter 7

PLANT SITE CONSIDERATIONS

Power plants have traditionally 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 reference to environmental protection. We are now becoming aware of the need for more care in the choice of power plant sites, and the environmental impact of any proposed power plant must be carefully assessed before it can be built. There are several criteria for power plant site selection. Most of these apply to both fossil fueled and nuclear plants, although some apply only to nuclear plants.

SITE ACCESS

It must be possible and economically feasible to bring construction equipment and power plant machinery to the proposed site. 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 site, the reactor and containment vessel. A ready access to the site is highly important, and one of the first factors considered after the decision is made on plant type and general location.

GENERAL ECOLOGY

Ecologyis that branch of science that deals with the inter-relationships between all living things and the environment. A complete understanding of all of the environmental problem is virtually impossible. Nevertheless, some reasonable level of understanding must be reached so that future power facilities can be sited and operated without excessive damage to the environment. The following ecological research is critical to the solution of power plant siting problems.

1. Improved techniques must be developed to determine the health and age of ecosystems so that we can predict accurately the changes which may result in any given ecosystem through even a slight alteration of the environment.

2. Certain animals and plants may serve as pollution indexes; that is, they indicate the presence of certain pollutants in the environment. These should be monitored.

3. Cumulative effects on ecosystems in distant areas must be watched closely. A distant ecosystem may actually be the critical system upon which to base pollutant release rates. For example, the Chesapeake Bay as an ecosystem serves as a sink for pollutants released in many inland watersheds. As several nuclear power plants are sited in Pennsylvania along the Susquehanna River, the Bay area may be the critical system upon which to base pollutant rates for each of these nuclear plants.

4. Detailed models should be developed which can be used in simulation experiments to predict the environmental effects of particular power plant effluents and effluent levels.

GEOLOGY

Power plants are extremely heavy structures with very low settling tolerances. The underlying bedrock must be extremely solid, and must not allow water to pass through it easily.

The probability of the occurrence of an earthquake and its potential strength must be taken into account in the selection of a power plant site. Current practice in the selection of sites for nuclear power plants is based upon the knowledge of earthquake potential plus a large safety factor. Nuclear plants are not located on or in the immediate vicinity of faults which are considered at all likely to display any earthquake activity. An earthquake risk map has been developed for the entire United States and should prove a valuable aid for those involved in plant siting decisions.

Large quantities of water are needed in today's power plants for cooling. It is thus necessary for a plant site to be near a source of water suitable for its cooling needs. A detailed study of the surface and ground water must accompany any site evaluation. Information on the cooling capacity of this water can then be used to determine the number and location of power plant sites along any major river lake, bay or over any major underground source

Cooling towers, which transfer heat directly into the atmosphere on the plant site, are considered in all new power plant installations. These towers produce environmental effects such as fogging which must be assessed.

METEOROLOGY

It is necessary to establish that a site has weather conditions suitable for a power plant. Such a determination requires an evaluation of the air pollution potential of the site and many weather and climate factors. Pollutant concentrations must be predicted for a range of weather conditions. Models based on correlation of pollution concentrations against weather conditions must be used.

LAND REQUIREMENTS

A comparison of land area requirements for different types of plants is given in Table 11. These examples are for power stations of a 1000 megawatt capacity.

Table 11

Land Area for Power Plants

Plant Fuel	Number of Acres Required
Coal	900-1200
Oil	150-350
Gas	100-200
Nuclear	300-900

One reason that a coal-fired station requires so much space is that at least a 90 day supply of coal must be stored on the site, along with the eventual waste ashes. A modern plant will burn 8,000 to 10,000 tons of coal per day, so that a 1000 megawatt station normally requires a reserve yard of 20 to 30 acres with the coal piled 40 feet high. There must be a large area for waste storage, and the train yard for the delivery of the coal also consumes much land area.

Oil and gas fueled power plants are usually supplied by pipeline, and therefore require only modest on-site fuel storage.

In a nuclear power plant, the area required for fuel storage is very small The only storage facility needed is a storage vault for new and used fuel. The relatively large site area required for a nuclear plant is necessary for providing distance between the reactor and people. This distance is called an exclusion distance and is required by law. It provides a protective factor between the public and the reactor in the event of a reactor accident. At nuclear stations, this exclusive distance runs between 1200 and 4400 feet. There must also be a low population zone immediately surrounding the exclusion area, and a population center distance representing the distance from the plant to the nearest boundary of a desnsely populated area.

ENVIRONMENTAL IMPACT EVALUATION OF PLANT SITE SELECTION

All power plants will have some adverse effects upon the environment. With the proper selection of sites, appropriate design of facilities and careful pre-construction and post-construction studies, much can be done to reduce such effects. The following factors need to be considered in assessing environmental impact.

Air Quality Studies

1 Determine present population distribution and expected growth patterns; determine existing and expected industries in the area and likely emissions to the air.

2 Consider factors of land surface affecting dispersion of air emissions; make measurement of prevailing wind directions and velocities, temperature ranges, precipitation values and factors related to temperature inversions; provide for air monitoring before plant startup and after plant operation—measuring wind direction and velocity, temperature, sulfur dioxide content, nitrogen oxide content, particulate content, dust fall and haze.

Water Quality and Quantity Studies

1. Determine quantity availability for once-through cooling water system; or for cooling towers where water supplies are limited; determine available average and firm flows in streams to be used to supply cooling water; determine available ground water supplies.

2. Measure physical and chemical properties of the water.

3. Algal studies, large invertebrate animal studies, fish population studies and any unique or

significant ecosystems studies should determine species and quantities present at proposed points of intake and discharge of cooling water supplies before and after plant startup to determine their seasonal variations and the environmental effects of plant operations.

4. Make temperature prediction studies to demonstrate the ability of cooling water systems to meet surface or ground water temperature standards.

Radioactive Waste Studies

1. Determine proposed releases based on site conditions, including background radiation, weather characteristics and related factors; measurements and studies necessary to predict the effects of project construction and operation on the environment must be made.

2. Monitoring programs must be set up; stations should be selected to measure radiation where maximum effects of the plant operation are expected and also where background radiation can be determined. the following materials should be sampled in the region of the site to determine the level of radioactivity airborne dust, precipitation, milk, external radiation, waters and sediments and water organisms.

Land Use Studies

1. Sufficient acreage must be made available, and in the case of nuclear plants must be according to AEC regulations; the relationship of nuclear plants to population centers must be in accord with AEC regulations

2. Study physical characteristics of the site, determine the incidence of flooding or wind storms.

3. Determine relationship to all historical, archeological or cultural areas in the site region and effects on these areas

4. The plant site should conform with adopted state and regional land use plans; full consideration should be given to recreational and other compatable uses of the plant site. visitor centers and other facilities to accommodate the visiting public should be provided.

5. The architectural design should blend with the surrounding area and be accompanied by appropriate landscaping

GOVERNMENT STANDARDS ON PLANT SITING

All proposed power plants must meet governmental standards. Many of these standards are set by the federal government, but state and regional control of site selection, air and water quality, transmission line routing and transportation methods is increasing

Many more governmental standards must be met by nuclear plants than by fossil fueled plants. The average nuclear power plant must get in excess of 100 state and federal permits to become operational. (See Appendix IV)

Finding sites that meet all these requirements is not an easy task. As the Tennessee Valley Authority's manager of power, G. O. Wessenauer, has said, "An ideal site for a nuclear plant is one for which there is no evidence of any seismic activity over the past millennia, is not subject to hurricanes, tornadoes or floods; is an endless expanse of unpopulated desert with an abundant supply of very cold water flowing nowhere and containing no aquatic life. Most important, it should be located adjacent to a major population center."

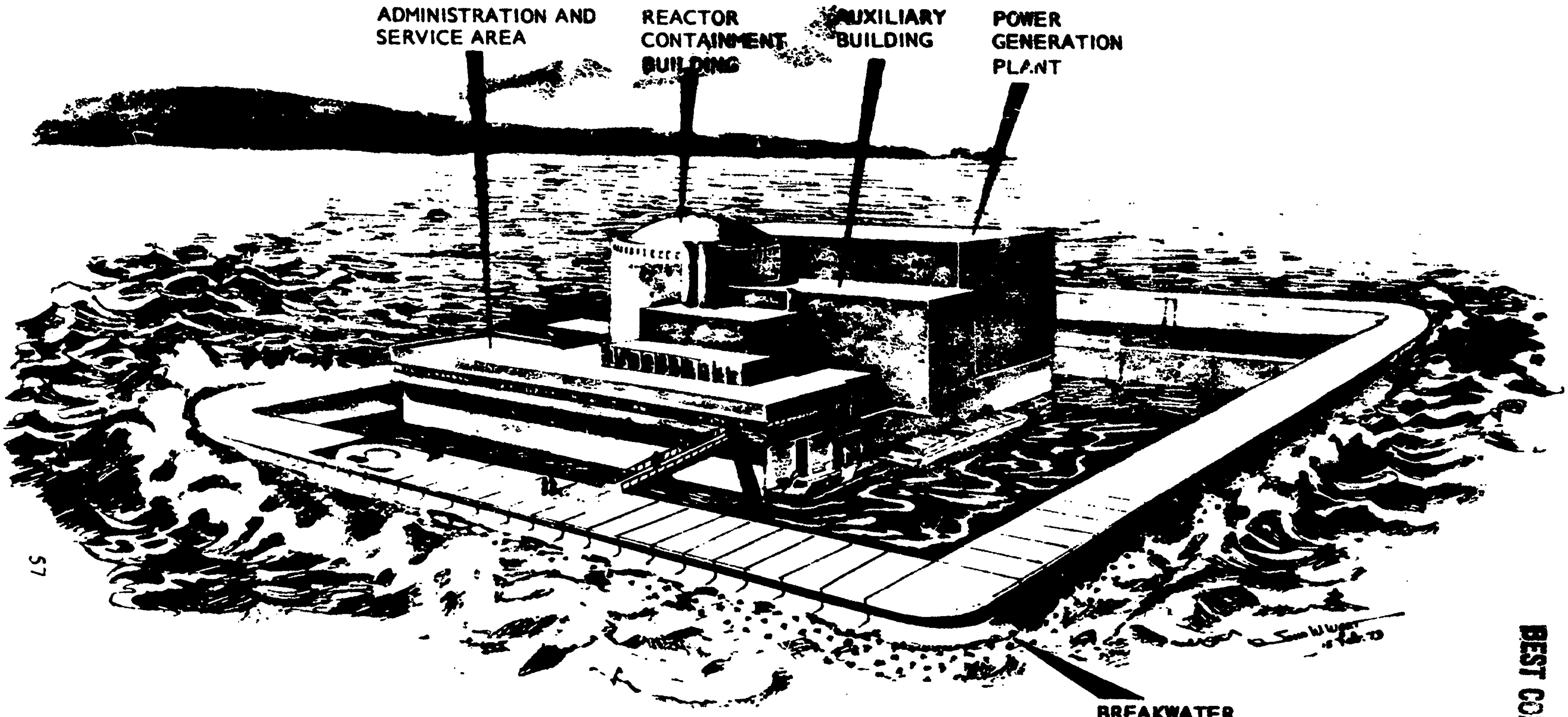
FUTURE SITING POSSIBILITES FOR NUCLEAR PLANTS

Offshore Siting

The use of offshore sites adjacent to coastal cities is under development. Figure 19 shows one of these proposed sites. These sites would alleviate the problems of land availability, esthetic compatability and cooling water supply. In addition, these offshore sites could be located close to the major market areas of the east and west coasts.

Nuclear power plants such as the one in Figure 19 may be built on a massive steel and concrete barge, about 400 by 400 feet. A nuclear plant on the barge would rise 175 feet above sea level, protected on four sides by a breakwater enclosure.

The breakwater enclosures resting on the sea bottom would have walls 100 feet thick and would rise 60 feet above the sea's surface. They would be designed to protect the plant from all natural perils such as hurricane-whipped seas or from stray ships.



OFFSHORE NUCLEAR POWER PLANT
FIGURE 19

Cables carrying the power from plant to shore would be entrenched below the sea bed.

The possibility of siting plants under the sea is also being investigated.

Underground Sites

Underground sites for nuclear power plants are being studied for location near urban centers. The primary reason for these studies is to determine safety advantages and the possible utilization of waste heat. Underground sites will not require valuable surface areas near cities.

Chapter 8

ENERGY CONSERVATION: THE NEED FOR MORE EFFICIENT USE OF ENERGY

In the past history of the United States, energy has always been a relatively cheap commodity. Because of its low price, little effort has been made to use energy efficiently.

But as we have seen, low-cost energy is no longer abundant. The growing shortages of traditional fuels will most likely result in a significant rise in the price of these fuels, and in an increase in the price of the energy derived from these fuels. The price of electricity rose in 1971, the first increase since 1946. Our national consumption of both natural gas and petroleum are now in excess of our production, resulting in a greater dependance upon foreign sources for imports. Thus the more efficient use of energy is necessary. Fortunately, it is possible to save on our energy expenditures.

The consumption of energy in the United States is estimated to be 63×10^{15} BTU per year. Of this amount, the greatest single use is for transportation (25 per cent). Space heating requires 19 per cent of our energy supply, while all industrial applications require about 36 per cent for such items as process steam, electrical drive of various processes and direct heating. The efficiencies of all these processes are less than 50 per cent, so that at least half of all the energy produced is discarded as waste heat. If this loss could be reduced by only one per cent, this would represent a savings in energy equivalent to 100 million barrels of petroleum per year.

HOW TO ACHIEVE INCREASED CONSERVATION OF ENERGY

The largest energy saving (and the easiest to accomplish) would be in the heating and lighting of homes and commercial buildings. These structures seldom have been designed to conserve energy. They usually have inadequate insulation, and allow excess leakage of outside air. Most commercial buildings have large window areas, excess ventilation and inefficient heating and cooling equipment.

Guidelines in the form of building regulations which would set minimum standards for construction based upon the economically optimum amount of insulation for new buildings could save up to 42 per cent of the heat energy required. These standards would also reduce air conditioning energy requirements.

Another step would be to design furnaces which would lose less heat in the exhaust. Modern furnaces are typically about 75 per cent efficient, but poor maintenance may reduce this from 35 to 50 per cent. Thus it pays to have a furnace serviced regularly.

Household appliances use a surprisingly large amount of energy. If electric igniters now available on the market were to replace pilot lights on gas appliances, the savings would be substantial. From six to 10 per cent of all the natural gas consumed in this country each year is burned by appliance pilot lights. Frostfree refrigerators or freezers use almost twice as much electricity as units which are manually defrosted. Fluorescent lamps use only one-fourth as much current as incandescent bulbs.

Industry consumes about 40 per cent of the total U.S. production of energy, but economic incentives will cause industry to increase its efficiency. The most substantial of these incentives in the near future will probably be rising fuel prices.

The utility industry has improved the efficiency of electrical generation from five per cent in 1900 to 40 per cent in the newest coal-fired plants. The proposed development of combined cycle power plants, which will use high temperature gas turbines or magnetohydrodynamic generators with steam turbines, could increase plant effieciency to 50 or 60 per cent.

Savings in transportation will be more difficult to achieve because more efficient modes of travel would involve changes in our life-styles, especially our commitment to the automobile. Automobiles accounted for 21 per cent of the total U.S. energy consumption in 1972. The average American car gets about 12 miles per gallon, which is about half the mileage of most smaller European cars. The installation of antipollution devices which have been required by law will further reduce the gasoline mileage. The growing U.S. dependance on foreign oil imports plus the price increases which the oil-exporting countries have already started to impose will cause a sharp rise in the price of gasoline. Newsweek magazine, in its January 8, 1973 issue (p.9), predicts that by 1977 the price of gasoline will be about $1.00 per gallon. This fuel price will give economic impetus to less automobile travel and a greater demand for more efficient mass transit systems.

SUGGESTIONS FOR GOVERNMENT INCENTIVES TO CONSERVE ENERGY

Several suggestions have been put forward which would provide government incentives for the conservation of energy and the control of pollutants. These include:

1. A tax on pollutants. Under this proposal, industries would be surcharged by the government for the amount of pollution they release. This tax would increase the cost of the products they manufacture, or would decrease their profits. This would provide an economic incentive for industry to reduce its pollution as much as possible to escape paying the surcharge.

2. Labelling legislation. Laws requiring that labels be put on consumer appliances stating the energy consumption of these appliances have been suggested. This would encourage the public to purchase brands with lower consumption, acting as an incentive to manufacturers to produce appliances with energy consumption as low as possible.

3. Altering rate structures. Present rate structures are such that those who use the least amount of electricity pay the highest rate, while those who use larger amounts pay a lower rate. Reversal of this structure would cause those who use large amounts of electricity to conserve it whenever possible because of its high price.

SUMMARY

We must keep before us the fact that all energy sources have some impact upon the environment. Table 12 summarizes the effects discussed in the preceding chapters. It also summarizes the supplies of the fuels.

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 upon the environment?

These are decisions which the American public must make. They are extremely important decisions and they will affect the lives of unborn generations. We must balance the availability and importance of fuels, the impact on the environment and human needs. We must keep in mind that pollution is more a by-product of affluence than of poverty.

Whether the production of energy will come from fossil fuels, nuclear reactors or from a variety of sources is a decision which must be made after a careful weighing of the facts. In the words of Congressman Craig Hosmer of 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 12

Environmental Effects of Electrical Power Generation

Energy Source	Effect on Land	Effects on Water	Effects on Air	Biological Effects	Supply
Coal	Disturbed land Large amounts of solid waste	Acid mine drainage Increased water temperature	Sulfur oxides Nitrogen oxides Particulates	Respiratory problems from air pollutants	Large reserves
Oil	Wastes in the form of brine	Oil spills Increased water temperature	Nitrogen oxides Carbon monoxide Hydrocarbons	Respiratory problems from air pollutants	Limited domestic reserves
Gas		Increased water temperature	Some oxides of nitrogen		Extremely limited domestic reserves
Uranium	Disposal of radioactive waste	Increased water temperature		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 exerpted 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 of 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 realtively severe doses of ionizing radiation. It is characterized by nausea, vomiting, diarrhea blood cell changes, and in later stages by hemorrhage and loss of hair
AEC	The U.S. Atomic Energy Commission.
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 independent civilian agency of the federal government with statutory responsibility for atomic energy matters. Also the body of five persons, appointed by the President, to direct the agency
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 (gas, solid or liquid), some of it may be reflected or scattered 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 charge 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	A process of obtaining methane and other combustible gases from coal, using the heat of the gas to generate electrictiy, then burning the gases to operate a steam cycle.
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 factors have been considered. The product of absorbed dose multiplied by a quality factor multiplied by a distribution factor. It is expressed numerically in rems.
dose rate	The radiation dose delivered per unit time. Measured, for instance, in rems 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 e^-) 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.
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 or 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 centimeter 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 cool' reactor	A nuclear reactor in which a gas is the coolant.
gaseous diffusion (pl t)	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 in 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 : 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 absorbes 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 as $E = mc^2$, 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 neutrino. 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 or 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 device 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 superheating	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.
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.

quality factor — The factor by which absorbed dose is to be multiplied to obtain a quantity that expresses, on a common scale for 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 reactions, 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 instruments — 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 radicactive 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 of cells, tissues, organs, or organisms to the injurious action of radiation. (Compare radiosensitivity.)
radiosensitivity	A relative susceptibility of 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.
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 for 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 1985.
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 does 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 health 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

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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
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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 through this minicourse) make such decisions? How does he evaluate the availabe 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 20. 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.

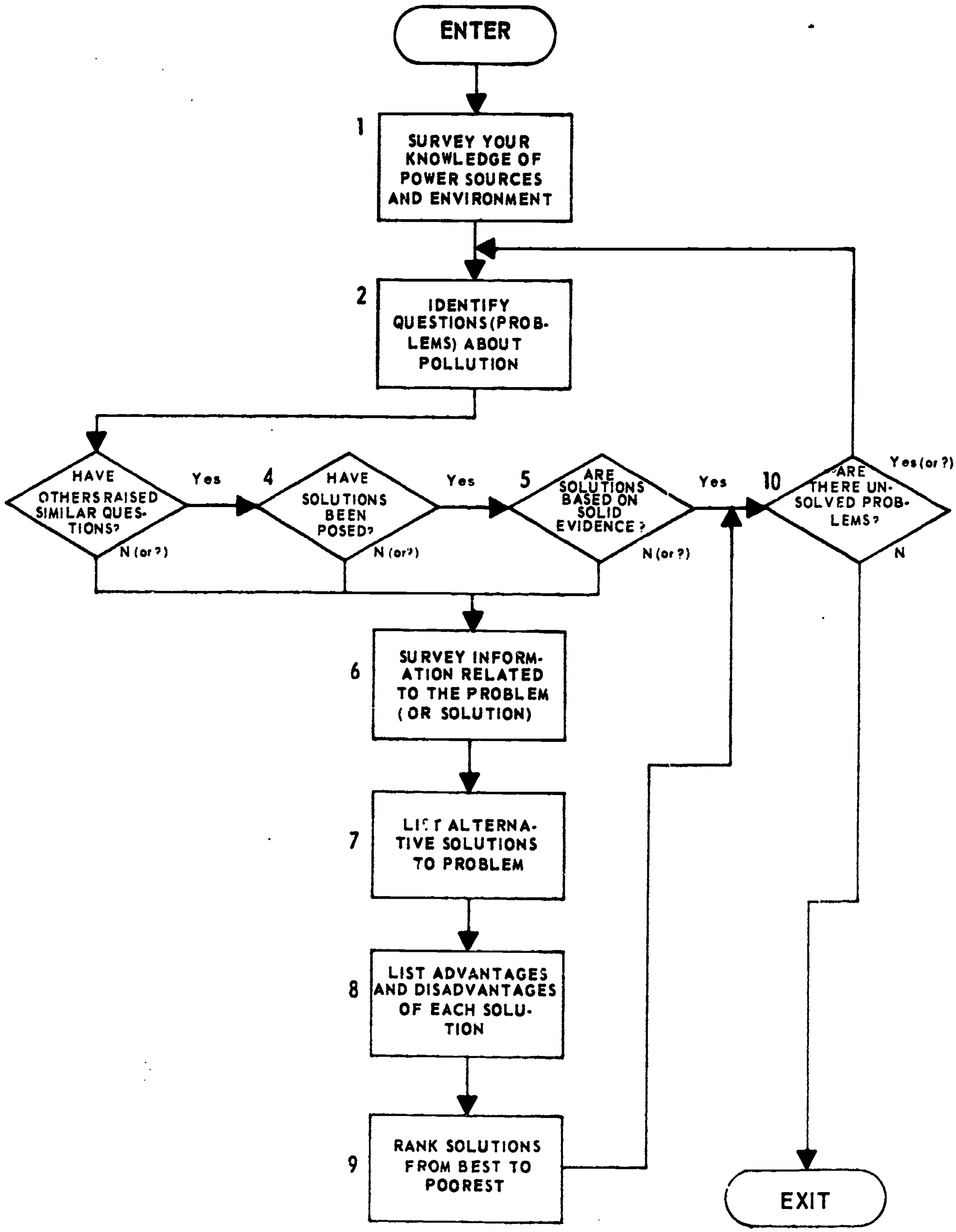
After Stage 9, the flow is cycled back to Stage 10.

Stage 10. Are there unsolved problems? Presuming affirmative answers to Stages 3, 4 and 5, we are now 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 judgements in technoligical 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 20

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. Atomic Energy 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. Atomic Energy 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 AEC Directorate of Licensing. An Analysis of the application is prepared.

3. Copies of the application are made available to the public and to the AEC 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 AEC-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 Atomic Energy 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 AEC Division of Compliance.

9. As construction progresses, the company applies to the AEC for an operating license.

B. Steps in Obtaining an Operating License

1. As construction of the reactor proceeds, AEC 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 AEC 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 AEC 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.