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ABSTRACT

This report contains the papers presented in the 1970-1971 Environmental and Ecological Forum series, planned to provide an overview of the significant environmental, social, and economic aspects of electric power generation, more specifically, the pros and cons of nuclear power production. The Forum was organized as a public service to foster community understanding of environmental problems that increasingly tax society's capabilities for remedial action. Speakers with widely divergent opinions discussed the various ways in which the increasing development and use of technology may affect man's well-being. Their presentations were titled: Man's Conquest of Energy: Its Ecological and Human Consequences; The Nucs: Energy vs. the Environment; Nuclear Power Plants: Present, Past, and Future; The Radiation Hazard for Man; A Proposal for a Rational Policy to Control Radioactivity and Other Forms of Pollution; The Public and Radiation from Nuclear Power Plants; Adequacy of Present Radiation Standards; The Nuclear Power Information Communication Predicament; Nuclear Power Licensing: Risk--Benefit Determinations and the Public Interest; Nuclear Power: You Never Had It So Good; Benefits and Costs of Nuclear Power; and What We Do Know About Low-Level Radiation. (BL)

the environmental and ecological forum 1970-1971

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Forum Coordinator
A. BURT KLINE, JR.

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Washington Section of the American Nuclear Society
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Montgomery County Public School Adult Education Program

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PREFACE

This publication contains the papers presented in the 1970–1971 Environmental and Ecological Forum series, which was planned to provide an overview of the significant environmental, social, and economic aspects of electric-power generation, more specifically, the pros and cons of nuclear power production.

The Forum was organized as a public service to foster community understanding of environmental problems that increasingly tax society's capabilities for remedial action. It was the purpose of the Forum to present a program in which prominent, knowledgeable speakers discussed the various ways in which the increasing development and use of technology may affect man's well-being. In the hope of building a communication bridge between the scientific community and the public, the Forum scheduled speakers whose concerns ranged widely across the multidisciplinary areas of technology, national policies, priorities, and their interrelationships. The sponsoring organizations believed that all sides of these issues should be presented by knowledgeable and articulate spokesmen to as broad an audience as possible in an attempt to generate open discussion, increase involvement, and overcome apathy. It was further believed that a series of this type would assist those attending to develop informed, independent judgments on matters which ultimately would have an impact on them and their families.

The editors of this volume saw the Forum as a method of bringing the technical and lay communities together in a meaningful dialogue that would provide an opportunity for each group to better understand the other. Since there was disagreement within the technical community with respect to the best approach to the production of power, great pains were taken to schedule speakers who held widely divergent opinions. A. Burt Kline, Jr., was selected as the Forum coordinator by the sponsoring organizations in June 1970 and was authorized by them to plan and implement a program that would create an opportunity for open discussion of the overriding issues surrounding the "power crisis" and to provide for the broadest possible dissemination of the presentations and subsequent discussions. The Environmental and Ecological Forum program was developed in response to this charge and, at its conclusion, received an award from the Atomic Industrial Forum in October 1971 as the outstanding program of its type conducted in the year preceding the presentation of their award. The award was presented to A. Burt Kline, Jr., representing the Environmental and Ecological Forum, at the annual joint meeting of the Atomic Industrial Forum and the American Nuclear Society in Miami Beach, Florida, and carried the following citation engraved on a bronze plaque: "The Forum Award honoring significant contributions to public understanding of atomic energy is bestowed upon *The Environmental and Ecological Forum* for its series of programs featuring outstanding experts on nuclear power and the controversy surrounding it. The initiative of the Forum led to a comprehensive series of meetings that presented a finely balanced view of nuclear power to the interested public in the Washington (D. C.) area."

The original goals of the Environmental and Ecological Forum were to promote understanding and to foster cooperation; it was intended to unite rather than to divide, and all decisions were made with these ends in mind. It is the hope of the coordinator, the sponsoring organizations, and everyone associated with this undertaking that the Forum was successful in remaining true to these goals and to some degree successful in achieving them.

A. Burt Kline, Jr., *Forum Coordinator*
Michael S. Terpilak, *Assistant Forum Coordinator*

ACKNOWLEDGMENTS

The Forum concept originated in May 1970 when I met with the Baltimore–Washington chapter of the Health Physics Society (HPS) to elicit help in conducting a series of discussions about the evolving controversy over nuclear power plants. The Society agreed to support such an effort, and shortly thereafter the Washington section of the American Nuclear Society (ANS), the Mid-Atlantic chapter of the American Association of Physicists in Medicine (AAPM), and the Montgomery County Public School Adult Education Program joined as cosponsors. In June 1970 the sponsors appointed a board of directors consisting of A. Burt Kline, Jr., coordinator; Michael S. Terpilak, President of the Baltimore–Washington chapter of the HPS, assistant coordinator; Dr. Robert W. Deutsch, President of the Washington section of the ANS; Robert W. Swain, President of the Mid-Atlantic chapter of the AAPM; and Norma Day, Director of the Montgomery County Public School Adult Education Program.

The success of the Forum must be attributed to the unselfish efforts of many people and organizations. It is impossible, however, to identify all of them by name in this space. It is our hope that everyone involved with this program will recognize the significant rôle they played and will feel a certain pride in this publication and in the Forum's honor in winning the Atomic Industrial Forum's annual award for 1971.

From the first we consulted with Dr. Norman Hilberry and during the series with Dr. Ralph E. Lapp. We gratefully acknowledge the help received from six organizations: the Bureau of Radiological Health, the U. S. Atomic Energy Commission, the Eberline Instrument Corporation, the Potomac Electric Power Company, the Victoreen Instrument Company, and the Washington Gas Light Company.

Since any program conducted over a long period of time faces the probability of losing a speaker owing to unforeseen circumstances, contingency plans must be made. Dr. Merril Eisenbud, Dr. H. Peter Metzger, Mr. James G. Terrill, Jr., and Dr. Abel Wolman agreed to support the Forum by serving as alternate speakers. Although circumstances did not require the Forum to call on these backup speakers, it was a great comfort to know these able men were available.

The overall assistance of Mrs. F. Patricia Nash and Mrs. Dolores Ann Kline was immeasurably responsible for whatever success the Forum may have enjoyed. They played an extensive part in all the Forum's many facets from the initial discussions to the publication of this book. Mr. Howard Roberts' efforts in providing direction to the audiovisual component of the Forum allowed those who attended to enjoy optimal listening convenience. His services permitted speakers maximum flexibility in the use of visual aids and provided for the videotaping by the Video Activities Branch, Division of Headquarters Services, USAEC. The high-quality films produced enabled the Forum and the AEC to make far broader dissemination of the information presented by the speakers. The videotapes, on 1-in. Ampex format, may be borrowed by writing the Office of Information, Bureau of Radiological Health, 1901 Chapman Avenue, Rockville, Md. 20852.

A. Burt Kline, Jr.

CONTENTS

MAN'S CONQUEST OF ENERGY: ITS ECOLOGICAL AND HUMAN CONSEQUENCES

M. King Hubbert

Research Geophysicist, U. S. Geological Survey, Department of the Interior

Dr. Hubbert received the B.S., M.S., and Ph. D. degrees in geology and physics from the University of Chicago. In addition to teaching at Columbia University and Stanford University, he has conducted and directed research at the Shell Oil Company in Texas and with the U. S. Geological Survey. He is a member of the National Academy of Sciences and a Fellow of the American Academy of Arts and Sciences and has served as Chairman of the Division of Earth Sciences of the National Research Council, as a member of the NAS–NRC committee advisory to the AEC on land disposal of atomic wastes, and as a member of the NAS Committee on Natural Resources advisory to President John F. Kennedy and author of its report on energy resources. He is the author of *The Theory of Groundwater Motion* and *Structural Geology* in addition to over 60 articles in scientific journals.

The topic I will discuss is man's progressive conquest of energy during the last million years and its consequences to the earth's plant and animal ecology and in particular to man himself. However, to appreciate our present situation and our prospects for the future, we must take account of the geological span of time in which our species has evolved and look at a longer period of human history than that to which we are accustomed.

The time scale of geologic history is shown in Fig. 1. The upper horizontal line is a graphical representation of the entire history of the earth. Recent radioactive datings

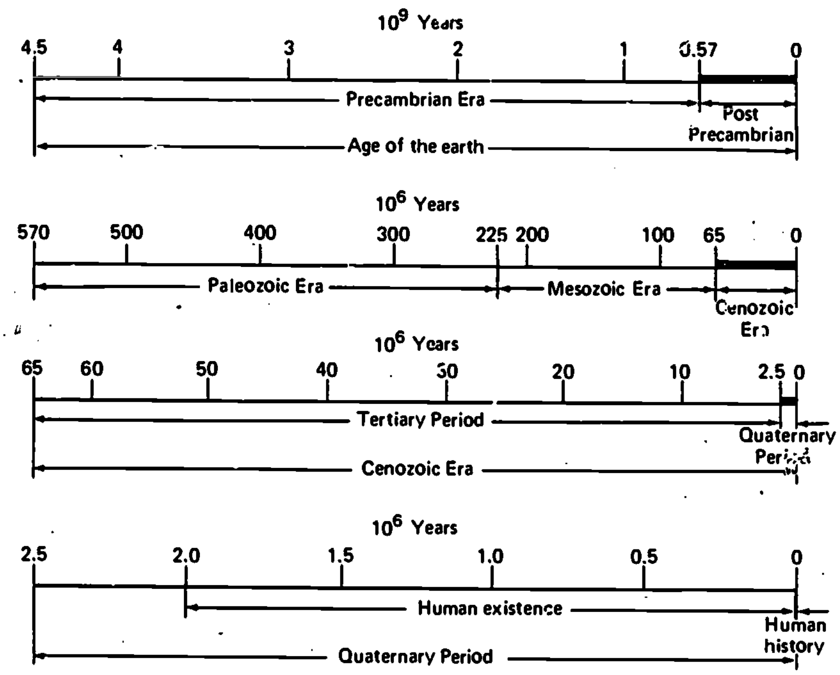


Fig. 1 Geologic time.

of meteorites are consistent in indicating that the catastrophic astronomical event that produced the solar system (including the earth) must have occurred about 4.5 billion years ago. On this linear chart, the total history of the earth is divided into two parts: that from the earth's origin 4.5 billion years ago to about 570 million years ago, the Precambrian Era of geological history, and the subsequent 570 million years, comprising the Paleozoic, Mesozoic, and Cenozoic Eras.

In the Precambrian Era geological history becomes increasingly less well known the farther back we go. In fact, the oldest known terrestrial rock is radioactively dated at only about 3.7 billion years. The oldest known fossils of primitive organisms are dated at about 3.2 billion years. Thus, although life must have originated earlier than this, the fossil record is scanty prior to the beginning of the Cambrian Period. However, during the Precambrian Era many of the earth's major ores of industrial metals—iron, copper, nickel, and the like—were deposited. Since the beginning of the Paleozoic Era, abundant fossils have been preserved in the succeeding sedimentary strata, affording us a reasonably continuous record of the evolution of the earth's organisms.

The second bar of Fig. 1 represents an enlargement of the last 570 million years. It is divided into three successive geologic eras: The Paleozoic Era, extending from the beginning of the Cambrian Period to the end of the Permian Period about 225 million years ago; the Mesozoic Era from 225 to about 65 million years ago; and finally the

Cenozoic Era, extending to the present. The final two linear scales represent an enlargement of the Cenozoic Era and show the period of the rise of man.

For the corresponding highlights in the evolution of organisms, all of the phyla of the animal kingdom except the vertebrates were already in existence by the beginning of the Cambrian Period. By Devonian time (395–345 million years ago), large fishes had appeared. Then, by Pennsylvanian time (about 320–280 million years ago), amphibians began to appear. During Permian time (280–225 million years ago), these evolved into fully land-dwelling reptiles which, during the Mesozoic Era, the so-called Age of Reptiles, proliferated into the huge dinosaurs and associated reptiles. Finally, during the following 65 million years of the Cenozoic Era, we witness the emergence and progressive evolution of the mammals including, during the last 2 million years, the human species.

In parallel with the evolution of animals, plants first emerged from an aqueous environment and blanketed the land surface in Silurian time (about 440–395 million years ago). Then, by Pennsylvanian time (about 320–280 million years ago), formerly known as the "Carboniferous," there occurred the dense forests whose plant remains produced the world's first widespread deposits of coal, including those of eastern North America. Great Britain, Holland, Belgium, and France.

In the last million or two years, the human species rose to dominance. Since our species did not originate suddenly, it cannot be said of any specific time that "man began here." However, from the recent excavations by Dr. L. S. B. and Mary Leakey in the Olduvai Gorge in Tanzania, Africa, it appears that near relatives, if not direct ancestors, of the present human species were already walking upright and using primitive stone tools as long ago as 1.7 million years. Subsequently, there must have occurred the succession of unprecedented activities, such as fire building, domestication of animals and plants, and the smelting of metals, which led finally to the proliferation of activities characterizing the world's present industrialized societies.

It is especially significant that most of this industrial evolution has required only the last century of the entire span of geologic history, yet it represents one of the major geological events of the earth's history.

TERRESTRIAL ENERGY FLUX

One of the most general views possible concerning events that occur on the earth is based on the recognition that the ensemble of such events—biological as well as inorganic—consists in the last analysis of a circulation of the earth's material constituents and a degradation of energy. From this point of view we may regard the earth as being composed of various amounts of the 92 naturally occurring chemical elements, which, with the exception of a few isotopes with an abundance of but a few parts per million, obey the laws of conservation and nontransmutability of classical chemistry. Into and out of the earth's surface environment there occurs a continuous flux and degradation of energy. Consequently the earth's surface materials undergo either continuous or intermittent circulation.

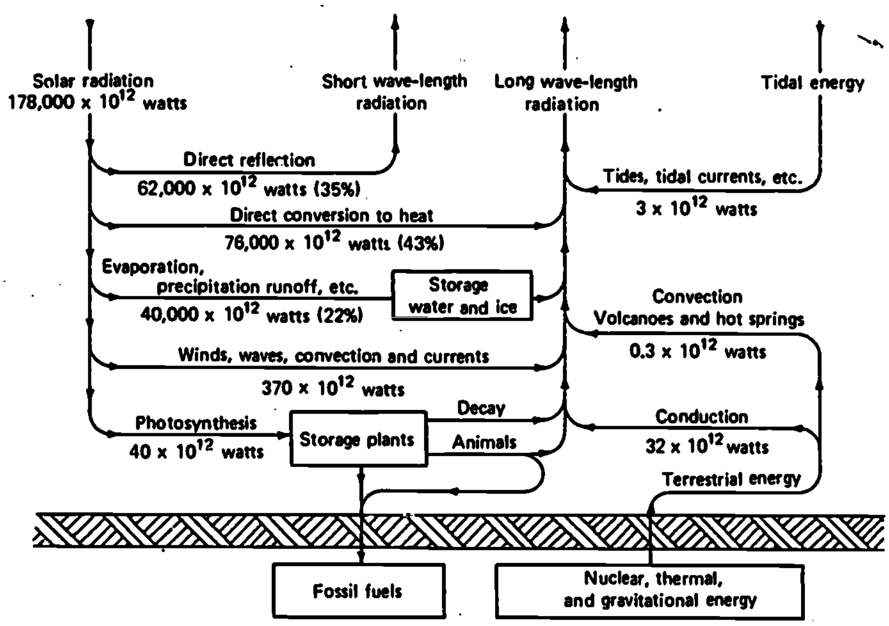


Fig. 2 Energy flow sheet for the earth.[1]

The nature of this energy flux is shown in Fig. 2. The significant energy influxes are from three sources: (1) solar radiation amounting to about $178{,}000 \times 10^{12}$ watts, (2) geothermal heat, heat conducted and convected from the earth's interior, amounting to about 32×10^{12} watts, and (3) tidal energy from the combined potential and kinetic energy of the earth–moon–sun system of about 3×10^{12} watts. Energy input from solar radiation is approximately 5000 times that from the other two sources combined. It is by a wide margin the largest source of energy available to the earth and also has an expectancy of future continuation for a time comparable to that of the past duration of the solar system.

The energy from each of these sources, after undergoing a sequence of degradations, eventually leaves the earth by radiation into outer space. In the case of solar energy about 35%, the earth's "albedo," is directly reflected. The remaining 65%, after undergoing various degradations, eventually terminates as heat at the lowest local surface temperature and is then reradiated into outer space as long-wavelength, low-temperature radiation. Of the total influx of solar radiation, about 43% is absorbed by the earth's atmosphere and surface materials and converted directly into heat. About 22% is expended in the evaporation, circulation, and precipitation of water in the hydrologic cycle; a small fraction of 1% is expended in winds, ocean currents, and waves of atmospheric and oceanic circulations and interactions. Finally, a still smaller fraction, about 40×10^{12} watts, is captured by the chlorophyll of plant leaves in the process of photosynthesis whereby the inorganic materials, CO_2

and H_2O, are converted into organic carbohydrates with an accompanying chemical storage of energy. This becomes the source of the biological energy requirements of the entire plant and animal kingdoms.

Photosynthetically stored energy is released by the reverse reaction of oxidation whereby

$$\text{Oxygen} + \text{organic materials} \rightarrow H_2O + CO_2 + \text{heat}$$

On the average, the rate of decay and oxidation of plant and animal materials is approximately equal to the rate of photosynthesis. However, during geologic time, at least since the Cambrian, a minute fraction of this material was deposited in peat bogs or other oxygen-deficient environments of incomplete decay. Eventually this material was buried by great thicknesses of sedimentary sands and muds, and through subsequent transformation has become the earth's supply of the fossil fuels. The present accumulation of fuels therefore represents chemical storage of a small part of the solar energy incident upon the earth during the last 600 million years.

Geothermal energy occurs principally as heat, although a fraction is responsible for the mechanical activities of volcanoes and hot springs. Tidal energy is responsible for the oscillation of seawater, which produces the semidiurnal cycle of the rise and fall of the tides and associated tidal currents. This energy is then dissipated by friction into low-temperature heat.

At an early stage our ancestors must have existed in some kind of ecological equilibrium with the other members of the plant and animal kingdoms and competed with these members for a share of the contemporary solar energy essential for their existence. At that stage man's sole capacity for energy utilization, in common with the other members of the animal kingdom, must have been limited to the food required—then as now probably about an average of 2000 kilocalories or about 100 watts per capita per day.

Since that early stage the human species has distinguished itself from all other members of the animal kingdom in its inventiveness of means for capturing an ever-larger fraction of the contemporary flux of energy. Initially, this inventiveness consisted principally in the manipulation of the contemporary ecological system. The use of tools and weapons, the control of fire, the invention of clothing and housing, and eventually the domestication of plants and animals and the employment of beasts of burden all increased the supply of energy available to man and continuously upset the ecological equilibrium in favor of an increase in numbers and a geographical spread of the human species, with corresponding adjustments of all other plant and animal populations.

Eventually the conquest of energy was extended to nonbiological sources when the Egyptians used the power of wind to propel sailing ships on the Nile and the Romans used water power for grinding grain. About 5000 years ago the energy of wood was extended to the nonbiological use of smelting metallic ores.

Although the prehistoric details are only dimly known, from the million or so years of time involved, the rates at which these successive changes occurred must have been extremely slow. However, since the time sedentary agriculture was introduced, estimated to have been 8000 to 10,000 years ago, the pace of successive developments has progressively quickened. Even so, the rate of increase of energy utilization must have been so slow that the increase of population was able to keep pace. Hence, the rate of energy consumption per capita could not have been more than a few times more than the biological requirements for food alone.

Escape from dependence upon the contemporary flux of energy with its approximately fixed energy allotment per capita was not possible until a larger and more concentrated source of energy became available. This occurred about nine centuries ago when the inhabitants of the northeast coast of England, near Newcastle-on-Tyne, discovered that the black rocks along the seashore—hence known as "sea coals"—would burn. The mining of coal as a continuous enterprise soon spread to all the coal fields of Great Britain and Western Europe. Next, in 1857 in Romania and in 1859 in the United States, the exploitation of the second major source of energy from fossil fuels, petroleum, began.

Since about the year 1700, an associated technology has evolved along with the exploitation of energy from the fossil fuels. This included the development of the steam engine and its use for stationary, and, later, mobile mechanical power and the use of coal for the smelting of metals, principally iron. With the discovery of petroleum came the internal combustion engine followed by the motor vehicle and the airplane. The development of means for the transmission of electric power, during the latter part of the nineteenth century, has made possible individual power units, including water-driven generators, of more than 1000 megawatts (Mw) capacity as compared with units of only a few hundred kilowatts based on mechanical transmission of power.

The mining of coal as a continuous enterprise began about the twelfth century and has steadily increased ever since. Although scattered statistics on production during the earlier centuries exist, statistics on the annual production of coal and lignite prior to the year 1860 are difficult to assemble. We do know, however, that by 1860 the annual production rate had reached 138×10^6 metric tons and by 1965, 2.80×10^9 tons (Fig. 3). The rate of production of coal and lignite during the years before 1800 must have been almost insignificant as compared with that which followed 1800. From available data it can be estimated that the average rate of growth in the production rate before 1860 must have been about 2% per year. The cumulative production during the preceding eight centuries has been estimated to be about 7×10^9 metric tons. By 1965 this had reached 125×10^9, and by 1970 it was approximately 140×10^9 metric tons. Hence, coal production during the 110-year period from 1860 to 1970 was about 20 times that of all preceding history. Similarly, the amount of coal produced during the 30-year period 1940 to 1970 was equal to that of all preceding history.

The rate of growth of production since 1860 falls into three distinct episodes [Fig. 3(a)]: (1) a steady exponential growth until about the beginning of World War I, (2) a slowdown between World Wars I and II, and (3) a resumption of rapid growth

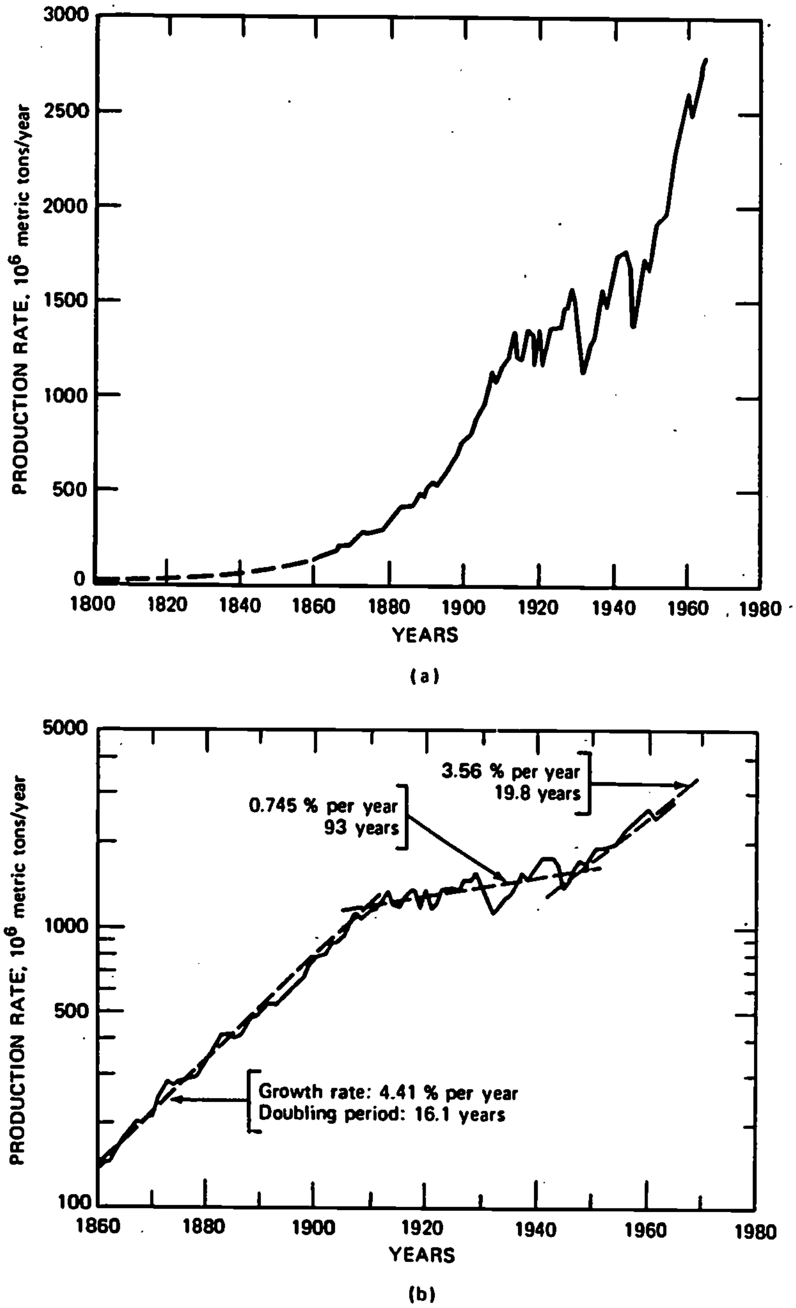


Fig. 3 World production of coal and lignite. (a) Arithmetic scale.[2] Dashed portion is an approximation. (b) Semilogarithmic scale.[3]

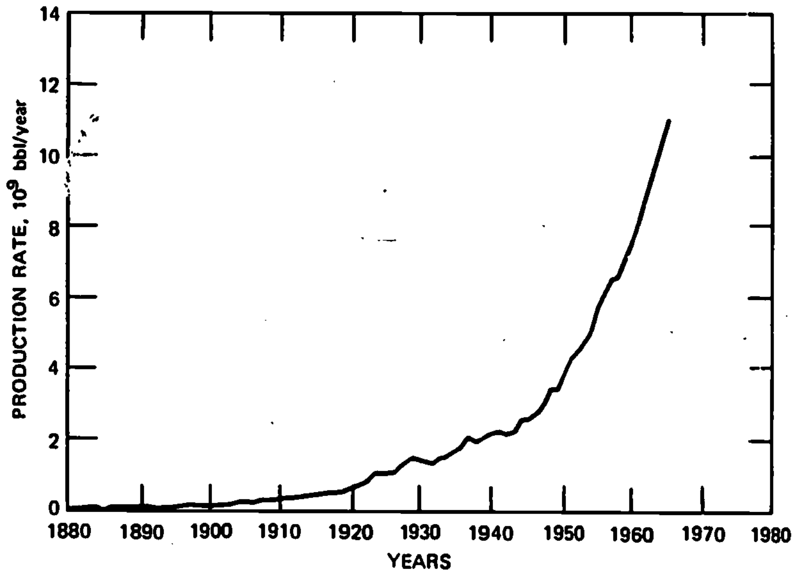
following World War II. This is shown even more clearly in Fig. 3(b), where a straight-line segment indicates an exponential growth at a constant rate of increase per year or a rate of production that doubles at equal successive intervals of time. Hence, Fig. 3(b) shows that during the period 1860 to 1914 annual production increased at a steady rate of 4.41% per year with a doubling period of 16.1 years. During the second period, 1914 to 1946, the growth rate reduced to only 0.745% per year with a doubling period of 93 years. Finally, during the period since 1946, a growth rate of 3.56% per year with a doubling period of 19.8 years has been achieved.

The annual production of crude oil (Fig. 4) had reached about 11.2×10^9 barrels per year by 1965, and by the end of 1970, about 16.2×10^9. Cumulative production amounted to 233×10^9 barrels. Of this, the 103-year period from 1857 to 1960 was required to produce the first half, and the second half required only the 10-year period from 1960 to 1970. Figure 4(b) shows that, except for a slight rise during the 1920s and a slight downward offset during World War II, the curve follows a straight-line exponential growth rate from 1880, corresponding to an annual rate of increase of 6.94% with a doubling period of 10.0 years.

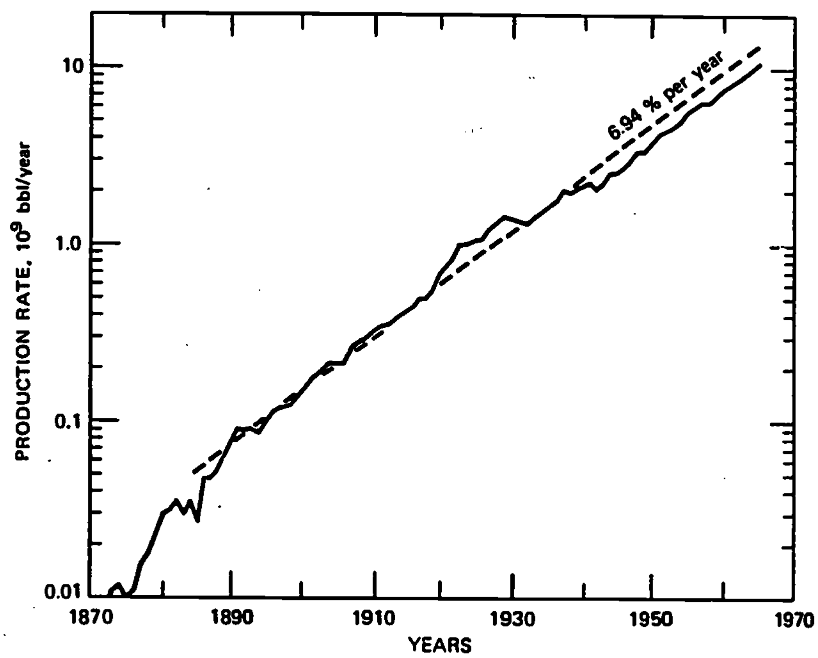
Since coal is measured in metric tons and oil in U. S. barrels, the two cannot be compared directly. When the thermal energy content of the separate fuels is expressed in a common unit of energy, however, they can be compared. In Fig. 5 this has been done in terms of the energy content expressed in units of kilowatt-hours of heat. The figure shows that the energy from crude oil was barely significant by 1900 but that by 1965 it was approximately equal to that from coal and lignite. By 1970 crude oil accounts for about 57% of the total energy from coal and crude oil combined. When we include the additional energy from natural gas and natural-gas liquids, we find that by 1970 about two-thirds of the energy from fossil fuels is contributed by petroleum fluids, only about one-third by coal. From 1850 to 1907 coal production in the United States (Fig. 6) increased exponentially, with a growth rate of 6.58% per year and a doubling period of 10.5 years. After 1907 the growth rate broke away sharply from its earlier trend, and during the last half century production has fluctuated about a mean rate of approximately 500×10^6 short tons per year.

Production of crude oil in the United States (Fig. 7) began in 1859 and from 1874 to 1929 it increased exponentially with a rate of increase of annual production of 8.27% and a doubling period of 8.4 years. Since 1929, following a minor setback during the depression of the 1930s, the growth rate has progressively diminished, and in 1970 it was approximately zero.

Until after 1940 a great deal of the natural gas produced in the United States in association with oil was "flared" by burning at the wellhead because of inadequate pipelines and market facilities. Statistics until recently have accordingly been restricted only to that fraction of the gas produced that was delivered to the consumer. Since World War II, in consequence of the construction of "big-inch" pipelines for delivery of gas to the major residential and industrial centers, such waste of gas has been curtailed and marketed statistics reflect approximately the total net production (Fig. 8). From about 1903 to 1965 annual production of marketed gas increased exponentially, with an annual growth rate of 6.57% and a doubling period of 10.5



(a)



(b)

Fig. 4 World production of crude oil. (a) Arithmetic scale.[2] (b) Semilogarithmic scale.[3]

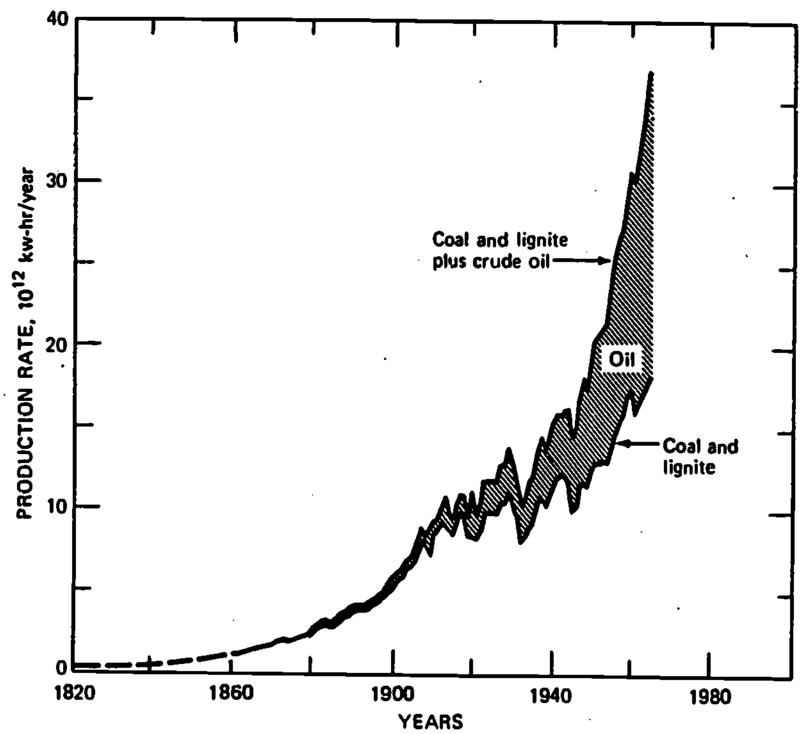
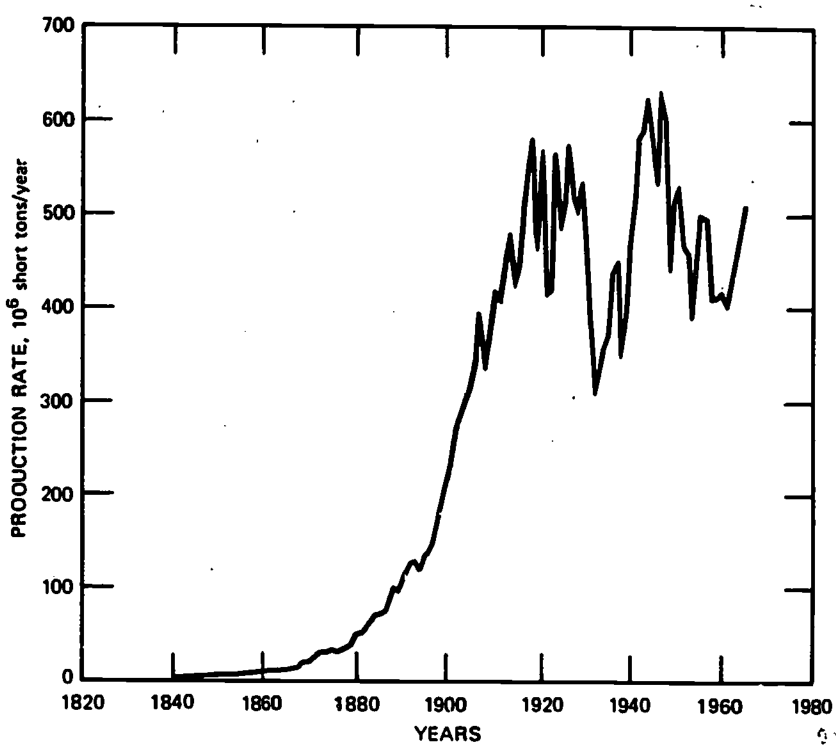


Fig. 5 World production of thermal energy from coal and lignite plus crude oil.[3] Lower curve, energy content of coal and lignite. Shaded area, additional energy contributed by crude oil. Upper curve, total energy of coal, lignite, and crude oil.

years. By 1970 the rate of production had reached 22×10^{12} cu ft per year (at 60°F and a pressure of 14.73 lb/sq in.).

The growth in the rate of production of total industrial energy in the United States from coal, oil, natural gas, water power, and nuclear power is shown in Fig. 9. Again, we note that from 1850 to 1910 the production rate increased at a steady exponential rate of 6.91% per year with a doubling period of 10.0 years. At this point the curve broke sharply downward. It then continued at the greatly reduced average rate of 1.77% with a doubling period of 39 years until about 1958. Subsequently it increased at a higher rate of 4.6% per year with a doubling period of 15 years.

The rate of energy consumption since World War II has been somewhat higher than the rate of production because about 1946 the United States became a net importer of petroleum. Imports have steadily increased; by 1970 imports amounted to about one-third of domestic petroleum production or one-fourth of domestic consumption.



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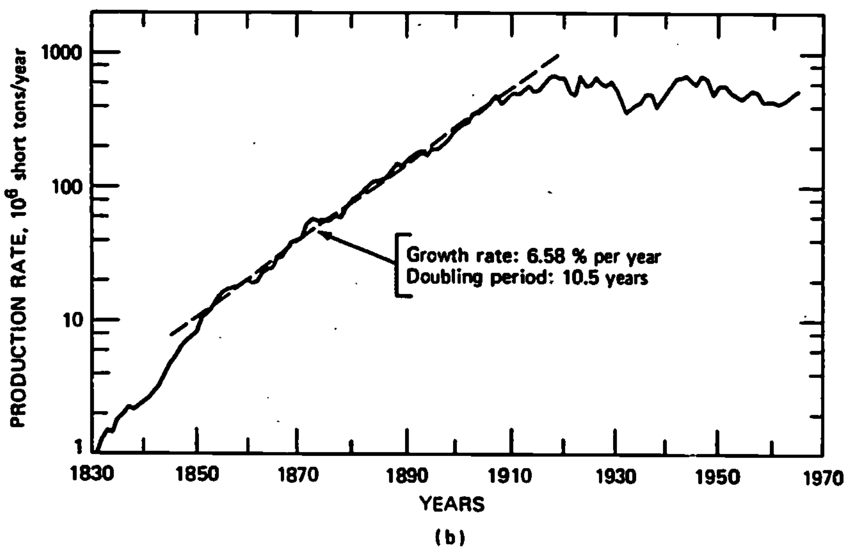
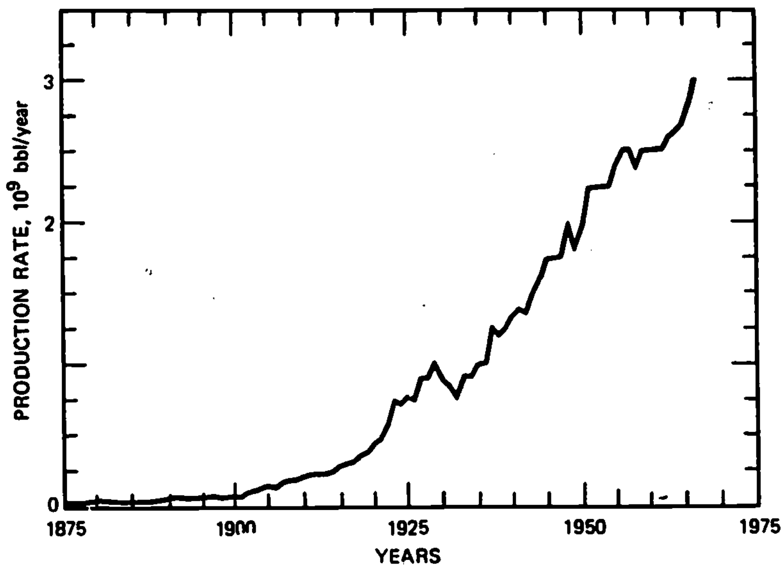


(b)

Fig. 6 U. S. production of coal and lignite. (a) Arithmetic scale.[2] (b) Semilogarithmic scale.



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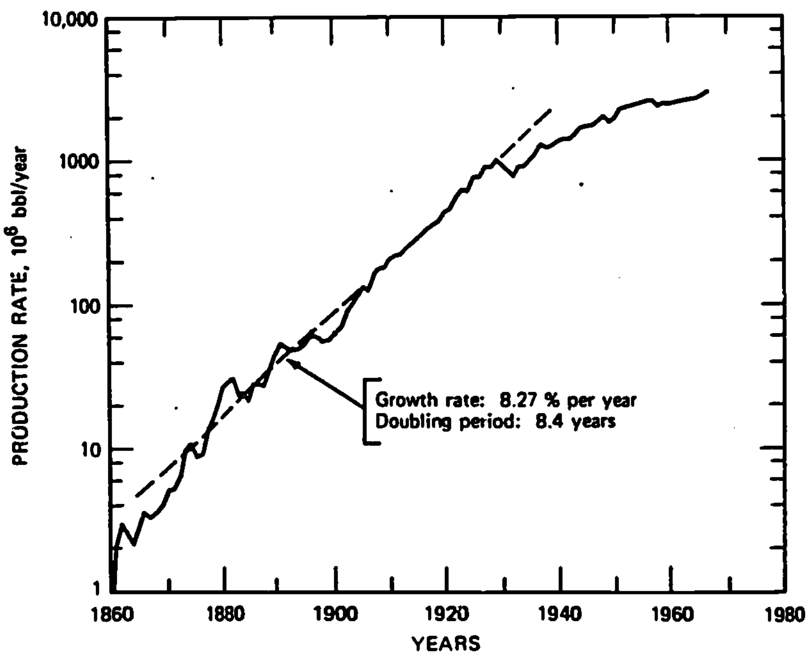

(b)

Fig. 7 U. S. production of crude oil, exclusive of Alaska. (a) Arithmetic scale.[2] (b) Semilogarithmic scale.

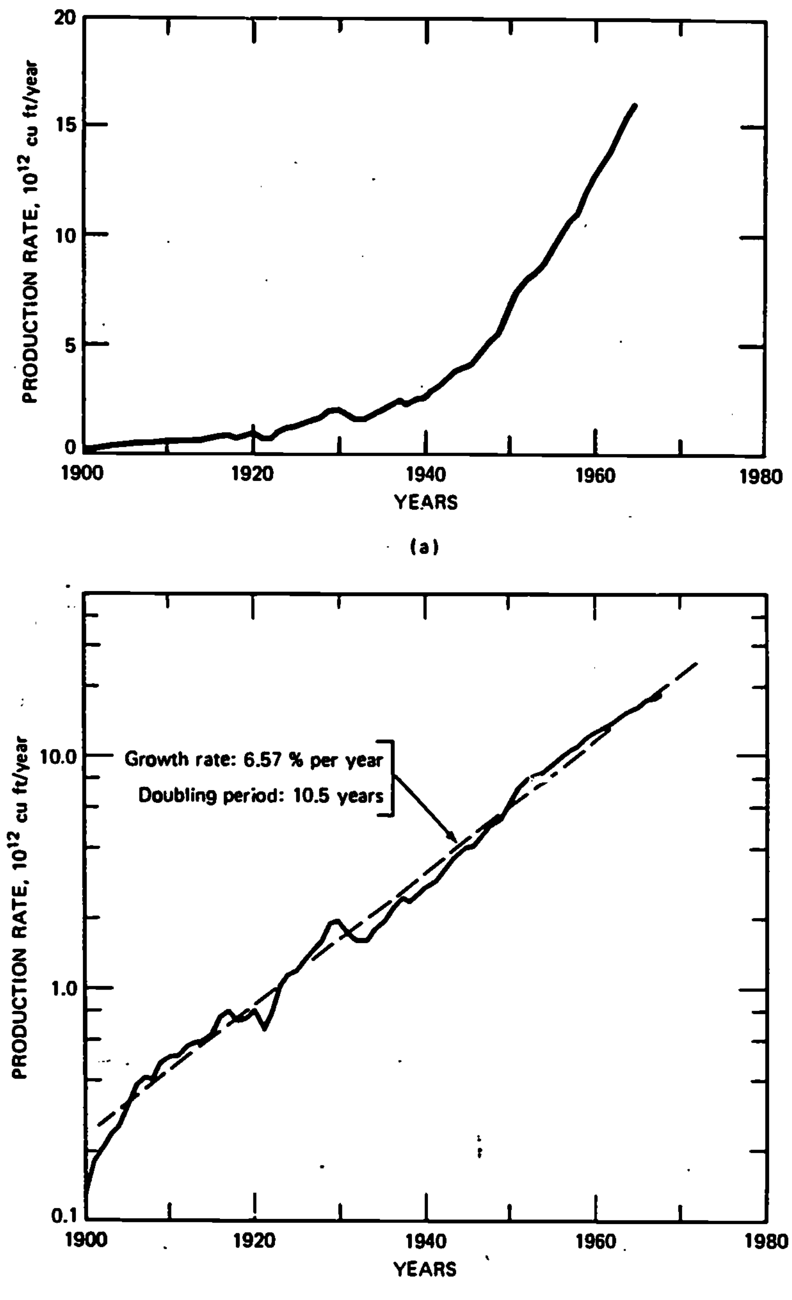

Fig. 8 U. S. production of marketed natural gas, exclusive of Alaska. (a) Arithmetic scale.[3] (b) Semilogarithmic scale.

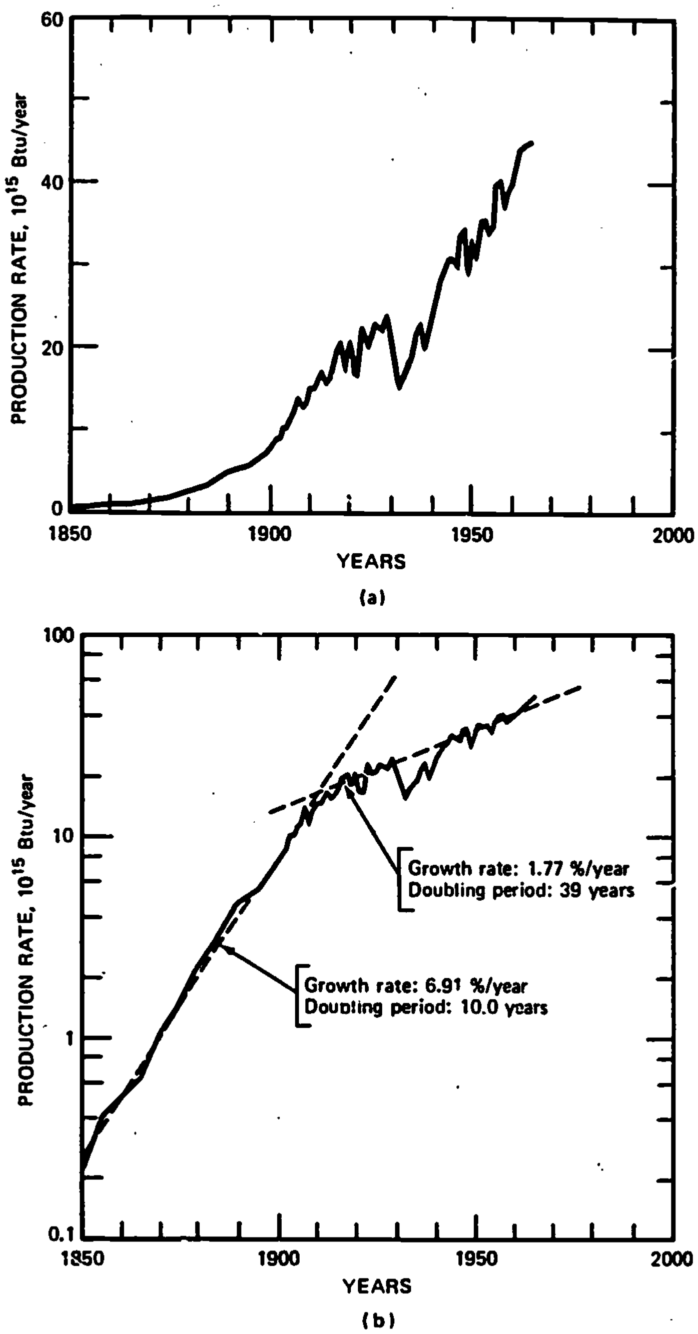

Fig. 9 U. S. production of energy from coal, oil, gas, water, and nuclear power. (a) Arithmetic scale. (b) Semilogarithmic scale.

FUTURE OF PRODUCTION OF ENERGY FROM FOSSIL FUELS

From this brief review of the growth of energy production from fossil fuels, we have seen that in each instance production has increased initially at an almost constant exponential rate between the limits of about 4 and 8% per year with doubling periods of between about 8 and 16 years. Also, in each instance, this steady exponential growth has been sustained for the order of a century; then, with the exception of world production of crude oil, the growth rate has begun to slow down. A question of great interest regarding the future of these curves is "How much longer can the growth rates that have prevailed during the last century be continued?"

An approximate answer to this question can be obtained when we consider the nature of the fossil fuels. These fuels are derived from the remains of plants and animals which were buried under conditions of incomplete decay over a geologic time span of some 600 million years. Although burial and preservation are still occurring, their present rates are so slow that no significant additions to the world's supply of fossil fuels are likely to accrue within a period of less than a million years. Hence, in the exploitation of fossil fuels, it is evident that we are simply depleting a fixed and finite initial supply with no replacement within the time span of the next few centuries.

The manner of exploitation of a fossil fuel for its energy content is shown diagrammatically in Fig. 10. The fuel is extracted from its underground deposit either by mining or by drilling. The energy of the fuel is then extracted chemically in the form of heat by a combustion reaction of the form

$$\text{Fuel} + O_2 \rightarrow H_2O + CO_2 + \text{heat}$$

Especially in the case of coal, mineral impurities are also present which produce the gas SO_2 and ash. The material constituents are thus returned to the atmosphere or to the earth. The energy content, however, after various transformations, whether directly as heat or from thermal to mechanical to electrical energy, eventually is reduced to heat at the lowest local temperature and is then radiated into outer space. Hence, the material constituents of the fossil fuels remain on the earth but the energy content, after being irreversibly degraded, leaves the earth. The fossil fuels, therefore, are absolutely exhaustible.

A guiding principle of fundamental importance in estimating the future course of the production rate of any given exhaustible resource is a consequence of a geometrical property of the curve of the rate of production when plotted arithmetically as a function of time. Consider a vertical column extending from the time-axis to the curve of the rate of production. Let the base of this column be a small interval of time dt and its height be the production rate

$$P = \frac{dQ}{dt}$$

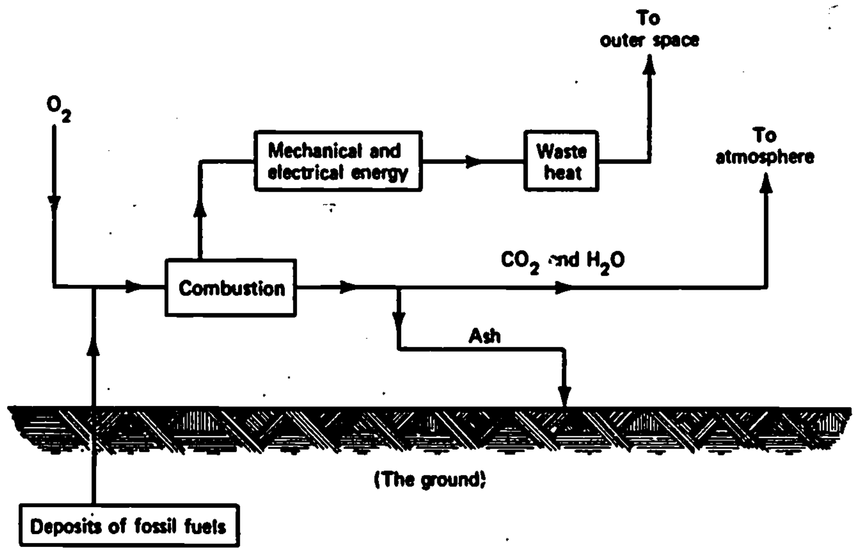

Fig. 10 Flow diagram for the production and combustion of fossil fuels.

where dQ is the quantity of the substance produced during the time interval dt. Then the area of this column, which will be the product of its base times its altitude, will be the quantity dQ produced during dt,

$$\frac{dQ}{dt} \times dt = dQ$$

The total area under the curve from the beginning up to any given time must represent the cumulative production Q up to that time.

Now consider how the curve of production rate must behave during a complete cycle from the beginning of the production of the resource until its exhaustion. The rate-of-production curve must begin at zero and then, after a period of steady increase, pass one or more maxima and eventually decline to zero as the resource becomes exhausted. The total area under this curve then represents the ultimate cumulative production Q_∞, and the basic equation of the process must be be

$$Q_\infty \leqq Q_i$$

where Q_i is the quantity of the resource initially present. This principle is illustrated in Fig. 11, which shows the complete production cycle of an exhaustible resource. If now, by geological or other means, we can estimate how much of the given resource was originally present, we can then extrapolate the production curve as known up to the present into the future, subject to the condition that when it returns to zero the area under the curve must not exceed the estimate of the initial quantity.

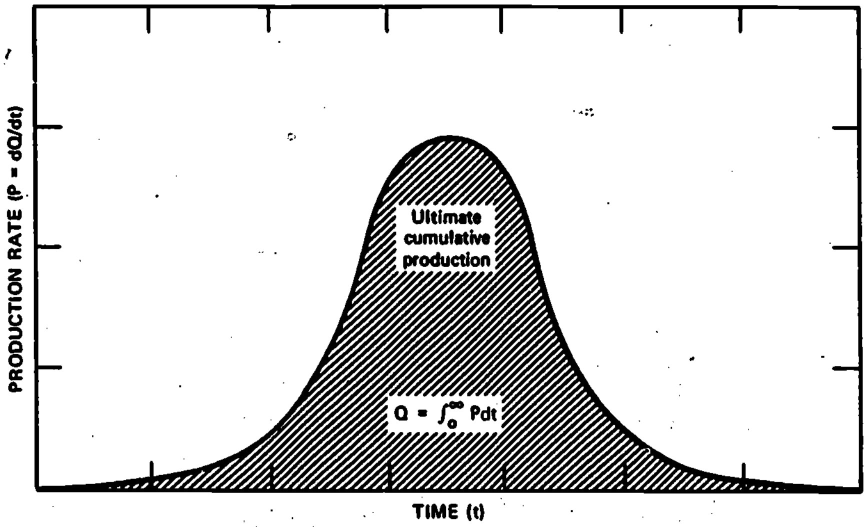

Fig. 11 Complete cycle of an exhaustible resource. Area under curve is proportional to cumulative production. [From M. King Hubbert, Nuclear Energy and the Fossil Fuels, in *Drilling and Production Practice (1956)*, p. 12, American Petroleum Institute, New York.]

Application to Coal

Coal, because it occurs in stratified beds or seams which commonly extend over wide areas and also frequently crop out on the surface, is a comparatively easy resource to estimate. Most of the areas in the world which are underlain by coal beds are known. Inventories of world coal resources have been compiled successively since 1913. The most recent is that for the year 1967 made by Averitt[4] of the U.S. Geological Survey. This compilation comprises an estimate of all the minable coal originally present to depths of 4000 ft (1.2 km) and in beds 14 in. (36 cm) or more in thickness. In mining, roughly half the coal is left in the ground. Hence "minable coal" is taken to be 50% of that estimated to be present. According to Averitt's estimates the total original quantity of minable coal in the world amounted to an estimated 7640 billion metric tons. Of this, 5000 billion metric tons was in Asia; 2100 in North America; 377 in Europe; and 182, or only 3.2%, divided between the three continental areas of Africa, South and Central America, and Oceania (including Australia). By countries, 4310 billion metric tons, or 56% of the world's original coal supply, was in the USSR, and 1486, or 19%, in the United States.

The quantity of coal consumed by 1970 amounted to 140 billion metric tons, or to about 2% of the quantity initially present. Using the principle illustrated in Fig. 11 and combining the curve of coal production with estimates of the world's minable coal, we can construct curves of the complete cycle of world coal production.

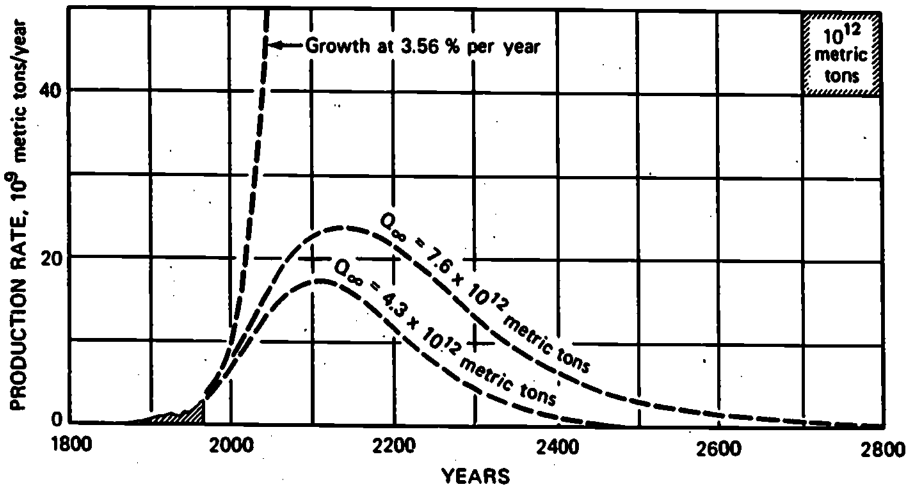

Fig. 12 Complete cycle of world coal production for two values of Q_∞ (Ref. 2).

Figure 12 shows two such curves plotted using two different values for Q_∞ (the estimated ultimate amount of coal to be produced), Averitt's value of 7.6×10^{12} metric tons and a smaller value of 4.3×10^{12}. In view of the depth and thinness of some of the seams in the Averitt estimate, the smaller figure may be the more realistic of the two.

In Fig. 12 the area scale is shown by the grid square in the upper right-hand corner, which has a vertical dimension of 10×10^9 metric tons/year and a horizontal dimension of 100, or 10^2, years. Hence its area represents

$$(10 \times 10^9 \text{ metric tons/year}) \times (100 \text{ years}) = 10^{12} \text{ metric tons}$$

Therefore, for $Q_\infty = 7.6 \times 10^{12}$ metric tons, the area under the curve during a complete cycle of production cannot exceed that of 7.6 grid squares. For the smaller value of Q_∞, the area cannot exceed that of 4.3 grid squares.

If we assume a modest future growth in the rate of coal production of not more than three more doublings, then we obtain the two curves shown in Fig. 12 for the complete cycle of production. If higher peak rates of production should be achieved, the two curves would be higher and narrower than those shown, but the respective areas would not be changed. Should lower peak rates prevail, the time span of the curves would be increased.

The dashed curve shown extending to the top of Fig. 12 represents what the production rate would be if the growth rate of 3.56% per year that has prevailed since World War II continues for another 75 years. According to the more probable curve shown in Fig. 12, it appears that the peak in world coal production will probably occur sometime near the period 2100 to 2150. Then, if we disregard the long periods

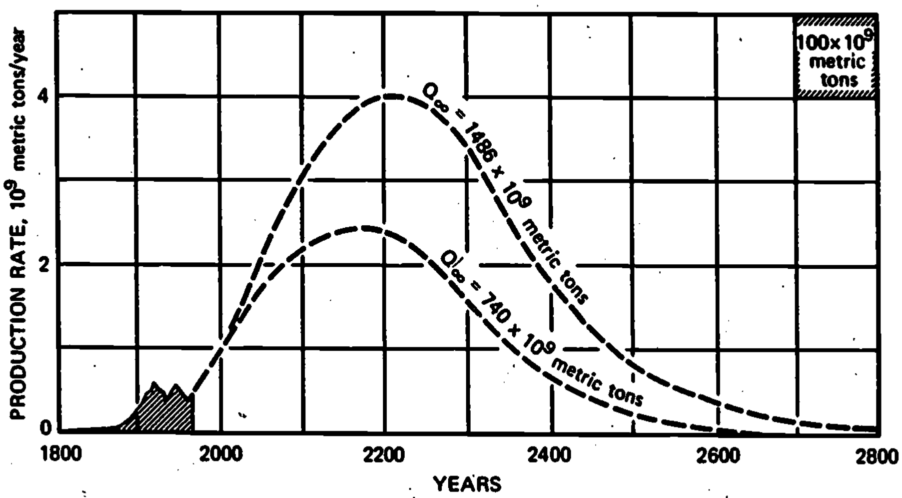

Fig. 13 Complete cycle of U. S. coal production for two values of Q_∞ (Ref. 2).

of time required to produce the first and last 10% of the ultimate cumulative production, Q_∞, it appears that the middle 80% will probably be consumed during the three centuries between the years 2000 and 2300.

The corresponding complete cycles of coal production in the United States are shown in Fig. 13. Here also two different values are used for Q_∞, that of Averitt of 1486×10^9 metric tons and a smaller value of approximately half this amount. For the peak rates assumed, the peak in production should occur about the year 2200, and the consumption of the middle 80% should require the three or four centuries centered at about the year 2200.

Petroleum

Petroleum, consisting principally of crude oil, natural gas, and natural-gas liquids, because of its fluid nature differs markedly from coal in its manner of occurrence underground. Whereas coal occurs in strata of large areal extent, oil and gas accumulations are found in the pore-spaces of sedimentary rocks in volumes of restricted areal and vertical extent. The pore spaces of sedimentary rocks are normally filled with water. In this porous-rock and water environment, oil and gas are driven into traps that are usually in domal structural configurations of porous rocks overlain by less pervious strata. In size, oil and gas fields range from a few hundred meters to more than 100 km in horizontal dimensions, and from a meter or so to hundreds of meters vertically. By far the greatest number of such fields are less than a square kilometer in area.

For these reasons, the estimate of the ultimate amount of oil or gas that a given region will produce is much more difficult than corresponding estimates for coal. However, as geological and geophysical mapping in a developing region progresses and as drilling and production proceed, this cumulative knowledge permits successively more accurate estimates of how much oil or gas the region may ultimately produce.

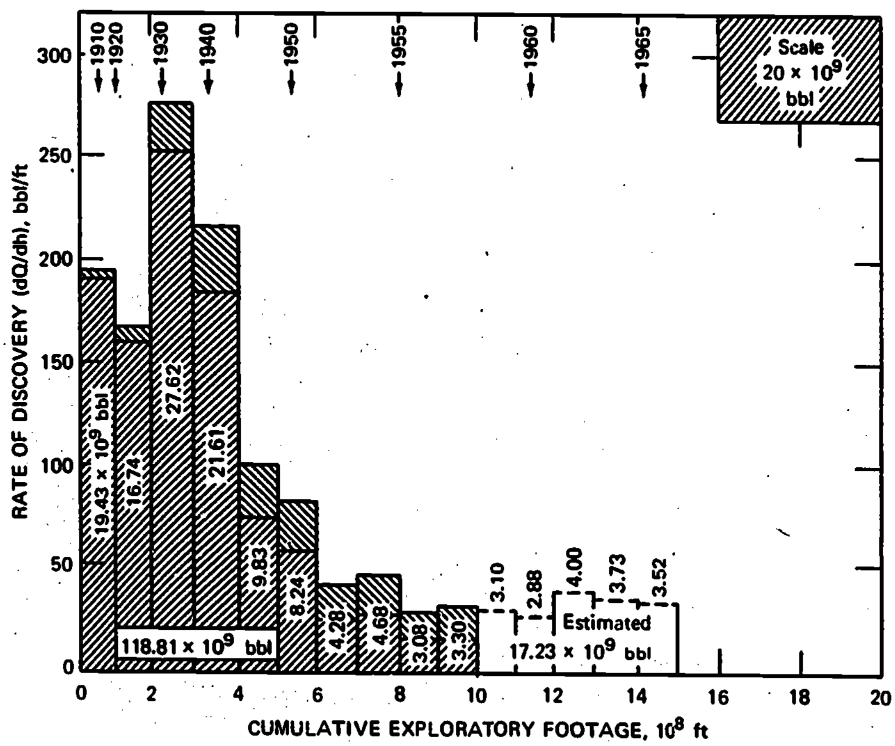

Fig. 14 U. S. discoveries of crude oil per foot of exploratory drilling (Alaska excluded), averaged for each 10^8 ft vs. cumulative exploratory drilling. [From M. King Hubbert, Degree of Advancement of Petroleum Exploration in the United States, *Amer. Ass. Petrol. Geol. Bull.*, 51: 2223 (1967).]

In the United States, which is one of the two earliest oil-producing countries of the world, the state of development is the most advanced. Therefore, the geological and statistical information accumulated within the last 20 years makes possible a number of different methods that give reasonably consistent estimates of the ultimate amounts of oil and gas that may be produced in the United States.

One of these methods is shown in Fig. 14. This figure shows the amount of oil discovered in the United States for each successive 100 million feet of exploratory drilling and the barrels of oil discovered per foot as a function of cumulative feet of exploratory drilling from 1860 to 1965. By 1965 cumulative exploratory drilling amounted to 1.5×10^9 ft, or to 15 units of 10^8 ft each. The first of these drilling units required the 60-year period from 1860 to 1920; the last half-dozen have averaged about 2 years each. The cumulative discoveries during this period amounted to about 136×10^9 barrels.

The most significant fact pointed out by this figure is that during the first period when oil was easy to find the discoveries averaged 194 barrels per foot. During the second period, extending from 1920 to 1928, the discovery rate dropped to 167 barrels per foot, indicating that oil was getting more difficult to find. Then, during the third period extending from 1928 to 1937, the peak rate of 276 barrels per foot was achieved. This was due jointly to the accidental discovery of the 6-billion-barrel East Texas field and to the development of superior geophysical methods of well logging and exploration. From 1937 to 1965 the figure shows a spectacular decline in discoveries per foot to an average rate for the last few intervals of only about 35 barrels per foot.

The fact that this decline in the effectiveness of exploratory activities occurred during the period of the most intensive research and development of improved methods of petroleum exploration and production can hardly have any other significance than that the diminishing supply of undiscovered oil is becoming increasingly difficult and expensive to find.

About as liberal an extrapolation of this decline curve into the future as can be justified by the data gives an estimate of about 165 billion barrels as the ultimate amount of oil, producible by present technology, that may be expected to be discovered in the conterminous 48 states and their adjacent continental shelves. If this figure is approximately correct, then the 136 billion barrels discovered up to 1966 would represent about 82% of that ultimately to be discovered.

In contrast with this estimate of 165×10^9 barrels based on the data of Fig. 14, mention should also be made of an estimate of 590×10^9 barrels for the same area made in 1961 by the late A. D. Zapp of the U.S. Geological Survey.[5,6] Zapp's estimate was based on the hypothesis illustrated graphically in Fig. 15. Zapp stated that petroleum exploration in the United States could not be regarded as completed until a density of exploratory wells of about one well to each 2 square miles had been drilled to depths either to the bottom of the sediments or to 20,000 ft in all petroleum-bearing areas. In 1959 Zapp[6] estimated that this amount of drilling for all the potential petroleum-bearing basins in the United States exclusive of Alaska would amount to 5×10^9 ft, whereas at that time the cumulative exploratory drilling amounted to an estimated 0.98×10^9 ft. Zapp further stated that there was no evidence that any decline had yet occurred in the oil discoveries per foot, and he assumed that this would continue to be true for the future 4×10^9 ft of exploratory drilling. He accordingly estimated that by 1959 the United States was less than 20% along in its petroleum exploration, yet had already discovered over 100×10^9 barrels of oil. This implied that the ultimate figure would be more than 500×10^9 barrels. In 1961 Zapp gave the definite figure of 590×10^9 barrels. This would require an average discovery rate of 118 barrels per foot for the postulated 5×10^9 ft of drilling, a rate equal to the estimated discoveries per foot up to 1961.

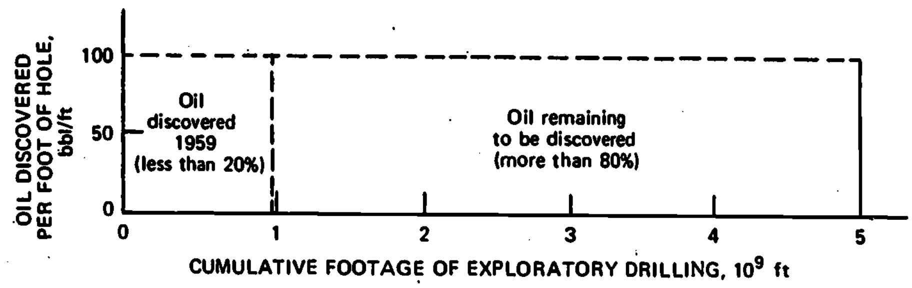

Fig. 15 Graphical representation of Zapp's hypothesis[6] of oil discoveries per foot of exploratory drilling vs. cumulative footage.[2]

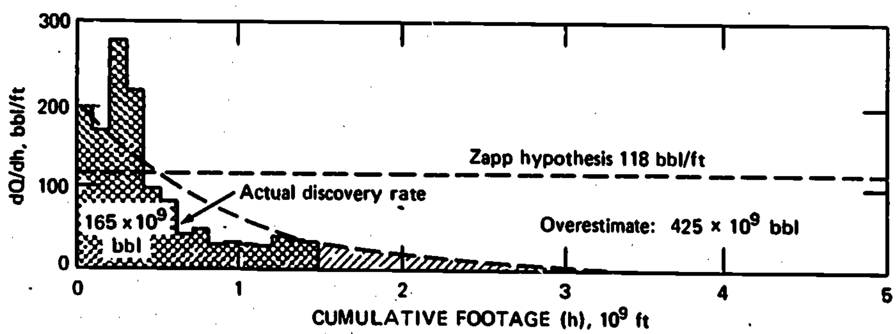

Fig. 16 Comparison of actual U. S. discovery rate shown in Fig. 14 with that predicted by Zapp's hypothesis in Fig. 15 (Ref. 2).

Zapp's hypothesis is especially significant because the estimate for the ultimate U. S. crude-oil resources to which it led was about 1½ times the highest previously published estimates and 3½ times the present figure of 165 x 10^9 barrels derived from the data of over a century of petroleum exploration and production. Also, either in its original form or in slight modifications, this hypothesis continues to be the principal basis for most of the higher estimates for the ultimate amounts of oil and gas to be produced.

Fortunately, the validity of the hypothesis is amenable to testing against petroleum-industry data. The oil discoveries per foot of exploratory drilling during the past century, as shown in Fig. 14, have not been substantially constant, as assumed by Zapp, but have declined drastically during the last 30 years. Also the data do not afford any basis for the further assumption that the oil discoveries per foot in the future will remain substantially constant and equal to the average value during the past. A direct comparison between Zapp's hypothesis, based on an average discovery rate of 118 barrels per foot of exploratory drilling, and the actual discovery data of Fig. 14 is shown by superposition in Fig. 16. The blank area between the two curves represents 425 x 10^9 barrels, which appears to be the approximate magnitude of the Zapp overestimate.

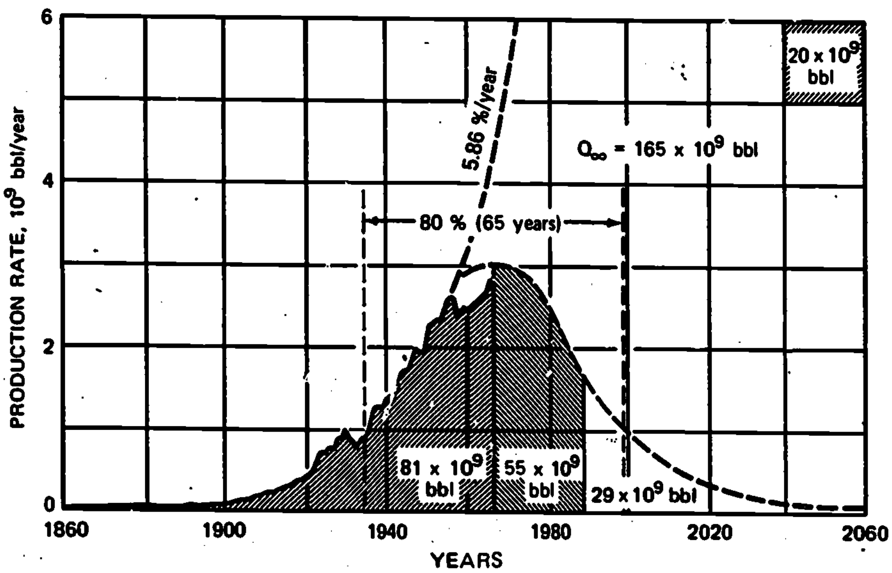

Fig. 17 Complete cycle of U.S. crude-oil production, exclusive of Alaska.[2]

Using our estimate of 165 × 10^9 barrels for Q_∞ for the conterminous United States and its adjacent continental shelves, we can construct the approximate curve for the complete production cycle of crude oil for this area (Fig. 17). This curve indicates that the production peak should occur very close to the year 1970. This figure was constructed on data extending only through 1965. Subsequently the production curve, plotted weekly, has steadily risen to a peak at about November 1970, after which it has steadily declined (*Oil and Gas Journal*, weekly statistics section). This date may prove to be that of the ultimate production peak of crude oil for the conterminous United States.

As with coal, the dashed curve in Fig. 17 extending to the top of the chart indicates what the production rate would be if it continued at the growth rate of 5.86% per year which prevailed from about 1933 to 1955. The vertical dashed lines at the years 1933 and 1998 represent the approximate dates at which the cumulative production reaches 10% and 90%, respectively, of Q_∞. The period during which the middle 80% will be consumed will accordingly be that of the 65 years between these two dates. In other words, about 80% of the ultimate amount of crude oil produced in the conterminous United States will probably be consumed within the average lifetime of people bom in 1930.

The ultimate quantity, Q_∞, for the cumulative production of natural gas in the conterminous United States may be estimated in various ways: (1) by compiling estimates based on the geology and production records of separate gas-producing areas, (2) by an analysis of the discovery and production statistics as a function of time, or

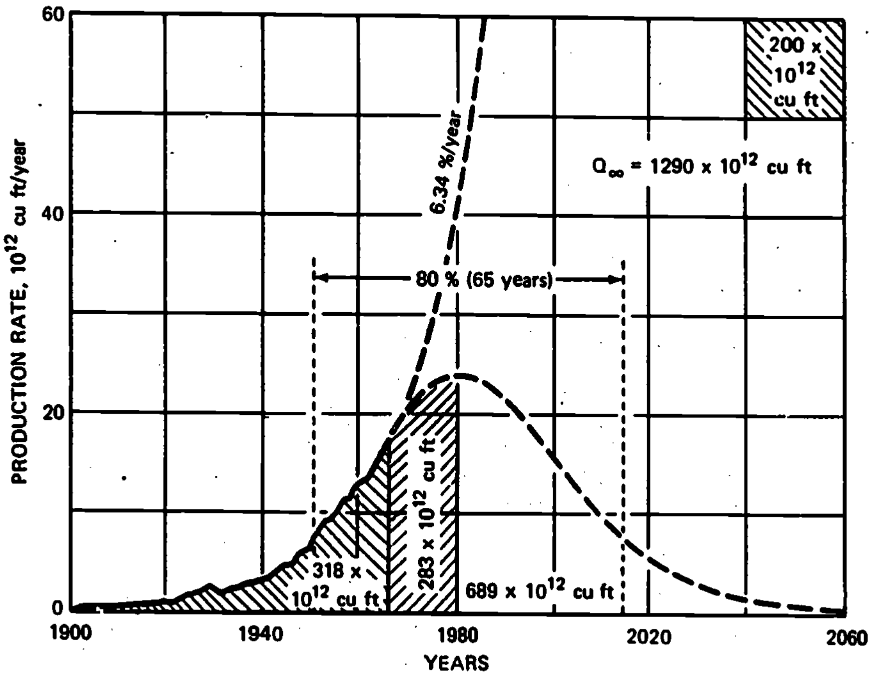

Fig. 18 Complete cycle of U. S. natural-gas production (Alaska excluded).[2]

(3) from previous estimates of the ultimate cumulative discoveries of crude oil in conjunction with the ratio of gas to oil discoveries.

The first of these methods is that used by the Potential Gas Committee, an industry committee that compiles biennial estimates based partly on unpublished industry data. Figure 18 shows the complete cycle of natural-gas production in the conterminous United States and adjacent continental shelves based on an estimate for Q_∞ of 1290×10^{12} cu ft made by the Potential Gas Committee[7] in its 1967 report giving data as of Dec. 31, 1966. As shown in Fig. 18, this value of Q_∞ implies that the rate of production will not reach its peak before about 1980.

In its October 1969 report,[8] giving estimates as of Dec. 31, 1968, this Committee increased its estimate for the conterminous United States including the adjacent continental shelves and slopes to a depth of 1500 ft to 1427×10^{12} cu ft. It may be noted, however, that, of the estimate of 1290×10^{12} cu ft, 180×10^{12} was classed as "speculative" and, of the 1427×10^{12} cu ft, about 240×10^{12} was classed as "speculative."

A direct analysis of natural gas based on its drilling, discovery, and production statistics has not been made, but an approximate estimate can be made from our previous value of 165×10^9 barrels as the value of Q_∞ for crude oil and from the gas-to-oil ratio. By Dec. 31, 1970, the cumulative proved discoveries of crude oil in the conterminous United States and adjacent continental shelves amounted to 122×10^9

barrels. At the same time, the cumulative discoveries of natural gas amounted to 648×10^{12} cu ft. Therefore, the ratio of cumulative discoveries of gas to those of oil amounted to 5320 cu ft per barrel. However, it is known that this ratio is increasing with time owing largely to the fact that with increasing depth of drilling the gas-to-oil ratio increases. For the discoveries during the last few years, it averages about 6500 cu ft per barrel. Therefore, for a rough estimate let us make the liberal assumption that, for all future discoveries of oil and gas, the gas-to-oil ratio will be 7500 cu ft per barrel.

Using the figure of 165×10^9 barrels as the ultimate amount of crude oil to be discovered and the figure of 122×10^9 barrels as the cumulative proved discoveries, we obtain 43×10^9 barrels as the amount of crude oil still to be added to cumulative proved discoveries. At 7500 cu ft per barrel, this gives an estimate of 323×10^{12} cu ft of natural gas still to be discovered. Adding this to the 648×10^{12} cu ft already discovered then gives 971×10^{12} cu ft, or roundly 1000×10^{12} cu ft, as a rough estimate for Q_∞ for natural gas.

A curve of the complete cycle of natural-gas production based on this lower figure would give an earlier date of around 1973 to 1976 for the peak in the rate of production. The fact that serious gas shortages are already beginning to occur in the United States affords some grounds for thinking that the estimates of the Potential Gas Committee may be considerably too high and that the smaller figure of around 1000 trillion cubic feet may be a better estimate.

The oil and gas potentials of Alaska have not been treated with those of the conterminous United States because Alaska is a new territory that has not yet made significant contributions. However, since 1958 several medium-sized oil fields have been discovered and have become productive in the Kenai Peninsula and Cook Inlet in southwest Alaska. On the Alaska north slope the unproductive Umiat field was discovered in 1947 and confirmed by further drilling in 1950 in U. S. Naval Petroleum Reserve No. 4. In 1968 the discovery of the large Prudhoe Bay field was announced. Its presently estimated reserves of 10×10^9 barrels make it the largest oil field in the United States.

Only crude preliminary estimates can yet be made as to the ultimate amounts of oil and gas that Alaska will produce, but, from present geological and discovery information, it appears that these amounts will probably not be less than 30×10^9 barrels of crude oil, 180×10^{12} cu ft of natural gas, and 6×10^9 barrels of natural-gas liquids. Although the discovery of a 10-billion-barrel oil field has produced a considerable amount of enthusiasm, it should be noted that a field of this size is less than a 3-year supply for the U. S. requirements, and 30 billion barrels of oil and 180 trillion cubic feet of gas offer less than a 10-year supply.

Estimates of the ultimate amount of crude oil to be produced in the entire world are made largely by geological comparisons between the better known areas, such as the United States, and less developed areas. Such estimates range at present from about 1350 to 2100×10^9 barrels. The higher figure is that given in 1967 by W. P. Ryman of the Standard Oil Company of New Jersey at a conference of the National Academy of Sciences–National Research Council Committee on Resources and Man.[2] The smaller figure represents about the lower limit of present estimates.

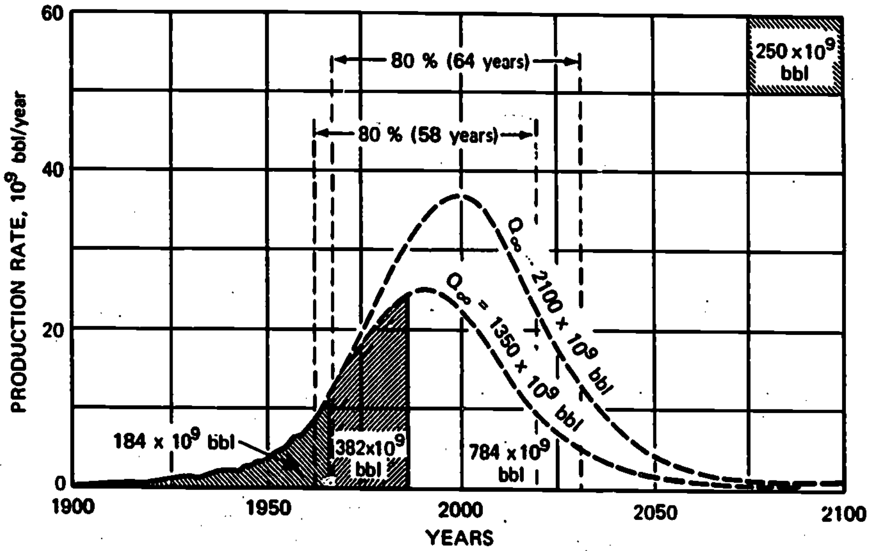

Fig. 19 Complete cycle of world crude-oil production for two values of Q_∞.[2]

The complete cycle of world crude-oil production based on these two figures for Q_∞ is shown in Fig. 19. For the higher figure, the production rate would reach a maximum by about the year 2000; for the smaller figure, by about 1990. In both curves the middle 80% of Q_∞ would be produced in a time span of between about 58 and 64 years.

FOSSIL FUELS IN HISTORICAL PERSPECTIVE

Time does not permit us to review in detail all classes of fossil fuels, such as the world supply of natural gas, natural-gas liquids, tar sands, and oil shales. However, the estimated relative magnitudes of the world resources of these different classes of fuels are shown in Table 1. Nearly 89% of the energy content of the fossil fuels is represented by coal and lignite, and close to 5% each by petroleum liquids and natural gas, with only about 1.3% accounted for by shale and tar-sand oil. Consequently, the picture that we have drawn for both the United States and the world will not be significantly changed by a more detailed account. In any case, it appears likely that the world will consume the bulk of its initial supplies of petroleum resources within a period of less than a century and the bulk of its coal and lignite within three or four centuries.

Lest three or four centuries may appear to be a long time, it may help if we view this episode of the fossil fuels in the context of a longer span of human history. This

Table 1

ENERGY CONTENTS OF THE WORLD'S INITIAL SUPPLY OF FOSSIL FUELS[3]

Fuel	Quantity	Energy content 10^{21} joules(th)	10^{15} kw-hr(th)	Percent
Coal and lignite	7.6×10^{12} metric tons	201	55.9	88.8
Petroleum liquids	2000×10^9 barrels (272×10^9 metric tons)	11.7	3.25	5.2
Natural gas	$10{,}000 \times 10^{12}$ cu ft (283×10^{12} m^3)	10.6	2.94	4.7
Tar-sand oil	300×10^9 barrels (41×10^9 metric tons)	1.8	0.51	0.8
Shale oil	190×10^9 barrels (26×10^9 metric tons)	1.2	0.32	0.5
	Totals	226.3	62.9	100.0

we may do if we plot the complete cycle of the consumption of the fossil fuels on a time base extending from 5000 years in the past to 5000 years in the future. The result, as shown in Fig. 20, is a curve that rises from near zero to a sharp crest and then returns to near zero in the narrow span of about one-third of a millennium. On such a time scale, it is seen that the entire epoch of the fossil fuels can be only a transitory and ephemeral event in human history—an event, nonetheless, which is unique in geological history and which has exercised the most drastic influence experienced by the human species during its entire biological history.

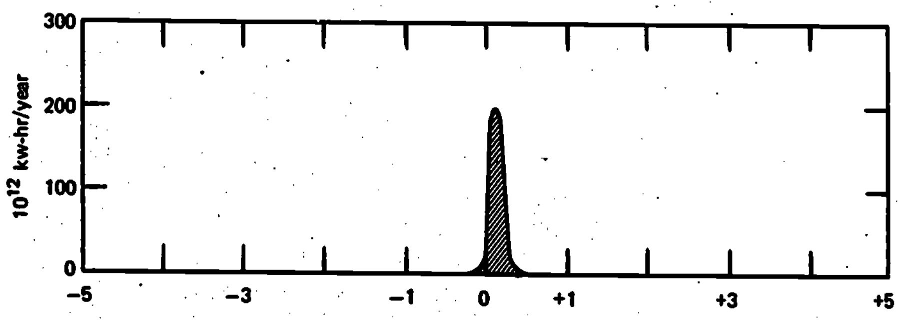

Fig. 20 Complete cycle of world consumption of fossil fuels on a time scale of 5000 years before and after the present. (Modified from Ref. 2.)

OTHER SOURCES OF INDUSTRIAL ENERGY

Solar Power

Figure 2 shows that the largest source of energy available to the earth is the solar radiation intercepted by the earth. This power amounts to about $178,000 \times 10^{12}$ watts, or, if we disregard the 35% that is reflected directly into outer space, to about $116,000 \times 10^{12}$ watts absorbed and utilized in the various terrestrial processes. This latter figure amounts to about 20,000 times the present world rate of use of industrial energy. In addition, solar energy is pollution free and has an expectable time span comparable to that of the age of the earth.

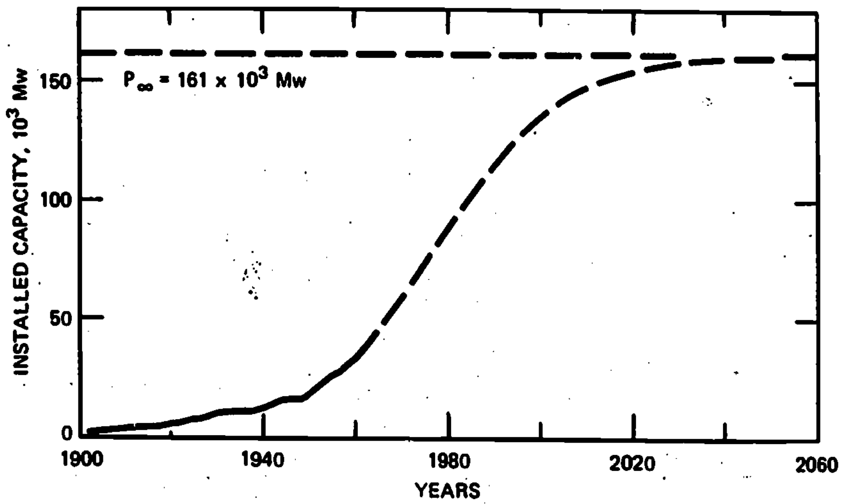

Fig. 21 U. S. installed and ultimate hydroelectric power capacity.[3]

At present the principal function of solar energy is to maintain the earth's moderate climate, to impel its material circulations, and by means of photosynthesis to provide the biological requirements of energy for the plant and animal kingdoms. Until now the only channel of this contemporary energy flux, other than photosynthesis, which occurs in a concentrated form and is thus suitable for large-scale power development is water power from the hydrologic cycle. The magnitude of the potential water-power capacity of the United States and its degree of development are shown in Fig. 21. The estimated ultimate capacity, P_∞, is 161×10^3 megawatts (Mw) of which about 50×10^3 Mw is now developed.

The potential water-power capacity of the major geographical land areas of the world and the degree of development of each are shown in Table 2. The total capacity is about 2900×10^3 Mw, or just under 3×10^{12} watts. Of this, only about 8.5% is

Table 2

WORLD POTENTIAL AND DEVELOPED WATER-POWER CAPACITY[3]

Region	Potential power,* 10^9 watts	Percent of total	Developed† capacity, 1967, 10^9 watts	Percent developed
North America	313	11	76	23
South America	577	20	10	1.7
Western Europe	158	6	90	57
Africa	780	27	5	0.6
Middle East	21	1	1	4.8
Southeast Asia	455	16	6	1.3
Far East	42	1	20	48
Australia	45	2	5	11
USSR, China, and satellites	466	16	30	6.4
World	2857	100	243	8.5

*Francis L. Adams, U. S. Federal Power Commission, Statement on water power to Committee on Natural Resources, National Academy of Sciences, unpublished, 1961.
†U. S. Federal Power Commission, *World Power Data, 1967,* 1969.

now developed—principally in the highly industrialized areas of North America, Western Europe, and the Far East, especially Japan. Among the areas with the largest potential water-power capacities are the industrially underdeveloped regions of Africa, South America, and Southeast Asia, whose combined capacities represent about 63% of the world total.

The logistic growth curve of the world's developed and potential water power is shown in Fig. 22. If fully developed, the 3×10^{12} watts of water power would be of approximately the same magnitude as the world's present rate of industrial power use. It might also appear that this would be an inexhaustible source of power, or at least one with a time span comparable to that required to remove mountains by stream erosion. This may not be true, however. Most water-power development involves the creation of reservoirs through the damming of streams. The time required to fill these reservoirs with sediments is only two or three centuries. Hence, unless a technical solution can be found for this problem, water power may actually be comparatively short lived.

The remaining prospect for the large-scale industrial use of solar energy is that of its conversion to conventional electric power or for such chemical uses as the separation of chemical compounds into their component elements by electrolysis. Heretofore the principal difficulty in developing large-scale power from solar radiation has resulted from the low areal density of solar radiation on the earth's land surfaces. The most promising areas are those of low rainfall lying within a belt of about ±35 degrees of latitude. The land areas satisfying these conditions are very large. They comprise a band in the southwestern United States, most of northern Mexico, a large

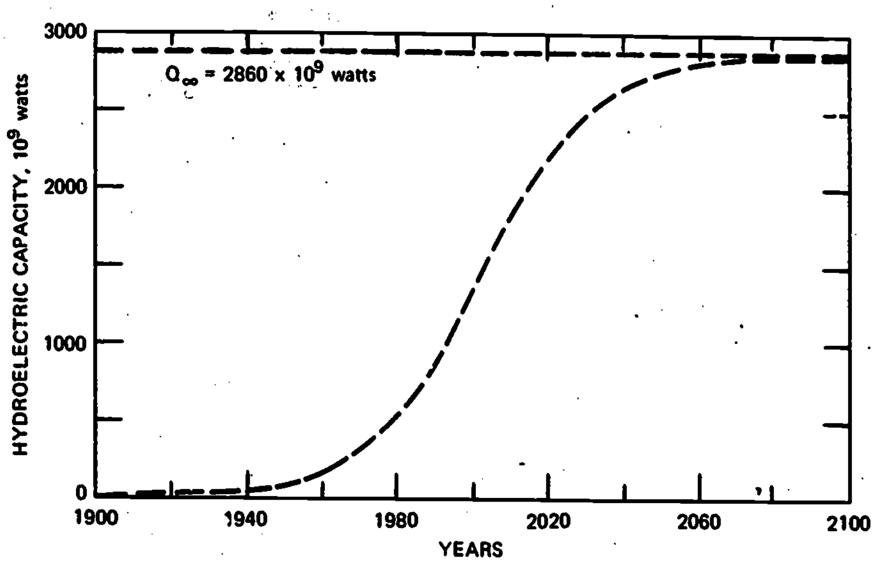

Fig. 22 Potential and developed hydroelectric capacity of the world.

coastal belt in Peru and Chile, and a band that includes the Sahara Desert and extends across northern Africa, the Red Sea area and the Arabian Peninsula, the Persian Gulf, Southern Iran, and West Pakistan.

For one such area, consider southern Arizona. Here the average solar energy incident upon a horizontal surface changes from a winter minimum of 300 to a summer maximum of 650, with a yearly average of 500 (calories/cm^2)/day. Restricting ourselves to the winter minimum, 300 (calories/cm^2)/day, when averaged over 24 hr, is equivalent to 145 watts per square meter, or to 145 thermal megawatts [Mw(th)] per square kilometer. Now suppose that by means of photovoltaic cells with a 10% efficiency enough solar energy were to be collected for a power plant of 1000 electrical megawatts [Mw(e)] capacity, what would the collection area have to be? This would require 10,000 Mw of solar energy, which, at a rate of 145 Mw/km^2, would require a collection area of about 70 km^2, or a square of 8.4 km, or 5 miles, to the side. For the same region the area required to produce the 350,000 Mw(e), which was approximately the electrical power capacity of the United States in 1970, would be about 24,500 km^2, or about 9460 square miles, which is less than 10% of the total area of Arizona.

Hence, although solar power is intermittent and of low areal density, its magnitude when integrated over comparatively small areas becomes surprisingly large. When it is considered that solar power is almost pollution free and is best developed in sparsely vegetated and populated regions and when the complexities of a solar-power plant are compared with one operated by coal, it may well be that such plants are not as technically impractical as they at first appear. In any case, it is significant that, principally within the last few years, a continuously increasing amount of study by highly competent scientists, engineers, and research institutions is being devoted to the possibility of developing solar power on an industrial scale.

Tidal and Geothermal Power

Only brief attention can be given to the development of power from the tides and from geothermally generated steam. Tidal power is similar to water power except that

Table 3

TIDAL-POWER SITES AND MAXIMUM POTENTIAL POWER*,†,[3]

Locality or region		Average potential power, 10^3 kw	Potential annual energy production, 10^6 kw-hr
North America*			
Bay of Fundy (nine sites)		29,027	254,445
South America			
Argentina, San Jose		5,870	51,455
Europe			
England, Severn		1,680	14,726
France			
(nine sites)		11,149	97,730
USSR†			
(four sites)		16,049	140,682
	Totals	63,775	559,038

*N. W. Trenholm, Canada's Wasting Asset—Tidal Power, *Elec. Eng. News*, 70(2): 52-55 (1961).

†L. B. Bernshtein, *Tidal Energy for Electric Power Plants* (English translation of Russian original), IPST No. 1205, Israel Program for Scientific Translations, 1965, Table 5.5, p. 173.

it must be developed from the alternate filling and emptying of tidal basins, whereas water power is derived from the unidirectional flow of streams. Tidal power is only practical in coastal configurations where a combination of high tidal amplitudes and bays or estuaries amenable to being enclosed by dams exists.

Table 3 summarizes the world's more favorable tidal-power sites. The power capacities of individual sites range from 2 to 20,000 Mw each. The world total of such sites as presently estimated amounts to about 63,000 Mw, which is only about 2% of the world's water-power capacity.

The world's first large-scale tidal-power plant is that on the La Rance estuary on the English Channel coast of France. It began operation in 1966 with an initial power of 240 Mw and a planned enlargement to 320 Mw.

Up to the present, geothermal power has been derived from natural steam generated in volcanic areas where elevated temperatures occur at comparatively shallow depths. Geothermal power has been produced in the Larderello region of Tuscany in Italy since 1904 and recently in the Monte Amiata region about 70 km to the southeast. The total capacity of these two areas amounted in 1970 to about 400 Mw. In Wairakei, New Zealand, drilling for geothermal steam was begun about 1950, and power-plant operation started in 1958. By 1970 the power capacity had reached only 160 Mw,[9] which is considerably less than the maximum capacity of 290 Mw originally estimated for the area. In the United States, at The Geysers in northern California, a 12.5-Mw geothermal power plant began operation in 1960. Subsequently the power capacity in this area has been increased to a planned 192 Mw by mid-1971 and 400 Mw by 1973. Small geothermal plants also recently began operation in the USSR, Japan, and Mexico.

At present, only an order-of-magnitude estimate for the world's potential geothermal power can be given. From a study of the known areas of volcanic heat appropriate for power production and the quantities of stored thermal energy, White[10] of the U. S. Geological Survey has estimated that there is enough geothermal energy to generate about 3×10^6 Mw years of electrical energy. With a life expectancy of 50 years, this would give an average electrical-power capacity for that length of time of about 60,000 Mw. This is about the same as the capacity of tidal power but only about 2% that of potential water power. However, since geothermal power production is now only in its initial phase and since the total quantity of thermal energy at temperatures above 100°C within depths of 10 km from the surface of the ground is much larger than the above figure, it is possible that a larger geothermal power capacity may eventually be achieved.

Nuclear Power

We next direct our attention to the world's newest source of stored energy, the atomic nuclei of some of the earth's natural constituents. Nuclear energy is obtainable by two opposite types of nuclear reactions: (1) the fissioning of certain isotopes at the heavy end of the scale of atomic masses and (2) the fusing into heavier elements of isotopes at the low end of the scale.

Fission. The only naturally occurring isotope which is capable of spontaneous fission under mild surface conditions is ^{235}U, which occurs in natural uranium with an atomic abundance of 1 atom of ^{235}U to 141 atoms of uranium. The remaining 140 atoms are of ^{238}U.

When ^{235}U is struck by a stray neutron, the neutron may be absorbed and cause the ^{235}U atom to fission, that is to divide into two roughly equal parts comprising two complementary atoms somewhere in the midrange of the atomic scale, plus one or more additional neutrons. The average amount of energy released per fission of ^{235}U is about 200 million electron volts (MeV), or 3.20×10^{-11} joules.

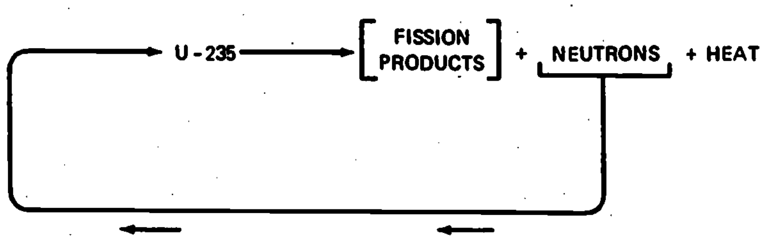

Fig. 23 Diagram of fission chain reaction. [From M. King Hubbert, Nuclear Energy and the Fossil Fuels, in *Drilling and Production Practice (1956)*, p. 20, American Petroleum Institute, New York.]

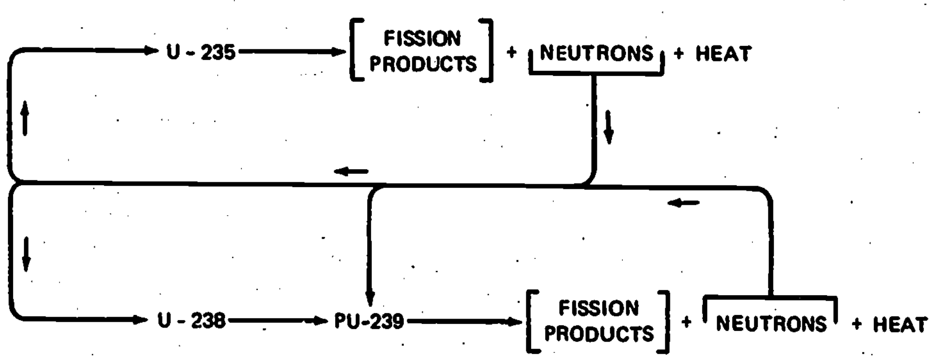

Fig. 24 Diagram of breeder reaction. [From M. King Hubbert, Nuclear Energy and the Fossil Fuels, in *Drilling and Production Practice (1956)*. p. 20, American Petroleum Institute, New York.]

With a suitable arrangement of a ^{235}U fuel supply in a reactor, a part of the neutrons released by fission are captured by other atoms of ^{235}U, and a sustained, but controllable, chain reaction ensues. This is shown diagrammatically in Fig. 23.

If ^{238}U or ^{232}Th (natural thorium) is also placed in the reactor, either of them may also capture neutrons and then undergo successive radioactive transformations. In this manner ^{238}U is converted into ^{239}Pu, and ^{232}Th into ^{233}U. Both ^{239}Pu and ^{233}U are fissile. Thus, ^{238}U and ^{232}Th, which are not themselves fissionable under ordinary circumstances, can be converted into fissionable materials. They are therefore called fertile materials. The process of converting a fertile isotope into a fissile one is known as breeding. A schematic diagram of the breeder reaction is given in Fig. 24.

The energy released per fission of ^{235}U, ^{239}Pu, or ^{233}U is very nearly the same, namely, 200 MeV, or 3.20×10^{-11} joules. The number of atoms of ^{235}U per gram is 2.56×10^{21}; thus the fissioning of 1 g of ^{235}U would release 8.2×10^{10} joules of heat. Approximately the same amount of heat is released by the fissioning of 1 g of either ^{239}Pu or ^{233}U. This is eqivalent to the heat of combustion of 2.7 metric tons of bituminous coal or of 13.4 barrels of crude oil.

In a reactor the heat released by nuclear fission is used to generate steam for a conventional steam-electric power plant. Whether the energy obtainable from the nuclear fission reaction will be sufficient to take the place of that from the fossil fuels as these are depleted depends mainly on two things: (1) the existence of sufficient quantities of uranium and thorium in an economically extractable form and (2) the early development of breeder reactors. With regard to requirements, we should first take note of the fact that nearly all the power reactors now in use in the United States, as well as in the rest of the world, depend almost entirely on the rare isotope ^{235}U.

By the end of 1970 the operable nuclear-power capacity in the United States, according to the Atomic Energy Commission,[11] amounted to 6708 Mw(e), and it is predicted to reach 150,000 Mw(e) by 1980. This would correspond to a growth rate of 31% per year with a doubling period of only 2.3 years. Nuclear-power capacity for the rest of the world is estimated to grow during this decade at about the same rate.

The projected U. S. requirements of uranium are estimated to amount to 206,200 short tons of U_3O_8 from 1971 to 1980 and another 452,100 short tons after 1980.[11] Against these requirements the ore reserves recoverable at $8 per pound of U_3O_8 amounted at the end of 1970 to 243,000 short tons. Although new discoveries will undoubtedly be added in the future, there is every indication at present that a severe shortage of ^{235}U will occur before the end of the present century. Hence, unless breeder reactors are rapidly developed, the episode of nuclear-fission power may be well past its climax within less than a century. With breeder reactors, however, the situation can be quite different because nuclear-fission power will no longer be dependent upon high-grade, low-cost sources of uranium but can be produced with the enormously larger quantities of low-grade ores.

A rough idea of the occurrence and distribution of both high- and low-grade ores of uranium and thorium in the United States may be gained by reference to the map shown in Fig. 25. The high-grade deposits that are now mined are principally those of the Colorado Plateau. For a low-grade deposit, consider the Chattanooga shale. This is a black carbonaceous shale of Devonian age which crops out along the western edge of the Appalachian Mountains in eastern Tennessee and neighboring states and underlies at minable depths most of the areas of Tennessee, Kentucky, Ohio, Indiana, and Illinois. Its stratigraphic equivalent, the Woodford shale, also occurs in the subsurface of the mid-continent states. In the outcrop area of eastern Tennessee, the Chattanooga shale contains a stratum about 5 m thick, the Gassaway member,[12] with a uranium content of about 60 g per metric ton. That the uranium-rich character of this shale is widespread is evident from the fact that when gamma-ray logs are taken in oil wells even as far away as Texas and Oklahoma the instruments are driven off their scales when transversing the Woodford shale.

Let us consider the energy potentially obtainable from the Chattanooga shale in eastern Tennessee by means of the breeder reactor. Bearing in mind that the energy releasable from the fissioning of uranium amounts to the equivalent of that from 2.7 metric tons of coal or from 13.4 barrels of crude oil, the 60 g of uranium per metric ton of shale would be approximately equivalent to 160 metric tons of coal or 800 barrels of crude oil.

With a shale density of 2.5 metric tons per cubic meter, a vertical column 5 m long and 1 m^2 in horizontal cross section would contain 750 g of uranium. This would be approximately equivalent energetically to 2000 metric tons of coal or to 10,000 barrels of crude oil per square meter of horizontal area. If we allow a loss of 50% of the uranium in mining and extraction, these figures would reduce to 1000 metric tons of coal or to 5000 barrels of crude oil per square meter, or to 1 billion metric tons of coal or 5 billion barrels of oil per square kilometer. Then, assuming 1500×10^9 metric

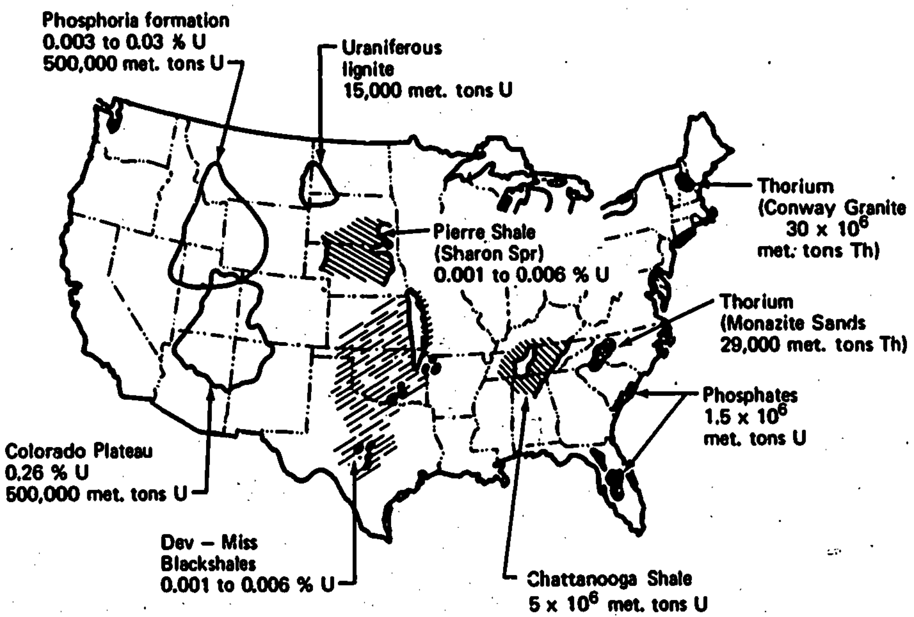

Fig. 25 Map showing the distribution of high- and low-grade ores of uranium and thorium in the United States. [Based on M. King Hubbert, Nuclear Energy and the Fossil Fuels in *Drilling and Production Practice (1956)*, p. 23, American Petroleum Institute, New York.]

tons of coal and 500×10^9 barrels as the oil equivalent of petroleum liquids, natural gas, and shale oil, an area of only 1600 km^2 would be required for the energy obtainable from the uranium in the Chattanooga shale in eastern Tennessee to be equal to that of the total supply of fossil fuels in the United States. This would be equivalent to a square area of 40 km, or 25 miles, to the side, which would represent less than 2% of the area of Tennessee.

When the total areal extent of this uranium-rich shale is considered, it becomes evident that with breeder reactors the energy obtainable from the uranium of the Chattanooga shale alone is orders of magnitude larger than that of the total initial U.S. supply of fossil fuels. An even larger amount of potential-nuclear energy is involved when other known low-grade sources of uranium and thorium, such as those shown on the map in Fig. 25, are also considered.

Fusion. It has been known since 1939 that the continuous outpouring of energy from the sun and other stars is the result of a fusion reaction whereby the nuclei of hydrogen atoms are combined to form those of heavier atoms of helium. In fact helium derives its name from the sun because it was detected spectroscopically in the solar atmosphere before it was identified on earth. Uncontrolled fusion has been achieved by man and is the basis for the so-called hydrogen, or thermonuclear, bomb. Intense research directed toward terrestrial attainment of controlled fusion has been under way in the United States, Great Britain, and the USSR for about 20 years, and progress is continuously being made, but this goal has not yet been achieved although there is hope that it may be within a few more decades.

A number of different fusion reactions are known. The one that is most favored at present involves the fusion of the two heavy isotopes of hydrogen, deuterium and tritium, of atomic masses 2 and 3, respectively.[13] Deuterium occurs in water with an atomic abundance of 1 atom of deuterium to 6700 atoms of common hydrogen. Tritium occurs naturally only in infinitesimal traces; so it has to be produced by the neutron bombardment of lithium.

Omitting intermediate steps, the deuterium–tritium, or D–T, reaction, beginning with deuterium and lithium, reduces to the following:

$$^{2}D + {}^{7}Li + {}^{6}Li \rightarrow 3\,{}^{4}He + {}^{3}T + 19.9\ \text{MeV}$$

The limiting factor in this reaction is lithium and especially the isotope ^{6}Li, which occurs with an atomic abundance of only 7.42% of natural lithium. Lithium is obtained on land from a rare type of igneous rock known as a pegmatite and from certain saline deposits. From the known and inferred occurrence of such deposits, it is estimated that the world supply of ^{6}Li amounts to about 67.5×10^{33} atoms of this isotope. On the other hand, deuterium is obtainable from seawater, and the entire deuterium content of the oceans amounts to about 1.35×10^{43} atoms.

From the D–T reaction 19.9 MeV or 3.19×10^{-12} joules of energy is released per atom of ^{6}Li consumed. Then, for the total supply of 67.5×10^{33} atoms of ^{6}Li, the total amount of energy released by fusion would be 215×10^{21} joules. This is approximately equal to the energy of the world's supply of fossil fuels.

Since deuterium is about 10^{8} times more abundant than ^{6}Li, the more difficult deuterium–deuterium, or D–D, reaction is potentially capable of releasing a very much larger quantity of energy. In this case, three separate reactions give the combined result:

$$5\,{}^{2}D \rightarrow {}^{4}He + {}^{3}He + H + 2n + 24.8\ \text{MeV}$$

Hence, the energy released per deuterium atom in the D–D fusion reaction is 4.96 MeV or 7.95×10^{-13} joules.

To obtain an idea of what this signifies, let us consider the deuterium content and hence the potential energy obtainable from 1 liter, or 1000 g, of water. Since water has a molecular mass of 18 g, 1 liter of water comprises 55.56 moles. One mole contains 6.022×10^{23} molecules, and each molecule contains 2 hydrogen atoms. Therefore 1 liter of water contains

$$2 \times (6.022 \times 10^{23}) \times 55.56 = 6.67 \times 10^{25} \text{ hydrogen atoms}$$

Since there is 1 atom of deuterium to 6700 atoms of hydrogen, we find that 1 liter of water must contain 1.0×10^{22} atoms of deuterium, each of which by the D–D fusion reaction is capable of releasing 7.95×10^{-13} joules of heat. The total energy per liter would therefore be

$$(1.0 \times 10^{22} \text{ D}) \times (7.95 \times 10^{-13} \text{ joules/D}) = 7.95 \times 10^{9} \text{ joules}$$

For comparison, the heat of combustion of bituminous coal is about 3.05×10^{10} joules per metric ton, and that of crude oil, 6.1×10^{9} joules per barrel. Therefore, the energy of fusion of the deuterium in 1 liter of water would be equivalent to the heat of combustion of 0.26 metric tons of coal or to 1.30 barrels of crude oil. With these figures as a base, the fusion energy from various volumes of seawater and the equivalent quantities of coal and oil are computed in Table 4. It is interesting that the energy of a cubic kilometer of seawater is approximately equivalent to that of the world's initial supply of crude oil, and the energy from 33 km^3 is equivalent to that of the world's total initial supply of fossil fuels.

Table 4

ENERGY OBTAINABLE FROM SEAWATER BY D–D FUSION

Volume of water	Energy, thermal joules	Coal equivalent, metric tons	Crude-oil equivalent, barrels
1 liter	7.95×10^{9}	0.26	1.30
1 m^3	7.95×10^{12}	260	1300
1 km^3	7.95×10^{21}	260×10^{9}	1300×10^{9}
33 km^3	2.62×10^{23}	World's total supply of fossil fuels	

Since the area of the ocean is 361 million km^2 and its average depth 3.8 km, its volume must be 1.37×10^{9} km^3. This is approximately 40 million times the volume of 33 km^3 given in Table 4 as being equivalent in energy content to the fossil fuels. If we assume the extraction of only 10% of the deuterium from seawater, this still represents an amount of energy roughly 4 million times that of the fossil fuels.

THE INDUSTRIAL METALS

Industrial energy cannot be used without machinery, and machinery is composed principally of industrial metals, such as iron, aluminum, copper, lead, and zinc. We need, therefore, to take at least a cursory look at a few of the principal industrial metals.

A generalized flow diagram for the production of a metal is shown in Fig. 26. Like the fossil fuels, metals are obtained from naturally occurring concentrations of

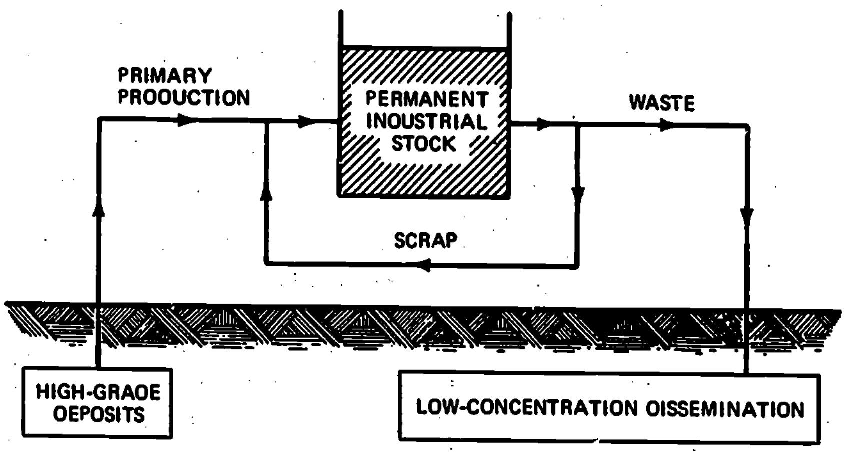

Fig. 26 Flow diagram for the production and use of an industrial metal.

minerals comprising the ores of the various metals, many of which were formed by geological processes more than a billion years ago. Unlike energy, which ieaves the earth, the metals are chemical elements which during their use are circulated but, with the trivial exception of spacecraft, do not leave the earth.

The usual cycle for a metal begins with the mining of the metallic ore. The metal is then extracted from the ore by some form of smelting, fabricated into a usable form, either metallic or chemical, and made a part of the industrial pool. Finally, after having served its purpose, a fraction is recycled as scrap, refabricated, and returned to the industrial pool. Another fraction, however, becomes irretrievably scattered or else rendered otherwise irretrievable as in the case of a ship that sinks in deep water. For iron, the scrap that is recycled is principally obtained from heavy iron and steel products, whereas the wastage is principally by oxidation and the scattering of small items ranging from sheet-iron cans to automobiles. For lead, that which is used in metallic form, such as cable sheathing, and in automobile storage batteries, is retrieved and recycled; that which is used as oxides in paints and as tetraethyl lead in gasoline is scattered and lost.

The usual cycle for any given metal begins with a natural concentration of the chemical element in some kind of an ore body and eventually ends in a state of complete dispersion. The one exception to this sequence occurs when the initial state is not one of concentration but is instead a large low-concentration occurrence. A prime example is the extraction of magnesium from seawater. Here the metal is taken from the ocean, used, scattered, and eventually returned to the ocean. The quantity of magnesium contained in ocean water is so large compared with any industrial requirements that it is most unlikely that a measurable decrease in the magnesium concentration in seawater will ever occur. In this system, it appears that we deal with a truly inexhaustible resource.

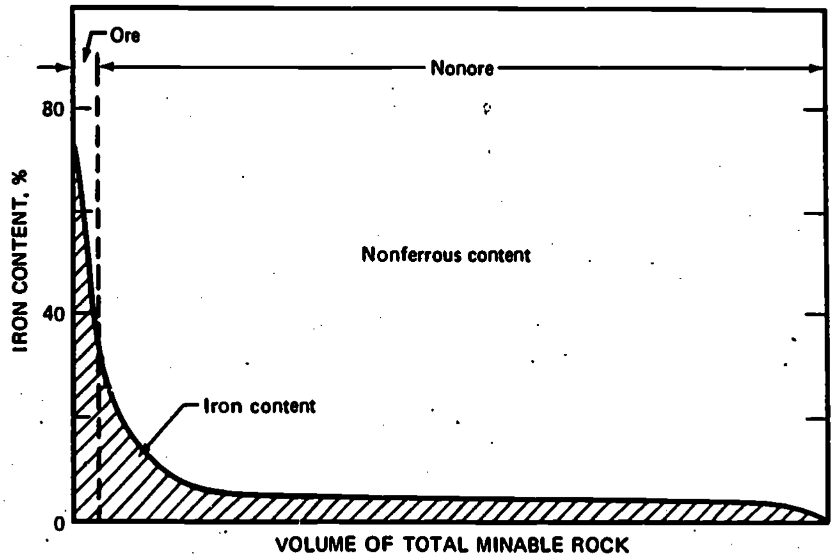

Fig. 27 Schematic diagram of the minable rock of the earth arranged in order of decreasing iron content. [From M. King Hubbert, Future Ore Supply and Geophysical Prospecting, *Eng. Mining J.*, 135: 19 (1934).]

The approximate manner of occurrence of the various levels of concentration of a given metal in the minable rocks of the earth is represented diagrammatically in Fig. 27, using iron as an example. Chemical analyses of thousands of rock samples show that the average iron content of the rocks of the upper few kilometers of the earth is about 5.6%. If we were to plot a graph in which the cumulative mass of all the rocks to a depth of, say, 10 km was the horizontal axis, and the percent of iron content was the vertical axis, then, descending from left to right, the graph would look something like that shown in Fig. 27. At the extreme left, the iron content would begin with a peak value of 72% corresponding to an iron ore of pure magnetite (Fe_3O_4). It would then descend very steeply and level off to a broad plateau ranging from an iron content a little above to a little below the mean value of 5.6%, and finally, at the extreme right, descend sharply to near zero.

The rock represented by the sharp peak at the left, principally that with an iron content of about 30% or more, represents the world's iron ores. Through mining, the ore represented by this peak is continuously removed, and the iron that it originally contained is transferred to the broad plateau of low iron concentration. From this it is clear that although a metallic element is not destroyed by use, the high-grade ores of such an element are both finite and exhaustible. Hence the metal must be obtained from rocks with progressively lower metallic contents and with corresponding increases of both physical and monetary costs for extraction, until eventually further mining is discontinued. This is illustrated in many of the mining districts of the world. For example, during the 18th and 19th centuries, Great Britain, utilizing domestic iron ores, was the leading iron producer in the world. Also, the ores of tin, copper, lead, and zinc in Cornwall had been exploited since Phoenician times. During the last half-century, however, Great Britain has become dependent upon imported iron ores, and the Cornish ores have now been largely depleted.[14]

In the United States, for nearly a century the iron mines of the Lake Superior district shipped iron ores with an average iron content of 50%. By about 1950 these high-grade ores were largely exhausted, and production is now principally obtained from taconite ores with an iron content of but 30%. For copper ores, the average copper content of the ores mined in the United States in 1922 was 1.7%, or 34 lb of copper per ton of rock. By 1968 this had declined to 0.6%, or to but 12 lb of copper per ton of rock. With lead and zinc, the Galena district of northwestern Illinois and southwestern Wisconsin and later the tri-state district of Missouri, Kansas, and Oklahoma were the leading producers of the country. By now both these districts have been virtually depleted.

The foregoing principles afford a basis for understanding the evolution of the metal-mining industries in any region. If high-grade ores are initially abundant, production tends to follow the customary exponential growth curves. As the higher grade ores are exhausted and lower grade ores are exploited, the growth rate slows down, and eventually the rate of production goes into a long decline. These principles are well illustrated by the production of industrial metals in the United States, of which we shall consider only iron, copper, lead, and zinc.

Fig. 28 is a graph of the U. S. production of pig iron from 1825 to 1958. Since iron and coal during most of this period represented the principal components of heavy industry, it is not surprising that the curves of pig-iron production and of coal production are so similar as to be barely distinguishable from one another. Both increased exponentially at annual rates of about 6.5% per year until about 1910; both broke sharply downward from this growth rate subsequently. This is seen even more clearly in Fig. 29 in which the pig-iron production is plotted semilogarithmically. It is significant that it was about the beginning of the present century that the United States became a net importer of both iron ore and pig iron.

Figure 30 shows the U. S. production of copper from domestic ores during the period 1850 to 1958. This also shows an exponential growth rate until about 1916

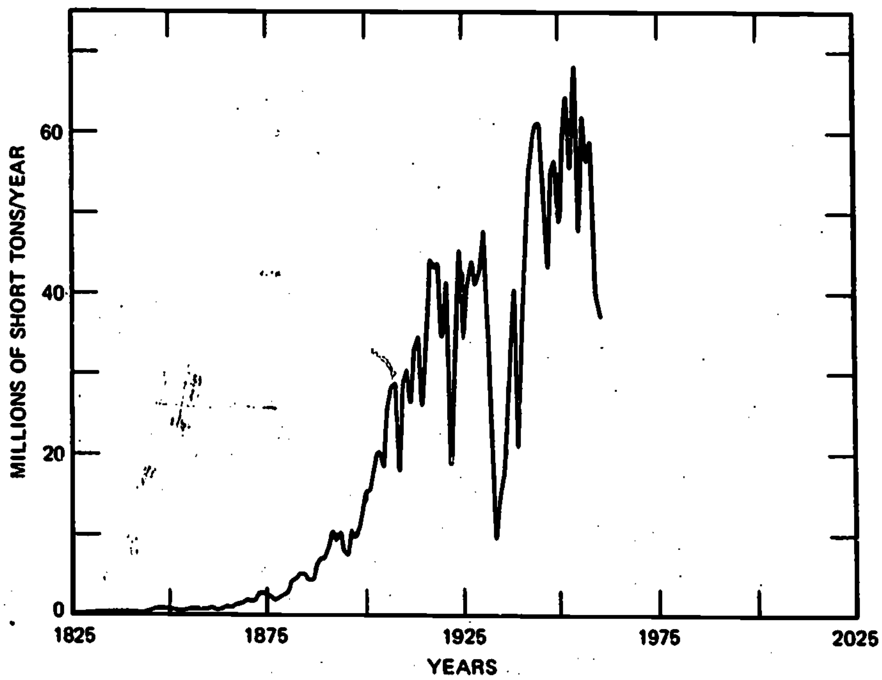

Fig. 28 U. S. production of pig iron, 1825–1958.

when production first reached a peak of 1.0 million short tons per year. Subsequently the production rate has oscillated rather widely but with a gradual increase to a level averaging about 1.7 million tons per year during the five-year period 1964–1968. Also, the United States made the transition from a net exporter to a net importer of copper in 1941.

Figure 31 gives the annual U.S. production of lead from 1825 to 1958, and Fig. 32 that of zinc from 1880 to 1958. These two metals are closely associated geologically, and the ores of both are commonly produced from the same mines. The peak rate of production for lead of about 680,000 short tons per year occurred in 1926. This was followed by a sharp decline which not even the requirements of World War II were able to reverse significantly. The decline has continued until, by the five-year period 1964–1968, the average annual production had descended to 320,000 tons per year. The transition from a net exporter to a net importer of lead was made by the United States in 1940.

The annual production of zinc, as seen in Fig. 32, reached two nearly equal peaks in 1926 and 1942 of 775,000 and 768,000 short tons per year, respectively. Since 1942 the production rate has declined to an average of 567,000 tons per year during the five-year period of 1964–1968. The transition from a net exporter to a net importer of zinc was made by the United States in 1943.

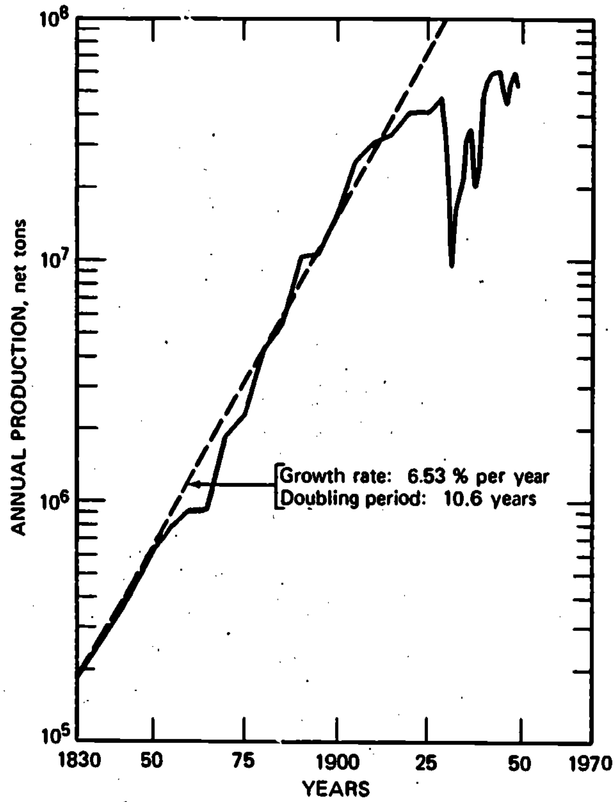

Fig. 29 U. S. production of pig iron, semilogarithmic scale.

While these are only individual examples, they serve to illustrate a basic principle: namely, that the earth's initial accumulations of high-grade ores of industrial metals are as exhaustible as the initial deposits of the fossil fuels, and during comparable periods of time. In New York, from Feb. 27 to Mar. 4, 1971, the American Institute of Mining, Metallurgical and Petroleum Engineers held its centennial celebration, during which broad-scale reviews were made of various aspects of the minerals industries. With regard to the ore resources for the industrial metals, one of the recurrent themes touched upon by various speakers was essentially the following:

> With the exception of the ores of iron and aluminum for which the known reserves are probably adequate for a century or more, the known world reserves for most of the other industrial metals are probably sufficient to meet all requirements until the end of the present century. Beyond that, it is uncertain what may be done.

A favorite rebuttal to this conclusion is that with enough energy metals may be extracted from rocks of lower and lower grade indefinitely. Even if this should be

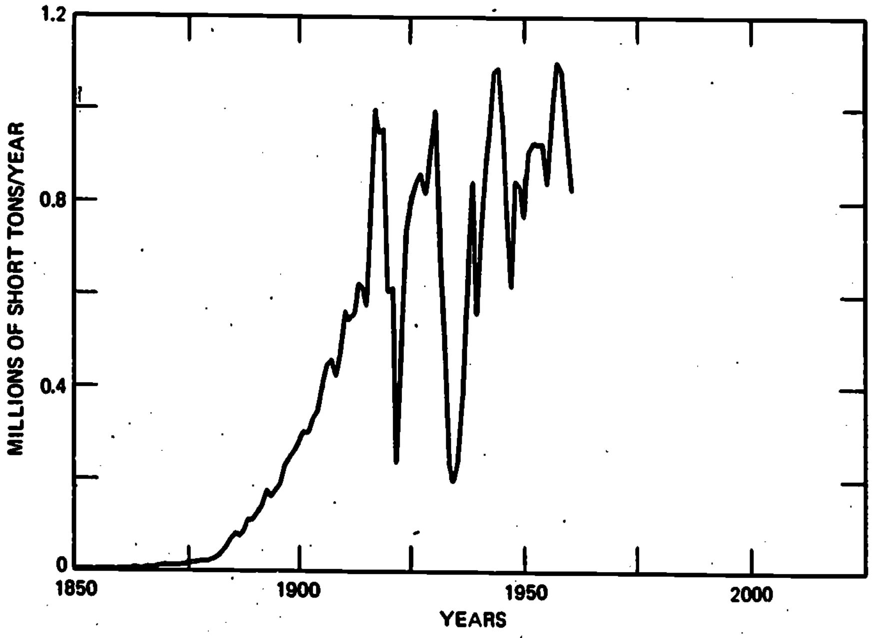

Fig. 30 U. S. production of copper, 1850–1958.

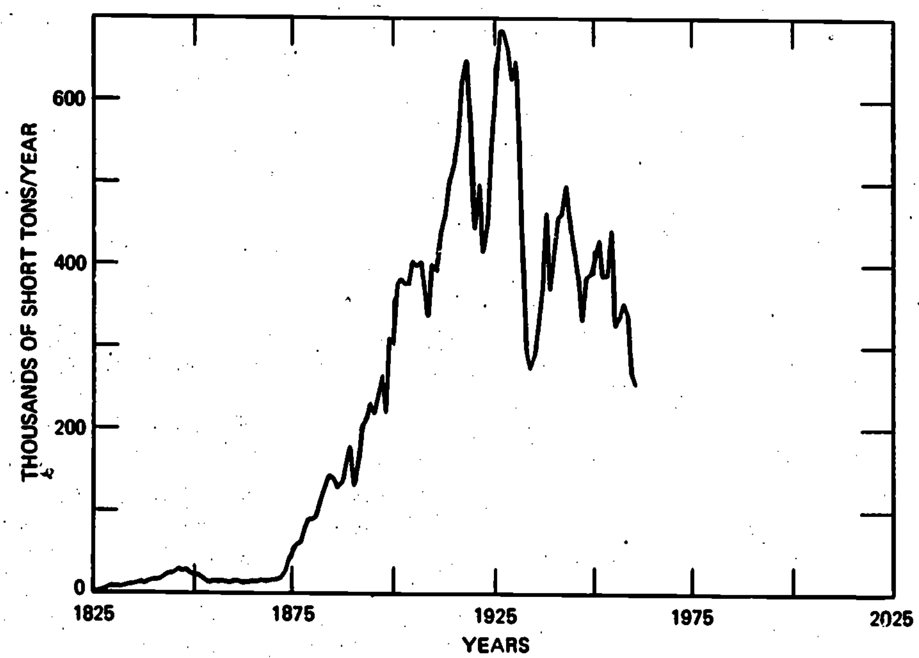

Fig. 31 U. S. production of lead, 1825–1958.

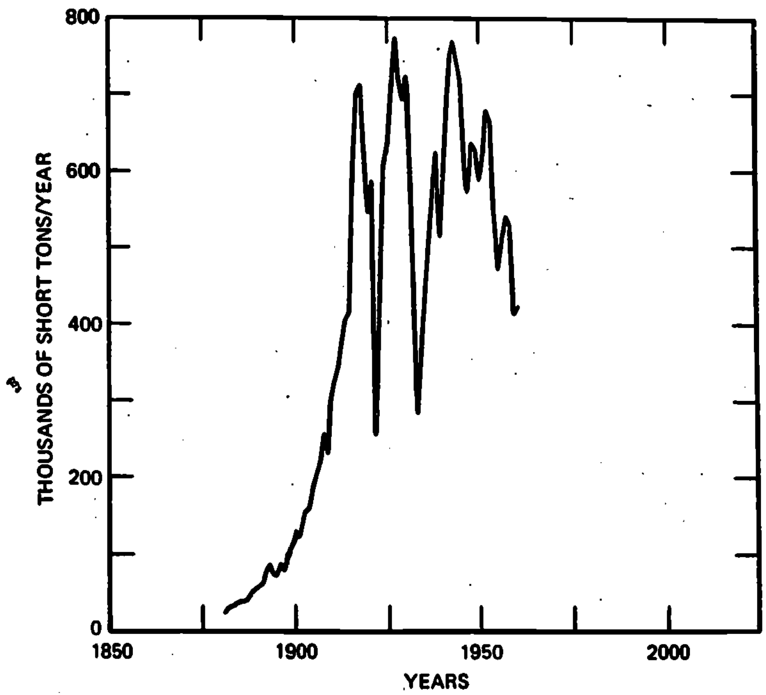

Fig. 32 U. S. production of zinc, 1880–1958.

physically possible, such a procedure is rendered doubtful by ecological constraints not usually taken into account.

PRINCIPLES OF ECOLOGY

One of the consequences of the developments that we have just reviewed is that they have been the cause of one of the more severe ecological disturbances of the earth's plant and animal populations in geological history. Let us therefore consider briefly some of the basic principles of ecology as a means of anticipating the constraints that these may impose upon future developments.

One of the first of these is the growth law of biologic populations. This may be stated in two parts. The first part is that the population of any biologic species from bacteria to elephants will, if given ample food supply and a favorable environment, increase exponentially or geometrically with time. A mathematical expression of this type of growth is given by the equation

$$P = P_0 \, 2^{t/T}$$

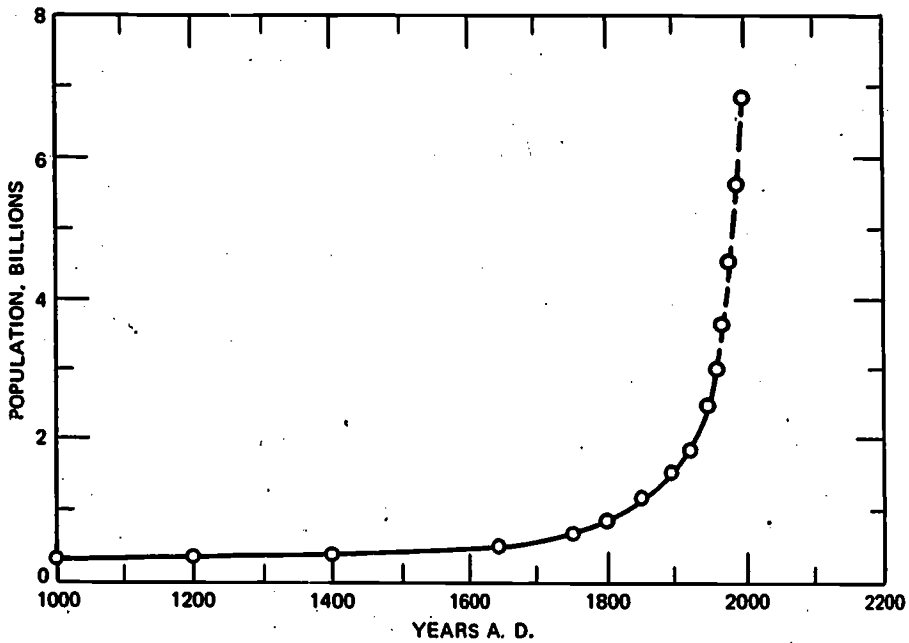

Fig. 33 Growth of world human population since 1000 A.D.[1]

Here P_0 is the initial population, P is the population after a period of time t, and T is the time required for the population to double. Hence, t/T represents the number of times the population doubles during the period t of exponential growth.

The growth of the world human population since the year 1000 A.D., as shown graphically in Fig. 33, is a qualitative example of this principle. The human population has increased from roughly 300 million at the year 1000 to a present figure of 3600 million, and it is expected to reach about 7000 million by the year 2000 A.D. This would represent a 23.3-fold increase in 1000 years, or 4.54 doublings during that period. This increase has occurred in response to a better food supply, a better environment, and improved standards of health, made possible by the concurrent technological advances and continuously increasing utilization of energy. The growth rate during this period was not uniform but accelerated with a corresponding shortening of the doubling period from close to 1000 years at 1000 A.D. to a present figure of only 37 years.

Although this first principle of exponential growth was originally formulated for biologic populations, it is also valid for the growth of industrial activities. We have noted already how the production of coal, of oil and gas, and of the industrial metals each increased exponentially for a century or more with doubling periods of from 8 to 16 years. The growth of world electric-power generating capacity, shown in Fig. 34, is another major example. Beginning at near zero in 1900, world electric-power capacity had reached 900×10^9 watts by 1967 and is increasing at a rate of 8% per year with a

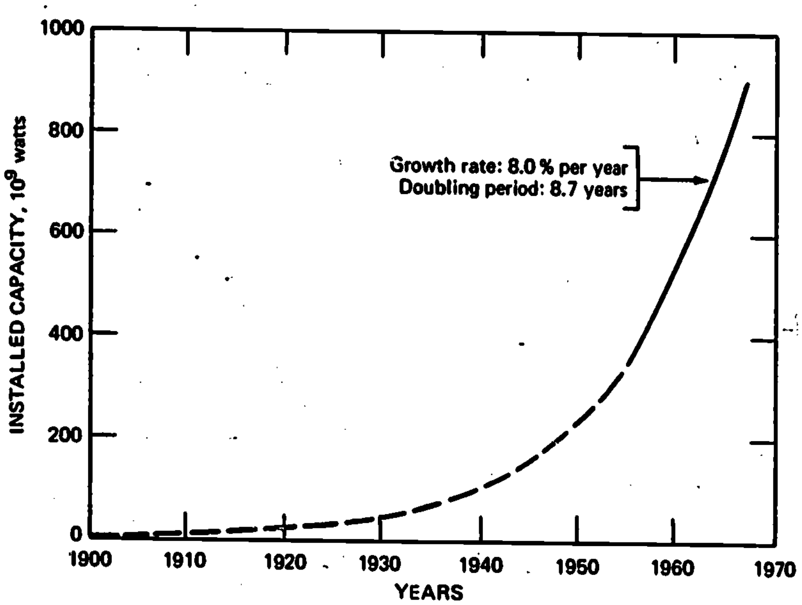

Fig. 34 Growth of world electric-power generating capacity.[3]

doubling period of but 8.7 years. Likewise, the world population of passenger automobiles is increasing at a rate of 6.69% per year with a doubling period of 10.4 years.

The second part of the law of growth is that the exponential phase can be sustained only for a temporary period of time or for at most a few tens of doublings. That this must be so can be demonstrated by elementary arithmetic. Consider, for example, the checkerboard problem of placing one grain of wheat on the first square, two on the second, four on the third, and doubling the number of grains for each successive square. The number of times the initial quantity of one grain will have been doubled by the time the last or 64*th* square is reached will be 63 times. Therefore the number of grains on the last square will be 2^{63}. By volume this would amount to approximately 1000 times the world's present annual wheat crop. The same principles apply also to biological populations and to industrial activities, whether the production of mineral raw materials, of automobiles, or of electrical-power capacity. The earth itself cannot tolerate growth of such activities from small beginnings for more than a few tens of doublings.

The complete law of growth, including both the initial exponential phase and the leveling-off phase, is illustrated by the logistic growth curve shown in Fig. 35. An inverted form of this is represented when a biologic population encounters unfavorable conditions and decreases before leveling off to a lower equilibrium number.

A second ecologic principle is that in an ecological complex of plant and animal populations coexisting in any given region, if the population of any single species is

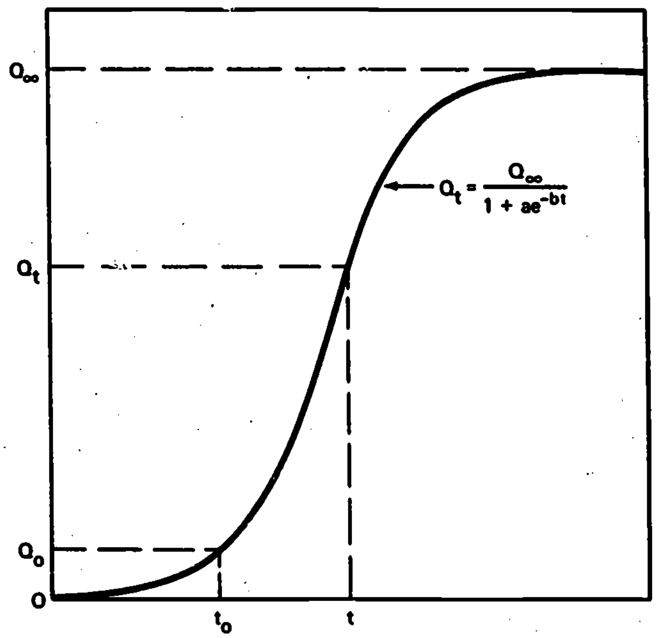

Fig. 35 Logistic growth curve showing both the exponential phase and the leveling-off phase of growth.

disturbed, those of all other species are affected. A simple example of this is the upset that sometimes occurs when an exotic species is introduced, as when European rabbits were introduced into Australia. That this relationship also applies to an industrial complex is evident in the effect of the rise of motor vehicles on the populations of horses and buggies and of railroad passenger trains. Another type of major disturbance is produced by secular climatic changes, such as from hot to cold or wet to dry.

Combining these several ecological principles with the known fact from paleontology that the time span for individual species is commonly measurable in millions of years leads to a very fundamental proposition: namely, a rapid rate of population change, when averaged over a few years to avoid seasonal variations, is a highly abnormal event, the normal state being one in which populations remain nearly stationary or else drift slowly with time. This can be shown for any given species by noting that the extreme range from the lowest to the highest population cannot involve as many as 100 doublings. If the species has existed for a million years and if this extreme change from the lowest to the highest occurred during this time, this would involve less than 100 doublings in a million years, or an average length of time per doubling of more than 10,000 years. Since populations, when disturbed, change with doubling times ranging from tens of minutes for bacteria to tens of years for large mammals, it follows that such periods of rapid change can only be of brief duration.

HUMAN AFFAIRS IN TIME PERSPECTIVE

When man's conquest of energy and its associated technological culture is considered in conjunction with essential ecological constraints and on a time span of human history extending from 10,000 years in the past to 10,000 years in the future,

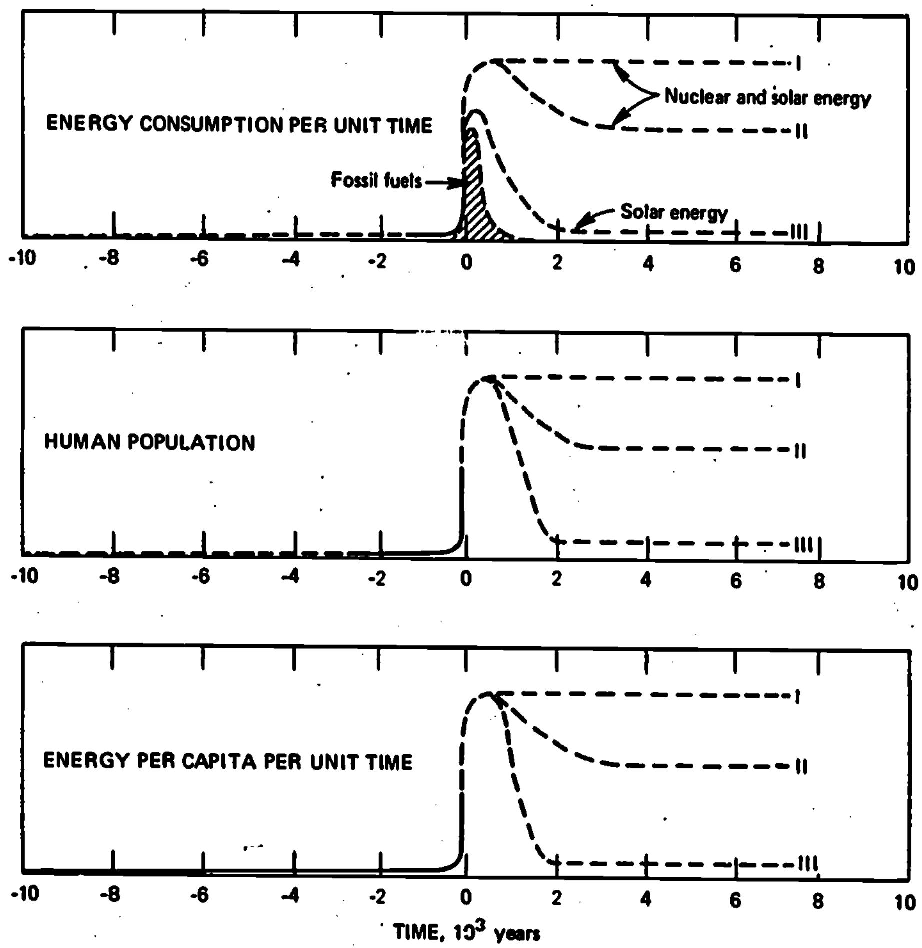

Fig. 36 Growth of human population and energy consumption viewed on a time scale from 10,000 years in the past to 10,000 years in the future.[1]

a much clearer picture of the nature of our present situation and problems emerges. On such a time scale, as is shown in Fig. 36, most of the major components of our present industrial civilization, including the human population, when plotted graphically would plot either near or at zero for all past history until the present is approached. Then in each instance the curve, after a short, barely perceptible rise, would turn sharply and almost vertically upward to its present magnitude. However, because of the impossibility of any one of these curves continuing to increase for more than a small number of additional doublings, each curve, depending on its nature, must level off in one of three ways: (1) as with water power, it could level off asymptotically to a maximum value that might be sustained for a long period of time; (2) it might overshoot and have to drop back and stabilize at a lower level more compatible with the earth's resources and ecological requirements; or (3) it might, as in the case of exhaustible resources or the extinction of a biologic species, decline to zero.

Because the rise of our technological society up to the present has been based principally upon the exploitation and exhaustion of an initial supply of fossil fuels and high-grade ores of metals and because the human population is already seriously too large, it appears most improbable that the leveling-off process can be of the type asymptotic to a maximum as indicated by I in Fig. 36. It is technologically and biologically feasible, however, to drop back and stabilize at an intermediate level, as indicated by II, which could be sustained as a near steady state for possibly a millennium or longer. Finally, there is also the possibility if not the probability that present trends of population growth and resource exhaustion could be continued to a catastrophic conclusion followed by a collapse of our technological culture and a return to the low-energy level of existence of our ancestors of only a few generations ago.

Regardless of which of these courses may actually be followed, it is clear that the episode of exponential industrial growth can be only a transitory epoch of about three centuries duration in the totality of human history. It represents but a brief transitional interval between two very much longer periods, each characterized by rates of change so slow as to be regarded essentially as a period of nongrowth. Although the forthcoming period poses no insuperable physical or biological difficulties, it can hardly fail to force a revision of those aspects of our present exponential-growth culture which lead us to contemplate a state of nongrowth as being either unthinkable or intolerable.

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THE NUCS: ENERGY VS. THE ENVIRONMENT

Joseph D. Tydings
Former Senator from Maryland

Mr. Tydings was elected to the U. S. Senate in November 1964, after serving for three years as United States Attorney for the District of Maryland under President John F. Kennedy and more than six years in the Maryland House of Delegates. He has been a legislative leader in the field of anti-crime legislation, court reform, conservation and water protection, and population policy. Among his awards are the American Criminology Society's August Vollmer Award for distinguished contributions to criminal justice; the 1969 Sierra Club Conservation Award; and the 1970 National Brotherhood Citation from the National Conference of Christians and Jews for distinguished contributions to improved human relations, justice, and equality. He was the first legislator to receive the Vollmer Award, which is usually accorded to those in the law enforcement field.

The recent controversy over the Calvert Cliffs nuclear facility, the future power plant on the Bush River in Harford County, and the absolute necessity of protecting the Chesapeake Bay make this Forum particularly relevant to Maryland.

The Forum's purpose, as I understand it, is to foster community understanding of environmental problems that, today, increasingly tax our capabilities for remedial action. The Forum thus performs a useful public service because there is a real need for building bridges between the scientific community and the general public. Only with such bridges and only with an atmosphere of trust and understanding between the citizen and the scientist, between what C. P. Snow called the two cultures, will we be able to continue enjoying the benefits of scientific discovery and modern technology. In this respect, scientists are like elected officials. Both are dependent upon public support. Neither can afford to get too far ahead of public understanding.

The topic of my remarks is "The Nucs: Energy vs. the Environment." The title, of course, is a misnomer. The question is not energy *versus* the environment. Rather, the question is whether at this point in time we in this country are willing to pay the cost and make the effort necessary to fulfill environmental considerations in the siting, design, and operation of nuclear power plants. It is not a question of energy *or* the environment, because it is not an either/or situation. Our demands for energy and the now obvious need to protect our natural resources are in fact compatible. Energy and the environment can coexist.

What is not clear, however, is whether the implications of this compatibility are understood and whether we are ready to act upon them. Are scientists ready to tell us what must be done to ensure environmental protection and operating efficiencies from atomic power plants? Are the utilities ready to recognize their responsibilities in providing both this protection and efficiency in the many atomic power plants they are proposing to construct? Are state governments equipped to regulate these nuclear power facilities? Have they organized themselves to meet the peculiar demands of atomic energy? And, finally, is the consumer ready to pay the extra costs of electric power that will result from considering the needs of our environment as we meet the phenomenal demands for power in this country? The answers to these questions, as suggested by the recent experience at Calvert Cliffs, are not reassuring.

The scientific community has not reached agreement on the standards for radioactive discharges from atomic power plants or on the impact, thermal or otherwise, of the discharges from these plants on the environment. Some conservationists believed the public utility involved at Calvert Cliffs did not adequately consider the environmental impact of its proposed plant, and this aroused their ire.

The State of Maryland did not have adequate authority or sufficient information and expertise to monitor the development of an atomic power plant. Only recently has Maryland passed a law providing for state review of proposals to locate and operate nuclear facilities. (This is, I think, pioneer legislation for the nation.) And the Atomic Energy Commission did not, and has not, fully recognized its responsibility in meeting the environmental problems of or objections to nuclear power facilities.

The inevitable result of all this was the confusion and ill will that developed at Calvert Cliffs. For an example of how not to do things, the Calvert Cliffs nuclear power plant provides many valuable lessons.

Last year I introduced legislation to remedy part of the situation. My bill would permit the AEC to consider the environmental impact of power plants when licensing commercial nuclear reactors. At present, the AEC can deny an application for a license on the basis of national security, public health, or safety. It cannot deny the license if the environmental impact of the plant is decidedly negative. The nuclear power facility might harm the waters or desecrate a lovely or historically important site. Yet the AEC could not consider these factors. It would have to grant the license.

The AEC does pass along to the power company involved the recommendations of the Department of Interior on the license application, which include environmental considerations. But these are merely recommendations, without force and often without impact. For example, the Interior Department report on Calvert Cliffs concluded that "the lack of specific information" precluded any "definite conclusions as to the probable effects of the plant on the Chesapeake Bay."

When I introduced the bill, I felt the time had come when we had to recognize environmental quality as a public trust equal in importance to our citizens' health and safety. I felt we had to give the AEC the authority to grant or deny licenses on the basis of the environmental impact which the proposed nuclear facility would have.

The bill was consistent with the now-accepted philosophy of bringing environmental considerations into the decision-making processes of government. It placed no unreasonable administrative burden on the AEC nor did it assign to AEC a new and difficult responsibility. It merely said that the AEC could deny a license to an applicant if, in the AEC's opinion, the proposed facility would violate standards of environmental quality that the AEC itself established.

Unfortunately, the AEC opposed the measure. This AEC opposition was sufficient to kill the measure.

The AEC opposed the bill on two counts, one technical and one substantive. The bill applied to commercial nuclear licenses, yet no such license can be issued until the AEC determines the reactor will be of practical value, a value beyond the purposes of research and development. I was surprised to learn that no certification of practical value has ever been made and that all power plants are operating under research licenses. Recently, however, the AEC has advocated abolishing the requirement for a certification of practical value, and a bill to do so was reported out of the Joint Committee on Atomic Energy just this month. [The requirement was abolished by Public Law 91-560 (84 Stat. 1472) (1970), Sec. 5.]

The AEC opposed the bill on substantive grounds because the Commission felt it "discriminated" against nuclear power plants by applying only to atomic generating facilities and not to conventionally powered plants. This misses the point, which is to provide a public agency with the legal authority to take steps within its area of jurisdiction necessary to protect the environment. That the bill did not apply to conventionally powered facilities is perhaps relevant, certainly instructive, but not paramount. What counts is protecting the environment while still meeting our power requirements. My bill allows the AEC to do this.

To be fair I should mention that the AEC did support a bill that would require a public utility seeking a license from the AEC to first obtain a certificate from the appropriate state agency saying that the discharges of the power plant would not violate the approved water quality standards. This bill is helpful and should do much to protect our waters. [The Bill passed becoming Public Law 91-224 on April 3, 1970. Section 21 requires federal agencies in issuing licenses or permits to require certification from the appropriate state agency that water quality standards will not be violated by the activity proposed by the applicant for a license or permit.] By itself however, I do not feel it is sufficient. It permits the AEC to abdicate its own responsibility for protecting the waters to the states. The burden is now on the state agency rather than on the AEC. Moreover, the bill just covers certain types of water pollution and ignores other areas of environmental concern.

I believe we must provide our political and social institutions with the authority and flexibility to act. We must give them the means to do the job we require of them. That is why I offered this bill on licensing nuclear power plants.

That is why I have introduced legislation to expand the jurisdiction of federal district courts to issue injunctions against those who by physical force or disruptive tactics interfere with the First Amendment rights of others. And that is why I support efforts to reform the workings of Congress.

If we want the federal government to protect the environment, we have to make sure that our public institutions have the power to act. And we must, of course, express disappointment when a federal agency like the AEC says it is satisfied with a limited review procedure in the hands of the states.

The role of the AEC in achieving the compatibility between environmental quality and the demand for electric power is a timely topic of debate and discussion because our requirements for power are growing at a phenomenal rate. And our concern for the environment is at an all time high.

The accepted rule of thumb is that the demand for power in the United States is now so great that we must double our generating capacity every 10 years. To meet this need, we will require many new and much larger power plants. Plans are now afoot to build power facilities three times the size of the largest plants constructed in the 1950s. And 200 of the 492 new power plants needed by 1990 will be nuclear fueled.

These new facilities, whether nuclear or conventionally powered, will have a substantial impact on the environment. The production of energy creates waste heat, which results in thermal discharges that may damage the ecology of our waters. And in just 10 years our demands for power will require one-sixth of the total available freshwater runoff in the country for cooling purposes.

The location of new power plants and the routing of high-voltage transmission lines pose additional environmental problems. Finally, nuclear facilities raise problems of radiation and the disposal of radioactive waste, which affect human safety and the well-being of wildlife and marine organisms.

The rising public concern over the deterioration of our environment demands that we become more sensitive to this impact. Such sensitivity does not mean that we either ignore or treat blithely the ever-growing demand in this country for more and more electric energy. As a conservationist I recognize the importance of power to our growing nation. The continued economic prosperity of this country and the ever-rising standard of living which her people enjoy are in part predicated on having an energy supply equal to this demand.

Meeting our energy requirements and at the same time protecting our environment will necessitate:

1. Long range planning of utility expansions on a regional basis at least 10 years ahead of construction.

2. Participation in the planning by the environmental protection agencies and notice to the public of plant sites at least five years in advance of construction.

3. Preconstruction review and approval of all new large power facilities by public agencies, with emphasis given to regional considerations.

4. Expanded research aimed at better pollution controls, underground voltage lines, and advanced siting approaches to minimize environmental problems inherent in existing technology.

These are the recommendations of a new report entitled "Electric Power and the Environment" prepared by the Office of Science and Technology. They have my support, and I look forward to their presentation by the President as specific, concrete legislative proposals.

There is one other aspect of the compatibility of energy and the environment that I would like to briefly mention. This is the issue of whether the Atomic Energy Act of 1954, the basic law which established the AEC and set our national policy on atomic energy, preempts from the states and leaves to the AEC alone the regulation of radioactive discharges from nuclear power facilities. The issue is not an obscure legal technicality because two distinguished scientists, Dr. John Gofman and Dr. Arthur Tamplin, have publicly stated that the levels of radioactive discharges permitted by the AEC are too high. Yet, when the State of Minnesota attempted to limit these discharges to about $\frac{1}{50}$ the level allowed by the AEC, a public utility that wants to build a nuclear power plant in Minnesota sued the State of Minnesota on the grounds that the 1954 Act did indeed preempt the field of atomic energy regulation for the federal government. The dispute is now before the United States District Court, District of Minnesota, and it is up to the courts to decide what exactly the Atomic Energy Act of 1954 says.

It seems to me that a state has an obligation to protect its citizens against environmental degradation and to take the steps it deems necessary to protect the health and safety of its citizens. If Minnesota, or Maryland for that matter, wants to set the radiation standards it feels are necessary and if these happen to be stricter than the standards set by the AEC, the state should be permitted to do so.

The point is an important one, for Maryland has in fact set standards for the average annual concentration of radioactivity in the circulating discharge of water from nuclear power plants at 1% of what the AEC permits the current maximum concentration to be. Maryland's standards are thus 100 times higher than those of the AEC. They are, however, achievable standards, well within the capabilities of present-day technology.

Maryland, incidentally, is going to file a brief in support of the State of Minnesota.

I expect within a short time to offer an amendment to the Atomic Energy Act making it clear that the states may if they so desire set radiation standards above those of the AEC. The states and not the federal government must have the authority to set such standards because they have the principal responsibility for maintaining the public health and safety of their citizens. The amendment would make certain that Maryland and not the AEC decides what is safe for Maryland waters and Maryland citizens.

Let me add that neither my amendment nor the Maryland standards are taken out of hysteria over nuclear power—indeed we want to take advantage of atomic energy in Maryland—rather the actions are taken out of concern for our natural resources and the health of our citizens.

The whole question of the compatibility of electric power with proper consideration of the environment is one that will receive increasing attention in Congress and in the executive agencies as we seek to maintain the quality of our environment while increasing our capacity to produce energy. It is an issue that will determine in part what our standard of living will be in the next few years. It is an issue that must be discussed rationally and without ill will.

NUCLEAR POWER PLANTS: PRESENT, PAST, AND FUTURE

Theos J. Thompson, *Commissioner, U. S. Atomic Energy Commission*

Dr. Thompson received the A.B. and A.M. degrees from the University of Nebraska. From 1942 to 1946, he served in the U. S. Army Chemical Warfare Service. From 1950 to 1952, he worked and lectured at the University of California Radiation Laboratory at Berkeley, where he was awarded the Ph.D. degree in nuclear physics. From 1952 to 1955 he was a Staff Assistant at Los Alamos from where he went to the Massachusetts Institute of Technology as Associate Professor of Nuclear Engineering. He was in charge of dismantling "Clementine," the world's first fast reactor, a pioneering effort which showed that even a highly contaminated reactor could be dismantled safely. In 1958 he became Professor of Nuclear Engineering and Director of the M.I.T. Nuclear Reactor Facility. He was serving in this capacity when President Nixon nominated him as Commissioner of the AEC. Dr. Thompson served as a consultant to the nuclear power industry, as a member and Chairman of the AEC's Advisory Committee on Reactor Safeguards, and as a member of U. S. delegations to international conferences. He received the AEC's Ernest O. Lawrence Memorial Award in 1964 for his leadership in developing safer and economical nuclear reactors and for his inspired teaching. In March 1970 he received the Distinguished Service Award in Engineering at the University of Missouri at Rolla. Dr. Thompson died in an airplane accident on Nov. 25, 1970.

I will try to give you some perspective on the environmental impact of nuclear power plants. To do this I will have to start by discussing the total energy situation in the United States and then go on into the specifics on nuclear power plants, covering thermal effects and the rationale of radiation standards as they are applied by the

AEC. Also I hope to be able to show you that we need to develop sources of fuel other than fossil fuels if we are to have any chance of preserving our way of life.

We all have to recognize the basic factors involved in man's use of energy and man's need for energy. I am sure that you all understand that the use of energy in the United States, as well as in other heavily industrialized countries, is woven inextricably into the basic fabric of our society. Without energy, it is likely that many of us here would never have been born or survived because, among other things, there would be insufficient farm machinery, fertilizers, and means of distribution to provide the food necessary to sustain our current level of population. The availability of energy has had a profound effect on man's recent past. It will clearly exert even more of an influence on his future.

Figure 1 shows the growth of the world's population from the birth of Christ to the present. It took 16 centuries for the world's population to double from about one-quarter of a billion people to about one-half a billion people. These people lived in a very rudimentary, largely self-sufficient, cottage economy. The current doubling time on a world basis is about 35 years, and this accounts for the projection of about 7 billion people in the world by the year 2000. Whether it is the cause or an effect, an even sharper rise in energy utilization has accompanied the rise in population. The U. S. electrical energy consumption is doubling every 10 years to provide for our growing population and to help raise our standard of living.

In Fig. 2 this population-growth curve is combined with a fossil-energy-use curve by the eminent geologist M. King Hubbert. One way to explain the interaction is to say that, as the energy from fossil fuels became available to man, population began to grow because individuals now had the wherewithal to produce more food than they could consume. Figure 2 also makes clear that there is a limit to our fossil-fuel resources, and it implies a dramatic reduction in our population and in our way of life if alternate sources of energy are not found. We must all realize that it took nature millions of years to make these fuels and that they are irreplaceable in mankind's time scale on earth. To be more specific, it has been estimated that only 300–400 years of coal and 60–70 years of oil are the total resources of fuel available to all of us. Clearly there will be some major changes in our way of life if our oil resources are depleted and if we can no longer use internal-combustion engines for our automobiles, airplanes, trucks, buses, and tractors. We will have to make fuel for moving machinery and transport vehicles from coal or use electric-powered vehicles. We will still need oil and grease for lubrication. We must remember, too, that the natural fossil-fuel resources provide the feed materials for chemical and plastic industries that are now vital to our civilization. Our nation must clearly make a greater effort to ensure that these precious materials are used as wisely as possible for our future well-being.

A further thought can be derived from an examination of Fig. 2. You are all aware of the seriousness of the air-pollution problem we are facing because of the combustion of fossil fuels. The area under the energy-use curve represents the total energy available to man from fossil fuels. The shaded area under the curve represents

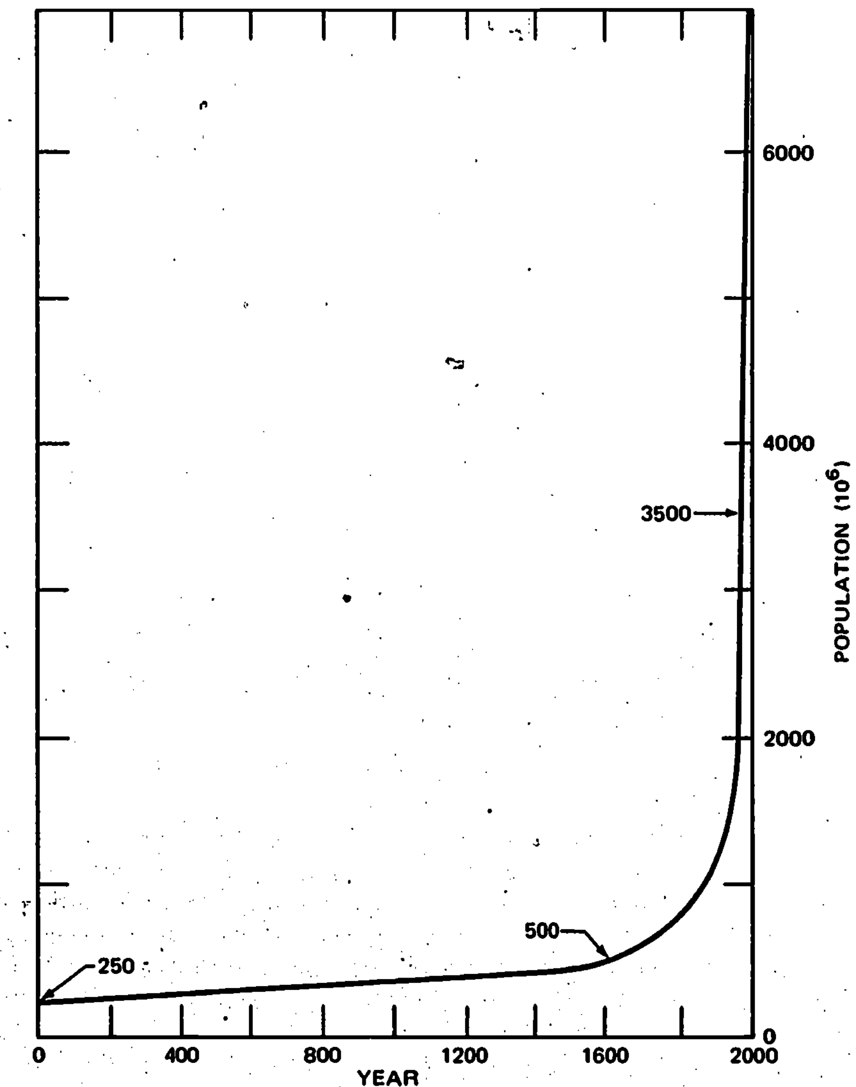

Fig. 1 World population.

that very small percentage of the total which has been used to date. If at this level we already have serious air-pollution problems, you can get some visual picture of what they might be in the future. Of course, our government and industry are now planning and taking actions to reduce the release of pollutants, but substantial questions remain as to whether the situation can be handled adequately, as I will discuss a little later.

Again looking at a few more specifics, Fig. 3 shows how the total energy usage in the United States has varied in the past and projects usage to the year 2000. Note

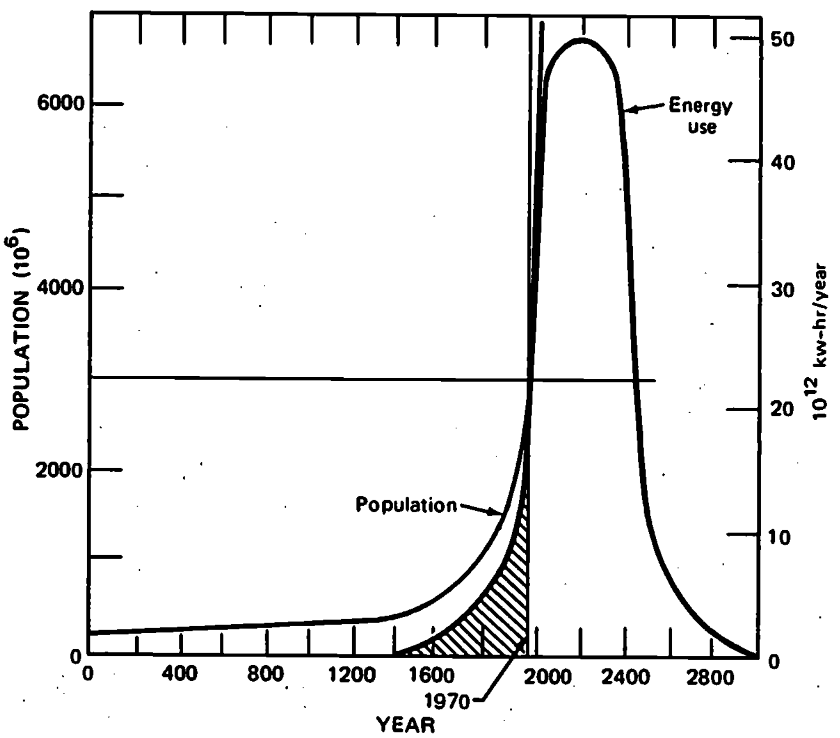

Fig. 2 World population and energy use.

that it is anticipated that coal will continue to increase gradually in total demand as the years go by in spite of the advent of nuclear power. Oil is probably right now near its peak demand level domestically. If nuclear power were not to be developed, there would have to be further increases in the use of fossil fuels up to the levels implied in Fig. 2. Major changes in means of transportation will, of course, have a great effect on these predictions. For instance, the development of a light, economic car battery would increase greatly the electrical energy used for transport and correspondingly might reduce the consumption of oil products for that purpose.

By the year 2000 our current population of 200 million is expected to increase to about 300 million. It is also expected that about 80% of these additional 100 million people will live close to existing centers of population. This means that the bulk of the pollutants from the combustion of fossil fuels by these additional people will likely be released into areas where pollution levels are already quite high.

Much of the literature currently being published, in my opinion, does not sufficiently emphasize the role of carbon dioxide as a pollutant. Carbon dioxide acts as a blanket to hold in radiation from the sun more efficiently—the green house effect. Consequently, the higher the percentage of CO_2 in the atmosphere, the higher will be the temperature of the atmosphere. If the amount of CO_2 in the earth's atmosphere

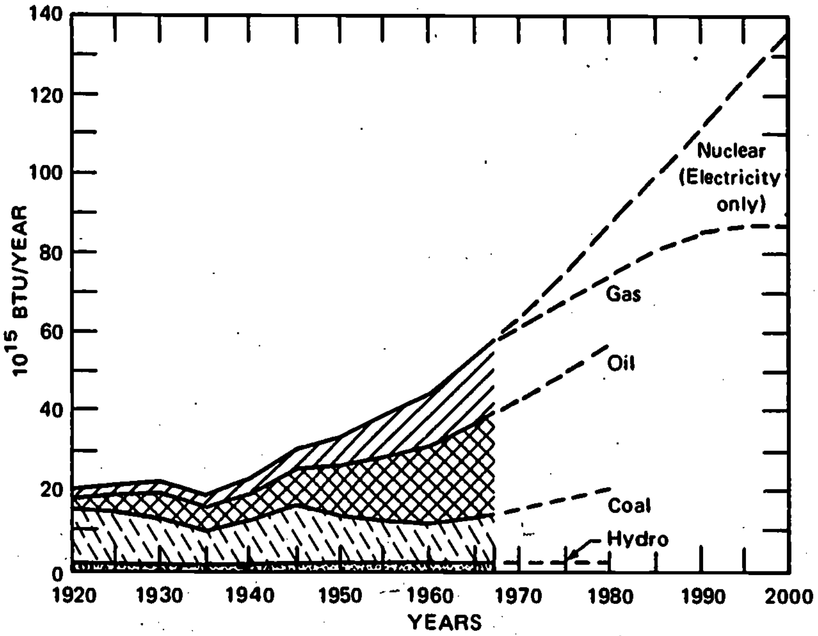

Fig. 3 United States energy consumption. (From Resources in America's Future, a special LMFBR study by the U. S. Bureau of Mines for the AEC.)

rises from the current level of about 320 parts per million to about 400 parts per million by the year 2000 as predicted, the atmospheric temperature could be expected to increase about 3°F unless particulate matter suspended in the atmosphere is the dominant effect. It is extremely difficult to extrapolate this temperature change and make any definitive estimates of what the effects of burning all our fossil fuels will be. We could accelerate the coming of another ice age, or we could melt the polar ice caps which would inundate the coastal regions of the world. Considerations such as these indicate that man, in his use of fossil fuels, is tampering with basic ecological cycles whose balance, if changed significantly, can have an environmental impact which is potentially more profound than those associated with the more commonly discussed air pollutants.

Let us now examine the alternate forms of energy available. Tidal energy, geothermal energy, and hydroelectric energy all represent feasible ways of generating power. However, the total amounts of such energy which can be made available will at best fill only a small fraction of our needs. Solar energy could supply all the energy we need. However, its power density is extremely low, and it appears that its only feasible use in the next several decades will be on a small scale to supplement other sources of energy. There is presently no practical way to utilize solar energy on a large scale, and none appears likely.

This leaves only two alternatives: nuclear power from fission or fusion. Nuclear power plants based on fission are economically available now. Controlled fusion is, however, as yet unproven even in the laboratory. We have not yet reached the point with fusion which we had reached in 1942 with Fermi's fission pile. Some in our laboratories say we will reach this goal in 10 years or less; others believe it will not happen till the end of the century; still others say never. My colleagues and I, however, believe that fusion will be successful, but, even after reaching the success of the Fermi pile stage, much engineering development will be necessary. In spite of fusion's great promise, we cannot afford to have our energy needs depend on a source which is unproven. Fission breeder reactors have been proven to be feasible, and much engineering has been accomplished. The next step is a demonstration commercial power plant. We must get on with the breeder development and demonstration tasks. Equally, we cannot neglect the research needs of our controlled fusion program.

Present-day reactors—pressurized, boiling-water, and gas-cooled reactors—use the uranium-235 (^{235}U) isotope as fuel, and this isotope represents less than 1% of the naturally occurring uranium. We are sure that there is sufficient ^{235}U available at current market prices to extend to about the year 2000 and to the year 2020 at about three times current fuel prices. I have already referred to our need to develop breeder reactors. Such a development will permit us to extend our nuclear-fuel resources. The breeder reactor holds the key to providing a world rapidly growing in population and energy needs with an abundant and economic source of useful energy for perhaps a thousand years or more.

What are the characteristics of a breeder-reactor system that will help fulfill the promises I have mentioned? A major one involves the efficient and economic use of fuel resources. As mentioned, only a fraction of 1% of natural uranium is the fissionable isotope ^{235}U; the remainder is ^{238}U. In the light-water converter-type reactors operating today, the uranium fuel used is enriched through the gaseous-diffusion process to contain about 4% of ^{235}U. As fission of the ^{235}U occurs, a small fraction of the fertile ^{238}U is converted to plutonium-239 (^{239}Pu), and part of this plutonium is also consumed by fission. Less than 5% of the total weight of fissile and fertile material in the core is fissioned before the core is removed from the reactor.

To make efficient use of the great potential energy in all natural nuclear resources—the uranium and thorium abundant in nature, we must make use of the breeding principle. Through this principle, involving the transmutation of fertile materials to fissionable materials [^{238}U to ^{239}Pu and thorium-232 (^{232}Th) to ^{233}U], we can make use of essentially all the nuclear fuel in nature. I should make clear at this point that two different breeder systems can be involved in this transmutation process. The thermal breeder employing slow neutrons works best on the ^{232}Th–^{233}U cycle (called the thorium cycle for short), and the fast breeder—employing more energetic neutrons—operates on the ^{238}U–^{239}Pu cycle (called the uranium cycle). By taking full advantage of breeder reactors—by establishing safe and reliable breeder power systems—we could extend our use of the uranium and thorium reserves from decades to more than a thousand years.

Now let us examine the environmental impact of our current generation of water-cooled reactors. Those of us who have been involved in bringing to fruition this new source of power believe in it and are proud to have played a part in its development. At the same time we must tell you in all frankness that there are some disadvantages along with the advantages. Although they completely eliminate any smoke, SO_2, or CO_2 discharges, these plants do add to already existing problems in our environment.

First, these plants are not as thermally efficient as the best of the coal- or oil-fired plants. Every plant that uses any type of fuel to heat water and make steam and drive an electrical turbine does so by generating heat at a high temperature and discharging heat at a low temperature. The thermal efficiency of a plant is determined by a law of physics that cannot be violated, so far as we know. This means that any device which converts heat to other forms of energy must in some way discharge waste heat to the environment. About one-third more heat is discharged from a present-day nuclear plant to the environment than is discharged from the most efficient coal- or oil-fired plants. This is one of the reasons why the Atomic Energy Commission is working hard to develop new types of reactors which will operate at higher temperatures—at least as high as the best of the conventional plants. The new gas-cooled reactors, the liquid-metal-cooled fast breeder reactors, and the molten-salt reactors all have these high-thermal-efficiency characteristics. Thus, you can clearly see one of our incentives for developing these new types of reactors is to reduce the thermal impact of nuclear power on the environment.

You are, I am sure, all aware that all nuclear reactors add small amounts of radioactivity to the already existing radioactivity in man's environment. You must also know, however, that mankind has lived since the beginning of time in a dilute sea of radioactivity. It has always been so. It will always be so. One of the most serious problems that the AEC faces in its public-information program is to explain radioactivity to the average citizen. I would like to make another attempt this evening.

Mankind receives radiation from a number of different natural and man-made sources. Let us take the natural sources first. In man's environment there are naturally occurring radioactive materials. Within the body of man himself potassium-40 (^{40}K) is a natural radioactive isotope, inseparable biologically from the other potassium isotopes which are absolutely vital for man's survival. The radioactivity man carries with him in his body gives the average man living at sea level about one-fifth of the total radiation he receives. All materials with which man comes in contact are radioactive to some degree. The average man receives about one-half of his naturally occurring radiation dose from his surroundings. These doses vary somewhat. For instance, a Wall Street banker who works in a granite building receives more radiation than a housewife who lives in a suburban wooden house. Man is bombarded continually by cosmic rays from outer space. These cosmic rays cause radiation exposures to mankind. The atmosphere provides a protective cloak for man. Thus, a man living at sea level receives less radiation from cosmic rays than does a man living in Denver, Colo. Almost one-third of the radiation that a man living at sea level receives comes from cosmic rays. If the same man lives in Denver, he may receive three times as much radiation from cosmic rays as he would in, say, New York City. In summary, the average man at sea level receives one-fifth of his naturally occurring radiation from sources in his own body, about one-half from his surroundings, and almost one-third from cosmic rays. A man living in a normal seacoast environment with no special radioactive minerals around might receive about half as much total radiation as a man living in Denver. If a jet pilot living in New York City were to fly twenty coast-to-coast round trips every year, he would receive as much radiation as a nonflyer who lived in Denver all year round. A Denver resident who receives a chest X ray receives an amount of radiation which may as much as double what he gets from natural background.

Now let us put the radiation that one might receive from the effluent discharges from a nuclear reactor into this picture of naturally occurring radioactivity. Operating experience has shown that the radiation one might receive by living in the near vicinity of a typical operating plant site for an entire year is equivalent to about what one would receive on a single round-trip, coast-to-coast airplane flight, which is about $\frac{1}{20}$ of the radiation one normally would receive in a year from natural sources at sea level or, in the case of Denver residents, perhaps $\frac{1}{40}$ of what one might receive by living in the "mile-high city" for a year. Put another way, the extra amount of radiation that one might receive from this reactor by standing at the edge of the site would be equivalent to the extra amount of radiation that one might receive in the same year by living at the top of a 400-ft hill rather than at the valley at its base. Obviously, this is a very small amount of radiation compared with the levels which mankind has been receiving through all of the ages. To date, in spite of many careful studies, no one has been able to detect any effect from these low levels of radiation, and it is unlikely that studies of literally millions of cases would show any such effects. In fact, the so-called "mega mouse"—one million mice—experiments carried out by Dr. Russell at the Oak Ridge National Laboratory are aimed at investigating this low-dose region as thoroughly as possible.

But you say, what then of the statements that have been made by Doctors Gofman and Tamplin regarding the possibility of deaths from cancer and leukemia. Let me address myself to that topic.

It is my understanding that the medical and statistical experts disagree with Dr. Gofman in regard to a number of his hypotheses. I shall not discuss these disagreements this evening since I am not an expert in the medical field. I would like to point out, however, that the Federal Radiation Council (FRC) standards that form the basis for the AEC regulations are based on the assumption of no threshold for biological effects of radiation; that is, that radiation effects are proportional to the dose received even at very low levels. This is the same assumption used by Dr. Gofman.

More importantly, I believe that Dr. Gofman has not properly understood, or has chosen not to understand, the AEC regulations. Under AEC regulations, should it appear that the daily intake of radioactive material from air, water, or food by a suitable sample of an exposed population group, averaged over a period not exceeding one year, would otherwise exceed 170 mrem/year (millirem per year), the AEC may

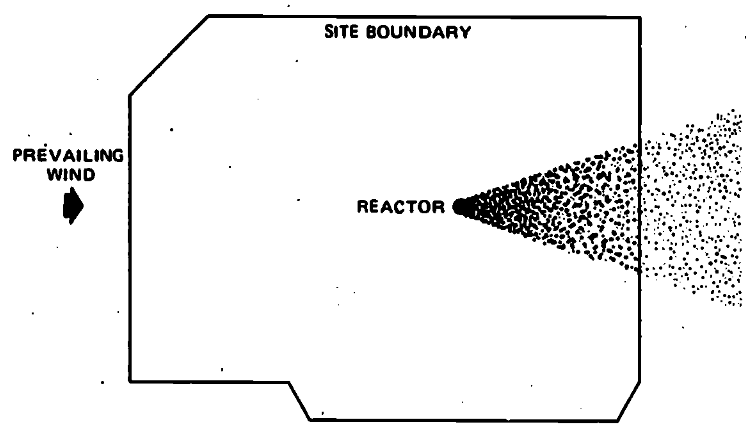

Fig. 4 Theoretical reactor site. Shaded area resprsents blue smoke.

limit quantities of radioactive materials released into air or water during a specified period of time. The intent here is clear. One must select a suitable sample from that segment of the population which can be defined as receiving the maximum amount of exposure. If, for instance, the radiation were to come from eating water lilies, which we will imagine for the moment are, for some strange reason, radioactive, then the suitable sample of the population would consist of those who regularly eat water lilies. The method then requires that the radiation dose to this water-lily eating segment of the population including all other nonnatural sources as well (except medical) be conservatively estimated. On the basis of these studies, limits would be set on the amount of radioactivity which might exist in water lilies by suitably restricting radioactive effluents in our stream. These water lilies are only imagined to be radioactive. I know of no radioactive water lilies.

Let me now discuss briefly how this principle is applied to reactor effluents. The AEC exercises its jurisdiction over reactor licensees by imposing limits on radioactivity in effluents which apply at the boundary of the restricted area. Although I will consider gaseous effluents in the example I am about to discuss, the same principles apply to liquid effluents.

Let us imagine that we have an irregularly shaped reactor site with a reactor located somewhere off center and a definite prevailing wind direction. Such a situation is shown in Fig. 4. The effluents from the site, both liquid and gaseous, are monitored as they leave the last control point. For instance, it is normal procedure to place in the stack of a reactor two monitors (one a backup) which transmit signals directly to continuously operating recorders to monitor the radioactivity level of effluent in the stack. It is not the concentration of radioactivity at the top of the stack that is important under the regulations, but rather the concentration of radioactivity at the site boundary. By the time the effluent reaches the site boundary, it is already much diluted by turbulent diffusion in the atmosphere. The concentration at the boundary is a calculated number that is predicted on the basis of conservative meteorological conditions including wind direction and weather conditions. The permissible maximum gaseous radioactivity discharge levels are established by working backwards through the conservative meteorological conditions and the permissible radiation levels at the site boundary to the equivalent amount of stack effluent passing the monitoring point. Measurements carried out at actual reactor sites indicate that the meteorological conditions and the calculational methods used are conservative by a factor of 2 or 3 and thus serve as an additional safety factor.

At the present time safety-analysis reports calculate these effluent discharge rates from gaseous effluents on the basis of not exceeding 500 mrem/year to an individual located in the most exposed position at the edge of the site 24 hr a day, 365 days a year. The FRC guidance covers both a maximum exposure for a single individual and also the 170-mrem/year exposure (which is about one-third of the 500-mrem exposure) for a suitable sample of the population. The 170-mrem radiation level is about what the average citizen of Denver receives annually from natural causes. In this way protection is afforded for every individual as well as for the most exposed segment of the population. Both methods of looking at the radiation exposure limits are used by the AEC, but normally only that dealing with the individual is reported in safety-analysis reports. Since Dr. Gofman has talked about the total-population dosage rate, I will confine my remarks to exposure levels of 170 mrem/year.

I hope that I have made it clear that under AEC regulations no suitable sample population in the United States can be exposed to more than 170 mrem/year in the limit, and no individual can be exposed to more than 500 mrem/year.

For a reactor, individual exposure limits apply to persons assumed to be at the reactor boundary or in the most exposed condition. It is clear that as the effluent gas moves out from the stack it becomes more and more dilute by diffusion in the atmosphere. If we imagine that the effluent radioactivity might be blue smoke, it fades gradually until it becomes completely undetectable and unnoticeable as does smoke from any smoke stack.

Dr. Gofman assumes that every person in the United States somehow receives the limiting 170 mrem/year. Under the assumptions of Dr. Gofman, the same color of smoke which is observed at the edge of the boundary must now, in some miraculous way, spread out and cover the entire United States, as is indicated in Fig. 5. Obviously, that cannot physically occur. Since we know from physical observation that smoke becomes more and more dilute, we can be assured that any radioactivity in the air leaving the site will also become more and more dilute as it moves farther and farther away from the site. Thus, it is clear that Dr. Gofman is wrong, and wrong by a large factor. Under his assumption, the entire country would be covered with, if you will, a rather dense blue smoke, as shown by the shaded area in Fig. 6. Obviously, this is not physically possible.

It becomes more difficult to make accurate estimates of how far he is wrong. If one takes the Indian Point site and estimates the total radiation dose that could be given to the surrounding population by the Indian Point reactor site, one finds that the average dose to the population within 15 miles of the reactor site is about 1% of the radiation levels that exist at the site boundary. Thus, even if the radiation level at the

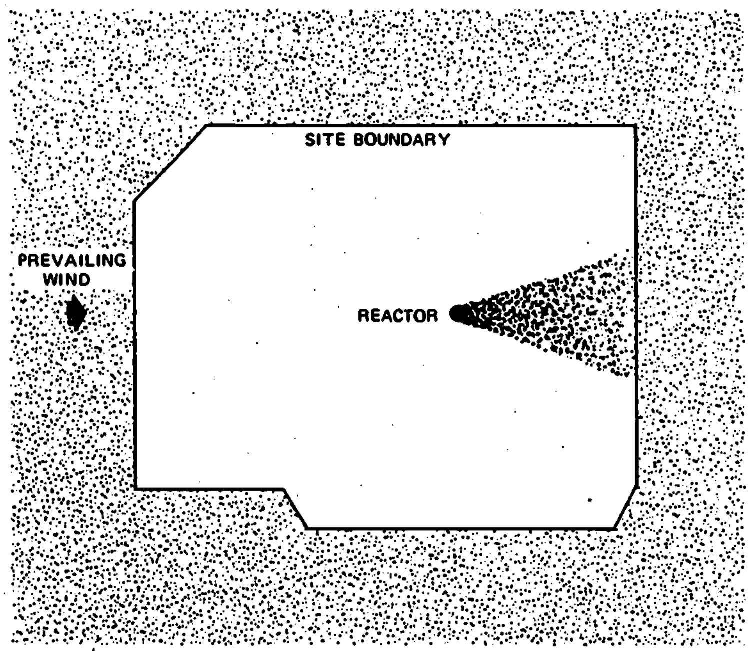

Fig. 5 Illustration of the illogical assumption of undiluted distribution of blue smoke from reactor boundary.

Indian Point site boundary were 500 mrem/year, the average person living within 15 miles of the site would be unlikely to receive more than 5 mrem/year if he stayed out of doors fully exposed all year long. I hope that helps to put these numbers in perspective. When one considers the entire country then, the sort of schematic picture we actually have is shown in Fig. 7. Here each of the reactor sites in the United States is shown surrounded by a 15-mile circle. Further studies on 11 different power reactor sites show that the resultant average dose rate for the whole population out to a 50-mile radius is 1 mrem/year—or $1/500$ of the dose rate assumed to be at the site boundary. In addition, experience with power reactors has shown that their discharge effluents are much lower than the AEC limits. It is estimated that the average exposure to the total population living within a radius of 50 miles of the 13 nuclear plants operating in 1969 was less than $1/100$ (0.01) of 1 mrem or less than $1/17{,}000$ of the 170 mrem/year limit.

On occasion, Dr. Gofman has said that there might be as many as 32,000 extra cases of leukemia and cancer per year if the radioactivity in effluents were allowed to reach the maximum permissible levels under AEC regulations. I hope that this discussion will show clearly that the numbers he uses do not represent the real world. Instead of having 32,000 cases per year, we probably have statistically less than one extra case of cancer or leukemia as a result of the presence of those nuclear reactors now in operation, under construction, or definitely planned.

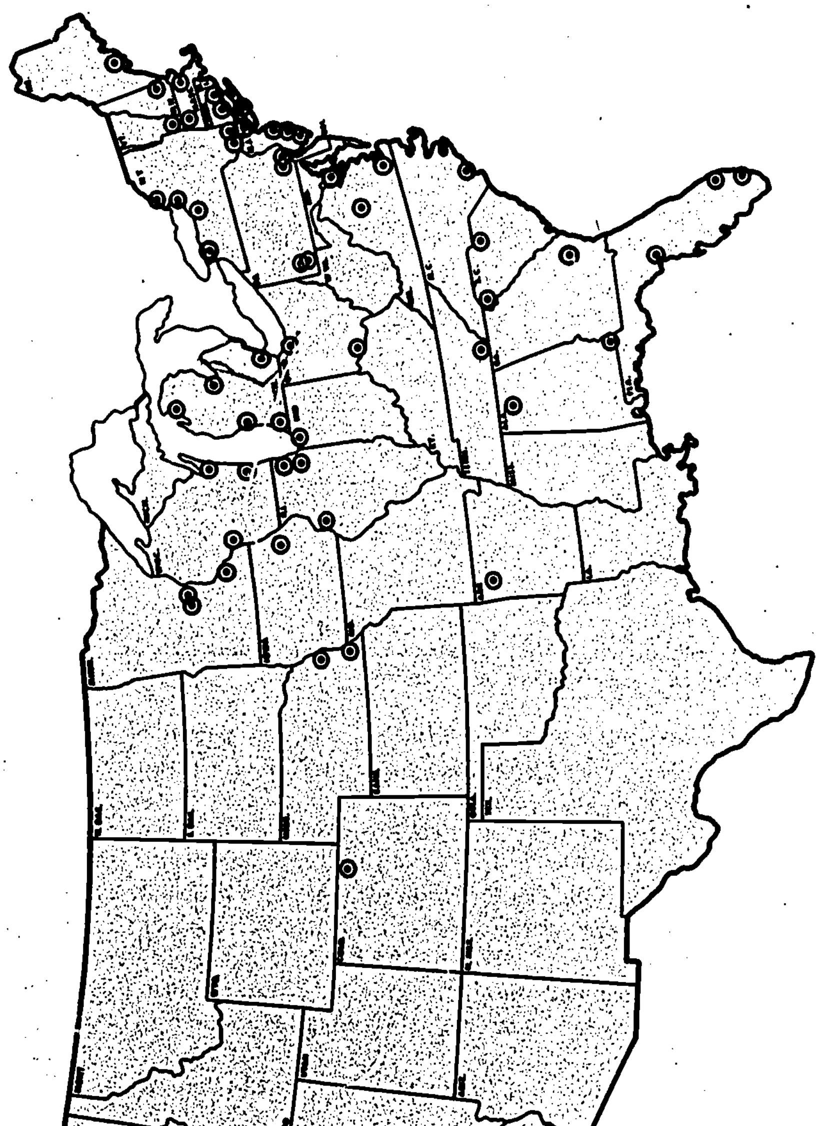

Fig. 6 Illustration of the illogical assumption of undiluted distribution of blue smoke over the entire United States.

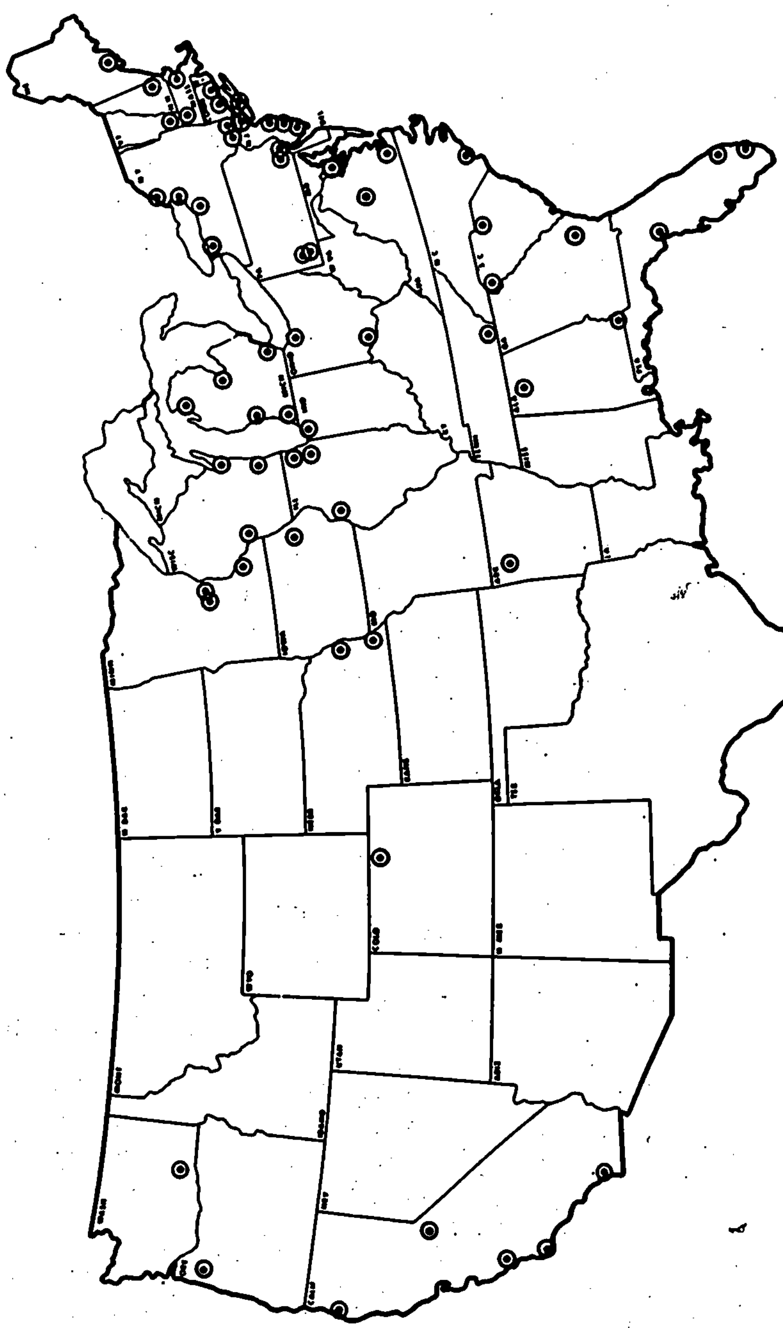

Fig. 7 United States reactor sites shown within circles with a 15-mile radius. Fifteen miles from the reactor site, radiation levels are about 1% of those at the site boundary.

One should contrast these small effects with the situation in regard to coal fumes and smog to put the situation in balance. In London, England, in December 1952, 4000 people passed away within 10 days because of air contamination caused by a combination of coal smoke and bad weather conditions. Even though such large numbers of people as this are not likely to be directly killed by coal smoke, the cancer-causing effects of coal smoke and organic compounds contained in smog and in automobile exhausts may, in a place such as Los Angeles, be similar to those caused by smoking cigarettes. Clearly, these effects of smog are of major proportions and are not even close to being fully understood or investigated.

In fact, the AEC finds itself in the unusual position of being severely criticized because it has done a better job than almost anyone else in trying very hard to understand and evaluate the risks of radiation. Radiation is understood much better than almost any other of the possible effects caused by man or his environment. The presence of radioactive atoms as a contaminant can be detected with a sensitivity about one billion times that with which chemical contaminants can be detected. It is strange that we who believe that atomic energy is an improvement in our environmental situation find ourselves attacked on the environmental basis, when we know full well that when the final choice is made nuclear power must prevail because the alternatives to nuclear power will have much worse effects on human health. In the long run there appears to be no other source of power to support our civilization.

It is probably worthwhile to mention an element called tritium. Tritium is a heavy radioactive isotope of hydrogen produced in small quantities during the operation of nuclear reactors and has been cited as a source of public concern by some when considering the use of nuclear power. It is necessary to put the quantity of tritium that could be involved in perspective. There is not much of it. Let me use an analogy. Picture the entire United States as a huge forest having one tree on each square foot of land, each tree having 10,000 leaves. Now, in this forest of a billion, billion leaves, if each leaf were to represent a hydrogen atom, there would also be dispersed throughout this forest about 80 tritium leaves due to cosmic rays and past nuclear weapons tests in the atmosphere. The amount of tritium that would be added to the environment from the operation of all the nuclear reactors planned through the year 2000 would be equivalent to about one additional tritium leaf. The nationwide forest of a billion, billion leaves would now contain about 81 tritium leaves.

In addition to tritium some radioisotopes with special characteristics are, or may be, produced in reactors which should be mentioned. The noble gases xenon and krypton are normally retained within the fuel-element cladding during operation. Since they are gases, they will be extracted from the fuel during reprocessing. The AEC has developed in its laboratories several methods to collect and retain these gases. As the reprocessing of fuel becomes more and more important, noble-gas-collection methods must be incorporated in the reprocessing. Additionally, in reactors where fast neutrons bombard nitrogen, extremely small quantities of carbon-14 (^{14}C) could be found. Other radioactive isotopes, fission products, or activation products are normally retained within the fuel elements or water-purification systems during operation and can be collected and stored safely by methods already developed by the AEC.

As responsible citizens we must make balanced decisions in matters as difficult and complex as environmental pollution. It is not adequate for the critics of nuclear power to point only to its weaknesses; nor is it adequate for the proponents of nuclear power to point only to the weaknesses of fossil plants. We all have to evaluate the benefits that power brings to us and then decide what kinds of risks are involved in the various methods of power generation in order to make the proper choices. We at the AEC have been doing this for years in regard to nuclear power and safety of the public, but perhaps our view has been, at times, too narrow. We have tried very hard for many years and believe that we have well-developed and conscientiously applied methods of risk evaluation. But we have not quantified the benefits very well yet, and it is only lately that we have begun to examine nuclear power vs. other forms of power on a risk–benefit basis with anything approaching the same degree of rigor. The risks involved from the presence of SO_2, CO_2, oxides of nitrogen, and particulates are not at all well understood. My own view of this balance is that, although nuclear power is a clear front-runner on an environmental-impact basis, we will have to use all the types of fuel and energy generation available to us, and we will have to improve the environmental impact of each of these to preserve an adequate environment.

On balance, I feel quite certain that nuclear power will stand up well now and in the foreseeable future as far as comparative risks to the environment are concerned. If you think about it just a little, you will perceive that our civilization must have adequate power, and you will find that most of it goes not for electric toothbrushes but for industrial uses. Even the gasoline pumps in our filling stations are driven by electricity. How shall we get this power? The decision is yours.

THE RADIATION HAZARD FOR MAN

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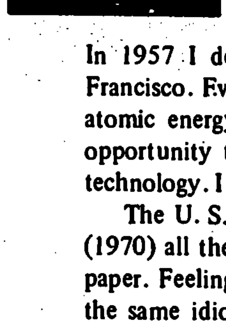

Dr. Gofman received the B.A. degree in chemistry from Oberlin College, the Ph.D. degree in nuclear and physical chemistry from the University of California (Berkeley), and the M.D. degree from the University of California (San Francisco). Dr. Gofman was a codiscoverer of ^{232}U and ^{233}U and of ^{232}Pa and ^{233}Pa. In addition to teaching for over 20 years, he has done research on low-dosage radiation, chromosomes, and cancer. He has been a group leader on the plutonium project, Medical Director, and Director of the Bio-Medical Division, Lawrence Radiation Laboratory, and Professor of Medical Physics at the University of California (Berkeley). He is coeditor of *Advances in Biological and Medical Physics*, an annual publication.

In 1957 I delivered a paper before a public-relations meeting of industry in San Francisco. Every one of the stupid platitudes and erroneous public-health principles of atomic energy promoters can be found in that paper. Since that time I have had an opportunity to learn a great deal about sound public-health principles in relation to technology. I am chilled by my ignorance of 13 years ago.

The U. S. Atomic Energy Commission and its supporters espouse vigorously today (1970) all the stupidities and erroneous public-health principles that were in my 1957 paper. Feeling lonely, the AEC is anxious to show that in my prehuman period I said the same idiotic things they say now. Therefore, if you want a copy of those 1957 remarks, you have only to turn your head in the direction of Germantown, Md. Immediately 500 or 1000 copies of my 1957 speech will be sent to you by AEC headquarters.

So, our currently allowable radiation dose could lead to between 100,000 and 1,000,000 extra genetic deaths per year. Not tomorrow—but in some number of future generations. If our population does grow to 300 million, then by the time the genetic death increase is felt, there would be 150,000 to 1,500,000 extra genetic deaths per year.

Lederberg, using his estimated 10% increase in mutation rate and considering the multigene diseases, estimates that currently allowable radiation doses would lead to a $10 billion annual increment in the health and medical care burden. Because of uncertainties he says the true cost could lie between $1 billion and $100 billion per year. Lederberg's estimates are in excellent accord with our estimates. Dr. Bibb of the redoubtable AEC does not contest the genetic hazard. However, at Charlotte, N.C., on Nov. 15, 1970, he enthusiastically pointed out that maybe research will enable us to undo the genetic damage. In the typical approach of the technology promoter, Dr. Bibb is telling us that, by dint of dollars and devotion, technology will undo all its harm. It is barely possible that people might prefer not to be genetically injured at all.

Only Chairman Holifield says the standards are "abundantly safe" with respect to genetic hazard. Mr. Holifield is remarkable as he faces the prospect of 1,500,000 extra genetic deaths per year to be caused by his promotions. He is brave with the lives of others. I am sorry Mr. Holifield is not here with us tonight, but he decided to compete by giving a lecture of his own.

THE RUSSELL MOUSE GENETICS STUDIES

Recently a number of absurd statements have been made in abuse and misuse of the Russell mouse studies. These studies provide nothing, I repeat nothing, to make us feel any easier about the genetic hazard of ionizing radiation. The claims are that the genetic hazard of radiation is less than previously thought on two grounds: (1) Slow delivery of radiation (based upon male-mouse studies) reduces the estimated human genetic hazard threefold, and (2) the female mouse shows a "threshold dose rate," and below this dose rate, genetic damage in the human female can be neglected.

The direct translation to the human is, of course, manifestly ridiculous. But the claims themselves do not hold up on careful examination. Indeed the Russell data support practically nothing concerning the potential hazard to humans.

The Male Mouse

Russell has indeed shown, at very high total doses (>300 rads), that slow delivery of radiation produces one-third as many mutations as does rapid delivery of the radiation. For the high doses this Russell observation is no doubt correct. Therefore, consideration of the most optimistic results of Russell is achieved by consideration only of the low-dose-rate data. If such optimistic data are used, the Russell mouse studies lead to 100 rads as the doubling dose. Now, 100 rads is one of the limits used by the UN Committee, and this doubling dose for genetic mutations leads to 100,000 extra genetic deaths annually for a population of 200 million people. This hardly leads one to feel that the most optimistic Russell data predict anything hopeful about the genetic hazard. One can say that before the Russell study the "standard setters" chose an allowable dose that would lead to a massive calamity (300,000 extra genetic deaths per year). In view of the Russell studies, the ineptness of the "standard setters" leads only to a major calamity (100,000 genetic deaths per year).

But, even though the most optimistic Russell data suggest a major calamity, there are several important reasons why the optimistic Russell studies may be irrelevant. Russell's data show a 30-fold difference in radiation-induced mutations in the seven gene loci studied. It is entirely possible that the doubling dose for some of the genes may be far below 100 rads. This, translated to man, could mean the 100,000 extra genetic deaths per year could rise manyfold.

Russell has pointed out that the mouse is 15 times as sensitive to radiation-induced mutation as is the fruit fly (*Drosophila*). Presumably Russell has considered the possibility that man may be more sensitive than mouse. If so, how much will the doubling dose fall below the optimistic 100 rad value? And how high will the estimated number of genetic deaths go above the 100,000 per year?

The Female Mouse

The claims for the female mouse are twofold: (1) The sensitivity to radiation mutation is less than for the male, and (2) a "threshold dose rate" exists for mutation in the female mouse. Neither claim is even remotely supported by anything in all the Russell publications up through the present (1970)!

As for the female mouse's being less sensitive than the male mouse, this claim rests upon an unjustified selection of data plus improper analysis of data. Russell's 6- to 9-month-old female mice are as sensitive as, or more sensitive than, male mice, with respect to radiation-induced mutation. The 2- to 4-month-old female mouse is less sensitive than the 6- to 9-month-old female mouse. Russell provides no justification for selection of the 2- to 4-month-old female mouse.

The claim of a "threshold dose rate" is totally unsupportable. Russell bases this upon almost no data at all. Indeed, the female data are totally consistent with a lower doubling dose for radiation-induced mutation than for the male mouse. The "threshold dose rate" for the female mouse is a mythical speculation, unsupported by the Russell data.

One can only shake his head in bewonderment at the misuse of the Russell data in the effort to paint a falsely optimistic picture of the genetic hazard of radiation.

Thus far, our considerations of genetic hazard have addressed only mortality. Several important socially crippling, but nonlethal, diseases are also multigene in origin, including diabetes mellitus, rheumatoid arthritis, and schizophrenia. Consider-how Dr. Mays arrives at our "enormous" number of errors. I do believe we did have one transcription error from his table. Dr. Mays agrees that none of the conclusions are altered in any manner worth speaking about, but he says we are careless. Here Dr. Mays commits a cardinal blunder in data presentation, and then he accuses us for being taken in by his absurd data presentation.

It is clear to us that none of the so-called AEC criticisms of our work are even remotely meant to be a serious effort to deal with the serious problem of estimation of the somatic and genetic hazards of ionizing radiation for man.

We think the time for fun and games is over, and we are hoping the AEC will begin to view the problem seriously before it has lost all opportunity for some credibility.

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A PROPOSAL FOR A RATIONAL POLICY TO CONTROL RADIOACTIVITY AND OTHER FORMS OF POLLUTION

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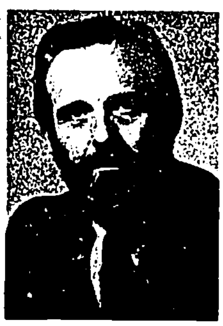

Dr. Tamplin received the B. A. degree in biochemistry (cum laude) and the Ph.D degree in biophysics from the University of California at Berkeley. At Lawrence Livermore Laboratory he has been responsible for developing the capability of predicting the ultimate distribution within the biosphere, particularly the concentration in man, of each radionuclide produced in the explosion of a nuclear device. His program has also investigated the effects of the radiation exposure to man from these nuclides. Before joining the Livermore staff, Dr. Tamplin worked for the RAND Corporation on space program problems. He has also served on the AEC's Committee on Space Nuclear Systems Radiological Safety, with emphasis on the hazards of plutonium.

Environmental pollution is a matter of extreme moment. Decisions concerning pollution should not be made in secret by so-called experts. The burden of proof should be shifted from the public and/or the government regulatory agency to the polluter. The polluter must be made responsible for convincing the public that he has done everything possible to reduce the level of pollution and that the benefits to be derived from his activity outweigh the risk of the remaining pollution.

POLLUTION AND THE FRAGILE HUMAN ORGANISM

Man seems to have an unbelievable amount of self-esteem. He believes that he can take a tremendous amount of adversity and survive, and in this belief he is correct. But the important fact that he seems to overlook is that he pays for these insults to his physiological competence. He pays for them in terms of reduced physical fitness and a shortened lifespan.

For the wide variety of toxic materials that are introduced into the environment as pollutants, there are various standards established that are called permissible levels or maximum permissible levels. Generally, these standards represent concentrations below, usually considerably below, the level where immediate and obvious symptoms of disease would occur. We are therefore lulled into complacency by being led to believe that concentrations below this permissible level are harmless. This is not necessarily true. In fact, for most pollutants it is undoubtedly incorrect. Although it is below its permissible level, a pollutant is most likely still causing its adverse effect but at a rate that was too small to observe in the small number of short-lived experimental animals on which it was tested or in the brief period of time that it was tested in a small group of human subjects. The human subjects are usually adults, and little is known about the long-term effects on the growing and developing child. As a result the pollutant may have an effect that was overlooked in the testing procedures or could not have been observed in the tests. Such would seem to be the case with thalidomide, and, as a result, new drugs are now tested for their effect on the developing fetus.

Moreover, the effect of two pollutants in combination may be far worse than the sum of the effects of the individual pollutants. For example, radiation combined with cigarette smoking is ten times worse than radiation alone. It appears most likely that this synergism among pollutants will prove to be the rule rather than the exception. We should seriously consider such statements as those of Dr. Saffiotti, Associate Scientific Director for Carcinogenesis, National Institute of Health: "The striking potentiation of effects of low levels of a systemic carcinogen in the lung by as simple a treatment as the pulmonary penetration of a dust warns against the dismissal of any carcinogenic exposure—even at low levels—as being 'safe'."

It must be remembered that even a food additive is a potential pollutant and could have a small adverse effect on every individual or a serious adverse effect on 1 in 10,000 individuals. Either effect could have been unobserved or unobservable in the testing procedures. Either effect could cause a large amount of injury when, aided by mass distribution and mass-communication advertising, the product is made available and attractive to 200 million individuals. Secretary Finch's decision on cyclamates was a courageous departure from the past and an essential step into the present.

The point I am trying to make here is that the uncertainties connected with the effects of radioactive atoms are shared by practically every form of environmental pollutant. We are most likely paying a price for each pollutant, and the net effect of all of them may be more than we would like to pay.

WHY DO WE HAVE POLLUTION?

When we survey the arsenal of scientific and technological knowledge that is available to this nation and its industry, it is obvious that the means are available to essentially eliminate all forms of environmental pollution. There is one exception to this, and that is waste heat. There are numerous signs today which demonstrate that the present levels of pollution are detrimental to man and his environment.

The developing nuclear industry in the country offers a current example of why we have such a serious pollution problem. At the same time, we can and should learn from this industry what is required to improve the quality of the environment and the quality of life in this country. This industry is at the heart of the problem because, in addition to being a polluter itself, it will generate the power to operate other industrial polluters.

As long as there is a legal limit or no limit to pollution, any nonsensical industry can pollute. A legal limit to pollution either implies that there is a safe level of contamination or that the process generating the pollution has a benefit to society that outweighs the attendant risk. We have no evidence whatsoever to indicate that there is a "safe" level for any form of pollution. Moreover, when a legal limit is established, pollution occurs without any balancing of benefit vs. risk.

The AEC suggests that they have done a risk-vs.-benefit calculation and have found that the benefit outweighs the risk. But they never present a benefit value, and they detest people like us who dare to present a risk value. Consider the statement by Dr. Werth, Associate Director for Plowshare at Lawrence Radiation Laboratory, commenting on a question posed by Senator Gravel: "It is difficult to balance a risk of radioactivity against a benefit. There is a need for natural gas. One of the most thorough studies is that by the Federal Power Commission entitled 'A Staff Report on National Gas Supply and Demand,'* Bureau of Natural Gas, Federal Power Commission, Washington, D. C., September 1969. If more gas were available, it could be burned in more cities and significantly reduce the smog and health hazard associated with the presence of smog. Balancing the health hazard due to smog against a possible health hazard due to background levels of radioactivity has not been done to my knowledge." Why not do this study before spending millions of dollars on the gas-stimulation program? Would such a study show that piping radioactive gas into homes is a reasonable solution to the smog problem? It would seem that even Congressman Holifield doubts the risk vs. benefit in this case because he asked why 50,000 million cubic feet of gas should be shipped to Japan each year if the shortage of natural gas was as serious as the AEC said. After you listen to their arguments for a second time, if you are not too terribly naive, you realize that all they have done is a cost analysis.

It is precisely this balance between benefit and risk that is the primary ingredient in the nuclear-reactor controversy. The nuclear technologists blithefully state that the

*Notice how he equates need with demand.

benefits from nuclear power outweigh the risks. But they only imagine the benefits and minimize the risk.

The risks associated with nuclear power plants are not just the radioactive releases during normal day-to-day operations. The risk must include the possibility of a major and catastrophic accident. We do not know what the chances of such an accident are. The risk must include the vast amounts of radioactive wastes that are accumulating in tanks at fuel reprocessing sites. We have not devised a system for managing these wastes. And finally, the risk must certainly include the realization that we have not developed an adequate system to prevent the diversion of special nuclear material, such as plutonium and enriched uranium, into the illicit manufacture of atomic weapons.

And what about the benefits? Nuclear technologists say that nuclear plants are clean compared to coal-fired plants and that we need more electricity to continually improve our standard of living. All the nuclear critics that I know deplore fossil-fuel generating plants as much as, and even more than, nuclear plants. No one can deny the ill effects of the noxious gases that belch from the chimneys of these fossil-fuel plants. Fossil plants can and should be cleaned up. If the present rash proliferation of nuclear power plants were meant to stop the drain on the world's fossil-fuel resources, one might be more willing to accept some of the risk associated with these plants. But the driving force behind this proliferation is not to replace but to augment the fossil-fuel plants. Present projections indicate a 10-fold increase of electrical power production by the year 2000. Only 50% of this is projected to be nuclear. That means a fivefold increase in fossil-fuel plants.

Consequently, focusing attention on the comparative or absolute risk of the two types of generating facilities has obscured the fundamental question associated with the electrical power industry. The fundamental question is, simply, "Why more power?" A flat and unqualified statement that ". . . power needs are doubling every eight years" is not sufficient. To accept this statement without question is to accept and endorse the notion that electrical power consumption is a desirable end in itself. Today, when environmental questions are paramount, it becomes necessary to question the basis for all intrusions on the environment. I do not know that we need more power. The population of the United States increases at about 1% per year. It is certainly not obvious that a population increase of 1% per year demands an increased electrical power consumption of about 10% a year. It is certainly not obvious that power demands are equivalent to power needs. How is the power to be used?

It is stated that this power is needed to increase our standard of living. Yet, although we are the most industrialized nation in the world, our infant mortality and age-specific death rates are 1.5 those of a number of countries, e.g., Sweden, and the average life expectancy is 4 years less. On closer inspection we find that those in the upper 25% income bracket in this country have death rates and a life expectancy comparable to Sweden. At the same time, these biological data demonstrate that 50% of the U. S. population (those below the median family income) have an infant mortality that is more than twice what it should be and have a life expectancy that is reduced by more than 8 years. Moreover, 20% of the U. S. population (those with the lowest family incomes) have an infant mortality that is four times what it should be and a life expectancy that is reduced by more than 16 years.

Over the last several years, our energy consumption (electrical and otherwise) and our gross national product have increased. Coincident with these trends we have observed the strange phenomenon of a continuation of the inflationary spiral while the ranks of the unemployed are growing. The gap between the affluent and poor appears to be growing. Where is the evidence that increasing our energy consumption will do anything but compound the problems of the poor and the environment? I think we must face the unfortunate fact that power consumption today does not correlate with the nebulous "standard-of-living." Power consumption is correlating with the production of garbage and the decline in the quality of the environment.

A RECOMMENDATION FOR POLLUTION CONTROL

This then brings us to the means of controlling pollution. The reason we have pollution is that it is permitted either by law or by the absence of law. As I stated earlier, if there is a legal limit or no limit to pollution, any nonsensical industry can pollute. A legal limit to pollution either implies that there is a safe level of contamination or that the process generating pollution has a benefit to society that outweighs the attendant risk. We have no evidence whatsoever to indicate that there is a "safe" level for any form of pollution. Moreover, when a legal limit is established, pollution occurs without any balancing of benefit vs. risk.

To properly protect the public health and safety, the laws should read that the acceptable limit of pollution is zero and that the privilege of releasing a pollutant to the environment must be negotiated. The prospective polluter should be required to demonstrate in a meaningful manner that his activity will produce benefits to those affected that outweigh the risk.

This weighing of benefit vs. necessary risk should occur in public hearings before pollution-control boards. It is important to emphasize the word necessary—the benefits must be weighed against the *necessary* risks. The right to overrule a decision of the control boards should be reserved for the public through the courts or by referendum.

Environmental pollution is a matter of extreme moment. Decisions concerning pollution should not be made in secret by so-called experts. The burden of proof should be shifted from the public and/or the government regulatory agency to the polluter. The polluter must be made responsible for convincing the public that he has done everything possible to reduce the level of pollution and that the benefits to be derived from his activity outweigh the risk of the remaining pollution.

THE PUBLIC AND RADIATION FROM NUCLEAR POWER PLANTS

Victor P. Bond

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Dr. Bond received the M.D. degree from the University of California (San Francisco) and the Ph.D. degree in medical physics from the University of California (Berkeley). He headed the Experimental Pathology Branch of the U. S. Naval Radiological Defense Laboratory in San Francisco from 1948 to 1954. In 1955 he joined the Medical Department of the Brookhaven National Laboratory and became chairman in 1962. He was deputy director of the team that cared for the Marshallese exposed to fallout radiation. Dr. Bond has been a member of the National Advisory Committee on Radiation. He has published over 200 scientific papers on the effects of radiation.

Because the overall question of radiation protection guides and hazards to the public from exposure to radiations is badly in need of perspective, I will deal first with the radiation guides, or "standards," and then with the radiation exposure of the public from nuclear power plants. I shall conclude by responding to some of the assertions made by Dr. Gofman in his paper given earlier in the Forum.

Concerning radiation standards, or, more accurately, radiation protection guides, you have by now heard many times of 0.17 rem per year (170 millirem per year), the average dose that applies to the general public. What is the origin of this number, and how was it derived? It is common practice with toxic substances to establish limits for exposure of the public which represent small fractions of those established for occupational workers. A radiation dose of 0.5 rem per year (one-tenth of that which applies to radiation workers) was adopted for individuals; one-third of this value applies to small groups. The 0.17 rem per year for the general public is approximately one-thirtieth of that set for occupational radiation exposure. Actually however, the 0.17 rem per year has yet another important basis, which was put forth in the recommendations of a committee of the National Academy of Sciences.

In the mid-fifties the National Academy of Sciences established a series of committees, the Biological Effects of Atomic Radiation (BEAR) committees, to investigate the biological effects of atomic radiations, and in 1956 the committee on genetic effects issued its report.[1] This committee recommended that, on the basis of potential genetic effects, the total population should receive no more than 10 rem over a 30-year period, which was taken as the mean reproductive age of the human being. The 10 rem was intended to apply to exposure from all man-made sources, including radiations used in medicine. Half of this value, or 5 rem over 30 years, was later allocated to all sources other than medical. This leads to 5 rem in 30 years, or 0.17 rem (average dose) per year.

The guideline of 0.17 rem obviously represented a value judgment. However, this value is equal approximately to the amount of natural background radiation that human beings receive, a fact which played a significant role in the derivation of this figure. Background radiation is discussed in the BEAR committee reports and in essentially all basic documents dealing with radiation protection.

Why does background radiation figure heavily in this judgment? The reason is that background radiation represents an exposure of human beings which has been experienced over eons. Living things evolved from the most primitive stages while being exposed continuously to background radiation levels that were probably higher than what we experience at the present time. We have evolved from Neanderthal man in the presence of this radiation and in the process have developed serious overpopulation problems. Further, the amount of background radiation varies considerably over the face of the earth. In large areas of France, the background radiation averages approximately twice what it is here in the United States. In some parts of India, very large populations of human beings have existed from the earliest known times in the presence of background radiation 10, 20, or more times that which is experienced in the United States with no noticeable detrimental effects. Thus, standards-setting groups feel confident about radiation protection guide numbers that are of the order of background radiation, and they feel less secure as exposure exceeds these levels.

The committee therefore set the number of 0.17 rem per year as essentially a bench mark, or an upper limit of exposure of the general population. In doing so, the committee made it clear that they were not necessarily saying that there would be no harm to the population at those dose levels or that such dose levels are "safe." They did say, however, that they felt confident that at levels near background exposure, the effect on the population, if any, would be quite small and that certainly the human species would not go "down hill" or disintegrate. Thus, it is quite clear that the 0.17-rem-per-year average dose to the total population does not represent a threat to the continued existence and propagation of human populations.

Although the BEAR committee provided a basis for 0.17 rem per year as an upper-limit bench mark, this was not their most important recommendation. Their most important recommendations for radiation protection guides and the reasons for it are as follows: Although they recognized that there may well be no harmful effects at low doses, they accepted the thesis that any amount of radiation exposure may carry some probability of harm to the population, no matter how small that probability may be. Thus, the recommendation they would have liked to make is zero exposure. However, they realized that zero exposure is not only impossible but also impractical. Exposure from natural sources is inevitable, and some additional exposure is unavoidable if man is to realize the enormous benefits derived from uses of radiations and radioactive materials. They therefore made it quite clear that the population guides were provided with the idea of "stay just as far under that figure as you can." This idea is stated in many ways and frequently, not only by the BEAR committee but by standards-setting groups as well. The real recommendation is "keep it as low as practicable," and "it should most emphatically not be assumed that any exposure less than this figure (0.17 rem per year) is, so to speak, all right."

Hence, it simply is incorrect for anyone to say that the BEAR committee or any standards-setting group has stated that 0.17 rem per year is "allowed" or that it is considered "safe." The words "allowed" and "safe" simply do not appear in the lexicon of radiation protection guides.

Why is the real radiation protection guide "low as practicable" and not the upper limit bench mark of 0.17 rem per year? It is realized that when one must assume some degree of effect in a large population even at low doses—when one cannot say with certainty that there will be zero effect in the population—then any number other than zero equates to some presumed degree of injury in man. To avoid this trap of saying, albeit indirectly, that some degree of injury to human beings is acceptable, the standards-setting groups introduced the "lowest practicable" approach as the real protection guide, and the numerical figure of 0.17 rem per year was introduced as an upper-limit guide.

Who were these people who established 0.17 rem per year and the guide of "as low as practicable?" The names are readily available in the widely publicized 1956 report of the BEAR committee,[1] and they are as follows: Warren Weaver, H. Bentley Glass, George W. Beadle, James F. Crow, M. Demerec, G. Failla, Alexander Hollaender, Berwind P. Kaufmann, C. C. Little, H. J. Muller, James V. Neel, W. L. Russell, T. M. Sonneborn, A. H. Sturtevant, Shields Warren, and Sewall Wright. These men are among the most respected and responsible men in American science. A British group composed of equally eminent individuals issued similar recommendations at approximately the same time.

Now let us examine what the standards-setting groups did with the recommendations of both the BEAR committee and the British study. The standards-setting groups are the International Commission on Radiological Protection (ICRP), the National Council of Radiation Protection and Measurements (NCRP), and the Federal Radiation Council (FRC).* The recommendations of all these groups are essentially identical. Let us deal with the recommendations of the FRC,[2] since this group has a more official status in the United States than do the others.

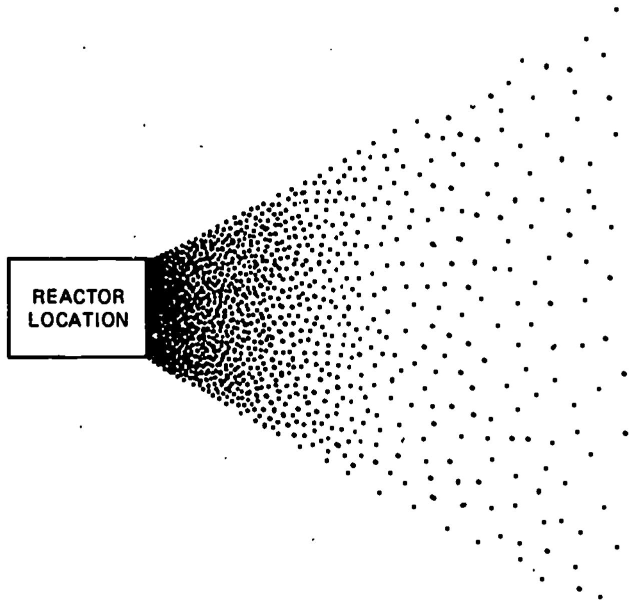

Fig. 1 Pattern of emission from a reactor stack.

The FRC, in its first report,[2] said, in essence, that the 0.17 rem per year recommended by the BEAR committee represents an acceptable bench mark, understood to be a barrier that is not to be approached or exceeded. However, it erected a much more restrictive limit or barrier in the form of a dose limit for the individual, i.e., 0.5 rem per year to the individual (still "not allowed" and "low as practicable" applies).

Why is the 0.5 rem to the individual more restrictive than the 0.17 average dose to the population? We can see this most easily by considering radiations from power reactors.

A principal AEC guide for radiation exposure from power reactors is identical to that of the FRC, or 0.5 rem per year to the individual at the site boundary. It is not the 0.17-rem-per-year average dose. That the 0.5 rem is much more restrictive than the 0.17 average can be seen from Fig. 1. Because of the rapid dispersion of material

*Since this presentation was delivered, the FRC has been incorporated into the Environmental Protection Agency (EPA).

coming from the reactor stack and because of the rapid decay of radioactive elements, the dose falls off very rapidly with distance from the reactor site. Thus, even if the dose at the site boundary were 0.5 rem per year, the dose to most individuals and the average dose would be very much below this value. This falloff of dose rate can also be seen in Fig. 2 in which the dose rate from a reactor is plotted as a function of distance.

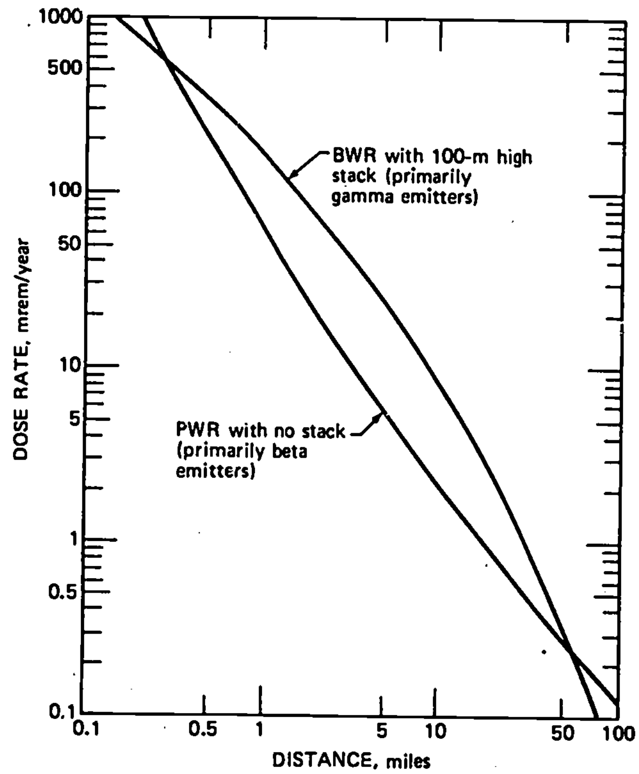

Fig. 2 Dose rate as a function of distance for a boiling-water reactor and a pressurized-water reactor normalized to give 500 mrem per year at 0.31 miles.

In this figure it is assumed that the individual at the boundary receives 0.5 rem per year. Note that the individual 50 miles from the plant would then receive one one-thousandth of this amount, or 0.0005 rem per year. The average dose to the entire U. S. population is far, far below this figure.

Thus one could easily see that, if the 0.5-rem-per-year guide for the individual is not approached or exceeded, the average dose to the population will remain far below 0.17 rem per year. This principle holds not only for reactor radiation but for most other sources as well. For exposure from color TV, jet travel, luminous watch dials, etc., the 0.5 rem per year is an enormously more restrictive standard than is the average dose of 0.17 rem per year.

Thus, when anyone refers only to the 0.17-rem-per-year average, he misleads by giving only a part of the radiation protection guides. Failing to explain the more restrictive 0.5-rem-per-year guide for the individual as well as the most important "low as practicable" clause and inferring that reactors can deliver an average dose of 0.17 rem per year to the entire U. S. population is tantamount to taking statements completely out of context.

We have stated that the effective standard is "low as practicable" and that the assigned numbers of 0.5 rem to the individual and 0.17-rem average to the population

Table 1

U. S. POPULATION EXPOSURE FOR THE YEAR 1970

Source	Av. dose, millirem/year
Natural background	100–150
Diagnostic X ray	50–150
The "standards"	170
Weapons testing	3
Jet travel, watches, color TV, etc.	1
Nuclear power plants	<0.001

Radiation risk x av. dose x 200 million people → less than 1 death per year

are upper-level bench marks. How well have we done in holding exposure of the population below these bench marks? The answer can be seen in Table 1, in which estimated average exposure figures for the U. S. population in 1970 are given. Note, as did the BEAR committee, that the principal exposure of the population comes from diagnostic medical X rays and that the next most important source is fallout radiation from nuclear weapons testing. Note that exposure from all other sources is very low indeed, well below 1% of the 0.17 average dose. Then note the average exposure from the 15 operating nuclear power reactors in the United States. The exposure here is of the order of 0.001 millirem (0.000001 rem) per year.

It should be pointed out that this low average exposure from power reactors has in no way been the result of the present controversy over radiation standards and nuclear power plants. The present plants were designed and many were in operation long before the current controversy began. This is an excellent example of the "low as practicable" clause in operation.

Why is exposure of the general population from all sources that come under the standards so low and so far below the 0.17-rem bench mark? This is not by accident. In the first place the "radiation industry" is one of the very few that began assessing since its earliest beginnings what effect it might have on people and on the environment. An enormous amount of research has been done on the effects of radiation, most of it financed by the Atomic Energy Commission. Scientists have been asked continuously to evaluate the results of research and to assess the possible effects of low-level radiation exposure on man. And the recommendation of the scientists, to keep exposure "as low as practicable," has been taken seriously and has been adhered to.

Also, a number of "watchdogs" were set up to ensure that excessive exposure is avoided. Who are these watchdogs? First, the AEC itself. Despite the unkind words that have been said about the AEC, some of which I am sure are deserved, the AEC is a hard taskmaster. Licensing procedures of the AEC are indeed difficult. Power companies have come to appreciate how strict indeed are the AEC regulations. From my personal experience at the Brookhaven National Laboratory, supported by the AEC, I know that all regulations having to do with the potential exposure of human beings are strictly enforced. If an AEC installation does not conform, the AEC can and will shut down that installation.

A second set of watchdogs are the national, state, and local public health departments. These groups observe very carefully potential sources of exposure of a population. Witness the fairly recent furor over color TV and possible "overexposure" of the public. The standards for X-ray emissions from TV sets are extremely restrictive, and the dose to the public from this source is very small indeed. However, the companies making TV sets were required to adhere rigorously to the standards.

A third watchdog is the scientific community itself; however, I shall return to this in a minute.

Radiation protection guides have been likened to a speed limit in that there is no absolute basis for setting a numerical value for a speed limit or a radiation protection guide, and judgment is required. The analogy is true to a degree; however, a real difference between the two situations exists. With a speed limit one experiences no difficulty with the police until he exceeds the speed limit. With radiation, however, the exact reverse is true. Figuratively, the minute one gets into his car and before he can even drive off, he has not one but a whole squad of policemen on his tail to see that he does not even move unless there is good reason, or, if he does move, that he does not drive any faster than is absolutely necessary.

Now, to return to the scientific community as a watchdog for radiation exposure of the public, as was stated scientists provided the 0.17-rem-average-per-year guide as an upper-limit bench mark as well as the "low as practicable" clause. The FRC introduced the 0.5-rem-per-year guide for individual exposure which virtually ensures that the 0.17-rem-per-year average could not be approached or exceeded. There are two situations in which the average of 0.17 rem per year potentially could be exceeded. One involves the use of diagnostic X rays; the other is weapons testing above ground.

Exposure from medical diagnostic X rays is not included in the radiation protection guides. Further, a most striking conclusion of the BEAR committee was that this is by far the largest man-made source of exposure of the population. This fact was pointed out to the medical profession, and a great deal of pressure has been brought to bear to reduce the amount of exposure incurred in diagnostic procedures. More along this line can be and is being done.

A large amount of testing of weapons above ground was done up to the middle fifties. Scientists saw that exposure of the public from this source was increasing and that it could easily reach 0.17 rem per year if such testing continued. As a result, a petition was circulated, and 2000 scientists signed it. There were two interesting side-lights to this petition. The first is that several individuals who were on the original BEAR committee and who had set the number of 0.17 rem per year also signed the petition. What they were saying, in effect, is "we gave you a bench-mark number and we said don't approach it. We meant what we said."

The other interesting aspect is that the petition was signed in May 1957. In June 1957 Dr. Gofman delivered his speech[3] on fallout radiation to the press—the same speech that he referred to in his Forum paper. The speech was clearly on the side of fallout being nothing to worry about. He was at that time carrying the banner on the opposite side from the overwhelming majority of the scientific community. Today his banner reads that the public should be greatly concerned about radiation levels far, far below those he said were of no consequence in 1957. The scientific community, however, has not changed its position at all since 1957. Scientists have always realized that radiation, as any potentially dangerous agent, can be injurious and that it must be strictly controlled. With common sense, however, one can reap enormous benefits from the use with only miniscule risk.

Hence, one can see that, when there is a real probability that exposure of the population may become excessive, the scientific community has arisen and will arise again if necessary to correct the situation. However, the scientific community is unwilling to call "wolf" or to defend unreal or hypothetical threats or straw men such as those now being set up by the opponents of nuclear power.

Now let us deal with a potential number of cancer cases per year. It has been stated repeatedly that there might be some 32,000 additional cancer cases per year if everyone in the United States were exposed to 0.17 rem per year. (Note that this means 0.17 rem per year for many, many years.) To obtain this number, one must use an equation similar to the one shown at the bottom of Table 1, i.e., risk times dose times 200 million people equals cases per year.

I believe the number 32,000 to be far too high because both the risk estimate and the dose used to obtain the number are greatly excessive. The risk estimates per rad of radiation are much too high, even as upper-limit estimates, for the following reasons: they assume that all types of cancers will result from a given radiation exposure; this simply does not square with observations to date. They assume the same "doubling dose" for all cancers; there is no evidence to support this contention. It is stated that the estimates are based on "hard incontrovertible facts." There is a total absence of positive findings in man or animals at doses and dose rates compatible with the guides, and one is dealing entirely with interpolation or extrapolation based on hypotheses that very likely are not true. All estimates of numbers of excess cases per year should be expressed as "zero to some upper limit" to indicate that the effect may well be zero at these low doses and dose rates.

Further, with respect to upper-limit estimates of risk, the standards-setting groups, such as the ICRP, FRC, and NCRP, state that linear extrapolation from data at high doses and dose rates yields an upper limit of risk and that "it is unlikely that the risk per unit dose at very low doses will be any greater than at high doses and is likely to be much less." The risk at low doses may well be zero. The upper-limit figures were never intended as firm incidence figures. The ICRP tried to guard against misuse of upper-limit figures by giving only "order of risk" estimates. In other words, the ICRP gave risk, even as upper limits to only factors of 10. "Best estimates" were never calculated because the likelihood of their misuse is even greater than that of upper-limit estimates. It is generally agreed, however, that the actual risk is very likely well below the upper-limit numbers.

Concerning the dose received by the general public, the 0.5-rem-per-year dose to the individual ensures that the 0.17-rem-per-year average dose frequently used in such calculations cannot be approached, as I have indicated. The doses actually received by the population at present are only a small fraction of 0.17 rem per year. Thus, because the risk per rad estimates are too high and because the dose value is also quite high, the estimate of 32,000 additional cancer cases per year has essentially no relationship to reality now or in the foreseeable future. For radioactive emissions from power plants, the dose now and in the foreseeable future (Table 1) is only an extremely small fraction of the 0.17 rem per year. Thus, the number of excess cancer cases per year from power reactors is not the 32,000-per-year figure that has been widely publicized in the context of nuclear reactors. The true figure is much less than one extra cancer case per year from power reactors, now and in the future.

Now let us deal with the risk of radiation exposure relative to that from other agents that we encounter in everyday life. Relative risks from different agents are shown in Table 2. The chances per year of an individual encountering serious injury or death from the various agents listed are given. Living next door to a power reactor is seen to be by far one of the smallest risks that we encounter in life.

It is most misleading to single out radiation or any one hazard and not put it into perspective by comparing it with other hazards. Also, it is not sound public-health practice to point out only the risks from an agent such as radiation without discussing the benefits to be derived as well. Also, it is not sound public-health practice to avoid discussion of the risks from alternative approaches to the same problem. With respect to the generation of electric power, the only practical approaches now available are fossil-fuel power and nuclear power. We have the best toxicity data on radiation but only minimal data on the effects of effluents from fossil-fuel plants. And remember Dr. Gofman himself has estimated that some 200,000 people per year die in the United States from exposure to the airborne products of fossil-fuel combustion.

Now, I must reply to some of the specific allegations made by Dr. Gofman in his paper presented to this Forum.

He has often asserted that no level of radiation has ever been proved to be "safe." As a scientist he knows that this statement makes no sense scientifically. His statement

Table 2

CHANCE OF SERIOUS INJURY OR DEATH PER YEAR

Cause	Chance	
Auto accident (disability)	1 in	100
Cancer, all types and causes	1 in	700
Auto death	1 in	4,000
Fire death	1 in	25,000
The "pill." death	1 in	25,000
Drowning	1 in	30,000
Electrocution	1 in	200,000
Reactor emanations; site boundary (5 to 10 millirem/year)	<1 in	1,000,000
Average for population within 50 miles of reactor	<1 in	10,000,000

applies to all substances—drugs, food additives, and even your coffee, mustard, or catsup. It is never possible to prove that any substance is "safe" in the sense that it might not be possible to demonstrate some subtle damage if an extremely large exposed population could be studied adequately.

The recommendation that any potential polluter or industry should be required to prove that things are "safe" makes equally little sense. Industry must be bound by rules or guides promulgated by some appropriate independent group of experts. What is asked is an impossible demand in the sense of the word "safe."

Dr. Gofman stated that I am getting close to his estimates of numbers of cases of cancer per year. Actually, he generously made a calculation that I did not make and said that we "agree" within a factor of 4 or 5. Let us examine this statement further and see who has changed his numbers. My numbers are derived from ICRP estimates of risk[4] and indicate, for 0.17 rem per year each year, 3400 cases per year as an upper limit, with the true value between zero and this figure and the most probable value far below this figure. My figures have not changed. His, however, have changed continuously, even though the basic data available have not changed. His initial figure was 16,000 extra cases per year. This later became 32,000, then 80,000, and in his recent book,[5] on p. 19, it has become 128,000. In this same book (p. 98), he agrees with Dr. Pauling's estimates of 0 to 32,000. So Dr. Gofman has the entire range bracketed, from 0 to 128,000 extra cases per year. He can thus easily prove that he agrees with anybody and everybody.

Dr. Gofman referred to the work of Dr. Mays and to our data on breast tumors in rats, and we have published our comments on his misuse of our data[6] as has Dr. Mays.[7] Dr. Gofman likes to deal with numerical values for "doubling doses." We agree with the ICRP:[4] "use of the concept of doubling dose for somatic (i.e., cancer) hazards is a specific misuse of the ratio of cancer rates." To show how silly the numbers can get, some 60% of our rats normally (no irradiation) develop tumors of the breast. How is one going to provide a radiation dose that will give a 120% incidence, or more rats with tumors than we have rats?

However, the doubling dose was not the main point with respect to his misuse of our data on rats to support his presumed doubling dose for breast cancer in women. Actually, most of the tumors that we observed in rats are not cancer at all. More than half of the tumors we observed are nonmalignant; i.e., if a human being had that type of tumor, it would be diagnosed as benign. We feel that it is a specific misuse of data to employ our results on noncancerous tumors in rats to bolster apparent results in the human being that have to do with as serious a disease as cancer.

In summary, my appraisal of the overall "radiation controversy" is as follows:

Information on possible late effects of radiation exposure has been analyzed and evaluated continuously for many years. Because of the well-known difficulties involved, extremely conservative approaches and rules for radiation exposure of the public have been promulgated and used. Exposure has been carefully controlled so that the dose received by the public is an extremely small fraction of the upper-limit radiation protection guides.

Dr. Gofman has presented no data of his own, no new data from the literature, and no new arguments that change this situation. What is new is that he chooses to misrepresent the radiation protection guides by dwelling only on one part of them—the 0.17-rem-per-year average dose. He fails to explain, for instance, the far more restrictive guide for the individual and the "lowest practicable" clause which ensures that exposure of the public will be low indeed. Nothing is said about how extremely effective the guides have been in keeping exposure of the public low.

Also new is his misrepresentation as "hard incontrovertible fact" that which is widely known to be hypothesis with respect to the risk of cancer per rad of radiation exposure at low doses and dose rates. The risk may well be zero. His estimates of hazard are highly excessive even for high doses and dose rates.

Because the radiation doses and the risk per rad of exposure used by Dr. Gofman do not conform to fact, his estimates of potential effect on the population of the United States (some 32,000 excess cancer cases per year) bear essentially no relation to reality, now or in the foreseeable future. His estimates of risk from power reactors to the U. S. population bear no relation to reality. It follows that his representing the presumed hazard to the U. S. population as an urgent problem in need of immediate action has no justification.

Thus. Dr. Gofman has presented a series of straw men to the American public and then proceeded to knock them down. Certainly no human activity is without fault and without need of or room for improvement. However, Dr. Gofman's attacks with respect to exposure of the public and its control simply are not warranted.

Perhaps most serious is Dr. Gofman's use of public gatherings concerned with the production of electricity by nuclear energy as a forum for promoting his views. The public goes away with the strongly instilled fear that a nuclear reactor will result in a large increase in leukemia and cancer in the community. Dr. Gofman indicated in his presentation here that routine releases represent no problem in this respect. Yet he continues to present his dire predictions in the context of nuclear reactors and makes no effort to indicate that his estimates of hazard simply do not apply to nuclear power plants. As to the "real" problems that he briefly mentioned (fuel reprocessing, transportation and storage of radioactive materials, etc.), all we have is his bald statement that they are "real." Actually, these problems have received and are receiving an enormous amount of attention; as a result the hazard to the public is even smaller than the miniscule hazard from routine releases.

The overall effect of Dr. Gofman's campaign is unfortunate. It contributes greatly to denying a world that is in fact seriously polluted not only the cleanest by far of the available sources of power but also the additional power that may well be required to clean up and control further pollution. It is ultimately the people who must decide if they want additional power and what kind of power; no individual, company, or agency can force such changes on a nonreceptive public. The public is taking this responsibility more seriously, and it has the right to all the relevant facts and considerations before such important decisions are made. It is a public disservice for anyone to engender an atmosphere of unbased fear in order to help force a one-sided decision that could lead to unreasonable and unfortunate consequences.

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ADEQUACY OF PRESENT RADIATION STANDARDS

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Karl Z. Morgan received the A. B. and the M. A. degrees from the University of North Carolina and the Ph. D. degree in physics from Duke University. In 1943 he helped develop and establish the new science and profession of health physics. He is chairman of the committee of the International Commission on Radiological Protection dealing with maximum permissible internal dose of radioisotopes. Dr. Morgan has published over 200 scientific papers and is editor of the journal *Health Physics*. In 1963 W. Binks (England) and he were awarded the first gold medals for meritorious work in radiation protection by the Royal Academy of Science (Sweden).

Ionizing radiation of course is not something new; man has been subjected to exposures from this type of energy since the beginning of time, and life on this earth has managed to survive, if not because of, certainly in spite of, it. In causing perhaps a 4 to 10% increase in the natural incidence of mutations, this exposure is in a sense beneficial over a long period of time. It is beneficial, however, only in the same sense that tigers were beneficial to those that might otherwise have been our forebears in the past because the tigers eliminated those that were not able to run so fast or were not quite as skilled in outguessing the tigers. In the cruel sense we could say that radiation is good for you because it provides a good chance of eliminating some of those that are less fit in society.

Table 1 indicates that even as early as the year 1500 it was observed in Saxony and Bohemia[1] that something in certain cobalt and pitchblende mines caused the miners to die of a so-called "miner's disease." High concentrations of uranium and radon were

Table 1

RECOGNITION OF HARMFUL EFFECTS OF IONIZING RADIATION

Date	Event
1500	In Saxony and Bohemia man first observed deaths from ionizing radiation exposure of certain miners
1911	These miners shown to have died of lung carcinoma
1930-1945	These carcinomas were shown to have been caused by daughter products of radon
1952	NCRP set MPC* for radon at 10^{-8} $\mu Ci/cm^3$ (~0.1 working level)
1959	ICRP set MPC for radon at 3×10^{-8} $\mu Ci/cm^3$ (~0.3 working level)
1959	Survey indicated 82% of U. S. mines operating at >1 working level and 29% >10 working levels
1970	Reported that over 150 deaths among the uranium miners from lung carcinoma were thought to have been caused by radon exposure

*MPC, maximum permissible concentration.

not appreciated then as a causative factor, and it was not until 1911 that it was shown that these men were dying of lung carcinoma. In the years from about 1930 to 1945, it was shown rather convincingly that the cause of death among these miners was very probably exposure to the daughter products of radon. In 1952 the National Council on Radiation Protection (NCRP) chose the level of 10^{-8} microcuries per cubic centimeter (10^{-8} $\mu Ci/cm^3$) or about $\frac{1}{10}$ working level as a reasonable and acceptable level for exposure. A few years later the International Commission on Radiological Protection (ICRP) selected the value of 3×10^{-8} $\mu Ci/cm^3$ or $\frac{3}{10}$ working level, and this value has continued to the present time. I personally feel that it is a rather sad commentary on our civilization today that in 1959 surveys indicated that 82% of the uranium miners operating in the Colorado Plateau were exposed at greater than 1 working level and 29% at greater than 10 working levels. It has been rumored, I do not know how accurate the estimates are, that as many as 150 persons may already have died as a consequence of these lung carcinomas. It is rather pathetic, I think, that we have to admit that although this risk was recognized in the year 1500, we have not had time enough or the inclination to recognize this risk in the Colorado Plateau and do something about it until very recently.

Figure 1 is given to orientate our thinking a bit and to emphasize, first of all, that, as far as the effects of radiation on man are concerned, anything we say is partly a guess. This figure indicates that we have chronic forms of damage, which seem to vary more or less linearly with the dose, and types of damage that seem to have a threshold below which you do not observe any effects. It is supposed that the numbers of

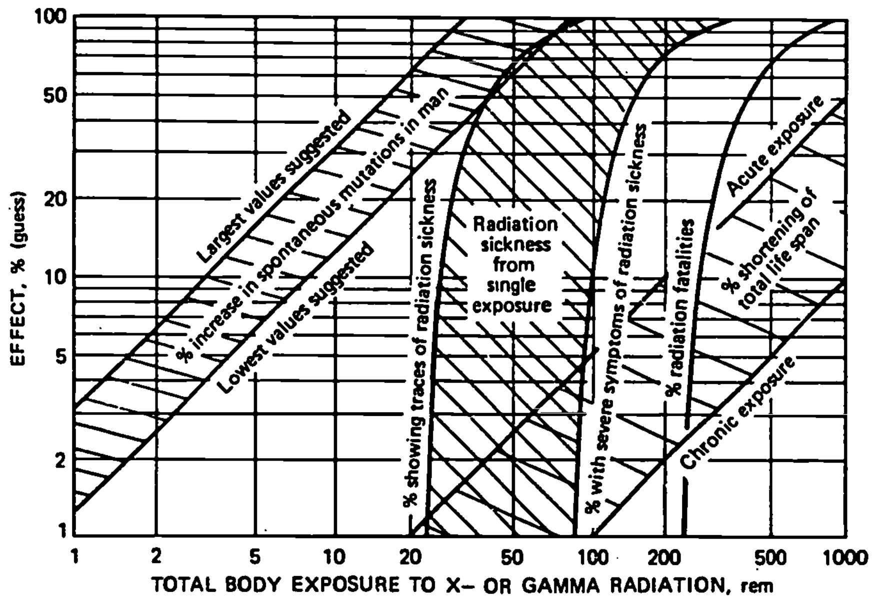

Fig. 1 Effects of radiation on man.

mutations increase more or less with the accumulated dose. You can see that 4 to 10% of the natural mutations might be caused by spontaneous exposure from natural sources. You can observe that the life-shortening curve has a value at very low dose rates of about 10^{-4} life spans per rem or 2½ days per rem. For single doses less than about 20 rem, you would not expect any radiation sickness though there is a wide range in variability in this regard among individuals. As shown by the fatality curve, you would expect no lethal effects from single doses less than about 200 rem, and you would expect the mid-lethal dose at about 400 rem from a single exposure. We might have added also the malignancy curve from ICRP data.[2] It is thought that the number of malignancies produced in man increases likewise, more or less linearly with the accumulated dose. In the simple mathematical terms of the ICRP,[2,3] you would expect to have about 2×10^{-4} deaths per rem at a low exposure rate due to malignancies, mutations resulting in first-generation deaths, and life-shortening. If you include the total mutations integrated out to infinity, this number becomes much larger, about 9×10^{-4}, and this again is for low dose rates. For high dose rates, including only the first-generation deaths from mutations, malignancies, and life-shortening, the slope of the curve would be about 4×10^{-4} deaths per rem, and, for the total number of genetic deaths introduced into the population plus malignancies and life-shortening, the slope is about 4×10^{-3} deaths per rem.

In regard to the mutation risk, the fine work of Russell[4] at Oak Ridge some years ago indicated that there is a rate effect for radiation exposure to mice. When the mutation frequency is plotted as a function of the dose rate, as I have done with

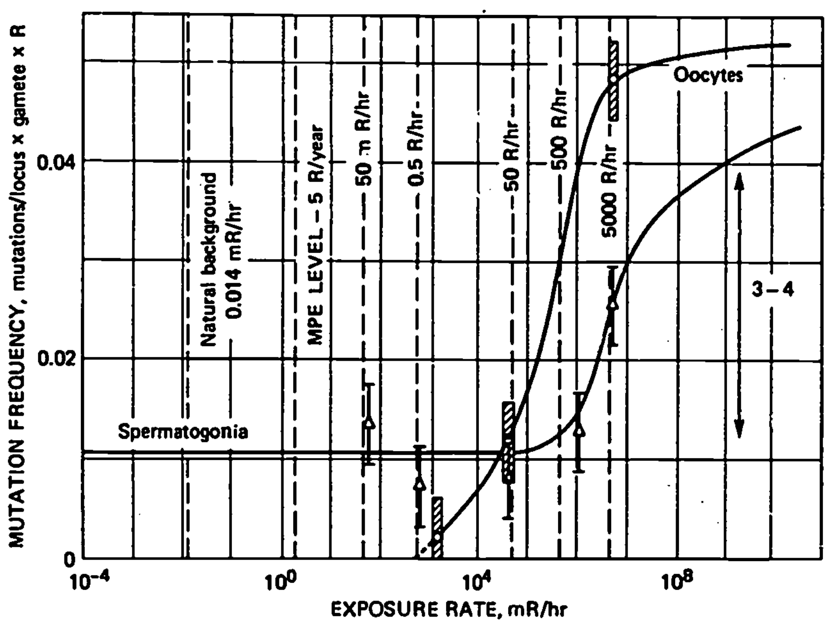

Fig. 2 Rate dependence of point mutations in mice. (Data from Russel.[4])

Russell's data in Fig. 2, mutation frequency at very high dose rates similar to those used by Muller with drosophila seems to be independent of rate; that is, the number of point mutations depends primarily on the accumulated dose. However, when you get down to dose rates of about 5000 R/hr, there is a rather precipitous drop off both in the oocyte curve and the spermatogonia curve. Oddly enough, for the female the curve seems to drop right on down into background. On the other hand, the spermatogonia curve levels off on another plateau after dropping down by a factor of 3 or 4. If for the male you get a drop off by a factor of 3 and you get a drop down to 0 for the female, you have an overall reduction factor of 6. Thus, you might want to reduce your estimate of risk from genetic mutations in man by a factor of 6 at very low dose rates. There is no evidence of further reduction or deviation from linearity of the genetic risk at lower dose rates.

Of course, when we talk about chronic radiation damage increasing with accumulated dose, we must keep in mind also that we have threshold effects at very large single exposures. Although we would expect a certain number of radiation-induced leukemias to result from 400 rem received by a large population over a lifetime, it would be quite different if this dose were received in a matter of a few days; i.e., 400 rem in a single exposure, as indicated in Fig. 1, is probably the mid-lethal dose for man.

Table 2 summarizes some of the consequences of natural background radiation based on the linear hypothesis. For natural background then you may expect that it

Table 2

DEATHS PER YEAR IN THE UNITED STATES CAUSED BY NATURAL BACKGROUND RADIATION*

Genetic deaths	17,000
Total malignancies	2,400
Life shortening	1,200
Total	~20,000

*Assuming the average dose is approximately 120 millirem per year (mrem/year), assuming a linear relation between dose and effect, and taking account of the modifying factor of 6 (described in the text) for point mutations in mice and applying it to man.

reduces the average life span about 10 days ($35 \times 2\frac{1}{2} \times 0.12 = 10$); that is, on the average you might live one or two weeks longer if it were not for natural background radiation. It causes over 2000 cancer deaths per year and 20,000 deaths per year from total mutations, cancers, and life-shortening. Very often you hear a person suggest, "Why not use natural background radiation as the starting point in setting permissible exposure levels?" You can do this if you like, but I think it would be a rather poor procedure because you do not know the effects of natural background radiation except by extrapolation from other data. In fact, it would be very difficult to find out the effects of natural background radiation from direct evidence or to set up an appropriate epidemiological study to get such information. As indicated in Table 2, I have assumed a linear relationship between dose and effect as have the national and international bodies that set these radiation protection standards. They state that in the light of present knowledge this seems to be the only prudent assumption. Looking ahead into the long-range future, we cannot think of any practical experiments which could be set up to show that you do or do not have a linear relationship between dose and effects at the very low dose rates we are talking about. I personally feel that the only way, the only real hope we have of answering this question is through basic research and by trying to develop a coherent theory of the effects of radiation on matter and on living organisms. Once we have this information, then we can talk with more confidence.

The work of Alice Stewart[5] has been very impressive to some of us in cautioning that radiation at very, very low doses might cause serious damage to man, especially to the younger members of the population. Figure 3 is a graph of some of her data showing the crude excess cancer risk increasing with the number of diagnostic X rays. The data seem to fit rather well on my straight line, which strongly suggests a linear relationship between dose and effect. Here we are plotting the malignancies (primarily leukemias) observed in children whose mothers received one, two, three, and up to five pelvimetries during pregnancy. In this case I would emphasize the average dose to the fetus per X-ray film was less than 2 rem (for comparison a person exposed at the

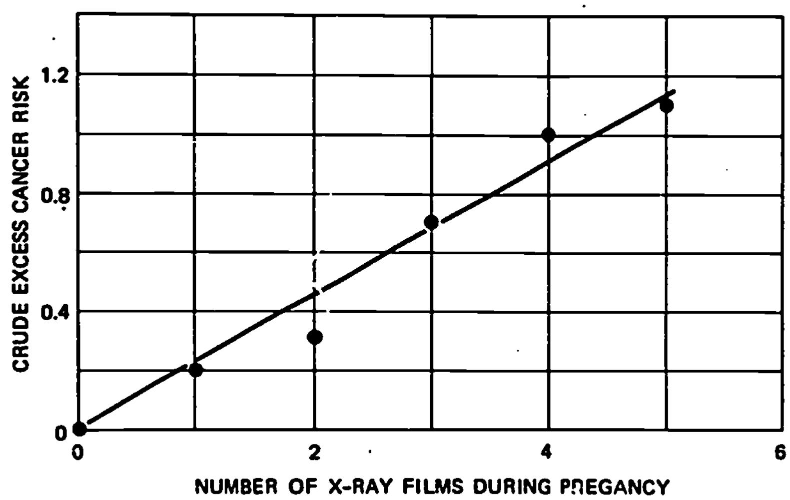

Fig. 3 Crude excess cancer risk from diagnostic X rays during pregnancy. (Data from Stewart and Kneale.[5])

recommended population dose limit of 170 mrem/year would receive 2 rem in 12 years).

There is a rather large mass of data, such as that referred to in Table 3, that suggests we are warranted in using this linear hypothesis and perhaps no other hypothesis at the present time. I have been impressed by the very fine work of Louis Hempelmann,[6] whom most of us here know quite well. In several of his publications, he has indicated his data on Marshallese children exposed to weapons fallout and on children in his Ann Arbor and Rochester study groups seem to fit the linear relationship beginning with 1200 rem right on down to at least as low as 20 rem.

Brian MacMahon[7] some years back examined the published data on the relationship between obstetric X rays and childhood malignancies. He was studying

Table 3

DATA SUPPORTING THE LINEAR HYPOTHESIS*

Thyroid cancer	Hempelmann found a linear relation between thyroid dose and cancer incidence from exposures of over 1000 rem down at least to 20 rem
Leukemia	Stewart, MacMahon, and the Harvard studies (involving 450,000 children) indicated a 30 to 50% increase in leukemia (and brain tumors) among children receiving in utero diagnostic exposure of less than 2 rem
Bone tumors	Studies at the Massachusetts Institute of Technology and the University of Chicago of persons with a body burden of ^{226}Ra indicate a tumor incidence consistent with the linear hypothesis

*The dose limit for individuals in a population is 0.5 x 70 = 35 rem/70 years; so there may be little or no safety factor in present MPE levels.

primarily the incidence of leukemia among children who had received exposure in utero. He took data from the various publications and weighed them according to the number of cases involved. He found that there seems to be about a 40% increase in the incidence of leukemia among the children who receive diagnostic X-ray exposure (<2 rem per exposure) in utero. There are many other studies we could point to that lead to the same conclusion; for example, in the Harvard study[8] roughly half a million

Table 4

LONG-TERM EFFECTS OF RADIUM IN MAN*

Ra body burden, μCi	Average bone dose, rem/year	Biological changes, %					
		None	Minimal	Mild	Moderate	Advanced	Malignant†
0.001–0.03	0.3–9	92	8	0	0	0	0
0.03–0–0.1	9–30	83	13	0	4	0	0
0.1–0.3	30–90	69	16	3	6	6	3
0.3–1.0	90–300	12	25	25	16	22	16
1.0–3.2		6	6	14	12	62	32
3.2–5.5		0	0	0	9	91	55

*From A. J. Finkel, C. E. Miller, and R. J. Hasterlik, Long Term Effects of Radium Deposition in Man, USAEC Report ANL-6839, pp. 7-11, Argonne National Laboratory; International Commission on Radiological Protection, Publication 11, *A Review of the Radiosensitivity of the Tissues in Bone*, Pergamon Press, Inc., New York, 1968.

†Those with malignancies were listed also under previous columns.

children were involved, and a 10 to 30% increase in cancer (primarily leukemia and CNS tumors) was found in children who had received in utero diagnostic exposure. When we talk about effects on man of doses in the range of 1 to 20 rem, you might at the same time ask this question, "What about the population dose of 0.5 rem, which is the limiting annual dose allowed to individuals in the population?" Since the average life-span is 70 years, this is 35 rems which is allowed to individuals. What about this limiting population dose; is it safe? Is it too low or too high? I think the present levels are satisfactory, but I do not agree with the statements some persons have made that they have built into them a very generous safety factor.

There might be some argument about the linearity of bone tumors with dose. Certainly Robley Evans does not agree that these data support the linear hypothesis. But I think he is rather unique in his interpretation of this data. Others[9,10] that have looked at his data have pointed out that it fits just as well the linear hypothesis and is very consistent with this hypothesis.

In Table 4 I have listed data from Finkel, Miller, and Hasterlik on the body burden of radium in the groups "no effects," "minimal," "mild," "moderate," "advanced," and "malignancies." Of course, those with malignancies are included also in the column of advanced cases. Having listed their data, I shaded a diagonal section across the table; you will notice that this diagonal area includes most of the numbers in the table, indicating that we seem to have a gradual progression beginning with no symptoms at very low doses and going right up through the permissible occupational body burden of 0.1 μCi of ^{226}Ra to a high malignancy rate at 1- to 3-μCi body burden. So again I do not feel we have any good evidence that there is an overgenerous safety factor in the maximum permissible body burden of 0.1 μCi of ^{226}Ra, which corresponds to an average dose rate of 30 rem/year to the skeleton of the standard man (an average adult radiation worker in the United States).

The basic assumptions of the NCRP, ICRP, and Federal Radiation Council (FRC) can be summarized as follows: Ionizing radiation can be both useful and harmful. (It is not fair just to look at one side of the equation.) The purpose of health physics or radiation protection is to maximize the ratio of the benefits of ionizing radiation to the risks. The maximum permissible dose levels are chosen so that there is a very low probability of severe injury. We do not say that they are chosen so that there is no chance of serious injury; we merely say that some of us feel that the probability of severe radiation damage is still finite even at the permissible exposure levels. We say even from exposure to cosmic radiation, on the linear hypothesis, you add to the risk of shortening your life span, of dying of bone cancer, etc. But we believe the risk is exceedingly low and should be acceptable at the permissible levels provided the benefits exceed the risks. We believe also that the frequently occurring effects, such as life-shortening, are minor and should be acceptable by the exposed individual and by competent medical authorities. We believe that at the present time and perhaps at no time in the future can it be said that there is a threshold dose so low that the probability of serious risk is zero.

I have summarized in Table 5 some of the present exposures to the population in the United States. Let us look first at the genetically significant dose (GSD). The average in the United States from natural background radiation is about 50 mrem/year. Medical diagnosis as indicated by the survey of the Public Health Service[11,12] in 1964 contributed 55 mrem/year, but, at the mid-year symposium of the Health Physics Society, John Villforth[13] predicted that possibly the 1970 survey would indicate this figure had about doubled. I have heard no official report; so I give you this figure of 100 mrem/year with some uncertainty.* This has been very distressing to me and I think to a number of health physicists. Some of us have been testifying in Congress and elsewhere that it would be very easy to reduce this diagnostic exposure to 10% of its present value while the trend, instead of dropping down to 5 to 10 mrem/year, has been to go the other way, perhaps up to 100 mrem/year. Medical diagnostic exposure is not included in the population dose limit of 170 mrem/year. I think it should be. In most countries of the world, it would make no

*The estimate of GSD in the United States in 1970 was finally reported in 1972 to be 36 mrem/year. The total number of X-ray diagnoses had increased as predicted, but, fortunately, the GSD did not increase proportionately because most of the increased exposure was to older members of the population who are beyond the childbearing age and perhaps greater care was exercised in reducing unnecessary exposure.

Table 5

PRESENT AVERAGE ANNUAL EXPOSURE (MILLIREM PER YEAR) OF THE U. S. POPULATION

	GSD(D)*	Bone marrow	Total body
Natural background	50 (126)	122	125
Medical diagnosis	55 (83)	63	100
Medical therapy	7 (10)	15–20	15–20
Weapons fallout	0.3 (0.8)	2	1
Occupational	<1 (2)	<1	<2
Nuclear energy (nonoccupational)	<0.2 (<0.5)	<0.2	<0.2
Other nonoccupational	~0.1 (~0.2)	~0.2	~0.2

*GSD, genetically significant dose. D, average gonad dose. The GSD is given by the equation $GSD = \Sigma_i D_i N_i P_i / \Sigma_i N_i P_i$ in which D_i is the average gonad dose to population age and sex group N_i and P_i is the expected number of children of group N_i. The GSD is less than the commonly quoted average gonad dose D because in some cases D_i differs for the various N_i groups, and P_i becomes zero when a person passes the childbearing age. The ratio of GSD/D is about 0.4 for natural background radiation and was estimated in the 1964 U. S. Public Health Service survey to be 55/83 or 0.66 for medical diagnosis.

difference if medical diagnostic exposure were included as part of the 170 mrem/year because it is such a small exposure, e.g., 12 mrem/year in New Zealand, 14 mrem/year in the United Kingdom, and 22 mrem/year in Denmark. We do not have any good estimates of the therapeutic contribution to the GSD, but it probably is greater than 7 mrem/year. Weapons fallout GSD has continued to drop, and I estimate both it and occupational exposure (including occupational exposure in the nuclear energy industry) are less than 1 mrem/year. The nuclear energy industry nonoccupational component of population dose I estimate to be less than 0.2 mrem/year and other nonoccupational exposure about 0.1 mrem/year. The values of bone marrow and total-body dose are rather uncertain estimates from published data. However, all the data in Table 5 focus attention not on the nuclear energy industry but on natural background and medical diagnostic exposure, which I hope we will be successful in reducing as soon as possible. I think it is rather evident we should turn our attention toward the principal sources of population exposure if we are sincere in our desire to reduce the harmful effects of radiation to the population.

In Table 6 I have listed a few of the common diagnostic exposures so you can see the ranges. At the Oak Ridge National Laboratory, we give chest X rays to our employees, and the average skin dose ranges between 10 and 20 mrem. The Public Health survey[11,12] in 1964 obtained an average of 504 mrem per photofluorographic chest exposure and 45 mrem per radiographic X ray. For a dental series we really do not know what the skin dose is, but I believe it is somewhere in the indicated range. There have been a few publications that have suggested this average dose might be as high as 20,000 mrem for the complete series I might refer again to the very useful survey of the Bureau of Radiological Health, U. S. Public Health Service,[11,12] carried out in 1964, which reported that more than half of the diagnostic equipment in this country was owned and operated by nonradiologists, many of whom had essentially no training in the use of this equipment. It is extremely fortunate the work load on these machines is relatively low. It was pointed out in this survey that on the average the skin dose for an abdominal X ray if given by radiologists is less than half of that if given by a nonradiologist, say a practitioner. It is well known that today only the states of New York, New Jersey, and California limit the operation of medical X-ray equipment to certified X-ray technologists. In other states a high school chap with

Table 6

COMMON DIAGNOSTIC X-RAY EXPOSURES (MILLIREM TO SKIN) IN THE UNITED STATES

	Range	Average
Chest X ray at ORNL	10–20	15
Chest X ray (photofluorographic)	200–2000	504
Chest X ray (radiographic)	10–300	45
Dental X ray series	1000–100,000	20,000

essentially no training other than to press the red button can operate this equipment; yet, if someone drives a school bus, he is required to know which is the brake pedal and to have a driver's license. Only in the state of California is it required that courses in radiation protection and X ray be given in the medical schools and that there be questions on the state board examinations on these subjects. It appears that we are going all out to subject our population to unnecessary diagnostic exposure. I have appealed to the medical and dental professions for over 20 years now to do something within their own house to correct this deplorable situation. They have been very slow, however, in getting this matter corrected and, in fact, have moved in the opposite direction, as we have indicated. So now some of the states are beginning to take action themselves to pass laws for the control of diagnostic X rays, and the Bureau of Radiological Health of the U. S. Public Health Service has begun to do something about the problem also during the past few years.

Typical measures to reduce unnecessary medical diagnostic exposure are:

1. Limit medical use of X-ray equipment to doctors (practitioners, radiologists, dentists, etc.) and X-ray technicians who have specialized training in radiation protection and X-ray and who have passed a state-approved certification examination.

2. Use "fast film". Pass state laws requiring such use except in very exceptional cases.

3. Pass state laws requiring all boundaries of the X-ray field to show on the edges of the film. Require the use of rectangular collimation in dentistry.

4. Include medical diagnostic exposure as part of the present MPE limit of 170 mrem/year for the population.

These are just a few examples from my list of about 100 which I have presented elsewhere.[14,15] I believe very strongly that one should limit the use of this equipment to medical men who have had some academic training and acquired some applied knowledge of radiation protection and the effects of radiation on man. A very simple measure to be taken would be to require the use of "fast film" in dentistry with the exception of a few special cases (<1%) where the dentist might need the slow film. I would urge the passage of state laws requiring that the boundaries of the X-ray field show on the edges of the film. I know of at least one state—our own state of Tennessee—that has a bill awaiting action that would require this. The step that really would require immediate action would be to include medical diagnostic exposure as part of this 170 mrem/year average population dose limit. This really would knock for a loop those medical organizations that sit by complacently, and it would encourage those in the congress or in government agencies to take brave but urgently needed steps independently of the American Medical Association (AMA), the American College of Radiology (ACR), and the American Dental Association (ADA). It would be difficult to do this now unless somebody with the insight, courage, and leadership of the late Senator Bartlett of Alaska does something about reducing unnecessary diagnostic exposure in spite of "help" from AMA, ACR, ADA, etc. Medicare and Medicaid have become important sources of revenue for certain medical groups and institutions, and perhaps we will see a further increase in the population medical dose in the years ahead unless all of us do something about it.

Table 7 indicates the recommended maximum permissible dose (MPD) rates.[16,17] I would like to point out that for the occupational worker the MPD quoted most often is the 5 rem/year to gonads, total body, and active (red) bone marrow; however, for most organs of the body, the dose limit has been 15 rem/year; and for skin, thyroid, and bones it has been 30 rem/year for many years. For the population at large, the limit of principal concern is the 0.5 rem/year to individual nonradiation workers. Under certain conditions the AEC has limited the average dose to a local population or to those living in the neighborhood of power reactor facilities to 170 mrem/year (0.17 rem/year).

A question that is often asked of health physicists is "What are the cornerstones and hallmarks on which the primary radiation protection standards are based which made them worthy of acceptance even at a very early period?" I believe Laurie Taylor is here in the audience, and this question really should be asked of him. I am sure he has asked this question of others who helped with the setting of early radiation protection standards. I too have discussed this question with Sievert, Failla, Gray, Binks, Mayneord, Stone, Rock-Carling, Newell, and many of the other early members of ICRP and NCRP, and they always mentioned (although they showed various degrees of belief in) the following two points:

1. Average exposure that had been received for decades by radiologists. It was thought by some members of ICRP that this corresponded to approximately 15 rem/year. This is presently the MPD limit for most organs of the body. This value was chosen by NCRP in 1949 and by ICRP in 1950.

Table 7

MAXIMUM PERMISSIBLE EXPOSURE TO IONIZING RADIATION: ANNUAL DOSE EQUIVALENT TO BODY ORGANS*†‡

Body organ	Maximum permissible occupational dose equivalent,§ rem/year		Dose limit to individuals not occupationally exposed, rem/year
Whole body	5¶	(5)**	0.5 (0.5)
Gonads	5¶	(5)**	0.5 (0.5)
Lenses of eyes	15	(5)**	1.5 (0.5)
Red bone marrow	5¶	(5)**	0.5 (0.5)
Fetus			(0.5)
Skin	30	(15)	3
Bone	30	(15)	3
Thyroid	30	(15)	3
Hands	75	(75)	7.5
Forearm	75	(30)	7.5
Hands, feet, forearms, and ankles	75		7.5
All other body organs	15	(15)	1.5

*Values are the recommended permissible doses of ionizing radiation to the various organs of the body and are in addition to doses from medical and background exposure. The values apply to both external and internal exposure.

†The values given in this table (except those in parentheses) are recommendations of the International Commission on Radiological Protection (ICRP). The values in parentheses are recommendations of the National Council on Radiation Protection and Measurements (NCRP).

‡The following references have detailed information regarding such questions as exposure simultaneously to several organs, planned special exposures, dose commitment, emergency exposures, and exposures to pregnant women: International Commission on Radiological Protection, Publication 9, *Recommendations of the International Commission on Radiological Protection*, Pergamon Press, Inc., New York, 1965; National Council on Radiation Protection and Measurements, Basic Radiation Protection Criteria, NCRP Report 39, 1971; K. Z. Morgan and J. E. Turner, *Principles of Radiation Protection*, John Wiley & Sons, Inc., New York, 1967.

§The ICRP specifies that in exceptional cases one-half of these values (all values not in parentheses) are to be permitted in any 13-week period provided the limits of the equation 5(N – 18), in which N equals age greater than 18, are not exceeded. Also on very rare occasions ICRP permits twice these limits in a 13-week period provided 5(N – 18) is not exceeded. The NCRP permits in exceptional cases ⅓ of these values to be received in 13 weeks, provided limits of the equation 5(N – 18) are not exceeded.

¶The ICRP limits the integrated dose to these organs by the equation 5(N – 18).

**The NCRP limits the integrated dose to these organs by the equation 5(N – 18). In exceptional cases, well distributed in time, the NCRP permits these dose limits to be increased to 15 mrem/year.

2. Average dose to skeleton from 0.1 μg of ^{226}Ra in the body. This corresponds to an average skeletal dose of 30 rem/year to the typical adult radiation worker. The 0.1-μg ^{226}Ra level was chosen by a committee of NCRP in 1941 and has been the maximum permissible body burden of ^{226}Ra for the past 30 years.

It was the opinion of some that the figure of 15 rem/year as the occupational MPD to most organs of the body was chosen because it was thought to relate in some manner to the average exposure received by radiologists during the early period. I think people in the United Kingdom were more inclined to use this argument or explanation than we are in this country. I consider the 30 rem/year average dose to bone of the occupational worker essentially the same number as the 15 rem/year (factors of 2 are not significant). The 30 rem/year corresponds to the average skeletal dose delivered by 0.1 μg (or μCi) of ^{226}Ra. This 0.1 μg was selected as the maximum permissible body burden of ^{226}Ra for the occupational worker by a committee that was either a part of or related to the NCRP back as early as 1941. So there appear to have been two early reference points used in setting the standards of 15 to 30 rem/year: (1) exposure of early radiologists and (2) the maximum permissible body burden of ^{226}Ra established 30 years ago.

There are many who would argue that this early occupational dose of radiologists was much larger than of the order of 15 rem/year, and they might well be right. Just for the fun of it, some time ago I looked at the matter this way: suppose we take the slope of the life-shortening curve for man as 10^{-4} life-spans per rem as it is for many species of animals and relate this to the reported[18,19,20] life-shortening of 2 to 5 years among the early radiologists. Then we have the following:

$$R = 2 \text{ to } 5 \text{ (years life-shortening)} \times \frac{1}{10^{-4}}\left(\frac{\text{rem}}{\text{l.s.}}\right)\frac{1}{35}\left(\frac{\text{l.s.}}{\text{year}}\right) \times \frac{1}{45}\left(\frac{1}{\text{years as a radiologist}}\right)$$

$$= 12 \text{ to } 32 \text{ rem/year}$$

Surprisingly, when I looked at the leukemic incidence among early radiologists[18,19,20] and related it to the ICRP figure of 1.8×10^{-5} leukemias per person per rem and the expected leukemia mortality rates adjusted for the age of these radiologists, again I got between 15 and 30 rem/year as follows:

$$R = \frac{8.4 \times 10^{-5} \text{ (leuk./year/person expected)} \times 5 \text{(factor of leukemia increase)}}{1.8 \times 10^{-5} \text{ (leuk./rem/person)}}$$

$$= 23 \text{ rem/year}$$

I would say it is probably fortuitous we arrived so close to this same number by these two estimates. However, one reason why such a low estimate of dose received by early radiologists might be right is that during the early period the X-ray machine voltages were very low, and it could well be that the average or the effective red-marrow dose received by these radiologists was as low as 15 to 30 rem/year.

Sometimes it is easier in retrospect to justify and explain reasons and decisions regarding choices of radiation protection standards that were made 30 or 40 years ago than it is for current decisions. At least it is interesting in retrospect that we can come up with essentially this same number (15 to 30 rem/year) from two independent approaches.

Table 8

COMPARISON OF CONSEQUENCES OF X-RAY DIAGNOSTIC EXPOSURE PRESENTLY RECEIVED BY THE U. S. POPULATION WITH THE CONSEQUENCES OF A CONTINUOUS EXPOSURE FROM ALL NUCLEAR INDUSTRIES OF 0.5% OF THE ALLOWED 170 MREM/YEAR (0.85 MREM/YEAR)

Types of radiation damage	Consequences of medical X-ray diagnostic exposure presently received by U. S. population, deaths/year	Consequences of hypothetical exposure of 0.85 mrem/year to U. S. population from nuclear industries, deaths/year
Genetic	1100* to 44,000†	3* to 120†
Leukemia	500	3
Thyroid cancer		0.2‡ to (2)
From dental X rays	16‡ to (160)	
From thorax X rays	2‡ to (20)	
Other cancer	500 (2000)§	3 (13)§
Life shortening	1200	8.5
Total deaths	~3300 to 46,000 ~(5000 to 50,000)§	~18 to 140 ~(28 to 150)§

*This includes only first-generation genetic deaths and assumes that the factor of $\frac{1}{6}$ does not apply to the high dose rates ordinarily used in medical X-ray diagnosis but does apply at the very low dose rate of 0.85 mrem that would be delivered during the year.

†This includes genetic deaths in 40 subsequent generations and assumes that the genetic recovery factor of $\frac{1}{6}$ does not apply in the case of man for medical diagnostic exposure but does apply at the very low dose rate of 0.85 mrem/year.

‡This is assuming 90% of thyroid cancers are cured by medical treatment and so are not included in this number. The numbers in parentheses include all thyroid cancers.

§These are estimates based on ICRP Publication 14 (Ref. 3). All other estimates are made using data from earlier ICRP Publication 8 (Ref. 2). All estimates of deaths from medical diagnostic exposure are based on the medical doses reported by the U. S. Public Health Service[11,12] in 1964.

Some people do not like to put numbers in print as I have done in Table 8 because they are so easily extracted and used without the necessary qualifications. However, in the long run I believe we are better off if we face these numbers and look at the linear hypothesis in terms of the number of deaths we would expect as a consequence of medical diagnostic exposure (90% of which is unnecessary and wasted) and in terms of deaths we might expect with the present nuclear power industry. I have not invented these numbers; I simply have multiplied the ICRP[2,3] risk probabilities by the average dose and by the exposed population to obtain them. First, for genetic mutations from medical diagnoses, you will note I have a very wide spread; the lower figure includes just the first-generation deaths. The higher figure integrates the genetic deaths out to infinity (essentially over 40 generations). In the lower figures I have assumed that 90% of the thyroid cancers are treatable. The total number of deaths from genetic mutations, malignancies, and life-shortening would be somewhere between 3000 and 50,000 per year from medical diagnoses. Unfortunately, in these estimates I was using the earlier figure[11,12] of about 55 mrem/year for the genetically significant dose; so these numbers would go up rather sharply if John Villforth's[13] prediction turns out to be correct that there may be observed a large increase in the GSD from medical diagnoses when analysis of the 1970 U. S. Public Health Service–Bureau of Radiological Health survey data is complete.* I was not using, in this case, the factor of $\frac{1}{6}$ in the genetic death estimates because this medical exposure is at a high dose rate. Then, looking at the nuclear power industry and applying the same linear hypothesis, try as I could, I was not able to get an integrated dose larger than about $\frac{1}{2}$% of the 170 mrem/year when I averaged over the 2×10^8 people in the United States. In this I seem to agree with many of the spokesmen for the AEC, but I am not speaking for anyone tonight except for Karl Morgan. Many that have talked on this subject speak only of the dose from nuclear power operations and think only in terms of the risk from this nuclear power plant on the river. To me, this is ridiculous; you cannot have these power plants in isolation. You have to consider the total dose not just that to the occupational workers in these plants and to those living in the neighborhood of them. You must add to it the dose associated with the operation of national laboratories where the research is done, the dose from processing fuel, from fabricating fuel elements, from the uranium mining industry, etc. Adding all this together—occupational and nonoccupational, this would be the estimated upper limit of the radiation-induced deaths as indicated in Table 8. The numbers as I see it are not frightening. This is a very small risk to the population—something like 20 to 30 deaths per year, or we are introducing at most into the population per year about 150 deaths. When I say introducing into the population per year, this will be the number of deaths expected under a stable condition if you had equilibrium and routine operations of the nuclear energy industry.

The following are what I believe to be the principal reasons why the estimates of risk from nuclear power operations obtained by Gofman and Tamplin are higher than mine:

1. They assume the AEC intends or would be willing for the entire U.S. population to receive 170 mrem/year solely from the nuclear energy industry.

2. They assume a 2% increase in the natural incidence of all malignancies per rem of exposure. ICRP assumes 10^{-4} malignancies per rem per person.

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*Fortunately this estimate of deaths from medical diagnosis goes down when one uses the data from the U. S. Public Health Service 1970 survey. In 1972 the U. S. Public Health Service announced this dose from the 1970 survey is estimated to be 36 mrem/year in comparison with the 1964 value of 55 mrem/year.

In some instances, I believe they have left the impression that allowed the public to conclude the AEC does now or might permit in the future the entire population of the United States to receive 170 mrem/year from nuclear power operations. This, I think, is contrary to fact. I do not believe it was ever intended, and I do not believe we anticipate for many many decades to come that the nuclear industry will use up very much of this 170 mrem/year. I would be willing to guess that by the close of the century the nuclear energy industry still will be using considerably less than 10% of this 170 mrem/year. Then Gofman and Tamplin have assumed that we had best represent the radiation insult per rem as a per cent increase of the natural incidence of malignancy. The ICRP and other groups have looked into this method of calculation and have discarded it because they feel it would be more in keeping with present experimental evidence to assume you get a certain number of malignancies per rem per person rather than, say, a 2% increase in the natural incidence per rem. The method we use does not depend on the natural incidence. If, for example, Japan had normally twice as many stomach cancers as the United States had, then, for a given dose of radiation to the Japanese population, there should be twice as many stomach cancers. This may or may not be true, but I do not think the data we have really warrants this assumption at the present. It will be most valuable in this connection to continue for many years observations of the Japanese survivors from the nuclear explosions in Hiroshima and Nagasaki.

We as health physicists must look at the possibility of accidents with these nuclear power plants. In Table 9 Struxness and I have assumed the same linear relationship between dose and effect as used above. We have considered only the chronic effects of such an accident and have not considered the few persons working in this plant at the time of the accident that might receive a lethal exposure. We are talking about a design accident. By design accident I mean what the nuclear engineers build into this plant, what it will be expected to do under certain conditions, and the consequent doses you would allow or expect to the neighboring population. Assuming that a million people get 10% of the design exposures, we would end up with an accident that would cause only 300 to something over 2000 ultimate deaths. The seriousness of such a predicted accident, of course, depends upon the probability of this accident's occurring. Some of my estimates and others of those at ORNL[22] are certainly higher than predictions made in many places, but I have not been able to find any justification of a number much smaller than 10^{-4}; that is, the probability of a given reactor having an accident per year is 10^{-4}. On this basis, if we assume, for convenience, that we will have an average of 333 nuclear power reactors operating over the next 30 years, we might anticipate one accident among these 333 reactors over a period of 30 years. This is nothing at all compared to other risks, such as from automobiles. This is like having one or two serious airplane accidents every 30 years. I believe it an acceptable risk if we continue to maintain our present isolation of these plants. This is why I feel it is very important that the AEC come out with a statement making it clear that it intends to continue its present policy of isolation and not move in the direction that Roddis[23] implied in his New York speech last summer, that it might be safe to put present reactors in our big cities. I do not agree, not at the present time.

Table 9

CONSEQUENCES OF AN EXTREMELY RARE HYPOTHETICAL POWER-REACTOR DESIGN ACCIDENT[21]

Type of radiation damage	Consequences of exposure of 10^6 persons to 10% AEC design exposures,* deaths/accident		
Genetic	40†		(1700)‡
Fatal neoplasms			
Leukemia	40		
Other cancers	40		(200)
Thyroid carcinoma	40§		(400)
Life shortening	120¶		
Total	300	to	2500

*This assumes 10^6 persons are exposed to an average of 10% of the AEC design exposures (i.e., 10% of 25 rem to total body and 10% of 300 rem to thyroid). This assumes the linear hypothesis given in ICRP Publication 8 (Ref. 2) applies in all cases except for category "Other cancers" where the value of 200 (in parenthesis) was obtained by assuming the linear hypothesis of ICRP Publication 14 (Ref. 3).

†This includes only the first-generation genetic deaths and assumes that the factor of ⅙ applies.

‡This includes genetic deaths in 40 subsequent generations and assumes that the factor of ⅙ applies.

§This includes only 10% of the thyroid carcinomas on the assumption that 90% respond successfully to medical treatment.

¶This assumes 70 years of life shortening corresponds to one death.

Those of us who discuss the adequacy of present radiation standards should ask (and answer) several pertinent questions and indicate action that should be taken. Is the population receiving damage from exposure to ionizing radiation? My answer to this question is yes, a resounding yes. What are the principal sources of this exposure? Natural background, which accounts for about 44% of the GSD, and medical diagnosis, which accounts for about 48%. How much of this population exposure is contributed by the entire nuclear energy industry? A maximum of between 0.1 to 1%. Well then, is this a problem? What is the answer? What do you suggest as the solution? What action? What is the priority of the action? Well, I would say that it is urgent that measures be taken to reduce unnecessary medical diagnostic exposure. Do something about the 3000 to 50,000 deaths per year which, on the linear hypothesis, medical exposures (reported[11,12] in 1964) are causing. Another possibility of reducing unnecessary population exposure begins with a serious look into the structural materials used in building our homes. About 20 years ago Davis and Gabrysh[24,25] in the Health Physics Division at ORNL did some work on what the exposures might be to persons living in

Tennessee who build their homes out of cement block constructed of some of the local shale, which is one of the important construction materials in our part of the country. They estimated that the level of air contamination in such homes could be as high as 1.5×10^{-7} $\mu Ci/cm^3$ of ^{222}Rn (or >70,000 mrem/year) to portions of the lungs of persons living in homes where radiant heating and recirculating air are used such that equilibrium could be reached with the daughter products of this radon. This would be five times higher than is allowed in the uranium mines at the present time. Why are we so slow in doing something about this? I do not know the answer; I guess some of us are asking, Whose problem is it? Who is supposed to do something about it? Is it a public health problem? We had to wait from the year 1500 when human damage was first recognized in mines containing uranium until the congressional hearings in 1967 before we got some public information on the uranium mines problem in the Colorado Plateau area of the United States and corrective action was begun. I think we should be giving some thought of whether we will use cement block made from Tennessee Conasauga shale or phosphate rock in Florida or maybe spend 2 cents more per block and choose safer material. I would be quick to say I believe it is important that we keep at least the present types of nuclear power reactors isolated from densely populated areas and maintain exposure levels to the neighboring populations as low as practicable and never more than a small fraction of 170 mrem/year.

In Table 10 I have indicated for comparison the radiation risks of a modern fossil-fuel plant with those for pressurized-water reactor (PWR) and boiling-water reactor (BWR) nuclear power plants. The primary data are taken from a publication of Martin, Harward, and Oakley,[26] and to this I have added a few numbers. The fossil-fuel plant does not stack up too well in comparison with the PWR, and, in this case, the PWR appears to have a strong lead over the BWR in terms of population exposure from routine operations. Comparisons of this type are most interesting, but what we really would like to know is how would these three power plants compare in terms of population dose over a 20- to 30-year period of operation. It is difficult to make any very meaningful estimates because data on environmental weathering and critical pathways of these radioelements in the environment are lacking. However, if weathering of ^{226}Ra were rather small and if operations were to remain unchanged at the three plants for 20 years, we would expect the activity of ^{226}Ra from the fossil-fuel plant to build up in the environment by a factor of 20, but we would expect little or no increase in activity around nuclear plants (barring accidents) because of the mobility of the principal radionuclides concerned, i.e., ^3H in the case of the PWR and ^{85}Kr in the case of the BWR. Thus, the radiation risk of the fossil-fuel plant (corrected for a 300-ft stack) might go up to over 8000 compared to 1 for the PWR. In addition, we have the serious risks from oxides of sulphur, oxides of nitrogen, hydrocarbons, etc., from the fossil-fuel plant, which are implicated as causing chronic bronchitis and emphysema.

To get some feel for the doses that might be received in the neighborhood of nuclear power plants, we might glance at Table 11. More recent and wider selections of data from surveys of other nuclear power plants suggest the offsite annual dose at the typical nuclear power plant is probably less than 5 mrem.

Table 10

COMPARISON OF MODERN NUCLEAR PLANTS WITH MODERN COAL-FIRED POWER PLANT*

	Coal plant	PWR	BWR
Stack discharges,† Ci/year/MW(e)			
$^{226,228}Ra + ^{228,230,232}Th$	4.8×10^{-5}		
Noble gases	4.8×10^{-5} ‡	8×10^{-3}	1200
Liquid discharges, Ci/year/MW(e)			
Fission products		8.2×10^{-3}	3×10^{-2}
^3H		3.8	1.5×10^{-2}
Critical organ	Bone	Total body	Total body
Limiting dose rate, mrem/year	3000	500	500
Dose rate, mrem/year	0.3 (24) §	0.005	150
Fraction ICRP MPE/MW(e)¶	11×10^{-8} (8.6×10^{-6}) §	2.1×10^{-8}	1.5×10^{-3}
Relative risk	5(410) §	1	73,000

*Estimates by K. Z. Morgan using data of J. E. Martin, E. D. Harward, and D. T. Oakley.[26]

†Coal plants are assumed to be similar to Willow Creek and are operating at about 1000 MW(e) with efficient air cleaning (97.5% efficiency) and tall stacks (800 ft). The PWR is the Connecticut Yankee plant operating at 462 MW(e), and the BWR is the Dresden-1 plant operating at 200 MW(e). Ground-level release is assumed for the nuclear plants. Measurements were those at 1.1 to 1.7 miles downwind from the plants.

‡Values for $^{220,222}Rn$ are not available so K. Z. Morgan has made the conservative estimate that the radon activity equals that of radium and thorium.

¶The ICRP[27,28] maximum-permissible-exposure values are based on bone for radium from the coal plants, on total body for noble gases from the BWR, and total body for ^3H from the PWR.

§The high coal-fired stacks (800 ft) simply disperse the exposure to more people. Thus a better comparison may be this figure in parenthesis which assumes the coal-fired stacks are only 300 ft high.

For a number of years, I have felt that our government ought to give more support to research of the thermal breeder reactor in addition to its support for the fast breeder reactor. The molten-salt thermal breeder reactor would, of course, operate on ^{232}Th with ^{233}U fissile material rather than ^{239}Pu; i.e., with the fast breeder the primary fissile material is ^{239}Pu, whereas in this case it is ^{233}U. In this big complex, the breeder nuclear power plant, a large accumulation of ^{233}U rather than an equal amount of ^{239}Pu gives a tremendous gain in terms of reducing the radiation risk. You no longer have such a large inventory of ^{239}Pu waiting for a design accident to happen. The primary fuel now is the ^{233}U. What is the relative risk in the two systems? I think you really should look at the risk on a gram basis, because if a gasket is leaking, it is not how many curies know how to get out through the crack, it is how many grams know how to get out. So, on a gram basis as indicated in Table 12, the ^{239}Pu of the fast breeder would be eight times worse as far as the body burden is

Table 11

SOME OFFSITE DOSE ESTIMATES FROM NUCLEAR POWER REACTORS

Reactor site	Reference organ	Estimated radiation dose*	Period of time
Humboldt Bay (BWR)	Whole body	35 mrem 50 mrem	1966 1965
Dresden (BWR)	Whole body	5 to 15 mrem/year	
Nuclear power reactors in general	Whole body	<5 mrem/year	

*W. H. Oates, Nuclear Power Reactors and Population, Bureau of Radiological Health, Office of Criteria and Standards, Publication 70-1, January 1970.

concerned. For water contamination it would be five times worse. As far as air contamination is concerned (the principal environmental risk), on a curie basis the ^{239}Pu is 300 times worse than ^{233}U, and on a gram basis it is 2000 times worse in terms of risk of bone tumors. Now this is not the whole story at all. Of course, a molten-salt reactor would have many, many other radionuclides besides ^{233}U—including the isotopes of plutonium. However, the fuel would be circulating and continuously removing a considerable fraction of the unwanted and more dangerous radionuclides. In theory at least you could be converting the separated fission products and certain of the unwanted transuranium radioelements on a frequent schedule to some solid form so that you could ship them out daily and get rid of them. Thus, you would not have as large an inventory of dangerous radionuclides waiting for something to happen.

Table 12

TEN PERCENT OF ICRP OCCUPATIONAL EXPOSURE MPC VALUES FOR CONTINUOUS EXPOSURE[27,28]

Organ	Body burden		MPC in water		MPC in air	
	µCi	µg	µCi	µg	µCi	µg
			Plutonium-239			
Bone	0.004	0.064	5×10^{-6}	8×10^{-5}	6×10^{-14}	10^{-12}
Lung					10^{-12}	1.6×10^{-11}
			Uranium-233			
Bone	0.005	0.5	4×10^{-6}	4×10^{-4}	2×10^{-11}	2×10^{-9}
Lung					4×10^{-12}	4×10^{-10}

Table 13

ESTIMATES OF RADIATION DEATHS FROM THE ENTIRE NUCLEAR ENERGY INDUSTRY FROM ROUTINE OPERATION (ASSUMING LINEAR HYPOTHESIS)*

Year	% of 170 mrem/year	Deaths/year†	Deaths committed/year‡
1970	0.5	18 (28)	140 (150)
	100§	3600 (5600)	28,000 (30,000)
2000	5	360 (560)	2800 (3000)
	100§	7200 (11,000)	56,000 (60,000)

*Values in parentheses were obtained using latest data in ICRP 14 (Ref. 3); the other values were obtained using data in ICRP 8 (Ref. 2). The assumed U. S. population is 2×10^8 in 1970 and 4×10^8 in year 2000.

†Deaths per year from first-generation effects, malignancies, and life shortening.

‡Deaths per year in first generation, malignancies, life shortening, and genetic deaths committed through 40 generations.

§It should be emphasized that the average dose to the U. S. population is conservatively estimated to be less than 0.5% of the population annual dose limit of 170 mrem at the present time and is not expected to reach, much less exceed, 5% by the year 2000. The values for 100% of 170 mrem/year are given only for comparison with published estimates of Gofman and Tamplin in which they estimate a total risk of greater than 10^6 deaths per year from exposure of the U. S. population to 170 mrem/year.

Table 13 summarizes estimates of radiation deaths from routine operations of the entire nuclear energy industry based on the linear hypothesis. If you take our conservative[21] estimate for the year 1970 of a population exposure from routine operation of the nuclear energy industry of less than ½% of 170 mrem/year, the risk still is quite small. The risk committed to the population is small even to the year 2000, assuming a doubling in the population and assuming that you are now up to 5% of the population dose limit (a rise much greater than expected). The figures are not frightening for the year 2000; in fact, they do not frighten you at all if you are not gravely concerned now about medical diagnostic exposure, where the present risk is 200 to 600 times greater. Do not forget either that medical diagnostic exposure could be reduced easily to 10% of its present value while at the same time providing far more medical diagnostic information to the doctor.

I thought it might be interesting also to average the nuclear energy industry risk on the ICRP linear hypothesis over this 30-year period to the end of the century. If you were to do this as I have done in Table 14 for routine operations, you would obtain an average of about 200 to 300 deaths per year, and you would be committing per year somewhere around 1600 deaths (mostly genetic). This may be a gross exaggeration of the risk since I do not believe the population dose from routine operations of nuclear power plants will be using 5% of the 170 mrem/year population dose by the year 2000.

Table 14

CONSEQUENCES OF NUCLEAR ENERGY INDUSTRY (ASSUMING LINEAR HYPOTHESIS)

	Average deaths per year during next 30 years	
	Deaths per year	Deaths committed per year
Routine operations	200 to 300	1600
Accidents*	15	120

*This is based on the arbitrary assumption of an accident potential of 10^{-4}, an average of 330 nuclear power plants, a doubling of the exposed population by the year 2000, an increase in the present dose rate by an order of magnitude by the year 2000, and linearity in dose–effect relationships. Average accident deaths might increase by an order of magnitude if nuclear power plants are built in densely populated areas.

From accidents, assuming a 10^{-4} accident potential, I would estimate an average over the 30-year period of only 15 deaths per year and 120 deaths committed per year. I believe this would be nothing to worry about at all in comparison with other common risks and in consideration of the great benefits. But I repeat this still is assuming the AEC maintains its present and past policy of isolating these plants from densely populated areas. However, even if you were to allow the plants to be built in big cities, you are not going to get any very large numbers of deaths on the average from accidents. For example, if nuclear power reactors located in big cities resulted in 10 times the figures for accidents in Table 14, this would correspond perhaps to nothing more than one serious airplane accident per year or a death potential about 1% of that expected from automobiles. However, even though when averaging over a 30-year period and building nuclear power plants in big cities you do not end up with a very large number of deaths per year on the linear hypothesis, I am strongly adverse to killing thousands of people in a single accident every 30 years and thus would oppose any attempts to place the present nuclear power plants in big cities. I do not think this is the sort of thing you want. We do not want to move in that direction. We must (at least in the immediate future) isolate nuclear power plants and not yield to the pressure of the power companies to move the power plants to the center of large populations.

As one interested in providing our country a safe, clean, and relatively unlimited source of energy in the future, I ask the question "How can the AEC improve its position and how can it respond more favorably in this public relations problem?" It seems to me that the AEC might improve its position first of all by stating very clearly that it has never intended to use up the entire 170 mrem/year in the nuclear energy industry. If it were to use up this 170 mrem/year, it would not leave any permissible exposure for anything else. The AEC should state that maintaining 10% of the ICRP occupational MPC values is not a necessary and sufficient condition for safe nuclear-plant operation. Actually the AEC does state this, but you have to be a lawyer to read through the Code of Federal Regulations, Title 10, Part 20, and find out the different parts that tell you this. I think these present regulations are written in such a way that they invite misunderstanding. Let us urge the AEC then to rewrite them so that you and I can understand them and do not have to read through the whole set of regulations to find out what they are talking about. I think the AEC should state that it does not and never has assumed a threshold hypothesis. At first, when Gofman and Tamplin raised this question, some spokesmen for the AEC actually gave us the impression that the AEC did assume the threshold hypothesis, but more recently the AEC has made it clear, I think, that it does not. I think the AEC should state that there are some important questions that remain to be answered. Let us not, for goodness sake, leave the impression that we have all the answers; we do not. There are many important questions to which we would like to have the answers. We need to continue research programs to try and get some of these answers. As I have mentioned repeatedly, I think the AEC should state that the present brand of reactors—the water boilers and the pressurized-water reactors—have not been developed to the state where we should move them into the centers of dense population. I feel that there should be some mechanism to ensure that they remain isolated; this is the more difficult problem.

Some of the other conditions or requirements you can find in the Code of Federal Regulations, Title 10, Parts 20 and 100, if you look hard enough for them are:

1. Licensee shall "minimize the radioactivity discharged in effluents to unrestricted areas."

2. Licensee shall make "such surveys as may be necessary for him to comply with the regulations."

3. "Reactors will reflect through their design, construction, and operation an extremely low probability of accidents that could result in release of significant quantities of radioactive fission products."

So it is necessary and it is required that other standards be maintained in addition to limiting the concentration of effluents at the boundary of a nuclear energy plant to 10% of the ICRP MPC for radiation workers, and AEC does require surveys to protect the neighboring population from overexposure due to possible environmental reconcentration factors, etc.

Table 15 summarizes some of the data I have talked about and makes some comparisons. I believe these numbers are a little more accurate than many I have seen published.

For comparison I indicate in Table 16 the deaths in the United States from all causes. The table begins with heart disease, and, as we come on down the list, we find that maybe we are causing 18 to 150 deaths per year at present from the nuclear energy industry. My response is let us make our record even better and reduce our exposure in this industry. Let us cut down the dose even more than we have in the

Table 15

SOME DOSE COMPARISONS

	Dose rate, mrem/year
Average medical diagnostic dose in U. S.	
Gonads (GSD)	55
Red bone marrow	63
Average chest X-ray skin dose (photofluorographic) in U. S.	504
Average medical diagnostic dose in U. K.	
Gonads (GSD)	14
Red bone marrow	~32
Average from weapons fallout in U. S.	
Gonads (GSD)	0.3
Red bone marrow	2
Increase in gonad dose in Denver over Chicago	
Cosmic-ray increase	20 } 70
Other background increase	50 }
Living one to two miles from a nuclear power plant	0.005 to 150
Nuclear energy industry average GSD	0.1 to 0.8
Average from color TV	0.002
Fly from New York to San Francisco	
At 25,000 ft	0.5*
At 30,000 ft	0.8*

*These values are average millirem per flight.

Table 16

DEATHS IN U. S. POPULATION IN 1967

Heart disease		721,000
Cancer		311,000
Stroke		202,000
Accidents (all)		113,000
Motor vehicle	52,900	
Falls	20,100	
Fire and burns	7,400	
Drowning	5,700	
Other	26,900	
Pneumonia		57,600
General arteriosclerosis		37,600
Diabetes mellitus		35,000
Deaths from medical diagnosis		3,000 (50,000)
Deaths from nuclear industry at 0.5% of 170 mrem/year		18 (140)
Other		370,000
Total		1,850,000

past. However, if you really are worried about the problem, let us shoot at the heart of the radiation problem and at other causes of death (e.g., medical diagnostic exposure) where we will get 100-fold more return for our efforts. I do not believe some people who are worried about the risks from nuclear power reactors are really worried about the total radiation problem.

The following are some suggested actions that could be taken, actions that I hope would cause us to move in the direction of greater nuclear power safety. For example, I hope the AEC will assure continued isolation of reactors. Some ways of doing this would be to use underground construction or caissons under water and establish remotely located nuclear power complexes. This would, of course, require the development of high-voltage a-c and d-c transmission to cut down on power losses and then perhaps the development of cryogenic transmission. The hardest step of all, perhaps, would be to place the land in the neighborhood of power reactors on a limited-use basis. Otherwise, you will just repeat the problem you have around some of your airports. You isolate them today; 10 years from now they are in a big city.

Certainly efforts must be continued and I would say accelerated to reduce the risk from a nuclear-power-plant accident. Let us put forth an effort to keep the risk of the accident down around 10^{-5} or less. I have already said I think it may be as high as 10^{-4}. I believe secondary shutdown systems should be required of all the reactors. I am not sure all of us are satisfied that we have this on all the reactors. Certainly we must avoid the possibility of autocatalytic reactions. Some persons shy away from the suggestion of planning a disaster control program. As long as the probability of major accidents is not zero, I believe it is reasonable to have some program. If you are wise, you do not wait until you have a fire to have your first fire drill even though the probability of a fire is very low.

As I have indicated already, let us consider seriously the safety advantages of the molten-salt breeder, that is, the thermal breeder as compared with the fast breeder. I believe that, if nuclear power plants are to move eventually into densely populated areas, the inventory of the more dangerous radionuclides in the reactor should be kept at the lowest possible level consistent with all other safety features of the reactor. The MSBR looks attractive to me because of the possibility of continuous removal of the fission products and the trade-off of some of the ^{239}Pu for ^{233}U.

In summary, with the linear hypothesis, population exposure to ionizing radiation in the United States and the consequent risks of radiation damage from the nuclear energy industry at present and to the end of the century are negligible in comparison with the exposure and subsequent risks from the careless and indifferent overexposure of the population by the medical profession in its use of diagnostic X rays. I would like to say that I believe the present levels of maximum permissible exposure are safe at the present time and they are acceptable as long as we do not use up much of this population dose limit of 170 mrem/year. I personally believe that this 170 mrem/year should include diagnostic exposure, which it does not at present. If it did, we would already be using up all the 170 mrem/year. I think that this is the real radiation-exposure problem. I believe quite a bit of action is under way to correct this problem, but progress in reducing unnecessary diagnostic exposure is discouragingly slow. I would like to make it very clear that I am not advocating that anybody avoid a needed diagnostic X ray. Certainly, if you need an X ray, you must have it. What I am saying is, let us apply some of the well-known principles of education, training, requirements for the use of good equipment, and proper techniques and reduce diagnostic exposure down to such a low level that it too is essentially negligible; I think this is the way we are beginning to move—but at too slow a pace to satisfy some of us.

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THE NUCLEAR POWER INFORMATION COMMUNICATION PREDICAMENT

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Francesco Costagliola, a former Commissioner of the Atomic Energy Commission, was graduated from the U. S. Naval Academy in 1941. He did postgraduate work at the U. S. Navy Postgraduate School, M.I.T., and Catholic University in engineering, physics, electronics, nuclear engineering, and education. He served on the cruiser USS *Phoenix* throughout World War II, receiving the Bronze Star with Combat "V" (twice) and other awards, including the Legion of Merit, citations from the Philippine and Korean governments, and the United Nations Medal. Prior to being appointed an AEC Commissioner by President Lyndon Johnson in 1968, Mr. Costagliola was staff consultant to the Joint Committee on Atomic Energy, Deputy Assistant to the Secretary of Defense for Atomic Energy, Chief of the Technical Division of the AEC Military Liaison Committee, and Chief of the Nuclear Weapons Research Section, Office of the Chief of Naval Operations.

To each of us the world is not necessarily as it is. Rather it is the way it appears to us as a result of our background, including our education and experience, and how our intellect reacts to the information we hear, read, and see. We are all quite aware of how relatively minor things can color our attitudes. For example, whether or not we have had a good night's sleep or a good breakfast can determine whether we have a cheerful or a gloomy outlook on life and the world around us on a particular day.

Of the various ways of sensing what is going on in the world, all of us have to depend in large measure upon the media to furnish us with information. The information is communicated to us generally in printed form in newspapers and magazines, in audio form on radio, and in audio–visual form on television. Today, those of us who have been in the atomic energy field for a long time do not recognize some of the information about atomic energy that is presented in the media. To us it is distorted. The individual facts generally seem true enough, but often other equally significant facts that would cast the particular subject in a different light are not mentioned. In the last several years, there have been any number of one-sided, unfavorable newspaper and magazine articles, books, and television programs about atomic energy. The same information that seems distorted to us in the atomic energy field keeps reappearing. Is the problem with us in atomic energy? Have we been wrong about atomic energy all this time? Is it the media? What is the nature of the problem?

My presentation here sets forth my current opinions based on my experience, on discussions with many different people, on research into such areas as public relations and education, and my reading. My view of the world around us may well be different from yours because it is highly unlikely that my total experience and yours are the same.

In examining biased information, we obviously should look at communications first. Communication, of course, involves two parties, those conducting atomic energy programs who in our democracy must try to keep the public informed in order to continue to receive public support and the members of the public who are concerned or interested enough to become involved in some way. This public also includes the press. Presumably, the success of communication depends on whether the ability and degree of effort of the transmitting party is sufficient to match the ability to understand or, if you will, the education and desire to learn of the recipient member of the public.

What has the Atomic Energy Commission done in carrying out its responsibilities, including communications, to the public? In putting the atom to work, the AEC, as one of its first steps, intensified the effort to learn more about atomic energy and its effects on man and the environment. The effort begun by the Manhattan District was expanded and intensified by establishing such national laboratories as Oak Ridge, Argonne, Berkeley, and Brookhaven and by promoting peaceful-uses research at the weapons laboratory at Los Alamos. In addition, the AEC supported and sponsored a multitude of nuclear research projects at virtually any interested college or university in the country.

As a matter of policy, the AEC used, in addition to the experts in its own staff and in its laboratories, experts outside the AEC to assist it in developing policy and conducting its programs. For example, insofar as health and safety matters with regard to radiation are concerned, the AEC looked to the International Commission on Radiation Protection (ICRP) and the National Committee on Radiation Protection and Measurements (NCRP). These two bodies, an international one and an American one, have been involved since their establishment in the late 1920s with recommending standards for the protection of the public and of workers in the field of ionizing radiation.

As nuclear power plants became practical, detailed regulations were developed to ensure that, in the design of the plants, features would be included which would minimize the release of radioactivity to the environment and prevent any release of such radioactivity from exposing the public to radiation in excess of the limits recommended by the ICRP and the NCRP.

The design of each plant is carefully reviewed by the staff of the Director of Regulation of the AEC to ensure that it meets their very conservative design criteria, and it is independently reviewed by the Advisory Committee on Reactor Safeguards. Each of these bodies during the process of review frequently does require changes to be made to improve the safety of the plant. Before the AEC will grant a utility company a construction permit to build a plant, these two bodies must indicate in writing to the five-man Commission that they are satisfied with the design. In addition, a safety review panel consisting of three people who together are skilled in law and the technical aspects of atomic energy holds a hearing in which members of the public can sit in on the proceedings and raise questions. This safety review panel also must indicate its approval to the Commission before a license is granted.

With regard to communicating with the public, under the forceful guidance of the Joint Committee on Atomic Energy, all information that was not strictly classified for national security reasons was made available to the public. The research the AEC supported generated volumes of information on atomic energy which has appeared and been widely disseminated in the technical literature. The AEC also provided the information in less technical format in pamphlets, in books, in movies, speeches, and lectures for the general public. There have, of course, been instances where the AEC, in hindsight, might have done a better job of communicating with the public. Considering the state of the art, the funding limitations, and other restrictions placed on the public-information activities of government organizations, however, I have so far been unable to find some specific fundamental fault with the manner in which the AEC has been carrying out its responsibilities in providing information for the public over the years.

The United States has one of the best educated publics in the world. But, insofar as preparing the public to cope with questions about not only nuclear power but other questions of the day, formal education, as we have known it, has failed to develop as rapidly as has technology. In technical areas the universities have been and continue to be in the forefront of technological development. But, with all our scientific know-how, we still know very little about how a person learns, and we have done little to increase the efficiency of learning, despite the doubling of information every 10 years. There is a small but concerted effort to apply technology to the learning process. There are teaching machines and there is computer-based education, but, by and large, teaching has not changed since the days of the one-room schoolhouse and, in fact, from the days of early Hebrew, Chinese, and Greek teachers.

An associated aspect is the fragmenting of education. Our school curricula are so cut up that we often see no interrelationship among the various subjects. This seems to carry over into everyday life. Our news media present predigested bits and pieces of information which in themselves are attention getting and seem to make sense but which, when looked at together and in context, oftentimes do not make sense.

To a large extent we are being "educated" by the media. Educators estimate that by the time a child goes to kindergarten he has watched over 4000 hr of commercial television. By the time a child graduates from high school, he has watched 15,000 more hours of commercial television than he has spent in school.[1] And after high school the proportion of media "education" to other more formal education increases even more rapidly.

This combination of mass-media communications and an educated public, together with the complexities of living in our highly specialized society, has led to the evolution of a sociopsychological phenomenon that has been labeled propaganda, or, more properly, "modern propaganda." It is different from the technique that has been called since ancient times "propaganda." By modern propaganda one does not mean lies or "tall stories." Modern propaganda is based on facts. It operates with many kinds of truth, with half truth, limited truth, or truth out of context.[2] One way to characterize propaganda is to take the example of this talk I am giving. If the talk causes you to take action of some kind, it qualifies as propaganda. One of the major aims of modern propaganda is to provoke action.[2]

There is no universally accepted definition of propaganda. A widely used definition is "Propaganda is the expression of opinions or actions carried out deliberately by individuals or groups with a view to influencing the opinions or actions of other individuals or groups for predetermined ends and through psychological manipulations."[2]

If we accept the idea that there is such a phenomenon as modern propaganda, a natural question is "What are the motives?" What the original source of a particular line of propaganda is or what the driving motives are of one who promotes a particular line is a subject I have not investigated, and I do not believe it is necessary in this discussion. What we must be concerned and careful about are the answers to these questions: Is the action that is urged desirable or undesirable? Is the full story in the propaganda message? And most important, can we tell?

Jacques Ellul, a professor of the history of law and of social history at the University of Bordeaux who wrote what is considered by many to be one of the better works on the subject,[2] says that modern propaganda cannot work without the modern mass media. Further, it cannot work without education. What is most disconcerting is that he designates intellectuals as virtually the most vulnerable of all to modern propaganda for three reasons: (1) they absorb the largest amount of secondhand, unverifiable information; (2) they feel a compelling need to have an opinion on every important question of our time and, thus, easily succumb to opinions offered to them by propaganda on all such indigestible pieces of information; and (3) they consider themselves capable of "judging for themselves."[2] In describing the effect of propaganda, he says, "Under the influence of propaganda certain latent drives that are vague, unclear and often without any particular objective suddenly become powerful, direct, and precise. Propaganda furnishes objectives, organizes the traits of an individual's personality into a system and freezes them into a mold. For example, prejudices that exist about any event become greatly reinforced and hardened by propaganda; the individual is told he is right in harboring them; he discovers reasons and justifications for a prejudice when it is clearly shared by many and proclaimed openly. Moreover, the stronger the conflicts in a society, the stronger the prejudices, and propaganda that intensifies conflicts simultaneously intensifies prejudices in this very fashion."[2]

If these ideas about propaganda are true or reasonably so, then this can provide an insight into some aspects of what is happening in the nuclear power field.

Atomic energy is a mammoth subject. It is virtually impossible to tell about any one aspect of atomic energy in a brief way and tell the full story. Therefore, in a sense, it is extremely difficult to impart the "whole truth." How can one really educate the average member of the public, or even highly educated persons, who have not specialized in the field on all the intricacies of atomic energy? Atomic energy lends itself readily to partial-truth propaganda. The existing adverse information, which is widespread, is composed of largely out-of-context facts.

Although my subject is the predicament in the communication of information on nuclear power, we should recognize that it is part of a larger problem. Some of the irrationalities that we are seeing today could be the result of this same propaganda phenomenon. For example, there is what I call the "doomsday irrationality" which goes something like this: "The world is in a terrible shape, we are all dying of pollution, and the worst part of it is the population is growing like mad." Another is what I call the "love–hate syndrome" common among some of the youth of today: Love, love, love everybody—but hate the "pigs," hate the authorities, hate the "establishment," hate the "military–industrial complex."

In opening this talk I intimated that it is quite unlikely that we are seeing the world as it really is. According to Ellul another aspect of propaganda is that it creates myths. In my experience the "establishment" is such a myth. The image of a monolithic, impenetrable inhuman thing that controls our lives and is incapable of change except by revolution is widespread. The "military–industrial complex" and the "corporate state" are similar or associated myths. Another myth appears to be that there is such a thing as absolute safety. Another myth is that we are rapidly running out of energy resources.

How do some of these propaganda phenomena affect the communication problem? Ellul says, "... propaganda cannot easily create a political or economic problem out of nothing. There must be some reason in reality. The problem need not actually exist, but there must be a reason why it might exist."[2]

From this point of view nuclear power has two unique basic vulnerabilities. One has to do with the association of atomic energy with destruction, war, and mass annihilation. This association is one that the uninitiated might also relate to nuclear power reactors. It was the nuclear weapon that dramatically introduced the general public to atomic energy. Hiroshima and Nagasaki, the two cities that were attacked with nuclear weapons in World War II, evoke images of mass horror and destruction because the news about them was so sensational at the time and World War II ended so quickly after the attacks. The results were well documented in photographs and reports. Reactors are different. They are designed and engineered to release the energy slowly in order to do useful work, such as generating electrical power. But the destructive image of the atom has never been completely divorced from the reactor. It has always lurked in the background.

Another characteristic of atomic energy that is a potential source of public concern in the nuclear power program is radiation. Over the years we have become aware that persons subjected to large doses of radiation appear to have a higher probability of developing cancer than those who have not been so subjected. Since radiation was first discovered just before the turn of the century, there has been an aura of mystery and fear associated with it. Although we have learned a great deal about it, the aura remains.

Much of the adverse material about nuclear power derives from these two characteristics of atomic energy. The so-called "thermal pollution" is another such vulnerability, but it is not unique to nuclear power.

I have talked to many electric-utility people about the problem of communicating information on nuclear power. Some of the utility management people stressed that one problem was finding answers to specific allegations directed at their nuclear power plants. They pointed out that their technical staff was spending an inordinate amount of time finding the answers. In addition to the basic problem of getting prompt answers to allegations, there is the additional problem of making the source of these answers credible to the public. I discussed the opposition to nuclear power plants with a man who has been in public relations for many years but who had never been involved in nuclear matters. He pointed out that in today's anti-establishment atmosphere utilities are generally considered to be big business and anything they say is looked on with distrust. He stressed that this lack of trust in big business and government lies at the root of many of today's problems and probably is at the root of the nuclear controversy. Some utility people that I have talked to agree that as big business they do have a problem in their relationship with the public. Not only do they have a problem in presenting information to the public, but, if they use consultants, including university faculty, the consultants automatically become suspect by association. And reactor manufacturers as big business have the same problem as the utilities. This, in my view, is a strong indication that the "establishment" myth has its impact on the communications problems of the utilities.

The AEC has been and is the authority on atomic-energy matters. But, as the late Commissioner Thompson indicated in this forum, the AEC has lost credibility in the eyes of many. One cause of the loss of credibility has been the attack on what I consider to be a basic reason for the success of the AEC program. The attack is on the "dual" role of the five Commissioners of the AEC. Under the Atomic Energy Act they are not only charged with developing and utilizing atomic energy for improving the public welfare but are also charged with the responsibility for assuring the health and safety of the public. In other words, they must balance the risks against the benefits to the public before embarking on any particular nuclear enterprise. This has been labeled as an incompatible role, one of both "promotion and regulation."

Another contributing cause for the loss of credibility of the AEC is a series of events that began about 1968. The first three events were what I call the "university opposition." First, organized opposition developed to the Monticello nuclear power plant's being built by the Northern States Power Company on the Mississippi River above Minneapolis. At one stage the opposition was reported to be 23 University of Minnesota faculty members. At Cornell University opposition developed to the proposed Bell station on Lake Cayuga. In 1969 still another group, who were reported by the news media as scientists from Johns Hopkins University, opposed the Calvert Cliffs nuclear power plant. Each of these universities had participated in the atomic-energy program by conducting research under AEC contract. Some of their faculty, although not those opposing nuclear power plants, were consultants to the AEC. In effect, these universities were partners in the effort to apply the energy of the atom to useful work and presumably would be happy to see some fruition of that effort in a practical nuclear power plant. Instead, the press reports conveyed the image that these universities were opposing nuclear power. I think it is generally accepted that in the minds of the public, universities are objective and authoritative. In our society as a whole, the universities seem to have the eminence that the church held in the past. Hence, the fact that "university scientists" or "university faculty" are raising questions about various aspects of a nuclear power plant inclines the average person to the same view and tends to raise questions as to the credibility and the integrity of the AEC as well as the utility concerned. Whether or not the propaganda phenomenon was in some way involved in initiating the opposition, I shall not conjecture other than to recall Ellul's suggestion that intellectuals are among the most vulnerable to propaganda.

In late 1969 Gofman and Tamplin of Lawrence Radiation Laboratory at Livermore, an AEC laboratory, began their crusade. Drs. John W. Gofman and Arthur R. Tamplin have been advocating that the permissible limits of radiation allowed the general population from the peaceful applications of atomic energy should be lowered from the present 170 millirads per year to one-tenth that value, or 17 millirads per year. As those of you who were here Nov. 18, 1970, know, they claim that, if everyone in the United States were to receive the present permissible level of radiation, there could be 20,000 to 40,000 additional cancer deaths per year.

In my view, the performance by Drs. Gofman and Tamplin in this auditorium fits the definition of propaganda. In his opening remarks Dr. Gofman dismissed forthwith the sea of radiation we live in. He then carried the audience along with a seemingly logical smooth flow of statistics and data and a liberal sprinkling of assumptions to support his views about standards, cancer, and nuclear power. He was followed by Dr. Tamplin, who discussed "pollution." Before the evening was over, what appeared to begin as a rational argument for a strict health-physics approach to establishing radiation standards had become a stirring appeal to the emotions against the AEC, the "nameless, faceless" ICRP and NCRP, and the electric utilities who are building nuclear power plants. It had the effect of arousing one to oppose nuclear power and, if not stop the building of nuclear plants, at the very least cause the declaration of a moratorium on the further building of nuclear power plants. Whether this is good or bad, you shall have to judge for yourself. But the effect on the credibility of the AEC is bad.

Before we get into a discussion of approaches to extricating the nuclear community from its predicament, there is another aspect of propaganda we should touch on. Is propaganda really something to be concerned about? The following ideas that Ellul sets forth are in my view worth pondering:[2]

> Once propaganda begins to utilize and direct an individual's hatreds, he no longer has any chance to retreat, to reduce his animosities, or to seek reconciliation with his opponents. Moreover, he now has a supply of ready-made judgments where he had only some vague notions before the propaganda set in; and those judgments permit him to face any situation. He will never again have reason to change judgments that he will thereafter consider the one and only truth. . . .
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> To the extent that man needs justifications, propaganda provides them. But whereas his ordinary justifications are fragile and may always be open to doubts, those furnished by propaganda are irrefutable and solid. The individual believes them and considers them to be eternal truths. He can throw off all sense of guilt; he loses all feeling for the harm he might do, all sense of responsibility other than the responsibility propaganda instills in him. Thus, he becomes perfectly adapted to objective situations and nothing can create a split within him. . . .
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> Through such a process of intense rationalization, propaganda builds monolithic individuals. It eliminates inner conflicts, tensions, self-criticism, self-doubt. And in this fashion it also builds a one-dimensional being without depth or range of possibilities. Such an individual will have rationalizations not only for past actions but for the future as well. He marches forward with full assurance of his righteousness. He is formidable in his equilibrium, all the more so because it is very difficult to break his harness of justification.

To get back to the credibility predicament, some of the utility people I talked with suggested that there might be a way to alleviate part of the credibility predicament. In their view, it would be helpful if nuclear utilities had access to an independent source of information which could provide a rapid response to questions of a technical nature concerning their nuclear power plants. If this source of information was sufficiently conversant with their particular problems, the utility could remove a large part of the current burden on their technical staff. It was suggested that the credibility of this source of information would be enhanced in the eyes of the public if it served other interests, not just utilities. For example, it might serve state governments and perhaps even conservationist groups.

I talked with an official of a conservationist group. I asked his opinion on the desirability of having an independent organization which would provide information on controversial matters concerning nuclear power plants. His initial reaction was that it would be an excellent idea. In his view, however, people quickly went to one side of the fence or the other, and, as a result, it would be virtually impossible for such an organization to stay strictly neutral. Nonetheless, he felt that there were many technical questions that required answers which such a quasi-public institution could work on. In a later discussion, in talking about how an independent information source might be financed, he stated that his organization was not in a financial position to assist in the support of such an independent information source nor did he believe other conservationist groups to be financially capable. Basically, he did not feel that conservationist groups should have to support such an independent group. He felt that, as a member of the concerned public, he had certain fears and unanswered questions about nuclear power plants which he voiced to the responsible authorities. It was up to those who promote nuclear power plants to present the information that would reassure him and the others concerned. Therefore, there was no real need for his organization to support an independent information source.

I next contacted responsible state officials. They also thought that having an independent organization which would provide information on controversial matters involving nuclear power plants was an excellent idea. But, in general, state governments have very limited resources insofar as developing their own information is concerned. Because of their limited manpower and funds, they have difficulty in obtaining or developing pertinent factual information and presenting a balanced state position. They have to weigh the information provided to them by utilities against that provided by conservationist groups and do the best they can. Discussions with state officials indicated that, although the states could use an independent source of information, their limited budgets preclude providing any substantial financial support to establishing or operating such a source.

Thus, I found agreement that an independent source of information which would be accepted by the public is desirable but that it is highly unlikely that such a group could be financed in such a way as to provide the broad base desired for more credibility. Nonetheless, a separate central but not necessarily independent source of information would serve two needed functions. First, it could be set up to provide rapid response to individual allegations and thereby remove a large part of the current burden on the technical staffs of nuclear utilities. In so doing, a large amount of duplication of effort could be eliminated since many of the allegations concerning nuclear power plants involve the same basic technical issues. Today, each nuclear-utility technical staff must review these issues in depth to respond to allegations. Second, a central source of information could also do a great deal to organize the technical specialists on nuclear power plants, particularly those specialists in the wide range of areas associated with environmental effects. Currently, it is quite difficult for utilities to find the right specialist to handle the particular problem at hand. In this regard, the university faculty can be an excellent source of technical support. Today, there are university faculties that are strong proponents of nuclear power; there are others who are strong opponents. However, I believe that most faculties directly involved in nuclear technology see nuclear power plants as the most promising alternative to meet the rapidly expanding need for electric power. Some faculties in the life sciences and humanities have taken a negative attitude on nuclear power plants even though they do not have expertise in this area. Some of these are quoted by the critics of nuclear power plants, and their statements have been used to frighten more than to inform the public. However, when these faculties raise questions that should be answered, it would be best if other faculties, not the AEC or the utilities, gave the answers. I see the separate central source of information which I have suggested performing a valuable service in this area.

In looking at other possible approaches to resolving the communications predicament, one should recognize a characteristic of the myth. Once a myth or a prejudice has taken hold in the mind of a person, it is extremely difficult to dispel it. Hence, it is most desirable to attack and dispel myths before they gain a foothold. The opposition to nuclear power is at present a regional phenomenon, but it is spreading. It is, in my view, extremely important to actively combat the spread in each region that has been relatively untouched as soon as organized opposition becomes apparent.

In my experience the public in general does not pay attention to matters like nuclear-power opposition unless it becomes a local issue. As soon as it does become a local issue, it is important then to come in with the facts, the data, and convincing expertise and to confront the opposition before the partial truths become gospel, because it is then that there is a sizeable, interested, and largely unpolarized audience.

I am now convinced that with proper preparation confrontation can be effective. The efforts of Dr. Bond, Dr. Whipple, and others are leading the way in this approach.

As I mentioned earlier, promptness is equally as important as accuracy in responding to specific allegations concerning particular nuclear power plants. The allegations create interest. If the answers are not given promptly, the public either accepts the allegations as true or assumes that there is some truth in them, otherwise the answer would have been given promptly.

In seeking an approach to rolling back the negative attitude toward nuclear power that has already developed, we should take cognizance of another characteristic of our modern society. That is, people tend to read publications that reflect their opinions. For example, in the nuclear community there are a number of publications that most everybody reads, and they reflect the opinion of the nuclear community. As opinion is shaded by new information, the readers' opinions generally shade with them. I am sure the same is true of the health physics community, and so on. On the other side of the coin, if a person reads an editorial in a publication to which he subscribes that does not agree with his convictions, he may drop the subscription, or he may voice his objections to the editor. Thus, there is a feedback system that tends to keep the publication and those who read it together. The same principle applies to newspapers, to magazines, and to radio and television programs. Those publications (or radio or television networks) that have become or have tended to become anti-nuclear are not going to be brought around to being neutral or pro-nuclear without good reason. They are not going to publish pro-nuclear articles or present pro-nuclear programs just because we submit them. Letters to the editor pointing out inaccuracies in articles would be a start, however.

But, again in my view, the main effort has to be an attack on the myths. Let us take the myth that there is no background radiation. If one were to tell a newspaper or magazine editor that radiation is nothing new to mankind, that man has always lived in a radiation environment, and that the radiation the general population receives now and will receive for many years to come from the nuclear power industry represents but a very small fraction of the total radiation he is receiving from natural background radiation and from medical diagnostic procedures, as Dr. Morgan told us here several weeks ago, it is not very likely the editor will believe it. If he wanted to believe it, where would he go to verify it? It is in obscure reports somewhere in the Department of Health, Education, and Welfare or the AEC or in an article in a medical journal or in a scientific book. But it is not where an editor or his staff can readily find it. Information on the background radiation levels in our cities, in my view, should be in every standard fact book beginning with the Department of Commerce *Statistical Abstract of the United States*. People would be able to see for themselves there is no obvious correlation between cancer mortality and radiation levels by looking at and comparing background radiation level with the cancer mortality statistics of various localities. Other myths have to be destroyed by pointing out the irrationalities in terms of everyday experience that people can understand.

An approach in tackling the establishment myth is to point out that organizations such as those that are concerned with promoting and regulating the atomic energy programs are not monolithic, nameless, faceless things. They are composed of people who are as much concerned about the environment, the safety of their families, their children, and their grandchildren as we are. They live in the same environment we do. Our democratic society does have organization, but it is not a rigid monolithic organization. The organization or organizations of which it is composed are assemblages of people like you and me. People make the policies. Even in the military it is people that determine the character of the organization; it is not the organization that determines the character of the people in it. Our government is still a government of the people, by the people, and for the people. The problems that we have today are not problems created by the nameless, faceless "establishment" or the nameless, faceless "corporate state." They are problems created by people. The problems are there because you and I exist and because you and I want to do more than exist. We want to live. To live rather than to exist requires organization, division of labor, cooperation, and it requires energy.

Then there is the myth that technology causes more deaths. Technology does not "cause" more deaths. We are not immortal, and each person that is born dies only once. Technology may shift the statistics so that a different percentage die of a particular cause. For example, the automobile, since its introduction at the turn of the century, has been the cause of earlier life termination for an increasing number of people. Yet, the overall average life-span of the population has increased from about 47 years to about 70 years in that same period owing largely, if not entirely, to technology.

An associated myth is that no one should have the right to determine the risks vs. the benefits for anyone else. You should be the only one to determine the risks vs. the benefits to yourself. But is this practical? First of all, there is virtually nothing we do that does not involve a risk of death. Most of the time that risk is extremely small, but it is finite. We risk our lives taking a bath; we risk our lives walking up and down stairs. Even lying in bed involves risks. These are very small risks that involve only ourselves. But we also risk the lives of others. If we contract to build a house, included is the cost of insurance to cover the possibility that someone will die or be injured during construction. Most of us carry hazard insurance against such possibilities as a passerby falling and injuring himself on our sidewalk or an invited or uninvited guest drowning in our swimming pool. In coming to this forum tonight, those of us who drove, as I did, risked not only each of our lives and those of our passengers but also those of pedestrians and of people in other automobiles. It is because of these risks that we carry bodily-injury liability insurance. Are we going to stop driving our cars because in so doing we are risking the lives of others? Are we going to stop building new homes or new office buildings because people might die in the process? Are we going to deprive ourselves of the benefits of nuclear power because of similar small but finite risks?

There is no practical way in our organized society for a person to determine in any precise way the risks vs. benefits to himself alone. The idea that having a single body promote and regulate an industry is "incompatible" is an associated myth. If a separate body were to be established with no responsibility but to assure absolute safety of the nuclear program, the nuclear program would stop dead because there is no such thing as absolute safety. Anything less than absolute safety will require balancing of risks vs. benefits. A fact that should be continually pressed is the remarkable safety record of the nuclear power program and the fact that the nuclear power reactors we are building today are not and cannot be made into or act like nuclear bombs.

The most serious reactor accident we have had occurred in 1961. There was a reactor excursion in an experimental military reactor, the SL-1, at the National Reactor Testing Station in Idaho. It was not a nuclear explosion. It is impossible for a power reactor designed for the generation of electricity like the ones we have and are building today to explode like a nuclear bomb. The SL-1 reactor accident was caused by a rapid rise in reactivity with its corresponding rapid rise in temperature which quickly generated a large volume of steam that burst some of the reactor components apart and created missiles. Damage was confined to the building. Three men who were in the reactor compartment at the time were killed. These, incidentally, are the only deaths that have resulted from the malfunction of a reactor in the United States in the more than quarter of a century of the program.[3] The fact that there has been but one fatal reactor accident in such a large program in that period of time is remarkable, and I believe the record is powerful evidence that the health and safety not only of the public at large but of its own people has been a primary concern of the AEC since it was founded.

Another fact that should be stressed is the record of the naval nuclear propulsion program. The record of the more than 100 nuclear power plants designed, built, and operated under Admiral Rickover's direction is powerful evidence that safe and reliable nuclear plants can be built. The tens of thousands of officers and men who have lived on U. S. Navy nuclear-powered submarines and surface ships are probably the best testimony that can be offered to convince the public that living near a nuclear power plant does not have to be dangerous.

My final point has to do with all energy, not just atomic energy. Energy is the key to improving the welfare of man and to improving his environment. It is the key to solving the problems of waste and pollution and to providing the means for more people to live better on this planet. It is the key to living rather than merely existing. There is a myth that we are rapidly running out of energy resources. Dr. Hubbert pointed out in his talks that with present technology we have several hundred years of energy resources left on this planet. Dr. Thompson in his talk said that the breeder reactor when developed will provide us with energy for a thousand years or more, and successful development of the controlled thermonuclear reaction should provide us with energy for many thousands of years. These are the resources on this planet. In 1969, in my view, one of the most significant events in the history of this planet occurred. The astronauts brought back rocks from the moon. In so doing they initiated the bringing of resources from outside this planet, from the vast universe around us to our earth. Our energy resources are as infinite as the universe itself.

Our future as a people is as bright as we wish to see it. It is as bright as we the people working together in harmony wish to make it.

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NUCLEAR POWER LICENSING: RISK–BENEFIT DETERMINATIONS AND THE PUBLIC INTEREST

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At the outset, I want to establish the outer limits of my competence and to disclaim the expertise which the sponsors of this program have attributed to me. The Forum has credited me with having "acquired a broad familiarity with the biological effects of radiation, which enables him to evaluate the risk–benefit balance as applied to radiation exposure." This simply is not true. Moreover, attributing such competence to me is somewhat compromising, since some of the members of the nuclear establishment—of which I have been critical in the past—have, in turn, criticized me for what they regard as my having expressed judgments as to elements of radiation risk with respect to which I have no competence.

Let me, therefore, state with complete candor that I am only a lawyer and law teacher. I have never studied, except superficially as part of my high school and general liberal arts college education, any physics, chemistry, engineering, or biology. I have, however, had considerable experience as a lawyer and law teacher in dealing with legal aspects of nuclear safety. I have also read widely in the relevant scientific and quasi-scientific literature, and, although I am not able to understand or assess all of it, I have no doubt as to my ability to comprehend accurately that information which I need to know to do "my thing."

There is a pernicious myth abroad in our society today that only technically educated and experienced experts are capable of forming valid judgments regarding the scientific and engineering components of public-policy issues. I do not for one moment downgrade the role of scientists and engineers; we could not possibly make sound public-policy judgments on science and technology without their inputs. On the other hand, their professional jargon obscures rather than enlightens public discussion, and the system of peer review tends to stifle meaningful public debate. It is vitally important that means be found to compel the experts to translate their public policy inputs into the language of ordinary political discourse; and, until this is done, it is vitally necessary that laymen make the effort to penetrate the technical obfuscation and to discuss the underlying moral, social, and political issues as effectively as they can.

During the past 15 years or so, it has been our national policy that nuclear power shall be rapidly developed and introduced in order to meet this nation's expanding energy needs in the decades ahead. To this end, the Atomic Energy Commission and the Joint Committee on Atomic Energy have zealously (and jealously) promoted, encouraged, protected, and subsidized nuclear power. At the same time, the AEC has adopted and implemented a stringent program of licensing and regulation to safeguard the health and safety of the public against the obvious and conceded risks involved in the operation of nuclear power plants. Let me make it clear that I believe the AEC regulatory staff is a well-run organization with outstandingly competent and dedicated personnel who are single-mindedly concerned with protecting the health and safety of the public. Also, I want to make it clear that I do not regard the dual, perhaps conflicting, promotional and regulatory responsibilities of the AEC as necessarily evil. While separating these functions might well improve the situation which I shall shortly describe, I believe that the basic difficulties are more deep-seated and would probably persist even if the licensing and regulatory functions were moved into a separate agency.

I turn now to the benefits and risks of nuclear power. No one can seriously question the proposition that nuclear power involves, at least potentially, immense benefits for our society. It is an obvious means for meeting our growing energy needs for the decades ahead in the face of dwindling supplies of fossil fuel. In addition, it provides a means for obtaining needed energy without our suffering the environmental pollution attributable to the use of fossil fuel for this purpose.

Looking at the risks, nuclear power plants involve their own unique form of environmental pollution in the form of thermal and radioactive discharges from the plant. I mention thermal pollution only in passing. With respect to radiation pollution, I am not saying that radiation discharges in the normal operation of a nuclear power plant in fact pollute the environment or are harmful. I do not know, and no one knows with certainty, whether or not such radiation discharges are harmful. What I am saying is that, as long as radiation protection is based on the twin premises that there is no threshold of radiation exposure below which no injury occurs and that any exposure to man-made radiation may be harmful, we must assume that there is a significant risk.

This conclusion is in no sense based on any personal technical competence other than my ability to read the English language. In an article in the Washington *Sunday Star*[1] criticizing the Gofman–Tamplin position, AEC Commissioner Dr. Theos J. Thompson and Dr. William R. Bibb began by saying: "All radiation is potentially dangerous and . . . radiation exposure should always be kept as low as practicable." Our present radiation protection standards are based on the findings of the Federal Radiation Council (FRC) that: "There are insufficient data to provide a firm basis for evaluating radiation effects for all types and levels of radiation. There is particular uncertainty with respect to the biological effects at very low doses and low-dose rates. It is not prudent therefore to assume that there is a level of radiation exposure below which there is absolute certainty that no effect may occur." And the basic principle underlying these standards is the statement by the FRC that: "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure."

Accordingly, it should be clear that the risk involved in radiation discharges from nuclear power plants lies not in knowledge that there may be harmful effects but rather in uncertainty as to whether or not there will be harmful effects. This uncertainty exists primarily because the environment and the population have been subject to significant low-level man-made radiation discharges for only about 25 years. In considering the relevance of this, we should note that a much longer period of time elapsed before we became aware of the adverse effects of sulfur dioxide from the burning of fossil fuels and automobile exhaust fumes. And DDT was widely used for about 25 years before there was general recognition of its adverse environmental effects. We must assume, I believe, that there is at least some possibility that some day in the future, after we have become irrevocably committed to nuclear power, we will learn that the low levels of radiation discharged into the environment are harmful. If this happens, it will be just as difficult for us to rid ourselves of radiation pollution as it has been to eliminate DDT, auto exhaust fumes, and sulfur dioxide from our environment.

There is another and more important risk of nuclear power—the possibility of a catastrophic accident. Fifteen years ago the AEC commissioned Brookhaven National Laboratory to conduct a study of the Theoretical Possibilities and Consequences of Major Accidents in Large Nuclear Power Plants. This study concluded, under quite pessimistic assumptions, that a single major accident might result in as many as 3400 deaths and 43,000 injuries, property damage of as much as $7 billion, and land contamination of vast areas. More recently, AEC Chairman Seaborg stated that potential damages might be even greater today because of the larger nuclear plants now being constructed.

On the other hand, everyone will agree that, because of the care exercised by industry, the stringency of AEC regulation, and the careful multiple safety reviews, the possibility of such an accident is extremely remote. But, however infinitesimally low the probability of such an occurrence may be, the risk of such an accident is sufficiently real that industry itself is not today willing to assume it. Industry, along with John Q. Public, knows Murphy's law—that what can go wrong will go wrong—and has not been willing to bear the financial risks of public liability ensuing upon a catastrophic accident. Accordingly, to eliminate this roadblock to nuclear power, Congress in 1957 enacted the Price–Anderson Act. As recently as 1965 the Joint Committee on Atomic Energy stated as a justification for extension of the Price–Anderson Act that the possibility of astronomic liability arising out of a catastrophic accident still remained a deterrent to industrial participation in atomic energy. The act is quite complicated, but in essence, as it stands today, a utility operating a nuclear power plant is required to carry $82 million of private insurance, the maximum available from the insurance industry. Over and above this, the AEC will indemnify any person who may be liable to members of the public on account of a major accident to the extent of $478 million. If aggregate liability exceeds this $560 million total, all liability in excess of this amount is arbitrarily cut off. Thus, there is no possibility that any utility or equipment manufacturer will incur one penny's worth of liability, on account of a catastrophic accident, out of its own pocket.

The continuing existence of the Price–Anderson Act, the insistence by industry that its continuation is necessary, and the tender loving care bestowed upon it by the AEC and the Joint Committee, as evidenced by a continuing effort to refine and improve it by amendment, clearly demonstrate that the AEC and the Joint Committee believe there is a credible risk of such a catastrophic accident. In effect, the public living in the shadow of a nuclear power plant is required to assume the very same degree of risk that industry will not assume without the protective umbrella of Price–Anderson. But there is no protective umbrella for the public. All the public has is the assurance that if total liability claims are not in excess of $560 million, the public will receive monetary compensation for damages it sustains in event of an accident. The public is fully entitled to give the risk of an astronomically catatrophic accident the same credibility and weight as industry, the AEC, and the Joint Committee gave it.

The fact that nuclear power involves significant risks does not mean that nuclear power plants should not be built and operated. Assumption of risk is an inevitable corollary of growth, progress, and change. The critical question that must be answered is how determinations as to benefits and risks are made in the AEC nuclear power licensing process.

The Atomic Energy Act of 1954 and subsequent amendments to this Act, as well as annual authorizations and appropriations to the AEC, clearly reflect a national policy that nuclear power should be developed, introduced, and used. The Atomic Energy Act, although it contains more than 20 explicit commands to the AEC to ensure protection of the health and safety of the public, does not provide any formula or standard for balancing benefits against risks. There are only the elliptical pronouncements that no license may be issued if in the opinion of AEC it would be "inimical to the health and safety of the public" and that applicants must provide information sufficient to enable AEC to find that there will be "adequate protection" of the public health and safety. The AEC's rules and regulations do, however, provide a standard for issuance of construction permits and operating licenses; a license or permit may be issued if there is "reasonable assurance . . . of no undue risk to the health and safety of the public." It is assumed that operation of the nuclear power plant will involve some degree of risk; and it is only a determination that there will be undue risk which will bar licensing of the plant. The concept of "undue risk" has not been defined in AEC regulations or decisions, although the U. S. Court of Appeals for the District of Columbia in the PRDC (Fermi) case stated that the phrase "without undue risk" is substantially equivalent to the phrase "adequate protection of the health and safety of the public." But "adequate protection" is every bit as ambiguous as "without undue risk."

I would suggest that what is or is not undue risk can be determined only by reference to anticipated benefits. This point is cogently made in the recent report of the National Council on Radiation Protection and Measurements,[2] which tells us that conceptually, at least, determination of what risks are "acceptable" involves a balancing of benefit against costs or losses. An activity is without undue risk only if assumption of the risk is acceptable in terms of the concomitant benefits which are expected to result. In most instances that are analyzed in benefit–risk terms, risk is assumed voluntarily by an individual because he expects to receive direct personal benefits. In the case of nuclear-power-plant risks, however, the risk falls upon the general public involuntarily. The question of undue risk must, therefore, necessarily focus upon whether the public wants the benefits of nuclear power sufficiently to lead it to accept the risks. And, of course, the problem is complicated because the risks may fall largely on those who neither want nor receive any benefits.

With these considerations in mind, I turn to a discussion of the manner in which benefit–risk factors are weighed in the licensing of nuclear power plants.

The first step in the licensing process is to determine whether an AEC permit should be issued for the construction of the plant. The determination of whether or not construction and operation of the plant involves undue risk is made in the first instance by two separate bodies, the AEC regulatory staff and the AEC Advisory Committee on Reactor Safeguards (ACRS). These groups consider the technical aspects of the proposed plant in meticulous detail and with meticulous care. The process of review involves continuing reciprocal feedback between these groups and the applicant and the equipment suppliers; and numerous design changes, all intended to enhance the safety of the plant, result from this process. When both the ACRS and the regulatory staff are satisfied that there will be no undue risk, the licensing process moves to the next stage. Conversely, it is likely that the applicant will withdraw its application if either of these groups cannot be satisfied.

When the regulatory staff and the ACRS have both signed off in written reports indicating their separate views that the proposed plant can be constructed without undue risk, the case is set for a mandatory public hearing before a three-man Atomic Safety and Licensing Board consisting of one lawyer and two technically trained members. Unless some third party intervenes and becomes a party to the hearing, the only parties are the AEC regulatory staff and the applicant. In either event, the role of the AEC regulatory staff in this hearing is largely one of advocating and defending its conclusions that there is no undue risk and that the construction permit should be speedily issued. If there has been an intervention, the AEC regulatory staff vigorously supports the applicant's position and opposes the intervenor's contentions. The ultimate decision on the factual issue of undue risk is made by the Atomic Safety and Licensing Board.

After the plant is constructed, the applicant applies for an operating license. Again the application is reviewed by the regulatory staff and the ACRS; and the regulatory staff, if it is satisfied, publishes a notice that it proposes to issue the operating license. There is no mandatory hearing at this point. The license will be issued at this point unless some third party intervenes and is granted a hearing before an Atomic Safety and Licensing Board. If such a hearing takes place, the resources of the regulatory staff are again fully deployed against the intervenor and in favor of issuance of the license. In the event such a hearing is held, the ultimate licensing decision is again made by the Atomic Safety and Licensing Board.

It is apparent that these procedures provide for multiple levels of safety review by independent groups: the equipment supplier, the applicant, the ACRS, the AEC regulatory staff, the Atomic Safety and Licensing Board, and, in some cases, even by the Atomic Safety and Licensing Appeal Board and the Commission itself. I assume, indeed I believe, that at each of these levels there is a meticulous and conscientious effort made to ensure that the plant will operate in a manner consistent with what these groups sincerely believe to be adequate protection of the public health and safety. More specifically, there is no question whatsoever in my mind that the government participants in this process are dedicated public servants motivated solely by considerations of the public interest. Nevertheless, from the standpoint of the public interest there are serious deficiencies.

1. At no stage in the licensing process is any consideration given to the question of whether the benefits of the plant outweigh the risks. The entire process is based on the premise that Congress has determined that nuclear power involves substantial benefits and that nuclear power plants should be constructed and operated. Thus every proposed plant is regarded as beneficial per se, and the sole issue becomes whether adequate health and safety safeguards are incorporated. Since it is always possible to make any nuclear power plant safer by imposing greater costs on the applicant, the end result of the process is a determination of what degree of risk the public should be compelled to assume in order to have the presumed benefits of nuclear power.

2. At every stage of the process, decisions are made by groups consisting virtually exclusively of experts in the technology. Their immersion in the areas of technical expertise tends, at least, to narrow their focus and to preclude a broad view

particularly with respect to human values and the realities of public policy. In short, although they are expected to make decisions in the public interest, there is little reason to believe that they have or can have any real conception of what the public interest is.

3. The entire licensing process is built on the concept of public participation—or at least the opportunity for public participation—in the process. This is more facade than reality. The key element from the standpoint of protection of the public interest is the AEC regulatory staff. Since there is no mechanism for public participation until the regulatory staff has made its decision that there is no undue risk and that the plant should be constructed or operated, the position of the regulatory staff is frozen before the public has had an opportunity to participate. Therefore, the regulatory staff always finds itself aligned against the intervenors who purport to represent the public interest. It seems to me that there is something fundamentally wrong with a system whose workings inevitably portray a competent and dedicated regulatory staff as an enemy of the public interest. Moreover, although the AEC's procedures are written so as to encourage public participation, in fact the AEC participants act in a manner that has the effect of discouraging such participation. In effect, public participation has become a device for soliciting the public's ratification of the decisions made by the experts behind closed doors rather than a meaningful opportunity for the public to participate in the process of balancing benefits against risks.

This last point warrants some explanation. Under the AEC's procedures the license application, amendments thereto, and all pertinent correspondence are contemporaneously available for public examination. This is a tremendous mass of highly technical material which can be digested and comprehended only by a team of experts and certainly not by the general public. Meaningful public comprehension cannot be expected until the ACRS and the regulatory staff release their written reports. But the ACRS report is usually terse, technical, and cryptic, and the public cannot learn too much from it about the basic issues. The regulatory staff's report reflects an effort to summarize and tie together all relevant facts in a manner that will be somewhat comprehensible to the public. This report is written, however, in a manner calculated more to justify the staff's conclusions that there is no undue risk than to apprise the public of what risks were involved in the plant, what has been done to minimize these risks, and what risks remain. It is calculated more specifically to allay public concern—to persuade the public to trust the experts. The report invites the public to assume that there are no risks. When an intervention nevertheless occurs, and intervenors seek, with their typically limited resources, to develop a public record that portrays the risks, they are met with the stubborn and unyielding resistance of not only the applicant but also the AEC regulatory staff. Indeed, it is a tragic fact that intervenors and the public generally regard the AEC itself and not the unfortunate utility caught in the middle, as "Public Enemy No. 1." The almost inevitable consequences are that the intervenor's contentions get into the record in highly exaggerated form and are easily snowed under by the applicant's and AEC's more accurate testimony. The interested public is then forced to accept either the intervenor's exaggerated version of the risks or the opposite position that the risks are virtually zero, with no opportunity to understand the actual risks in perspective. Another consequence is that intervenors, frustrated by what they consider to be AEC's intransigence, have resorted to what some industry spokesmen have called "guerilla warfare," especially at the operating-license stage when the economic consequences of delay are severe.

Public participation in the AEC licensing process has generally been regarded as essential and desirable, without any real consideration of what is gained by it. On the other hand, the public does not participate in risk–benefit decisions made in other areas, such as food and drug, building elevators, and commercial aircraft safety. For example, the Jan. 4, 1971, Washington *Post* carried a story about failure and fire problems with the Boeing 747 engines. According to the *Post*, the Federal Aviation Administration (FAA) prodded the Boeing Company, Pratt & Whitney, and the airlines to undertake corrective modifications but decided not to ground the 747's while these modifications were under way. The Washington *Post* story tells us:

> At no time during this decision-making process was the public brought into the picture. Regardless of an individual's expertise, unless he worked for an airline, or a manufacturer, or the FAA, it was not for him to decide whether to ride—or not ride—747's. That decision was made for him by the parties most interested, by those with fortunes or reputations at stake, by what might be called the civil aviation establishment.

Why should not nuclear power licensing determinations be made similarly—without public participation—by the atomic energy establishment?

There are, I believe, a number of good reasons. First, there is a long history of lack of public confidence in the AEC coupled with what many influential observers believe to be a massive credibility gap. Whether this is justified or not, the present requirement for a mandatory public hearing at the construction-permit stage is a direct outgrowth of the lack of confidence in the AEC arising out of its issuance of a construction permit for the Fermi reactor in 1956. Second, the risks of nuclear power are many orders of magnitude greater than any other activity in our society, and they are borne by the public generally and not by individuals, who, as a matter of volition, eat certain foods, take certain drugs, enter elevators, or fly in commercial aircraft. Third, nuclear power technology, because of its governmentally sponsored antecedents and strong government support, has come into being and is being developed and introduced at an exceptionally rapid rate as compared with normal commercial technologies, despite its risks, particularly the risk of a catastrophic accident. The normal processes through which the economic marketplace assesses and prices risk have been largely preempted out of the picture by federal subsidies and the Price–Anderson Act. Some form of public participation is probably necessary to replace the market system as a cautionary curb on overly rapid expansion of the technology. In particular, if we recognize that the push for nuclear power comes as much, and perhaps more, from government than from industry, public participation in the licensing process is a means for perfecting and implementing the democratic process. It is perhaps the most effective means for citizens to tell the governmental atomic-energy establishment what is "bugging" them about nuclear power.

Still, I have real doubt as to whether public participation in the licensing process is really worth the expense, effort, and delay. Certainly the present public participation in the form of largely ineffective intervention by citizen groups is not particularly productive in contributing to an appropriate determination of risk–benefit considerations. On the contrary, the facade or illusion of public participation gives false legitimacy to the decisions made behind closed doors by experts. Moreover, it is difficult to believe that public participation can contribute anything useful with respect to the technical details of the facility—the design, the adequacy of the equipment, and the gadgetry. The concern of the public is not with what happens inside the plant but only with what comes out of the plant into the environment under normal operating conditions and under potential accident conditions. I think it can fairly be assumed that the plant is designed, constructed, gadgeted, and operated to meet the AEC's standards with respect to discharges into the environment. The basic concern of the public is with the adequacy of these AEC standards, and the AEC has steadfastly insisted that the Atomic Safety and Licensing Boards are constrained to make their decisions within the scope of these standards. It is, therefore, an exercise in futility for public intervenors to attempt to attack these standards in a licensing proceeding by arguing that operation within the standards creates undue risk. Looking at the question of public intervention objectively, therefore, one must conclude that the principal purpose served is one of harassment, i.e., using the leverage of delay and expense to induce the applicant and the AEC to incorporate additional health and safety safeguards. Although even this could be regarded as justifying public participation in the licensing process, I have serious doubt that the advantages outweigh the delays, expense, and consequent deterrent to introduction of nuclear power. In saying this, let me emphasize that I am not saying that the nation in fact needs more electrical power capacity or that, if it does, nuclear power is needed. My point is simply that the public-policy decisions with respect to these questions should not be made and shaped in the forums in which AEC licensing decisions are made.

There is, however, a compelling need for ensuring that the AEC and the Joint Committee on Atomic Energy are truly accountable to the public for their nuclear power policies and responsive to the public will with respect to the costs, risks, and benefits of nuclear power. Professor Joseph L. Sax of the University of Michigan Law School began the foreword of his recently published book, *Defending the Environment*,[3] by saying:

> We are a peculiar people. Though committed to the idea of democracy, as private citizens we have withdrawn from the governmental process and sent in our place a surrogate to implement the public interest. The substitute—the administrative agency—stands between the people and those whose daily business is the devouring of the natural environment for private gain.

Sax lucidly points out that the procedures of administrative agencies typically discourage or effectively prohibit public participation in agency decisions affecting the environment. Consequently, although these agencies are invariably charged with responsibility to protect and advance the public interest, they do not know what the public's interest is and base their decisions on responses to narrow bureaucratic pressures. What Sax says, I believe, is at least as, and quite likely more, applicable to the AEC than to any other administrative agency.

In its famous *Scenic Hudson* case decision in 1965, the United States Court of Appeals for the Second Circuit, addressing itself to the Federal Power Commission's contention that it was the representative of the public interest, said:

> This role does not permit it to act as an umpire blandly calling balls and strikes for adversaries appearing before it; the right of the public must receive active and affirmative protection at the hands of the Commission.

These considerations point in the direction of fixing agency accountability in terms of judicial review of agency action. Two months ago the United States Court of Appeals for the District of Columbia decided a pair of cases involving agency decisions with respect to the insecticide DDT and the herbicide 2,4,5-T. Speaking for the court, Judge Bazelon stressed that a statutory procedure for public participation in administrative decision-making "may not be lightly side-stepped by administrators." Such decisions, he said, must take place "in the full light of a public hearing and not . . . behind the closed doors of the Secretary" (of Agriculture). Moreover, particularly where the agency action "touches on fundamental personal interests in life, health, and liberty," it is necessary, in order to assure appropriate judicial review, that the agencies "articulate the standards and principles that govern their discretionary decisions in as much detail as possible."

These considerations appear to be even more cogent in the area of exceedingly complex technologies like nuclear power than they are in the cases of mere siting of power plants, the use of insecticides and herbicides, and the authorization of highways, dams, and landfills. They point, moreover, to a rational format for the role of the public in nuclear power licensing.

In my view, the interests of the public would be adequately served if the nuclear power licensing process involved a full and candid articulation, in a public forum, of the benefits and risks of the particular facility, coupled with what Judge Bazelon terms a "principled decision" which fairly, candidly, and in detail sets forth the AEC's assessment of the benefits and the risks and the considerations underlying its decision to license the plant. This decision should be written in the spirit of full disclosure and in a manner calculated to permit the ordinary educated man to understand the facts and the issues. This should include a delineation of what the risks are, what the applicant has done to minimize the risks, and what risks remain. There should be, among other things, a candid statement of what is not known about the long-term effects of continuing discharge of low levels of radiation and a frank discussion of the risks and potential consequences of a major accident in the event the engineered safeguards do not work as advertised. The applicant's dependence on the Price–Anderson Act umbrella should be disclosed. Similarly, the benefits of the plant should be fully discussed in the light of alternative sources of power as well as in the light of a decision not to install additional capacity.

Presentation of evidence with respect to these matters in the first instance might well be made the responsibility of the applicant. Alternatively, or to supplement the applicant's presentation, the AEC regulatory staff itself might be required to make this record. If this were done, I am confident that citizens' groups would have little incentive to intervene in the licensing proceedings before the AEC. The licensing hearings could then proceed expeditiously and without the delays and costs which now characterize them.

The evidentiary record, as well as an AEC decision that would fully and candidly evaluate the benefits and risks and the bases for the decision, would serve a salutary purpose. It would, first of all, provide a firm basis for judicial review at the instance of citizens who are not pleased with the result. More importantly, it would serve to educate the public and provide a firm basis for political action which citizens might wish to initiate to persuade Congress to change the ground rules for nuclear power licensing.

There are, I believe, other steps which might be taken, without prejudice to the public interest, to streamline the licensing process. I see little point in the present two-step licensing process, especially since at both stages the focus is on the technical aspects of the plant. It would be preferable to have a single hearing that would concern only the suitability of the site based on clearly articulated specifications as to what the maximum discharges to the environment will be in normal operation and in the event of an accident. The focus would be on what comes out of the facility and not on the equipment and gadgets incorporated within the facility. At this hearing, the kind of record I discussed above would be made, and in its decision the AEC would fully and candidly discuss and evaluate benefits and risks. If the proposed plant is approved, a construction permit would be issued subject to the stated specifications, and the public would rely on the AEC's experts to ensure that these specifications are met. As is presently the case, the AEC's order authorizing issuance of the construction permit would be subject to judicial review. When construction of the plant is completed, the AEC regulatory staff would prepare a description of the plant, the manner in which the previously prescribed environmental specifications have been met, and a detailed and candid discussion of the benefits and the remaining risks. The construction permit would thereafter automatically ripen into an operating license unless an intervention petition is filed. Intervention would be permitted solely on the issue of whether there is undue risk that the environmental specifications are not or may not be met. In the event of a hearing at this stage, both the hearing and the AEC's decision would again reflect the principle of full disclosure. If the operating license is issued, there would again be opportunity for judicial review—the same opportunity as now exists.

These suggested improvements in the AEC licensing process would, I am confident, discourage interventions and, where interventions do occur, would make them much less disruptive of expeditious, efficient, and economical licensing. At the same time, they would contribute to the public interest by focusing attention on those matters which are of paramount public concern and by giving the public better and more useful data on which to base legal or political action. Although I have no doubt that these suggestions would, in fact, eliminate many of the present anomalies and torturous difficulties in the present licensing system, I must say in all honesty that I do not know whether they would serve to encourage or to retard the growth of nuclear power.

Some will say that a candid articulation of the risks of nuclear power would tend to alarm the public unduly and to foster an irrational opposition to nuclear power. But implicit in this objection is the notion that Big Brother knows best what is in the best interests of the public—Big Brother in this case being the AEC, the Joint Committee on Atomic Energy, and their massive array of experts. Such a position reflects a lack of faith in our democratic processes. It is my firm belief that in our democratic society the public itself should have the maximum opportunity to decide for itself what benefits it wants and what price it is prepared to pay for these benefits. It is more important that government be responsive to what the public wants, rationally or irrationally, than it is that the correct decision be made. Our democratic system is bottomed on the premise that a democratic society will make mistakes but that in the long run truth and right will prevail. The public is entitled to know the facts, even though some members of the public may use the facts irrationally or irresponsibly. After all, we permit the American public, through its elected representatives, to make erroneous or even irrational decisions as to who should sit on the Supreme Court; as to tax, fiscal, and economic policy; and as to war and peace. Why not permit the same latitude with respect to the far less important issue of nuclear power?

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NUCLEAR POWER: YOU NEVER HAD IT SO GOOD

G. Hoyt Whipple

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G. Hoyt Whipple received the bachelor's degree at Wesleyan University. He studied physics at the Massachusetts Institute of Technology, where he became a staff member in the Division of Industrial Cooperation. In 1947 he joined the General Electric Company to work on radiation protection. After receiving the Ph. D. degree in biophysics from the University of Rochester, he was assistant professor of radiation biology there. In 1957 he became associate professor, later full professor, of radiological health in the School of Public Health, University of Michigan, where he developed the graduate program in radiological health.

My position here is much like that of a fellow who went swimming in the Baltic Sea on a summer day a number of years ago. He was sighted by a fisherman, who mistook him for a seal. In those days there was open season on seals, and so the fisherman got his gun, laid it across a rock, took aim at the swimmer, and fired. Fortunately for my purposes the shot missed. While the fisherman was reloading, a neighbor came over to see what the racket was all about. As the fisherman was taking aim for the second shot, the swimmer raised himself up out of the water and shouted, "Don't shoot, I'm not a seal." The neighbor peered out to sea for a moment and then said, "Shoot. I think he lies."

Most of the speeches you hear in Washington are written by ghosts. This means that on many occasions both the audience and the speaker are hearing the speech for the first time, and this tends to make things exciting for everyone. Sad to say, I cannot offer you this form of excitement. My ghost discovered recently that he could make more on welfare than I am paying him, and so I had to write this myself.

You must wonder, as I have wondered, whether there is anything to be said for or against nuclear power that has not already been said hundreds of times in dozens of different ways. The réflexes have all been well conditioned. Pavlov rings the bell and the dog's saliva flows; nuclear power is mentioned and fists clench, breathing deepens, and adrenaline flows. When there is no time to think, the properly conditioned reflex can be a powerfully protective mechanism, but it is a poor substitute for rational thought. If I am able to trick just a few of you into rational thought on the subject of nuclear power, this evening will be successful beyond my wildest expectations.

My plan of trickery is simple: first, to tell you why nuclear power is the luckiest thing that has happened to us in quite a while, and, second, to consider the alternatives. The pea will be in full view all the time the walnut shells are being shuffled about. There will be no mirrors, no cards up the sleeve, no paid henchmen in the audience, and no cry of "hey, Rube" when the tent falls in.

Why is nuclear power the best thing that has happened to us since prohibition was repealed? There are three reasons; you know them all, but let us list them once again:

1. The fissioning of uranium offers a large, new source of energy that has become practical at a time when traditional sources of energy are beginning to become scarce, difficult to obtain, and expensive.

2. The safety standards under which nuclear power has developed are the best ever seen by any industry, even in its worst nightmares. The nuclear safety standards incorporate more scientific knowledge and more cautious judgment than do any other standards we have.

3. Nuclear power plants are intrinsically clean and safe. Were this not so, no sane engineer would consider building and operating one under the limitations imposed by the Atomic Energy Commission.

These things are true. Why, then, the uproar? Why the loud cries to prohibit nuclear power? I do not understand the reasons for the protests, but, as the protesters skip from one reason to another, I have come to believe that the reasons may have come after the conclusions, rather than before.

One seeks an analogy that may suggest a way out of the impasse in which we find ourselves. Analogies can be treacherous, and I have promised to be simple and honest. The analogy I find most helpful in the present situation is simple and, in fact, childlike. Further, it is a circumstance familiar to most of you in spite of television, Walt Disney, and the *Reader's Digest*. I refer to that afternoon when Alice climbed up on the mantelpiece and found she could get through the looking glass into the garden on the other side. There she met the Red Queen, and there she struggled with a bewildering system of logic where one had to run to stay in one place, to walk away from a distant point in order to reach it, and where the White Knight turned his lunch box upside down to keep the rain out of it. Alice found nonsense on the other side of the looking glass, but she coped and finally made it to queenhood. Let us take what solace we can from that most perceptive of ecologists, Lewis Carroll.

With your sense of humor girded up, let us consider the alternatives to nuclear power. So as not to appear even more frivolous than I am, I shall not speak of Reddy Kilowatt in Wonderland but instead shall ask you to put yourself in the position of a confused, unimaginative person whose children do not understand him, whose wife understands him all too well, and who has an incipient ulcer. In other words, I ask you to put yourself in the place of the average electric utility executive.

In the position you have now assumed, you find that the demand for electric energy in the community you serve is increasing steadily and that this demand will shortly exceed your ability to produce it, even if all your customers give up their electric toothbrushes. In this situation, you have only three choices: (1) to install a coal-fired generating plant, (2) to install a nuclear plant, or (3) not to provide your customers with any additional energy. I shall devote my remarks to the first and second choices.

In making the choice between a coal-fired plant and a plant fueled with uranium, you will consider four factors: cost, health, ecology, and esthetics. Under the heading of cost, you will consider such things as the costs of design, construction, and start-up and also such long-term costs as fuel, maintenance, operation, and final decommissioning of the plant. You will give thought to the possible harmful effects that each type of plant may have on the health of your customers and of your employees; you will think about what the construction and operation of the plant will do to that lovely stretch of the river where it is to stand, whether the fish and the wood ducks will continue to live there. Finally, in a moment of starry-eyed idealism, you may even give some attention to how the plant will look, and sound, and smell.

With a certain amount of diligence you could, in principle at least, assemble a balance sheet with the four entries cost, health, ecology, and esthetics under two columns, one for coal and the other for uranium. If it should happen that one type of plant is superior to the other in all four categories, then the choice is an easy one. However, if this is not the case, you will be faced with such questions as how much more you (or rather your customers) are willing to pay for more safety, more ecology, or a more tasteful plant. Such questions are difficult to answer, particularly because we have had so little practice in trying to answer them.

Actually, a balance sheet of this kind has probably never been prepared. It may not even be possible today to prepare a complete one, but let us see how far we can get.

For the nuclear plant the principal effluent from the standpoint of public health is tritium, and for the coal plant the principal effluent is sulfur dioxide. A nuclear plant that generates 1000 electric megawatts [Mw(e)] for one year will produce about 10,000 curies (Ci) of tritium; the corresponding coal plant, burning coal with 3% sulfur, will discharge 150,000 tons of sulfur dioxide. Thus, one necessary step in deciding which plant is preferable for human health is to determine which has the lesser effect on health: 10,000 Ci of tritium or 150,000 tons of sulfur dioxide. Let us suppose you start the exercise with tritium.

The 10,000 Ci of tritium, once released into the environment will wander about quite freely in the company of its cousins, the two stable isotopes of hydrogen, for tritium is the radioactive isotope of hydrogen. There is a great deal of hydrogen in the environment; most of it is tied up with oxygen in the water molecule, and the hydrogen atom is kept quite busy. Since tritium is radioactive, it decays and gradually disappears with a half-life of 12 years, which is to say that, if the 10,000 Ci were released this year, there would be 5000 Ci remaining in the year 1983, 2500 Ci in 1995, 1250 Ci in the year 2007, and so forth. During these decades the tritium atoms will be passed about in the environment among some 3 billion people, from hand to mouth, you might say delicately. Up until that far future moment when the last of these tritium atoms has finally decayed, the entire radiation exposure of the world's population produced by the 10,000 Ci will be 1.3 man-rem spread over the whole teeming mass of humanity.

What, you ask yourself, are the consequences of subjecting the world population to 1.3 man-rem spread over many decades? Please understand that this dose of 1.3 rem is divided fairly evenly among the population, so that on the average each individual gets only one three-billionth of this dose. In order to estimate the consequences of this dose, you must, perforce, indulge in the fashionable numbers game. In fact, failure to play the numbers game is now a federal offense, punishable by disbelieving stares from the Environmental Protection Agency.

Anyone who is anybody can play the numbers game with one hand tied behind his back. The only way to tell whether the player is an expert is to see whether the fingers of this hand are crossed. So you play the numbers game with the 1.3 man-rem to the world's population; you consider the years of life expectancy lost from premature aging, from leukemia and other malignant diseases, and in all future generations from mutations. You add up all the years of life lost because of the tritium produced by the nuclear plant in one year, and you arrive at the figure of $\frac{1}{10}$ of a man-year. In other words, the production of 1000 Mw(e) for one year with a nuclear plant will, according to your estimate, have the ultimate overall effect of shortening one life by about one month.

In case you are surprised by this number, let me say again that there has been no trickery. The estimate has been obtained in the same way and using the same proportionalities that are now in general use. The only way this estimate differs from others you have heard is that it uses the entire world population instead of taking the provincial approach of using just the population of the United States. In so doing, one could be said to have out-Gofmanned Tamplin.

Very well, you have an estimate for the public-health entry under nuclear power in your balance sheet. Now let us see what can be done for the coal-power entry. You find that the half-life of sulfur dioxide in the atmosphere is about 40 days, which is to say that it will disappear from the atmosphere about 100 times faster than tritium. This bodes well for coal power, You also find that not a great deal is known about doses and dose–effect relations for sulfur dioxide. It seems that until recently no one has been very interested in the public health or toxicological aspects of this gas. But you take what data you can find, and, being scrupulously honest, you treat them in exactly the same way you treated the data for tritium. Surely, if the numbers game is good enough for radiation and tritium, it should be good enough for sulfur dioxide. The result of applying the linear no-threshold extrapolation to the available data on sulfur dioxide is the estimate that producing 1000 Mw(e) for one year with 3% sulfur coal will have the ultimate overall effect of reducing life expectancy in the world population by about 10,000 man-years.

You enter this in your balance sheet and reflect for a moment. The figures you have before you mean that, if these two types of plants are to be comparable with regard to public health, some way must be found to reduce the discharge of sulfur dioxide from the coal plant by a factor of 100,000. You telephone your chemical engineer to ask him how much it will cost to install a sulfur dioxide removal system with an efficiency of 99.999%. At this point we leave you; after all there are ladies present.

There is not time to walk through the exercise for ecology and esthetics, but, if you do and if, in so doing, you treat both plants by the same rules, I believe you will find, as we did for public health, that it will cost a great deal more to provide electricity with a coal plant that is as kind to the birds and bees and to the five senses than to produce the same amount of electricity with a nuclear plant. This is why I have chosen the title: Nuclear Power: You Never Had It So Good.

But, having made this point, I must make another, which in its way is just as important. My second point is this: you do not even need it so good.

The reasons why people object to nuclear plants are difficult to understand; perhaps they just do not know any better. But it is even harder to understand why federal and state agencies, which should know better, are in such full and frightened retreat from nuclear power. Take the AEC as an example. It is said that the AEC has been placed in an impossible position, having, as it does, the responsibility for both promoting and regulating nuclear power. Howsoever this may be, as the electric utility sees it, the AEC is the foremost opponent of nuclear power. Apparently the AEC has never believed its own safety standards; certainly it has never licensed a plant to operate anywhere near the limits set by these standards. Now, in further retreat from the best energy source we have ever had, comes "as low as practicable." In other words, let us reduce nothing by a factor of 10 or 100 and become even holier than the holiest opponent of nuclear power.

This flight from common sense, lead by a frightened AEC and largely unopposed by timid, short-sighted electric utilities, will lead inevitably to increased costs of electricity. The high costs of building and operating safer-than-safe nuclear plants, or comparable coal plants, will be passed on to the customers in their light bills. And then, after a few years, when these customers rise and ask why their bills are so high, the answer will have to be: this was the price of peace, timidity, and fear in the early 1970s.

Now it is time to say: "Shoot, I think he lies."

BENEFITS AND COSTS OF NUCLEAR POWER

Sheldon Novick
Editor, Environment

Mr. Novick graduated from Antioch College. In 1964 he became assistant to the Committee on science in the Promotion of Human Welfare of the American Association for the Advancement of Science. He helped organize, and became Program Administrator of, the Center for the Biology of Natural Systems at Washington University. In 1964 he began his association with *Environment* magazine (then called *Scientist and Citizen*). In 1969 he became editor, a position he still holds. Mr. Novick is the author of *The Careless Atom*, a book about the hazards of the nuclear power industry, and many magazine articles on this and related topics.

Before I say anything about nuclear power plants, I want to talk for a moment about why they are being built. This is ground that has already been covered, but I think the landscape appears very different to me and to some of the other participants in this symposium.

Why are nuclear electric power plants being built? The reasons usually given are in the general categories of conserving resources like coal and oil, preventing air pollution from conventional plants, and providing substantially cheaper electricity.

To take the last one first, we do not need to spend much time on economic discussion as long as we consider only the near future. Coal and uranium are generally conceded to be competitive fuels—that is, electricity costs about the same whichever fuel is used. In 10 or 15 years, when the competition may be among advanced types of both coal and nuclear plants as well as, perhaps, geothermal, solar, and other power sources, the picture may change. I doubt that anyone is really in a position to say. Too much depends on what environmental restraints are imposed and on how much money is spent on what sort of research and development.

The conservation of resources and the prevention of pollution are more immediate and more obvious benefits, and they are real enough. Although we are not facing any immediate shortages of conventional fuels, their conservation is certainly something to be desired as a matter of principle. And, of course, there is no disputing that nuclear power plants, whatever else one may say about them, are entirely free of sulfur dioxide, nitrogen oxides, fly ash, mercury, radium, and probably a long list of still uncatalogued pollutants from coal-burning power plants.

Even more important, perhaps, nuclear plants produce no carbon dioxide, and the accumulation of this gas in the atmosphere from the burning of coal and oil is certainly one of the most serious long-range environmental hazards we face.

One could add other factors. Uranium mining may or may not be less destructive of the environment and of the lives of miners than the digging of coal. I have not seen any good comparisons.

In short, there are some definite advantages to nuclear power, to be laid against its drawbacks. But, before I go on to talk about the debit side of the nuclear ledger, I want to look at these benefits from a different point of view.

Electric-power production is increasing very rapidly, as you all know. Over most of its history, the electric-power industry has doubled its capacity roughly every 10 years, on the average. This rate of increase is expected to continue for some time. All the projections I have seen carry it to at least the end of this century—another 30 years. During this time, of course, total electric-power production will continue to exceed even a rapidly expanding nuclear power industry. If nuclear power fulfills the more optimistic predictions, it will account for about half of all generating capacity by the end of the century. But the other half, presumably most of it from coal-burning plants, will itself be four times the size of the whole present industry. Despite the most rapid practical expansion of nuclear power, the burning of coal, with all its substantial drawbacks, will quadruple in the next 30 years.

What will we have accomplished? The burning of coal will not be diminished, it will be vastly increased. Strip mining, air pollution, and all the other ills that coal is heir to will still present an enormous problem.

In short, the benefits of nuclear power do not solve the environmental problem. If present trends continue, nuclear power will only forestall an even worse disaster than we would otherwise experience. By enormous expenditures of money and talent, we will have managed only to slow somewhat the increase in the rate at which people are being killed by air pollution and the environment is being rendered unfit for comfort or health. This sounds a little less than glorious and gives me the feeling that perhaps we are looking at the problem the wrong way around.

The assumption in all of this is that electric-power consumption will, in fact, continue to grow at its present rate. It is this rapid growth that makes the rapid introduction of nuclear power plants seem to some to be desirable and even necessary.

Let's look at this a little more closely. Who uses all this electric power? Nationwide, after deducting for various kinds of losses, roughly one-quarter of all electric power is used in the home (residential consumers), about the same in various business offices and stores (commercial consumers), and the remainder, about 50%, is used by industry. Three-quarters of all electricity, therefore, is used by commerce and industry, and about one-quarter goes to residential consumers.

The biggest consumers of electric power are the chemical and metal industries. They take the biggest bite out of the consumption accounted for by industry. Aluminum manufacturing takes a lot of electric power, for instance. It alone accounts for one-tenth of all industrial power use. Steel takes a lot of electric power; it also consumes great quantities of coal and so produces many of the same pollutants produced in coal-burning power plants. Plastics use a good deal of electricity in their production. Electricity and mercury are also used to make chlorine and soda ash, basic materials for the chemical industry and the worst source of mercury pollution of the environment. The heating and cooling of interiors—homes, offices, factories—also uses a large amount of electricity. Electrically powered air conditioners are one of the greatest boons to mankind, and I would be the last to say anything against them—but electric heating is something else again. Heating is done far more efficiently and cleanly, and in most areas more cheaply, by natural gas or oil.

These are some of the supposedly inexorable demands for electric power. Why are they growing so rapidly? We are using more aluminum, more plastic, and more cement and are heating more space electrically—these are the biggest sources of increased demand. Your electric toothbrushes are hardly a drop in the bucket.

There is a pattern here, and it is a pattern of waste. Look at aluminum, for instance. It is a rare product that is made of aluminum which could not be made of something else. The biggest markets for aluminum are in packaging and transportation. This means aluminum beer cans and aluminum auto radiators and engine blocks, which could easily be made of steel. (Aluminum for aircraft is an exception.) Now these things have always been built of steel and seemed perfectly satisfactory. Aluminum, however, because of preferential electric power rates, can be made cheaply enough to compete with steel. The difference in cost is paid in environmental pollution. It takes 2700 kilowatt-hours (kw-hr) of electricity to make a ton of steel, but it takes 17,000 kw-hr of electricity to make a ton of aluminum. If the differences in density are taken into account, aluminum is two or three times as costly, in energy, as steel.

But there is an even more basic point here. We throw away most of the steel and aluminum we make and therefore have to mine more, with resulting damage to the environment. If we reused the metal, recycled it, the costs to the environment would be very much less. A ton of steel made from scrap in a modern electric furnace consumes only 700 kw-hr of electricity. This is three times cheaper, in terms of energy, than steel made from ore.

In other words, what we should be doing is reusing, and reusing again, the steel we have already made; this would mean a reduction in energy demand to one-third of what we now spend on this metal. Instead of reducing energy consumption by one-third, without any loss of the consumer products we have come to expect, we are increasing energy needs threefold by employing aluminum in place of steel.

Similar things could be said about electric-power consumption for plastics, which replace recyclable materials like paper and cotton; electric-power consumption for cement to build useless and destructive highways; and power wasted on advertising lighting and space heating where other fuels would be preferable. Space heating with electricity, only half as efficient as the direct use of fossil fuels, is a particularly glaring example of waste without any appreciable counterbalancing benefit; yet this is by far the largest component in projected increases of residential demand.

The rapid increase in demand for electricity, in other words, is in large part a reflection of the wastefulness of our society. This wastefulness is a central fact of our economy and can be seen operating in every environmental problem but in none so clearly as in electric power production. Which is not to say that all uses of electricity are unnecessary. I have an air conditioner and wouldn't be without it, and I keep a light burning in my hall all night.

The point I want to make is that the genuinely valuable and irreplaceable benefits of electric power are being swamped by useless and unnecessary consumption for heating and for the production of such excrescences as the aluminum beer can. This is part of a general pattern in our society. We are rich enough to throw away 1 million automobiles each year, but we do not have the money for decent housing and decent schools. We can afford plastic packaging but not adequate hospitals. Present increases in power consumption are not in the interest of a generally better life for all—they just spell more waste.

All this may seem a little far afield from the topic today, but I am going to work my way back around to nuclear power plants now.

The point I am trying to make is that nuclear power is intimately a part of the electric-power industry as a whole. Nuclear power plants, most simply considered, are just another means of boiling water, as Senator Gravel has remarked. The benefits, as well as the hazards of nuclear power, are dictated by the way in which electric power is consumed and the rate at which it grows.

This is a less dramatic view than we are used to taking of nuclear energy. From the tragic and spectacular first nuclear explosions, all the applications of nuclear energy have been expected to transform our lives for better or for worse. These expectations were written into the laws governing the use of nuclear energy. The 1946 Atomic Energy Act contained the following passage:

> The effect of the use of atomic energy for civilian purposes upon the social, economic and political structures of today cannot now be determined .... It is reasonable to anticipate, however, that tapping this new source of energy will cause profound changes in our present way of life....

That was 25 years ago. More recently, Congress in 1954 described the purposes of the new Atomic Energy Act, which is still the law of the land:

> It is declared to be the policy of the United States that... the development, use and control of atomic energy shall be directed so as to promote world peace, improve the general welfare, increase the standard of living, and strengthen free competition in private enterprise.

These are very large demands to make of atomic energy. After almost 30 years of intensive development, I think it is time to recognize that the peaceful uses of the atom have not transformed our lives in any important way and are not likely to do so. The principal civilian application of nuclear energy is in meeting the goal of expanding electric-power production. This is the real benefit we are being asked to accept in exchange for the hazards of nuclear power production. It is a very dubious benefit indeed. There are very few risks I would take to assure myself of the continued use of aluminum beer cans and TV dinner trays. But this is the reality of the peaceful atom that has so long been obscured by the sensational beginnings of nuclear energy.

In this context, it seems to me that very little risk at all should be sufficient to rule out new electric power plants we should not be building in the first place.

What, then, are the risks of nuclear power? A good deal of attention has been paid to the problems of thermal pollution. These problems, of course, are not restricted to nuclear power plants, and I will not go into them here. Suffice it to say that nuclear power plants discharge more waste heat per unit of electricity than coal-burning plants and that all the problems of disposing of this waste heat are greater in nuclear than in conventional plants. More attention should be given to the special hazards of nuclear power, i.e., those which concern the release of radioactive materials to the general environment.

One of the difficulties one immediately meets in talking about these problems is the lack of experience with operating nuclear power plants. We have something like one hundred reactor-years of experience with civilian power plants. If this were enough experience to give us an estimate of their safety, they would be very unsafe indeed. If the chance of a major accident were greater than one in a hundred per year, we would be having annual disasters in the nuclear industry well before the 1980s. Unfortunately, the hundred and more plants that are already firmly committed or are in operation will reveal their secrets slowly, and we can only make estimates of what their safety record will be. This makes for some heated disputes. If nuclear power plants only release the amounts of radiation projected by their manufacturers, John Gofman and Arthur Tamplin assure us they will have no objection.

The question is one of how much radioactivity will be released in practice when there are a great many reactors and fuel processing plants and other ancillary facilities. Will the optimistic projections be realized? One may be permitted to doubt. A good deal depends on the controls that are exerted over a rapidly growing industry. Right now, the Atomic Energy Commission is a fairly large regulatory body compared with the number of power plants it must oversee. Each plant receives a good deal of attention not only from the AEC but from the plant's neighbors and critics. Whether or not this careful attention can be maintained for long is a reasonable question. Will the manufacture of fuel and the maintenance of safeguards be of such high quality as to fulfill present projections? One would like to have a little more than the manufacturers' promises of good intentions, and, of course, this is the reason for the present debate over radiation standards.

Other speakers in this series have addressed themselves to the hazards of radiation in the environment, and I will not try to develop the subject further. Let us just agree that the hazards are not trivial. It is a matter of great importance that radiation levels be kept as low as the supporters of nuclear energy say they will be kept. The AEC has tightened its standards, but the real questions lie in the realm of enforcement. Constant public scrutiny and criticism will be needed if regulations are to be translated into practice.

The gratifying thing is that nuclear plants can, in fact, be constructed to meet extremely stringent radiation standards. With a modest additional expenditure, they can be built to retain almost all wastes for deep burial. The industry is to be congratulated that steps are being taken to reduce plant emissions, and I certainly hope the trend will continue.

Another problem, which has always seemed to me to be more difficult to surmount than the problem of routine emissions, is the problem of serious accident. One of the worst features of the present hasty growth of electric-power production is the very large size of new power plants being built. There has been a good deal of trouble with the conventional portions of the very large nuclear plants and with the larger coal- and oil-burning plants. Aside from operating difficulties, however, the great size of nuclear plants is disturbing because of the way in which it creates whole new accident problems.

In my book *The Careless Atom* I quoted the following passage, which I will repeat here, from Clifford K. Beck:

> Let me just mention one technical fact to point up the significance of the changes that are occurring. There is a very large difference in the implications of a major meltdown in a [1,000,000-kilowatt reactor—the size which was then being planned] as contrasted to that in a [100,000-kilowatt reactor—roughly the size which was typical at the time of Wash-740]. For the small reactor, it may make good sense to surround it with a leak-proof, concrete "thermos bottle" containment, and, in the case of accident, just walk away and let everything inside settle down and cool off. For the [1,000,000-kilowatt] reactor. . . if you walk away from that "thermos-bottle," its temperature curve, after perhaps a momentary decline, will rise continuously and will simply heat up until it bursts, so a reliable cooling system must be added.

This is such a good explanation of the new hazards of large plants that I will not try to enlarge on it. We have all been sufficiently frightened by the significance of a reactor containment "bursting," and there is no need to repeat the statistics given in USAEC Report WASH-740. We are all agreed that this would be an unacceptable accident and, apart from its enormous destructiveness, would probably mean the end of civilian nuclear power.

The important point to remember is that such accidents are only really difficult problems with very large plants. This, of course, is because of the problem of after-heat. The nuclear fission going on in present-day reactors is probably not a hazard, because just about anything that happens to the plant will shut it down. This is in large part due, of course, to the fact that the nuclear chain reaction in present reactors depends on the presence of a moderator; if the moderator is physically displaced, boiled away, or what have you, the fission chain reaction ceases.

Unfortunately, the heat created by the decay of radioactive wastes within the reactor fuel cannot be turned off in any way, and it is this residual heat that requires what Mr. Beck calls "reliable" cooling. Now, some might feel that reliable is too mild a word in this context since, once the reactor is operating, under no circumstances whatsoever may there be an interruption of cooling for more than a few seconds. If cooling is interrupted for as much as a minute, the physical distortion of the fuel as a result of overheating and the chemical reactions that will occur may make further cooling impossible, and the irreversible process of fuel meltdown will occur. Once again, I think there is no disagreement that, once the fuel of a 1000-megawatt reactor melts down, there can be no assurance that radiation will be contained. This, of course, is the reason for the present scrutiny of emergency cooling systems.

Despite the inherent nuclear safeguards of all present light-water reactors, therefore, there is an inherent difficulty in large plants, such as those being built now. The question is really one of whether cooling can be maintained under all possible circumstances. Whatever the intentions of the designers and the efforts made to accomplish this end, I do not think it is possible to make a system that cannot fail, and I think it is misleading to describe reactors as safe. In fact, they are a gamble. Partly because we cannot know in advance how the industry will really function and how the plants will perform over their lifetimes and partly because we cannot predict every occurrence in advance, there simply can be no certainty, with large reactors, that there will not be a catastrophic accident.

Now I am aware that great efforts are being made to reduce the risk of losing this gamble, and I am the first to agree that the chances of a serious reactor accident are small. None of us know how small it is, however. One thinks of a game of Russian roulette—the chances of winning are large, but the consequences of losing are fairly drastic.

Do we want to take such a gamble? The answer depends a good deal on what the rewards of winning are. But we have already seen that, as it is presently being conducted, the benefits of the nuclear power program consist largely in more waste, an even greater expansion of the senseless pell-mell growth of the electric-power industry.

Should we take such a gamble for such rewards? To me the answer is obviously "No," and that means we should stop building nuclear power plants until this nation has a rational energy policy and is able to make some use of the undoubted benefits of nuclear power in small, entirely clean plants.

WHAT WE DO KNOW ABOUT LOW-LEVEL RADIATION

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Dr. Taylor received his principal education at Stevens Institute of Technology and Cornell University and holds honorary degrees from the University of Pennsylvania and St. Procopius College. In 1927 he organized the X-ray Standards Program at the National Bureau of Standards. In 1928 he was a member of a group that formed what is now the International Commission on Radiological Protection. In 1929 he helped form the Advisory Committee on X-ray and Radium Protection, now the federally chartered National Council on Radiation Protection and Measurements. In 1962 Dr. Taylor was made an Associate Director of the National Bureau of Standards, and in 1965 he went with the National Academy of Sciences as Special Assistant to the President and Director of its advisory committee to the Office of Emergency Planning.

I shall endeavor to explain in general terms what we do and do not know about radiation effects, especially those produced by exposures at low doses and low dose rates. During the last couple of years, we have witnessed some fantastic declamations on the subject of radiation hazards. Some have been based on speculation and misinformation, some have been well intended but uninformed, and some have been reasoned and well informed. A small fraction of them have been downright and

THE PROBLEM OF SETTING PROTECTION STANDARDS

In trying to arrive at "safe" or acceptable levels of radiation exposure, whether for occupationally exposed individuals or nonoccupationally exposed population groups, one should recognize from the outset that there is no such thing as absolute safety where radiation is concerned—or, for that matter, any other environmental pollutant. Safety is relative, and its quantitation can only be considered within the framework of all the risks that man is faced with. A high level of safety in one area may be completely negated by some seemingly unrelated low level of safety from some other cause. For example, when we use the term "safe," as we are certain to do in some discussions, the difference between relative safety and absolute safety must be clearly understood.[2] It is often better to use the word "acceptable."

During the past two years or so, the basis for establishing radiation protection standards has been needlessly confused and misrepresented through the failure of a few persons to use properly the models designed to assist in estimating effects at low doses and low dose rates. The difficulties center about the matter of thresholds, recovery, and the shape of the dose–effect curves. These will be referred to repeatedly in the discussions to follow.

Concerning radiation protection, the point is frequently brought up that higher degrees of protection are technically feasible under certain circumstances; therefore why are they not used? I might add that precisely the same argument may be, and is, applied to almost every agent that may be regarded as possibly detrimental to health. Stopping at any point in a protective procedure is a matter of cost, judgment, and experience and may quite reasonably be set at different points depending upon what the circumstances and the needs may be.

In the setting of any kind of safety standards, it is important to have some understanding of the range of technical uncertainty and of judgmental involvement and uncertainty. If these uncertainties for radiation are better and more clearly presented to the public, as well as to the scientist, it will permit a much more reasonable basis for open discussion and broad understanding of the problem. I recall, as an example, the furor that was raised by some of the press in 1959, when the NCRP, as a result of some new postulates and calculations based on more up-to-date knowledge, changed the permissible body burden for ^{90}Sr from 1 to 2 microcuries (μCi) without changing the calculated risk. The NCRP was attacked, scientists were attacked; we were all accused of having calloused disregard for the health of the nation. As a matter of fact, there were elements of the biomedical information which were fed into the calculations that were certainly not known within a factor of 10 and possibly larger. On the other hand, the fundamental process of radiation effects was well enough understood so that numbers could be assigned to the particular conditions with the reasonable certainty that if they were in error, the error would at least lead to less risk rather than more risk to the individual.

It is therefore important to have an understanding of the mechanisms of radiation

Statistically significant injury to miners has not been demonstrated for exposures over several years in mines in which the average concentration of radon daughters has been less than about 1 WL. The dose would be on the order of 3 rads/month. The FRC has recommended mine control such that no individual would receive more than 6 WLM in any consecutive 3-month period or 12 WLM a year. The Department of Labor has stipulated $\frac{1}{3}$ WL per month.

Radiation in sufficient amounts will cause an erythema, or a reddening of the skin. In fact, until about the mid 1920s, radiation exposure was measured in terms of fractions of the amount necessary to produce a barely detectable reddening of the skin. This was called a threshold erythema, and indeed an erythema is strictly a threshold phenomenon.

There are other bench marks for radiation effects. For example, thyroid cancer resulting from childhood exposure of the thymus, and incidentally of the thyroid, to large doses of X rays has been demonstrated. Support for this is also shown in the cases of the Japanese atomic bomb exposures. A relationship between dose and incidence of thyroid cancer—usually not fatal—may be demonstrated for high doses. Similarly there is now some limited evidence of the same nature for lung cancer and breast cancer. The doses involved in all these individuals range from a few tens of rads up to several hundreds, but there are no demonstrable effects in the low range. Each effect, even if the dose–effect relationship is linear over the range of observation, is at a different effect rate. In other words, there will be a series of linear dose–effect relationships depending not only on the effect under study but on the rate of delivery of the dose and undoubtedly on many other factors.

One of the seemingly best established dose–effect relationships of a decade ago was that for genetic mutations. This was based primarily on the early experiments of Muller. However, within the last decade, the Russells[17] at Oak Ridge and others have carried out elaborate and sophisticated genetics experiments with hundreds of thousands of mice, and they find that not only is there no single linear dose–effect relationship but there are different linear relationships depending on the level of dose and the rate at which it is delivered. They have also clearly established for one effect that there is a threshold dose rate in the female, whereas in the male there is no similar evidence of threshold in the same dose-rate range. The Russell studies appear to demonstrate, at least in females, that there is recovery in genetic material exposed at low dose and low dose rates.

And so it goes. There is evidence for linear dose–effect relationships of various slopes depending on the specific effects; there is also evidence for at least practical thresholds of effects, but generally speaking there has been no statistically significant information obtained on dose–effect relationships for doses of less than a few rads, or tens of rads, delivered more or less all at once.

Before I leave this part of the discussion I want to point out that while speaking about some of the preceding effects I have referred to the possibility of threshold of effect on biological systems. I wish to emphasize that whether there is or is not a threshold has never played any part, as such, in the setting of radiation protection standards. It is simply a part of the description of the effect—possibly a cut-off limit for the effect expected. As a matter of fact, if we were to establish radiation protection standards on the basis of practical thresholds, they would probably be set in many instances at dose levels substantially higher than they are at the present time; use of the linear hypothesis, without threshold, leads to the most conservative practices.

From the preceding discussions it should be clear, without going into further detail, that a given biomedical result is dependent on the rate at which the dose is delivered, the intervals between doses when they are given in fractions, and the total dose administered. For example, a person receiving a whole-body dose of 50 or 100 rads distributed more or less uniformly over a year's time would almost certainly show no obvious and possibly no detectable effects at the end of that time. However, to receive the same dose in the matter of a few minutes would almost certainly be detectable without difficulty and might even be sufficient to cause almost immediate vomiting in a few sensitive individuals. In cancer therapy it is customary to deliver extremely large doses to substantial fractions of a patient's body in a series of doses of several hundred rads given three to six days a week for several weeks. Doses on the order of several thousand rads per treatment series are fairly standard, whereas the same amount of radiation given to the trunk in one treatment could be lethal.

Fractionated treatment of this type, accompanied by moderate intervals between treatments, have permitted total doses to be given to cancer patients amounting to as much as 20,000 rads over a period of several years. This obviously means that there is substantial recovery from radiation injury to organ systems, and hence there cannot be a simple additivity of protracted or fractionated doses in predicting a given effect.

These facts are all clearly established in the high dose range, and it may be inferred that similar repair mechanisms are effective in the very low dose range—say below 1 rad. But even such exposures as these are high, compared with exposures likely to be encountered in the normal operations of, say, nuclear power reactors or most other activities involving radiation.

LOW-LEVEL RADIATION EFFECTS

Having stepped rather spottily through some of the high-level radiation effects on which we do have substantial knowledge, we must of course turn to the possibility of low-level dose effects in humans, such as might be encountered in diagnostic radiology or the environs of a nuclear power reactor. Our knowledge of dose effects in the region below 1 rad or 1 rem can be summed up very easily. Despite many millions of dollars worth of experimental studies carried out the world over and despite many attempts at the clinical level, no one has yet been able to establish a dose–effect relationship in this range. On the contrary, there is a tremendous amount of information in the form of negative results based on doses to radiation workers and a few others at levels up to 1 or 2 rads/year. Farther up, at 5, 10, or even 15 rads/year, effects are observed infrequently. The amount of such experience with large numbers of people is enormous, and it must be given substantial weight even though the results are negative. But, at the same time, we must be prepared to answer the argument that the reason why we cannot measure the indirect effects is because they are too small or occur too infrequently. This may well be the case, but of course it is also part of the answer. If the indirect effects cannot be measured by any of the fairly sophisticated methods that we have available today, it automatically means that the potential hazard—if any exists at all—is sufficiently small so that there is a great deal of time during which to further study and analyze the question without at the same time putting a large number of people at serious risk.

It is, however, this very fact of being unable to detect any deleterious effect in humans, accompanied by an unwillingness to say that there is no effect at all, that has led the protection scientists into the dilemma that is now faced. How can one ever prove the negative case empirically? It is this question which is poorly understood by the general public and many others who may be charged with the responsibility of controlling our health and safety.

It is the dilemma that has led several of our responsible protection bodies to postulate—for purposes of discussion and to provide a sense of proportion—the most conservative positions:

1. There is a linear dose–effect relationship for all radiation effects from high dose levels in the ranges of several hundreds of rads down to zero dose.

2. There is no threshold of radiation dose above which an effect would occur and below which it would not.

3. All low doses delivered to an organ are completely additive no matter at what rate they are delivered or what intervals there may be in the delivery.

4. There is no biological recovery of radiation effect from low doses.

It is known that none of these assumptions is strictly correct. The amount of deviation from them under some circumstances is known for limited situations. One of the most important areas of research ahead of us is to attempt some kind of evaluation of the nature and the extent of the deviations from these assumptions. The question is—not whether there are deviations—but how large are the deviations? Safe—how safe?

Having arrived at this position with regard to our knowledge and the assumptions we make for radiation protection purposes, we then face squarely into the basic philosophical question of how standards are set for conditions for which there are no observable or no statistically discernable effects.

THE PHILOSOPHY OF THE LINEAR AND NO-THRESHOLD CONCEPT

Up to this point the discussion has dealt schematically with the low-level effects of gamma and beta radiations. Neutrons may present a special and possibly more serious problem, but it is one of primary concern only to certain radiation workers and to the effects from nuclear weapons.

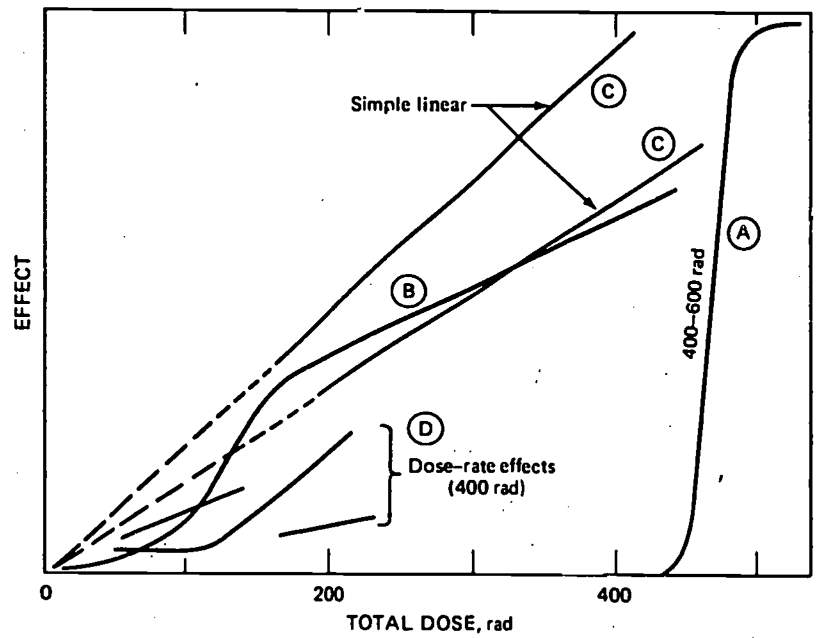

Fig. 3 Possible radiation dose–effect relationships. Curve A, threshold effects, e.g., cataracts. Curve B, sigmoid relationship without threshold. Curves C, two linear dose–effect relationships. Curves D, two relationships for certain genetic effects dependent on dose and dose rates.

makers, our protectionists, and the public to understand this fallacy and to adjust their considerations of radiation protection problems accordingly.

In closing, I would like to repeat: ionizing radiation, including its effects on man and the environment, whether regarded as a biological insult to the individual or as a general environmental pollutant, is probably the most studied, best understood, most wisely used agent found essential to our health and well being. Its improper use—or any use—may also carry some element of risk to man.

There is the cliché that the insidious part of radiation is the fact that you cannot feel it, see it, or taste it. But radiation can be detected and measured easily and instantly and at levels well below those occurring in the natural environment. This cannot be said for any of the other environmental pollutants of common concern.

NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

Since most of radiation protection standards and philosophy used in this country have come directly, or indirectly, from the NCRP, it was suggested that I take a few moments to tell you about the organization.

In 1929, because there were several informal society committees dealing with radiation protection matters, it was decided to combine these efforts into a single committee, then known as the Advisory Committee on X-Ray and Radium Protection. The National Bureau of Standards was willing to provide a home for the Committee and print its reports but from the outset made it very clear that there was no official relationship of any kind between the committee and the government. During the 1930s the committee developed the level of tolerance dose allowed for radiation workers, which was a slight abridgment of an international value. In 1940 it established for the first time a permissible body burden for radium for radiation workers. Immediately after World War II, the committee was reorganized and enlarged and since that time has provided much of the basic philosophy and actual numerical standards used not only in this country but throughout the world.

The standards developed by the FRC are essentially those of the NCRP, which have been accepted after extensive reexamination and reevaluation.

In 1964 the NCRP was given a federal charter by an act of Congress. This was done on the behest of Representative Holifield, and one of his strong arguments was the necessity of having a strictly nongovernmental organization involved in the development of radiation standards. The charter clearly recognized the council's capability in the field and helps to set it clearly apart from government. It is, in fact, something that the council is extremely proud of even though it does not vest it with any official position, special privilege, or any special authority. Neither does it make the work of the organization in any way subject to government control.

At the present time the NCRP is made up of 65 elected members, of which 11 are further elected to act as a board of directors. In addition, some 150 to 200 individuals participate in the work of its 36 scientific committees, covering just about every aspect of radiation protection and measurement. The organization now has its own secretariat and offices and is funded from a variety of sources including some government contracts, foundation support, and annual contributions from some 21 scientific organizations in this country.

The question of funding is one of our most sensitive spots. It is essential that the organization not only remain in a nonprofit status but that it must also avoid having too much of its funding coming from any one source, which might dominate its activities. Our objective is to have less than 50% of our funding in the form of contracts from government agencies. Actually at the present time it is considerably greater than this although we are at some pains to ensure that the sources are diversified between different federal agencies.

Most of the noncontract funding comes from professional societies in small amounts. Very little comes from industry or industry-oriented groups, and none comes from labor. It is our feeling that both industry and labor should support the effort, but both must participate and neither must be allowed to dominate.

Studies by the NCRP are usually aimed toward a published report and are generated mainly by recommendations from the members; they, in turn, try to be responsive to current needs. In a few instances a specific study has been undertaken because of an outside request. We have more studies planned than we can carry out.

A report prepared by standing or ad hoc committees is examined first by "critical reviewers"; these would be the members of the NCRP most knowledgeable in the area concerned. It is then submitted to the entire elected council for review and approval—or rejection. This is sometimes a slow and laborious procedure, but it does give a very high degree of assurance that not only is the finished report objective but it is also technically sound. It is because of such reviewers, coming from all areas of science and technology, that the reports and the recommendations of the NCRP have not only stood up well with time but, also have been widely adopted by other organizations.

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