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NUCLEAR POWER AND RADIATION IN PERSPECTIVE

SELECTIONS from *NUCLEAR SAFETY*

J. R. Buchanan

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NUCLEAR POWER AND RADIATION IN PERSPECTIVE

Selections from *Nuclear Safety*

J. R. Buchanan

Reactor Division

MARCH 1974

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
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FOREWORD

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ABSTRACT

The risks of nuclear power and radiation are described to place them in perspective with other potential hazards faced by the public on a day-to-day basis in our complex industrial society. Twenty articles on this general topic that have appeared in *Nuclear Safety* are reprinted, since they collectively form a valuable reference source. Topics covered include the effects of radiation, risk-benefit concepts, radiation risks relative to other risks, nuclear plant risks relative to fossil plant risks, licensing requirements, nuclear insurance, nuclear industry safety record, and public attitudes.

INTRODUCTION

During 14 years of publication *Nuclear Safety* has carried many articles on the comparative risks of nuclear power and radiation relative to risks routinely faced in our everyday life. Nuclear power and radiation are other potential hazards added to those which our complex industrial society faces constantly. While our lives are enriched by the use of electricity, airplanes, automobiles, chemicals, etc., these conveniences introduce, along with the benefits, hazards that are neither to be ignored nor exaggerated. Other topics covered by the articles include the effects of radiation, risk-benefit concepts, radiation risks relative to other risks, nuclear plant risks relative to fossil plant risks, licensing requirements, nuclear insurance, nuclear industry safety records, and public attitudes. Since they collectively form a valuable reference source, the articles are reprinted in this report for the convenience of those working in the field and interested members of the general public. Brief resumés of those selected for inclusion follow.

Radiation and Its Effects

Radiation effects on humans, noticed shortly after the discovery of x rays, were usually from exposures due to ignorance. Now we have instruments to detect and measure all types of radiation. Furthermore, there has been considerable scientific study into the two types of effects: (1) somatic, what happens to our body, and (2) genetic, what happens to our offspring.

In the spring of 1964, *Nuclear Safety* published the first article in the series entitled, "Radiation in Perspective." This article (p. 1), excerpted from a lecture by Francis L. Brannigan of the U.S. Atomic Energy Commission, discussed the potential hazard from radiation and observable body effects from exposure to radiation. Low-level radiation effects were treated in a novel fashion by T. J. Jankowski (p. 23). Acknowledging that there is no firm basis for interpolating or extrapolating radiation effects to very small exposures, he raised the question as whether all

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radiation is harmful and called for experiments at levels below background dose rates.

D. B. Yeates and colleagues at the Harvard School of Public Health (p. 99) summarized data on natural background radiation levels in the urban environment. The effects of building type, construction materials, and ventilation were discussed. The data indicated that there can be substantial differences in the doses from sources of natural origin depending on the mode of life of the individual.

Two articles by Merril Eisenbud of New York University Medical Center are included in the series. The first (p. 19) analyzed some of the fallacies underlying frequently quoted adages used to question the acceptability of nuclear power as a source of energy such as "The air and water will become radioactive," and "There is no such thing as a safe dose." The analysis served to illustrate the way in which statements of this type contribute to misunderstanding when taken out of context. The second article (p. 51) described U.S. radiation standards and their genesis. The standards were felt to contain extensive built-in conservatism; however, some changes were recommended. [Subsequently, AEC proposed changes in its regulations to keep radioactive effluents from light water power reactors "as low as practical" — *Federal Register*, 36(111): 11113 (June 9, 1971).]

Risk Benefit

Man's every effort to provide the goods and services he needs and wants results in some measurable risk to him in terms of injury, illness, and death. J. H. Sterner of Eastman Kodak Company (p. 16) traces technological advances over the years to show that society has dealt unevenly with the development of guides for determining acceptability in balancing benefits vs hazards. So that we do not discriminate against atomic energy, he suggested that it is essential that its benefits and hazards be placed in perspective with other comparable activities and their environmental activities or else society will be deprived of needed and beneficial goods and services.

Radiation vs Other Risks

For purposes of perspective, potential injury due to radiation dose has been compared with other risks which man faces in his everyday life. For example, Andrew P. Hull of Brookhaven National Laboratory (p. 58) compared injury from radiation to firearms, automobiles, smoking, diseases, natural disasters, etc. He further suggested that the radiation levels in the vicinity of large nuclear power reactors will be insignificant and that the risk of fatal injury from the anticipated maximum exposures is small compared with that of other accepted hazards of everyday living. C. Roger McCullough (deceased) of NUS Corporation (p. 11) developed a similar thesis while examining a number of factors that influence the health and longevity of populations. Values were presented on estimated loss or gain in average life-span due to background radiation, man-made radiation, smoking, country vs city living, etc. In an article mentioned earlier, Jankowski (p. 23) drew an analogy between the biological effects of inorganic chemicals and the effects of radiation. Brannigan (p. 1) also compared radiation risks with those faced by man in his daily life.

Nuclear Plants vs Fossil Plants

Several of the articles in the series have compared the relative hazards between nuclear and fossil power plants. Hull (p. 58) suggested that from evidence to date the hazard potential of nuclear plants had been greatly overexaggerated by adversaries of such plants due to the unparalleled means taken to guard against the risks that do exist. Regarding effluents, nuclear plants were shown to produce less air pollution, relative to applicable standards, than fossil plants. Birny R. Fish, Oak Ridge National Laboratory (p. 40), described several air pollution disasters of the past and proposed that nuclear energy has a critically important role in combating the growing assault on our atmosphere by supplanting fossil fuel for most of the power plants to be built late in the century.

The two most recent articles in the series were also concerned with health risks of electricity generation from fossil-fuel and from nuclear-fuel plants. Chauncey Starr and M. A. Greenfield, both at UCLA at the time (p. 133), compared the public health risks of nuclear power plants with oil-fired plants for a 1972 state of California long-range planning study. They concluded that the risk from each is roughly comparable to the hazards from uncontrollable natural events such as lightning, insect or snake bites, etc. [In an earlier article in 1964, Starr (p. 3) concluded that the public interest would best be served if the utilities maintain the freedom to select atomic power where appropriate.] The occupational and public-health effects of electricity generation from coal, uranium, and oil were compared by L. B. Lave and L. C. Freeburg of Carnegie-Mellon University (p. 140), with particular emphasis given to accident and chronic disease rates for fuel extraction and airborne emmissions from power and reprocessing plants. It was concluded that, based on current operating practice, uranium as a fuel offers a lesser health hazard than coal. However, reductions in both occupational and public health risks of each can be expected due to advances in technology.

Licensing Requirements

The U.S. Atomic Energy Commission has statutory responsibility for the regulation of nuclear power plants through the issuance of construction permits and operating permits. This responsibility is executed by the AEC Regulatory Staff, headed by the Director of Regulation, who reports directly to the five Atomic Energy Commissioners. The AEC Rules and Regulations are published in the Code of Federal Regulations, Title 10, Chapter 1 and have the force of law. Paramount in these activities is the protection of both the public health and safety and the environment.

Two articles by Joyce P. Davis of Consolidated Edison Company (pp. 110 and 118) reviewed the regulatory process and discussed the radiological and nonradiological effects of nuclear power plants. While giving particular attention to the jurisdiction of the AEC, the role of other federal agencies, including the Federal Power Commission, the Corps of Engineers, and the Environmental Protection Agency, was also explored. Some related cases and controversies were discussed. In 1971, the time required to obtain construction and operating licenses for nuclear power plants was studied by G. O. Bright, then with the Aerojet Nuclear Company (p. 90). It was obvious that the environmental protection movement was greatly affecting the licensing process by extending the time required to obtain a license.

Insurance

Liability insurance for nuclear facilities in the U.S. is provided under arrangements specified by the Price-Anderson Act, which was passed by Congress in 1957 and amended in 1965. The total of private insurance and government indemnity for power reactors was set at a constant $560 million. The history and experience of nuclear liability was thoroughly summarized by Joseph Marrone of NELIA (p. 77). Starr in an earlier article (p. 3) pointed out that the government has traditionally stepped in where the normal functioning of private insurance becomes financially hazardous due to a lack of actuarial data and when the furthering of a national interest would be inhibited by the absence of insurance coverage. Fifteen examples of such programs were cited.

Safety Record

The extraordinary safety record of the nuclear industry is the most significant fact issuing from the claims records of the nuclear insurance pools. Marrone (p. 77) states that the pools have never received a claim for bodily injury or property damage caused during the operation of a nuclear reactor. He suggested that the effective control of a relatively new and serious hazard presented a positive image of safety that could be presented as an example that warrants emulation in other areas.

McCullough (p. 11) also discussed the excellent safety record of the nuclear industry. Though published earlier (Fall 1964), it included the record of AEC nuclear installations as well.

Public Attitudes

As we see it is not difficult to defend the nuclear industry on the basis of its safety record. Nevertheless, additional public understanding is clearly needed. While there are responsible critics from which the industry can learn, there exists as well extremists who generally serve no good cause. Henry B. Piper, formerly on the Nuclear Safety Information Center staff, examined some sensational handling of the potential hazards of nuclear power by several writers (p. 31). Piper's article originally appeared in *Nuclear News* and is reprinted by permission of the American Nuclear Society.

Nearly 800 items in the daily and periodical press pertaining to the nuclear industry were examined by Dan N. Hess of ORNL (p. 69) on the assumption that the public press is both a molder of opinion and a reflector of public interest. The articles were assigned to 1 of 12 subject categories and the relative antipathy toward controversial issues measured for each. Hess suggested that the "against" articles, though perhaps not in the majority, do get and hold the public's attention. Additional effort by the industry to develop full public understanding of the complex and sensitive issues appeared to be clearly warranted. H. G. Slater of Niagara Mohawk Power Corporation (p. 82) also explored public and press attitudes on nuclear power, though from the industry point of view. He called on the leaders in nuclear technology to do all they can to inform the public and to listen to all responsible critics and seriously consider their objections.

Epilogue

These 20 articles that have appeared over the years in *Nuclear Safety* form a very important collective source of information in the comparative risks of nuclear power and radiation relative to the risks that man routinely faces in his everyday life. Equally important are the comparisons of the benefits and risks of nuclear power generation. While the articles are quite general in their coverage, they do not discuss every conceivable facet of the risks and benefits of nuclear power and radiation. *Nuclear Safety* will continue to inform and stimulate its readers with articles on these same topics in the future.

THE POTENTIAL HAZARD FROM RADIATION*

[*Nucl. Safety*, 5(3): 226–228 (Spring 1964)]

We, as transient occupants of this terrestrial sphere, are the inevitable recipients of substantial quantities of radiation whether we like it or not. This radiation originates both from cosmic sources and from sources in the earth itself. As a consequence of these sources of radiation, we are not only subjected to radiation from our surroundings but, as a consequence of our environment, are ourselves radioactive sources. Considered in this light, the real question is not how dangerous radiation is but how much radiation is dangerous. This is particularly true when we realize not only that man has never existed in a radiation-free environment but also that it is possible that he owes his own development to changes induced in part by radiation.

"The background level of radiation to which we are subjected varies widely all over the world and scientists have not yet been able to come up with any correlation between these variations in the background level and any injury. We have on the one hand this background level of radiation, and on the other hand the fact that high doses of radiation can cause death. The [real] question is: 'How much more radiation over background can we take without injury?' "

This question may be compared to slapping one's hand on the desk. "It is possible to argue that I have damaged my hand, though the damage is invisible. At a harder slap, I would get a reddening. At even a harder slap, black and blue marks. Harder than that, broken bones. The ultimate degree of damage, of course, is to break the hand off at the wrist. So the question 'Is it dangerous to slap your hand on the desk?' is answered by 'It depends upon the energy involved.' "

*Except where noted the information herein was adapted from a 16-mm film entitled "Radiation in Perspective," which presents a lecture by Francis L. Brannigan of the AEC, Division of Health and Safety. The film is available on loan from the motion picture libraries of the AEC.

On the basis of our knowledge of radiation exposure delivered in a short time, we conclude that the effects corresponding to various levels of exposure (i.e., amounts of energy) are as tabulated below:

Total body exposure, r	Effect
Below 25	No observable effect
At about 25	Threshold level for detectable effect
At about 50	Slight temporary blood changes
At about 100	Nausea, fatigue, vomiting
From 200 to 250	Fatality possible, though recovery more likely
At about 500	Half of the victims might die
Around 1000	All victims would die

Although the above effects and exposures describe conditions that might be expected in the event of nuclear hostilities or in the confined environs of a nuclear facility following an incident, it does not describe the significant situation of public concern, viz., what is the effect of repeated small doses of radiation, each one of which is so low that there is no identifiable effect. This problem, in turn, divides into two parts—consideration of the somatic effect and of the genetic effect. Thus, if we attempt to extend the exposure vs. effect relation (as in the above table) to smaller and smaller doses, we run out of information. The most conservative extrapolation of this relation is the so-called "dose equivalent" concept in which we extend the dose-effect relation to zero, assuming implicitly that for every dose there is an "insult"—regardless of how small and regardless of the fact that we cannot find it. This is the approach adopted by the federal government in establishing recommended radiation limits. In particular, radioactive operations are regulated by the government so that no member of the general public receives a whole-body dose in any calendar year in excess of 0.5 rem.[18] Thus in 50 years an individual member of the public could receive a maximum of only 25 rem (an amount that produces no observable effect when received in a short time) without taking any credit for the body's natural repair processes, which would have been quite effective for low-level insults in a prolonged period.

The other part of the problem is the genetic effect. However, although it is true that radiation can produce genetic effects, it has also been estimated[18] that the background radiation (which in this country averages 0.13 r/year and is greater than 1 r/year in some areas) accounts for only a small fraction of spontaneous mutations. Further, some hundreds of chemical agents are known to be mutagenic, although none has been studied in such detail as radiation. Some active mutagens are listed in Table 1-1 (from Ref. 19). These are substances that affect the genetic material at concentrations lower than those which would cause cellular

Table 1-1 SOME EFFECTIVE MUTAGENS STUDIED IN DIFFERENT ORGANISMS*

Mutagen	Drosophila	Neurospora reversions	Higher plants	Bacteria	Source of exposure
Mustard derivatives	†	†	†	†	Therapy
Nitrogen mustards					
Epoxides‡	†	†	†	†	Industry
Epoxide					Domestic use
Diepoxybutane					
Imines	†	†	†	†	Therapy
Triethylenemelamine (TEM)					
Alkane-sulfonic esters	†	†	†	†	Therapy
Dimethylsulfonoxybutane (Myleran)					
Other alkylating agents	†	†	†	†	
Dimethyl sulfate					
Diethyl sulfate					
Peroxides‡					Smog
Tert. butyl hydroperoxide	†	†	§	§	
Dihydroxymethyl peroxide	†	†	§	§	
Aldehydes‡	†	†	¶	¶	
Formaldehyde					Industry
Propionaldehyde					Smog
Acrolein					Disinfectant
Basic dyes‡	†	§	§	†	Industry
Proflavine					
Pyronine					
Acridine orange					
Purines‡					
Caffeine	¶	§	§	†	Beverages
8-ethoxy caffeine	**	§	Chroms††	§	Widespread use
Antimetabolites‡	**	§	§	†	Therapy
5-bromouracil					
2-aminopurine					
Pyrrolizidine alkaloids	†	§	§	§	Herbs
Miscellaneous					
Nitrous acid	§	§	§	†	
Phenol	†	**	Chroms††	§	Industry
Manganous chloride	**	§	§	†	
Urethane	†	**	Chroms††	§	
Diazomethane	†	†	§	§	
Beta-propiolactone	§	†	†	†	
Maleic hydrazide‡	**	**	Chroms††	**	Food and agriculture
Ethyl alcohol‡	**	**	Chroms††	**	Widespread
Nicotine‡	**	**	Chroms††	**	Widespread

* One or more typical examples listed in each class of mutagen.
† Mutagenic.
‡ Of common occurrence, at least in certain human environments.
§ No reference to mutagenic activity available.
¶ Weakly mutagenic.
** Not mutagenic.
†† Produces chromosome breaks in plants.

(somatic) damage. Although none of the results tabulated are for the human species, it is reasonable to presume that these chemicals can also produce mutations in man and may be responsible for the majority of the mutations known to occur.

We can get some feel for the conservative nature of the radiation regulations if we compare the ratio of the allowable to dangerous levels for radiation with the ratio of allowable to dangerous levels for another substance, such as carbon monoxide gas (see the accompanying tabulation).

This does not necessarily mean that the prescribed maximum radiation levels are 80,000/15 or > 5000 times safer than allowable exposure levels for carbon monoxide, since "the two cases are not directly comparable. However... [it is true] that there is a tremendously greater spread between the acceptable level and the immediately dangerous level in the case of radiation than there is for other noxious substances" and this undoubtedly reflects both the extremely conservative approach employed in establishing permissible radiation levels and the empirical approach used in establishing permissible levels for other substances.

Carbon monoxide	Radiation
We are permitted 100 ppm in the air of carbon monoxide gas for breathing over an extended period of time	If we were to divide the lifetime exposure figure by the number of working hours in a lifetime, we would come out with an hourly average of 2.5 mr/hr
A level of 1500 ppm of carbon monoxide gas in the air is extremely dangerous such that, if we were to breathe that level of carbon monoxide gas for 1 hr, we would be in serious danger of death	The dangerous level of radiation exposure comparable to the 1500 ppm of carbon monoxide is 200,000 mr/hr, inasmuch as a 200-r dose is the level at which an employee would be in danger of death
The ratio between the acceptable level and the dangerous level is 1 : 15	The ratio between the acceptable level and the dangerous level in the case of radiation is 1 : 80,000

References

18. AEC Rules and Regulations, Title 10 of *Code of Federal Regulations*, Part 20, Standards for Protection Against Radiation, June 1, 1962.
19. Third Report of the Expert Committee on Radiation, Radiation Hazards in Perspective, *World Health Organ. Tech. Rept. Ser. No.* 248, 1962.

ATOMIC POWER AND THE PUBLIC INTEREST

By Chauncey Starr

[*Nucl. Safety*, 5(4): 325–335 (Summer 1964)]

The first charter of the atomic energy industry, the Atomic Energy Act of 1946, had as a principal objective the improvement of the public welfare. All subsequent modifications of the Act have reiterated this goal and have emphasized public health and safety. Because of the awesome nature of the birth of atomic energy, everyone associated with the application of this new technology for peaceful purposes has been acutely aware of this emphasis.

Atomic scientists and engineers are members of the community of man and have a personal as well as professional concern with the public interest. For two decades there has been detailed technical consideration of these problems and much professional debate, followed by positive action and the establishment by the government of extremely rigorous criteria of nuclear safety.

The users of atomic power plants, the electric utilities, have the most to gain by attention to the public interest. First and foremost, the public is the customer for electric power. Second, the requirement that the utilities provide maximum service to their customers certainly includes consideration of the effect of their operations on public health. Finally, the utilities have every motivation, economic and otherwise, to render the best service consistent with public health and safety.

The technological approach taken by the atomic power industry has been the most cautious in engineering history. It has been customary heretofore, in other new technologies, to proceed with applications first, safety being secondary, and then to await an empirical balance between safety constraints and social value. Examples of this are present in the history of the automobile, air transport, and, of most recent public concern, the use of insecticides. The novel approach of the atomic industry in attempting to establish public safety prior to the construction and operation of atomic power plants is a direct consequence of the fact that the public interest has been the principal objective, rather than the immediate economic gain of a few. It has been assumed by the atomic industry that long-term economic gains will follow demonstrated social value.

Why then is the industry presently in the arena of public debate and the target of attack on a subject that is technically sophisticated? There are several reasons. The great international controversy on the testing of atomic weapons and their consequent fallout, and the exaggerations of the scare literature associated with this issue, have created a large body of "nuclear hypochondriacs." In addition, the vacillation of self-nominated science-statesmen in their mixing of fact, value judgments, and policy has created a public "crisis of confidence" in the reliability of technical experts generally. The result has been a disquieting undercurrent of fear, an irrational anxiety, on the part of an inadequately informed public.

The public issue can be summarized in one question: If atomic power is only "just as good," then "why take a chance"? The interest of the power utility market substantiates the position that atomic plants are "just as good" in many areas now and will be "better than" fossil fuel plants in the future. The most significant question of the general public, however, is "why take a chance"?

In order to discuss this subject in any rational way, it is necessary to establish a measure of the danger to public health from atomic power plants. Although it is recognized that it is difficult to develop a rational approach to public safety in any area, whether it be cigarette smoking, the use of insecticides, or driving, it is believed to be essential that the atomic power industry make an attempt to establish some comparative basis for a public evaluation of the risks created by alternative power sources.

The traditional professional approach of the atomic industry in studying the safety of nuclear reactors has been to accept a recognized maximum permissible radiation dose for public exposure. The designer is satisfied if his analysis indicates that under hypothetical, adverse conditions the public exposure would not exceed this dosage.

This traditional design approach does not appear to be adequate for the public. It implies a personal value judgment by the industry as to what quantitative level of risk the public should take — a judgment which the industry does not have the authority to make. In addition, it is believed that the question as generally asked by the layman, "why take a chance," can have only one acceptable answer, namely, that the alternative means of providing electric power, other than atomic power, may involve equal or greater hazard to the public. *If it is not possible to establish that atomic power is as safe or safer than alternative sources of meeting electric power needs, then the public cannot be expected to accept this new energy source.*

It therefore becomes of paramount importance to examine the effect on the public health of the alternative of using fossil fuel for the generation of electric power. In attempting this analysis the hazard to employees of the industry should be considered separately because they voluntarily accept risks as part of their day's work, unlike the population at large.

Public Health Aspect of Conventional Power

In considering the health of the population at large, there is the difficult task of evaluating the hazard from the discharge of the noxious by-products resulting from the burning of fossil fuel, such as sulfur dioxide, nitric oxide, carbon monoxide, hydrocarbons, and particulate matter. This subject was reviewed in great detail[69] by the U. S. Senate Committee on Public Works in September 1963. It is evident from the testimony presented at the hearings that the major urban centers of the country are faced with a very serious public health problem arising from the use of coal and oil. In some cities, notably Los Angeles, there exists a mandatory requirement that less noxious natural gas be used in lieu of other fossil fuels because of excessive air pollution.

The effect of air pollution on public health is twofold.[70] First, there is the possibility of direct calamity, such as the 1948 Donora, Pa., incident in which one-third of the population of 14,000 became ill and 17 died. A more acute catastrophe was the one of London in December 1952, when 4000 deaths were attributed to severe air pollution resulting from adverse meteorological conditions. After major preventive measures were taken, a similar incident occurred again in London in 1962, which resulted in 750 deaths attributable to air pollution. Some air-pollution calamities are only statistically evident. Typical is the event in New York City in November 1953 when, due to adverse meteorological situations, sulfur dioxide reached a high concentration, and nine years later, 200 deaths were statistically attributed to this event.

In addition to these acute episodes, where a large number of deaths occur in short intervals of time, there is a continuously growing body of evidence that long-term low-level air pollution contributes to and aggravates certain diseases, particularly the diseases of the respiratory tract and, most dramatically, lung cancer.[70]

Looked at in this light, the poisonous substances, cancer-producing agents, and body irritants contained in coal and oil create damage to the public quite parallel in many ways to that which has been speculatively attributed to radioactivity. As a practical matter, the primary difference is, on the one hand, the acute awareness of the public of the controlled but potential health hazards associated with radioactivity and, on the other hand, an unawareness and apathy concerning the existing public health hazard arising from the use of coal and oil.

From the general information available, it can be inferred that the approximate magnitude of the long-term effect of low-level air pollution is a nationwide average of about 10 deaths per 100,000 of the population.* This corresponds roughly to 19,000 deaths per year in the United States, approximately half of the number of deaths caused by motor vehicle accidents. Not included are the previously mentioned mass fatalities in acute air-pollution disasters. These estimates, of course, do not take into account the very much larger number of persons involved with the more subtle and costly aspects of public health arising from physical discomfort and disability. The death rate is only the statistically visible part of the iceberg of air-pollution effects.

In the United States there is approximately 200,000 Mw of electrical generating capacity, of which about 111,000 Mw utilizes coal and

*According to the Staff study, page 420 of Ref. 69, the mortality rates for white males from lung cancer show a difference of 14 deaths per 100,000 inhabitants between large cities and rural areas. This difference appears to be proportional to the measured air pollutants. The summary of the medical evidence relating lung cancer to smoking in "Smoking and the Public Interest," Consumers Union, Mt. Vernon, N. Y., 1963, page 61, shows that the death rate from lung cancer for nonsmokers varies from "none" in rural areas to 14.7 per 100,000 man-years in cities of over 50,000. Averaging over the population distribution of the United States, and giving consideration to the plausible contribution of air pollution to other causes of death, a magnitude of 10 deaths per 100,000 of the population appears to be reasonable for the purpose of this discussion.

Pages 416 to 421 of Ref. 69 review the possible effects of air pollutants on health. All diseases of the respiratory tract are aggravated by air pollutants. In particular, the pulmonary emphysema death rate is constantly growing, appears to be air-pollution related, and is of the same magnitude as lung cancer. It also represents about 7% of the disability cases (page 419). Chronic bronchitis is the cause of 10% of all deaths in Great Britain and appears to be related to air pollution. Bronchial asthma is particularly aggravated by SO_2 pollutants.

oil.* These utilities burn about 18% of all the coal and oil used in the country. An examination of the origin of air pollution from motor vehicles and from combustion sources indicates that, in spite of the different nature of the air pollutants produced by these two types of sources, the overall contributions are roughly proportional to the amount of fuel used.†

As a practical matter, until the advent of atomic power, the utilities had no alternative to the use of fossil fuels. For this reason, the utility industry has gone to great lengths to reduce the air pollutants issuing from power plants. The following statement on behalf of Consolidated Edison Company of New York, Inc., was presented by George T. Minasian and is taken from page 372 of Ref. 69.

> Since 1937, Consolidated Edison has spent more than $100 million on air-pollution control. Even before that date, our company made it a practice to install in all new plants the most modern control equipment available. The development of equipment for control of stack emissions has now progressed to the point where the most recently installed large boilers operate and maintain efficiencies in the collection of particulate pollutants of better than 90 percent. Our program includes not only the installation of highly efficient equipment in our newer coal-burning plants but also the renovation of existing equipment in our older plants.

Also, a statement by Minasian on "Air Pollution Control as Seen by the Electric Light and Power Industry" is quoted here from page 375, Ref. 69:

> The total amount expended or appropriated, for work now underway, can be conservatively stated to have passed the $350 million mark. This covers the period since World War II and includes both the investor-owned utility companies and the government-owned systems of which the TVA is, by far, the largest. There is, naturally, considerable variation in the expenditures in different parts of the country. For example, in the Southwest, where natural gas is used to such a great extent, there is relatively little capital expense for air pollution control. Expenses run very high for those companies whose plants are located in the midst of heavily populated areas, as compared with those whose plants are remote. On the other hand, heavy expenditures have also been made on plants in river valleys, where population density is relatively light, but there is possibility of severe damage to vegetation.
>
> The costs can run high. A combined mechanical and electrostatic installation for a 360,000-kilowatt unit today costs about $5 million. This represents an investment in air pollution control equipment of about $14 for each kilowatt of customer demand.
>
> In addition to the expenditures made for equipment, much money has been spent by utility companies in the search for even better control methods. The funds have gone to research organizations, to schools and other groups that might come up with worthwhile answers. These activities are well known to the association and have been the subject of many papers presented at its meetings.
>
> Costs, while impressive, do not alone give a true picture of the utility companies' efforts in this direction. For more than 10 years a very appreciable part of my time has been connected in one way or another with air pollution matters.

It may be assumed for this discussion that, as a result of these efforts, the public health significance of the air pollutants from modern utility plant operation has been reduced by a factor of 10. Thus, on a purely proportional basis, electrical stations burning coal or oil might statistically be the indirect cause of about 3×10^{-3} death/Mw-year due to the public health hazards of air pollution.‡ Although such a number is easily lost in the death statistics of a big city, it is a starting point for comparing the public health hazards of a nuclear plant with those of a conventional plant.

This may appear as an oversimplified arithmetic approach to the relation between air-pollution hazards and fossil fuel plants, but it

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*The national consumption of coal and oil in 1961 was equivalent to $29{,}139 \times 10^{12}$ Btu (1962 Minerals Yearbook, Vol. II, U. S. Government Printing Office, 1963). The consumption by electric utilities was equivalent to 5300×10^{12} Btu (Electrical World Annual Statistical Report, January 1963), or 18% of the national consumption.

†The levels of air pollutants considered "adverse" or irritating may be a rough measure of their comparative health hazard. With this assumption, the volume of air polluted with SO_2 from combustion of fossil fuels, other than by motor vehicles, is about six times the volume polluted with CO by motor vehicles (page 408 of Ref. 69, applied to both coal and oil). This is also the approximate ratio of the Btu equivalent of the fuels consumed.

‡If it is assumed that all air pollution produces 10 deaths per 100,000 population per year, then, with a U. S. population of 190 million, there would be

$190 \times 10^6 \times 10 \times 10^{-5} \times 18\% \times 10\% = 340$ deaths/year

and $340/111{,}000 = 3 \times 10^{-3}$ death/Mw-year.

is to be emphasized that there is a lack of detailed information as to the cause and effect relations that are germane to this whole subject. This lack of precise scientific data must not be used, however, as an excuse to deny the reality of the magnitude of the air-pollution problem. The following quotation is from "Report of the Panel on Health Considerations," National Conference on Air Pollution, Washington, D. C., December 1962:

> It would be a mistake to leave this conference with the impression that there is insufficient evidence for action—now. The evidence that air pollution contributes to the pathogenesis of chronic respiratory disease is overwhelming. The classical concept of one agent being responsible for one disease is ... an investigational convenience ... the demonstration of a cause and effect, or one-to-one relationship is an unrealistic approach to this problem ... the interactions of various chemical irritants, of infectious agents, and of carcinogenic substances together with meteorological factors as affecting human respiratory health, are entirely what should be expected of complex man in his complex environment. Neither these complicated interactions nor the variabilities of the types of pollution in different communities should be used to camouflage the need for action.

Public Health Aspect of Nuclear Power

For answering the question "why take a chance," it is necessary to try to estimate the comparative damage to the public health by the operation of a nuclear plant. In order to convince the public that atomic power plants are safe, much has been made of the fact that routine exposure of the public to radiation from a nuclear plant is very much less than the exposure from natural background. As an example, the following quotation is from "The Facts of the Matter," by L. H. McEwen and J. M. Smith, Atomic Power Equipment Department, General Electric Company, San Jose, Calif.:

> The small radiation exposure above natural background around a nuclear power plant is shown by the actual 1962 experience at the Dresden Nuclear Power Station, a boiling water reactor, near Chicago. For the entire year, it is estimated that the maximum exposure at any location in the neighborhood was about $\frac{1}{2}$ a millirem for the year.[*] This was about $\frac{1}{250}$th of natural radiation, and about $\frac{1}{1000}$th of the permissible exposure.

Another way of illustrating this point is that the total exposure of a lifetime spent next to a nuclear plant would statistically result in a reduction of longevity of a fraction of a day, the same effect as smoking one or two packages of cigarettes in a lifetime.† The point that an atomic power plant is a "clean-air" plant has been emphasized.

The difficulty with this argument is that the public is concerned not only with the routine situation but also with the danger that might result from some unanticipated accident in the plant. Here the assurances have been that the uncontrolled exposure of the public to excessive radiation has only a remote possibility. However, the fact that this possibility cannot be stated to be zero raises the very legitimate question as to why accept any risk, no matter how small, if it is not necessary.

The early attempts of the atomic industry to establish a quantitative approach to public hazards necessarily involved arbitrary assumptions concerning the release of radioactivity from these plants. The most thorough study of this nature is the now famous USAEC Report WASH-740, which AEC published in March 1957, seven years ago.[71] The nature of this study is best described by its official subtitle: "A study of possible consequences if certain assumed accidents, theoretically possible but highly improbable, were to occur in large nuclear power plants." As indicated by this subtitle, the basis for the analysis was not only highly arbitrary, but, because the report was intended to explore a most imaginary extreme situation, it was heavily biased in the direction of increasing the possible public hazard. The most extreme assumption made, and the one whose results are most frequently quoted by the unsophisticated, is the assumption that it would be possible for 50% of all the fission products stored in an operating nuclear reactor core to be released to the atmosphere.

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*This exposure of $\frac{1}{2}$ mrem/year may also be compared with 1 mrem for one jet flight across the United States and 10 mrems/year from a radium-dial wristwatch.

†"Estimation of Effect of Radiation Upon Human Health and Life Span," Hardin Jones, Health Physics Society Meeting, June 1956.

On the subject of the likelihood of such extreme accidents, the report provided no analytical basis except the intuitive judgments of the knowledgeable technical experts of the time. The estimates for a combination of circumstances which would release 50% of the core fission products from the building varied from one chance in 10^5 to one chance in 10^9 per reactor operating year. The study indicated that, under the assumed meteorological conditions and the assumed distribution of population, approximately 3000 people might be killed by the dispersed radioactivity from a 500-Mw(t) reactor core.

This approach contains the fallacy that the worst imaginable accident is a true measure of the public health significance. The average accident and its probability are the truly important issues. It has been pointed out that this is best illustrated by the public approach to the airline industry. For those of us who are familiar with football stadiums, such as the Los Angeles Coliseum, which holds 100,000 persons, or the Yankee Stadium, which holds about 70,000 persons, it should be possible to imagine an accident in which a modern jet transport inadvertently plowed into the grandstand at the time of a major sport event. This is certainly a "worst imaginable accident" and would undoubtedly result in tens of thousands of deaths. The probability of this is the same order of magnitude as the "worst imaginable reactor accident" described in USAEC Report WASH-740.* It is obvious that such a situation is sufficiently remote in possibility that the public has not suggested the abolition of football, or the abandonment of airline service.

It is evident that the worst imaginable accident of any type involves an incredible simultaneous occurrence of a complex series of adverse circumstances. The probability of such simultaneous conditions is so small as to be almost without statistical public health significance. Of greater public health consequence are milder average accidents whose probability is greater.

About 1500 reactor years of experience have been accumulated,* five times as much as when Report WASH-740 was written. In addition, there have been specific core meltdowns of reactor fuel elements. In none of these events has more than 5% of the fission products been released from the fuel elements, and only a fraction of this leaked into the reactor buildings.[72,73] Further, actual experience in handling the release of radioactivity into reactor buildings has given much greater confidence in the adequacy of containment. The estimates of the experts today on the probability of the release to the public of significant radioactivity from a U. S. atomic power plant would probably be at the very low probability end of the judgments made in 1957, i.e., one in a billion reactor operating years.

To establish some conception of what such low probabilities of these imaginary accidents might mean, the probability of one in a billion can be multiplied by the estimated number of deaths associated with each accident. With the Report WASH-740 method,[71] this gives, as a statistical consequence, 2×10^{-8} death/Mw-year.†

Nuclear Liability Insurance

The issue has been raised publicly as to why, if the atomic power industry is so confident of the safety of nuclear plants, there was and continues to be a desire for government indemnity against public liability as provided by the Price-

*A stadium is approximately 100 yd (300 ft) in radius. On the basis of the assumptions that there are 100 stadiums in the United States, that there are 3.6×10^6 sq miles in the United States, that the stadiums are occupied 4 hr per 168-hr week, and that there are, on the average, 3.5 crashes on scheduled airlines per year in the United States, the most conservative estimate of the probability of an airplane crashing into an occupied stadium is

$$\frac{(300)^2}{(5280)^2}\frac{100}{3.6 \times 10^6}\frac{4}{168} \times 3.5 = \sim 3 \times 10^{-8}$$

*Nuclear Reactors Built, Being Built, or Planned in the United States as of December 31, 1962, USAEC Report TID-8200 (7th Rev.). At the end of 1950, there were 18 reactors (including critical facilities) in operation in the United States; 49 in operation at the end of 1955; 195 at the end of 1960; and 261 at the end of 1962. By extrapolation it was estimated that 350 reactors and critical facilities would be in operation at the end of 1963. Graphical integration results in 1500 reactor years of cumulative experience at the end of 1963.

†Scaling up from 3400 lethals from the accident to a 500-Mw(t) reactor in Ref. 71 to a larger reactor size, using the 1.2 power formula from Ref. 71, results in approximately 200,000 lethals from a 3000-Mw(t) reactor:

$$20{,}000 \times 10^{-9} = 2 \times 10^{-5}$$

$$= \text{one death per 50,000 reactor years}$$

Anderson Act. As indicated earlier, the traditional approach to public health in a new industry is the early establishment of a balance between actual experience and social acceptability. The insurance industry normally utilizes a process of actuarial determination of statistical performance to determine its economic approach to insurance coverage. In any field where the actuarial data do not exist, the normal functioning of private insurance companies becomes financially hazardous. Under such circumstances, when the furthering of a national interest would be inhibited by the absence of insurance coverage, the government has traditionally stepped in to provide such coverage. The following quotation is from "Federal Disaster Insurance," Staff Study, Report of the Committee on Banking and Currency, U. S. Senate, January 1956, pages 251 to 252:

> The Congress has already enacted into law several programs incorporating the insurance method or a related indemnity method with the payment of fees or charges. These include such programs as—
>
> 1. Crop insurance;
> 2. Bank deposit insurance;
> 3. Savings and loan account insurance;
> 4. Housing mortgage insurance (FHA and VA);
> 5. Maritime vessel mortgage insurance;
> 6. Maritime cargo wartime insurance;
> 7. Aviation wartime insurance;
> 8. Veterans's life insurance;
> 9. Unemployment insurance;
> 10. Old-age and survivors' insurance;
> 11. Government employees insurance;
> 12. Export-Import Bank tangible property insurance;
> 13. Mutual Security Act investment guaranty program;
> 14. V-loans guaranteed by Federal Government agencies; and
> 15. War damage insurance.
>
> It can be readily seen that the insurance device has already gained wide use in Federal programs. Several of these programs were inaugurated by Federal legislation at a time when persons active in private business cast strong doubts on their workability; but, as operating experience progressed, the confidence of private businessmen in the programs grew so that now many of them have become part and parcel of everyday business transactions stoutly defended by some of the same groups that were first hesitant about their practicality.

This policy and its many previous applications were discussed fully at the Senate Banking Committee Hearings during 1956. The concept in the Price-Anderson Act was therefore not novel, and it does not represent, in fact, a true financial subsidy. So far, no payments of any kind have been made under this coverage, and no likelihood is foreseen that any will be. It should be remembered that the private insurance coverage extends to the first $60 million of public liability, the government covering beyond this point. The Price-Anderson Act does represent a device for removing a major inhibiting factor in the development of atomic power in our private economy.

Interestingly enough, the very fact that nuclear reactors are likely to continue their excellent public safety record will probably require that the Price-Anderson Act be continued for a much longer time. In order to establish an empirical statistical basis for determining both a proper cost for insurance and a proper magnitude of coverage, there has to be accumulated either enough operating accidents to determine what actually can happen or enough reactor years of operation without public hazard to make the uncertainties vanishingly small.* Hopefully, the industry expects many thousands of reactor years of operation without incident. Certainly, based upon the present record, another 20 years will be needed to provide the private insurance industry with a suitable actuarial base for complete inclusion of this general area into their insurance domain.†

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*The cumulative power reactor operating experience to the end of 1962 is 19 reactor years with no major (public hazard) failure. If the probability of a major accident is 1 in 100,000, the probability of observing a major failure to that time would be about 1 chance in 5000. By 1967 we will have only accumulated 80 reactor years. This would mean that the probability of observing a major failure before 1967 would be about 1 in 1000. By 1975 the reactor operating experience will be 450 reactor years. On the same basis the probability of observing a major accident prior to 1975 (accident probability of 1 in 100,000 per reactor year) would be about 5 in 1000 or at most 1 chance in 100.

†The actual fee being paid for large reactors under Price-Anderson ranges from $90,000 to $120,000 per year for 1000-Mw(e) reactors [$30 per 1000 kw(t)/year] and corresponds actuarially to an accident-free reactor operating experience of 4 to 5 thousand reactor years. This amount of reactor years of operating experience would not be reached at the very earliest until about 1980, with the most optimistic estimates of installed nuclear electrical generating capacity in the United States. The more probable estimate is about 1987.

Waste Disposal

A great issue has been made of the hazards of handling and disposing of radioactive by-products from atomic power operation. Those in the industry realize the necessity for careful monitoring, handling, and disposition of these materials, but their complete confidence in being able to handle these materials apparently has created an incorrect public impression of industry indifference. The whole debate has been highly illogical. For example, there is enough insecticide produced to kill the population of the world many times over. A statement from "Our Daily Poison, The Effects of DDT, Fluorides, Hormones and Other Chemicals on Modern Man," by Leonard Wickenden, Devon-Adair Company, New York, 1956, is as follows: "In the year 1951 the quantity of pesticides produced in the United States was sufficient to kill 15 billion human beings—approximately six times the population of the world." However, there appears to be so little concern about this matter that our children can walk into any market and purchase enough insecticide to kill themselves and their families. The chemical industry produces sufficient poisonous materials to destroy the whole population, and yet insecticides and poisons rank low as a cause of death. The National Safety Council reports in "Accident Facts," 1963 Edition, pages 6 and 7, that the average annual accidental death rate in the United States from all solid or liquid poisons during the last 10 years is less than 1 per 100,000 population. This is less than the accidental death rate from firearms or railroad accidents.

It is an obviously accepted fact that in responsible hands these lethal substances can be controlled so as to perform their useful functions without endangering the population. In view of the highly alert and extremely cautious approach which the whole nuclear industry has applied to the handling of radioactivity, and in view of the very close federal and state surveillance in this area, the public hazard from the handling of radioactive materials is very much less than the hazard from the other toxic substances to which we are likely to be exposed.

Conclusions

The information presented above indicated that 3×10^{-3} death/Mw-year could be attributed to the operation of electrical stations burning coal or oil. Similarly, based on the WASH-740 statistical relations for determining the estimated deaths per megawatt-year from the operation of nuclear power plants, the figure is 2×10^{-8}. Thus the operation of the atomic power plant may be 150,000 times safer than the routine operation of a fossil fuel plant. Assuming the most pessimistic probability estimate of WASH-740, it may still be 10 times safer.

It is evident that from the public health point of view the comparison should be made between the remote statistical probability of a serious nuclear accident and the routine pollution from a fossil fuel plant. The additional contribution from the continuous "clean-air" operation of nuclear plants is negligible.

Thus there is a sound basis for the position that atomic power is now "just as good" as fossil fuel power and is certain to be "better than." Indeed, if the costs of property damage attributable to air pollution from fossil fuel plants were included, the cost of atomic power, which already includes safety and waste-disposal costs, would now be better than.

Although it is also true that fossil fuel plants could be made as safe as the atomic power plants by the inclusion of additional scrubbing and absorbing devices for the removal of pollutants, it has been estimated that the cost of equipment for such a task might run between $50 and $200 per kilowatt, certainly sufficient to make the fossil fuel plant compare unfavorably with atomic power.

Relative to the question of "why take a chance," this quick look at the continual public hazard of the conventional fossil fuel plant, compared with only a remote potential hazard of an atomic plant, certainly demonstrates that the atomic power plant is very much safer and much more desirable. *Now that the development of atomic power provides an alternative method for the generation of electricity, the public interest will best be served if the utilities maintain the freedom to select atomic power for their systems where appropriate.* Thus, on every count, including both cost and safety, it is believed that the public welfare is best served by the continued development and construction of atomic power plants.

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SIGNIFICANCE OF CONTRIBUTIONS OF ATOMIC ENERGY TO PUBLIC HEALTH HAZARDS

By C. Rogers McCullough

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Those of us engaged in the development and use of atomic energy have a duty to keep the public informed about the advantages to be gained, the penalties to be paid, and the risks to be taken. This responsibility has been recognized from the very beginning of the development of atomic energy. It is perhaps fair to say that more effort has been expended on informing the public about atomic energy than on any other new field. The task is a particularly difficult one, partly because of the way atomic energy was first introduced, but mainly because of the radical new concepts involved which are difficult to comprehend and accept by the layman and the technical man as well. As a result, there has been criticism of the atomic energy industry for not making information available and, from some sources, for minimizing the hazardous aspects of the atomic energy applications. Such criticism is unfair and wrong, as could be easily demonstrated by piling up the immense amount of material that has been written and published in this attempt.

At present there appears to be a rising tide of criticism of the use of atomic energy for the generation of power, particularly when it would be close to concentrations of population. There is no evidence that this protest represents a majority opinion. In fact, the evidence seems to be that it is a very small minority, but certainly a noisy one. The motivation of the protesters is mixed and various aspects are emphasized, depending on the interests affected and the power plant location. In all these protests, however, there is, as part of the reason, the charge that the nuclear power plant poses too great a safety threat. It is with this aspect of the protests that I would like to deal briefly.

As one of the participants in the effort to make sure that the application of atomic energy to peaceful purposes, especially the building of reactors and their use for the production of electrical energy, will not threaten the health and safety of the employees and the public, I could assume an air of injured virtue, since there has been a very studied and elaborate effort to make sure that there was adequate, yes, even more than adequate, protection. I can say with conviction that there has been much more effort spent on safety in the atomic energy field than on safety in any other field. This has been so from the very beginning of the exploration of atomic energy. I am afraid, however, that these persons raising this safety question would not be impressed by any such attitude. I also become indignant at the half-truths, distortions, and actual falsehoods which frequently creep into the statements and testimony of these protesters. In response to this the only practical course I see is to continue with a studied, deliberate, and vigorous effort to acquaint the public with the truth and to welcome investigation and inquiry. Another part of this problem arises from the difficulty that people have in really understanding atomic energy concepts, and therefore the dangers and risks, in their proper perspective. This is the issue which I am attempting to develop, suggesting, I hope, ways in which the public's understanding can be improved so that the advantages and risks of atomic energy can be understood in their proper context within the complex pattern of life as it is lived today.

Health Effects of Radiation

Let me state at the beginning of this discussion that too much radiation is harmful. As will be brought out later, it is not the only source of harm. The question is how harmful. Because of the very large amount of effort spent on understanding the effects of radiation, partly as basic scientific research and partly as a means of avoiding damage to people, we know more about the effects of radiation than any other substance. We know that certain radiation damage is repairable, a certain amount is not and shows up as delayed effects, and there is a genetic effect. The Federal Radiation Council (FRC) accepts the philosophy that there is a linear relation between dose and damage, even down to very low doses.[21] Accordingly, the benefit must be balanced against the biological risk, and doses should be kept as low as practical.

As the result of careful study and discussion on the part of the well-qualified scientists on the International Commission on Radiation Protection (ICRP) and the National Committee on Radiation Protection (NCRP), radiation protection guides have been set[22,23] and are implemented by the regulations of the Atomic Energy Commission.[24] The limits set by these regulations imply that below these limits there is a minimal or negligible amount of harm. It is worth examining some of the specific numbers relating to dose and effect. Whole-body gamma exposures will be used as a convenient comparison. It is estimated that the average life span is shortened by seven to four days for each rem of whole-body radiation exposure.[25] On this basis, natural background accounts for life shortening of 49 to 28 days. If a large number of persons were exposed continuously to whole-body radiation at the maximum allowable doses[24] for the general population, the average calculated life shortening for a 70-year lifetime would be 245 days (0.7 year) to 140 days (0.4 year). The best estimates that can be made of radiation levels in the vicinity of actually operating large atomic power plants result in average doses of 0.0005 rem[26] per year or less. Again, performing the arithmetic, this calculates to an average life shortening in 70 years of less than 0.25 day. Persons farther away receive doses that rapidly diminish with distance. These are *estimated* doses, since there is no practical way of measuring doses as low as this. It should be emphasized that life expectancy itself has meaning in terms of a population. The numbers cannot be applied as predicting a change of life expectancy for individuals or even small groups of people.

Health Effects of Other Factors

If one believes that figures such as I have given above have any real significance even for large numbers of people, then it is worthwhile to examine the other factors that influence the health and longevity of populations. Table I-2 gives these values together with those for radiation exposures mentioned above. Note that all other factors listed give greater negative effects than those for radiation workers, except being a man instead of a woman. No cases exist where either radiation workers or persons in the environment are exposed to anything like maximum permissible doses continuously. Actual exposures are small enough to give calculated life shortening of a small fraction of a day. Obviously, any such quantity as one thousandth of a year is the result of an exercise in arithmetic with no real meaning. The effects of other factors are only crudely known. Comparisons are valid only in the range of more than several years.

It would be interesting to compare the effects of air pollution, but unfortunately the data are not expressed in terms of life shortening. However, records do show that in London, in 1962, 340 people died as a result of smog which persisted only a few days and, in 1952, a "pea soup" fog for five days resulted in 4000 more than usual deaths during the week starting the first day of the fog.[28] In the United States, studies of urban areas with populations from 10,000 to 3,000,000 show excellent correlation

Table I-2 LOSS OF AVERAGE LIFE-SPAN (MINUS) AND GAIN OF AVERAGE[62] LIFE-SPAN (PLUS) AS A RESULT OF VARIOUS FACTORS

	Loss or gain of average life-span, years
Nonradiation factors	
Country vs. city dwelling	+5.0
Married status vs. single, widowed, or divorced persons	+5.0
Smoking	
1 pack of cigarettes per day	−7.0
2 packs of cigarettes per day	−10.0
Overweight by 25%	−3.6
Female vs. male sex	+3.0
Both father and mother lived to age 80	+3.7
Rheumatic heart disease	
Heart murmur	−11.0
Heart murmur plus strep infection	−13.0
Natural background radiation	
Calculated life shortening due to natural background radiation, 7 rem in 70 years	−0.1
Man-made radiation	
Radiation worker, 30 years' continuous exposure to maximum permissible dose of 5 rem/year	−2.9
Individual, general population, 70 years' continuous exposure to maximum permissible dose of 0.5 rem/year	−0.7
Person in immediate vicinity of nuclear power station, estimate of actual condition	−0.0007

between mortality rates and the amount of benzene-soluble organics in suspended particles. The variation of the pollution and the mortality rate per 100,000 due to respiratory-system cancers is about a factor of 2, being greater for the larger populations.[28] It is likewise disturbing to find that from 1950 to 1959 the death rate per 100,000 for males due to pulmonary emphysema increased from 1.5 to 8.0, or over five times.[28] On the basis of this evidence, it would appear more useful to the world to find ways to reduce the damage from air pollution, disease, and other harmful factors than to attempt to cut radiation doses below levels now being experienced from atomic energy plants.

Mutagenic Agents

As a result of this extensive research in the field, radiation has been found to be a mutating agent. It is generally agreed, however, that of the naturally occurring mutations, a relatively small fraction, perhaps 5 to 10%, is due to radiation. The other causative factors are not defined, but higher temperatures and some chemical compounds are known to be mutagenic. I have been unable to find any data on the mutagenic effects of air pollutants, but it seems quite probable that some of these may have significant mutagenic effects. (A list of some known chemical mutagens was included in the first article of this series.[28])

Accident Statistics

One of the big worries about nuclear plants, including nuclear power plants, is the possibility of accident. This worry has been given attention from the beginning and has been the major effort on the part of the Advisory Committee on Reactor Safeguards. Since the very word "accident" prevents forecast and there is insufficient statistical data, the probability and consequences of an accident are solely a matter of judgment. The system of review that has been set up for nuclear reactors is unusually thorough and painstaking. It is far above any other review system for industrial plants. For example, not only is it demanded that a pressure vessel and piping system be supplied which are in accord with the accepted standards, but there must be emergency shutdown and emergency cooling systems of high reliability. Finally (at least in most cases), there must be another containment of high integrity surrounding at least the primary system.

Although not sufficient for statistical purposes, there is a considerable accumulated history of nuclear reactor operation with an outstanding safety record. Hanford reactors have been operating since 1944; naval reactors started in 1954, and there are now more than 35 nuclear-powered ships; Shippingport has operated for over six years; Dresden for over four years; and Yankee for over three years. There are many other smaller reactors. In no case has a reactor accident in the United States released significant amounts of radiation to the public. There is no evidence of any damage to the public from any nuclear accident in the United States. In all AEC nuclear installations, 226 fatal injuries to employees from all causes occurred from 1943 to 1961. Of these, only six were due to radiation.[29] It is useful to compare the accidental death rate in AEC installations with all industries. Over a period of 17 years, 1943 to 1959, inclusive, the accidental death rate in all U. S. industries was 26.9 per 100,000 workers, whereas in AEC installations it was one-half of this, or 13.4, from all causes, and 0.19 from radiation.[30] Table I-3 compares the death rates in the United States from all causes.[31] From this table, if one uses death

Table I-3 DEATH RATES IN THE UNITED STATES—1961 PER 100,000

All causes	930.3
Diseases of the cardiovascular system	507.6
Malignant neoplasms	147.5
Influenza and pneumonia (except pneumonia of the newborn)	29.8
Asthma	2.7
Bronchitis	2.4
Other bronchopulmonic disease	9.7
Accidents	
All categories	50.7
Motor vehicle	20.5
All other	30.2
In all industries*	26.9
Accidents in AEC installations*	
All causes	13.4
From radiation	0.19

*Average 1943 to 1959, inclusive.

rate as a yardstick, the emphasis on the cure of disease is of far more importance than reducing the accident rate. It is interesting to note that the respiratory-disease death rate totals 44.6, very comparable to the rate for accidents from all causes. The rate for all industry of 26.9 is one that has been reached because of a consistent safety effort. The value of 13.4 for the atomic energy industry shows the greater emphasis that has been placed on safety in this industry. The rate of fatal injuries due to radiation is vanishingly small, representing only three cases in 17 years. Including the three unfortunate deaths in 1961 raises the rate to only about 0.4. In making comparisons, readers should note that the accident data for industries relates to workers and not the general public. So far as radiation is concerned, there are no fatalities other than workers.

A study was made in 1957 of the possible consequences of a hypothetical nuclear accident.[32] In this report three cases were considered. Case I assumed all the engineered safeguards failed except the final containment. In this case there were no lethal exposures. Cases II and III assumed failure of all the engineered safeguards including the containment and a variety of conditions relating to the dispersal of the fission products. The calculated lethal exposures ranged from 2 to a maximum of 3400 people. Since this report was written, there has been considerable progress in the design of nuclear power plants and understanding of dispersion conditions. The designs being proposed today are superior to those considered in this report, and it is highly desirable that a study be made to update this report in light of present conditions and knowledge.

It is worthwhile to look at the record of disasters that have occurred over the years to give perspective. In 1961, 24,700 people were killed in automobiles and taxis.[33] This is really a disaster but in a different context than is being considered here. A study of the more serious marine disasters, worldwide, since 1860, excepting military action, shows the single worst accident caused a loss of 1517 lives (sinking of the *Titanic*, 1912).[33] Railroad wrecks in the United States have resulted in as many as 101 deaths in the worst case.[33] In the United States there have been fires that killed 119 (Winecoff Hotel, 1946), 168 (Ringling Circus, 1944), and 491 (Cocoanut Grove, 1942);[33] there have been explosions[33] that killed 10 (chemical plant, 1960), 13 (dynamite truck, 1959), 22 (rail tank cars, 1959), 17 (gas pipeline, 1957), 561 (ship and pier, Texas City, 1947), and 8 mine disasters, mostly coal mines, over the past 16 years resulting in a total of 352 deaths, with 119 in one disaster alone.[33] These unpleasant numbers are given to show that in the world in which we live we do experience disasters. We have not yet learned how to eliminate them. However, I can state that in all cases of the disasters quoted above there has not been anything approaching the rigorous specifications and searching review which is given nuclear reactor plants.

This discussion would be more complete if it included data on injuries from various kinds of accidents, including radiation, which did not result in deaths. This more complicated and lengthy subject is not covered here. It is worthy of a considerable amount of discussion so that the public may have a clear understanding of the character of radiation injury as compared to the other kinds with which it is more familiar. Briefly, there have been several cases where persons have been exposed to doses of radiation of 100 to about 400 rem and have subsequently borne normal children and continued to work and live a normal life. This can be compared to the situation of persons who recover after an accident involving fire, explosion, a fall, or poisoning.

Conclusions

The effects of radiation are well understood, better than the effects of many materials. There is a considerable and increasing history of successful and phenomenally safe operation of nuclear installations. The amounts of radiation to which workers and the public may be exposed will result in effects which can be expected to be much less than those from ordinary hazards of life, including the rapidly growing air pollution. There have been no disasters in the nuclear industry, and in my opinion disasters are most unlikely—I can almost say impossible.

Those of us in the atomic industry are biased. For my part I believe that atomic energy has tremendous possibilities for the benefit of the world in the future. In the case of nuclear power plants, we have the possibility of the generation of electric power *without* air pollution at locations and in such sizes as the public requires. We have tried and are trying to build these plants so that they are economic and safe, safer than any other kind of plant. The record shows that we have succeeded so far. Let us increase our efforts to help the public understand the advantages of nuclear power. Let us try to help channel protest effort toward the alleviation of the dangers that are more serious than radiation. The facts are available. The people can read and study for themselves. They should look to the benefits that nuclear power can bring in improving the urban and suburban environment rather than being misled into believing that fossil-fuel plants and their increasing pollution of the atmosphere are a satisfactory solution to our growing power needs.

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ATOMIC ENERGY FOR SOCIETY AND THE BALANCE BETWEEN HAZARD AND GAIN

By J. H. Sterner

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The health problems created by atomic energy thus far in all of its manifestations, and for the foreseeable future in its projected peacetime applications, are not significantly different, quantitatively or qualitatively, from many other of the environmental health problems facing our society. The way in which the health problems associated with radiation have emerged, and have continued to be presented to the public, distinguishes—and, in the considered view of many responsible observers, overemphasizes—the hazard of the peacetime applications in relation to the substantial benefits that can accrue to society from an orderly development of the atomic energy industry.

Every effort man has made, or makes, to provide the goods and services he needs and wants, whether the essentials of food, clothing, and shelter, or the additional elements that have raised his standard of living above bare subsistence, has an inexorable and measurable risk to him in terms of injury, illness, and death. In primitive societies, with little delegation of social or work responsibilities, inequalities of hazards exist which are determined by chance of climate, abundance and kind of food, competition from other men and animals, and a host of other factors. In our more highly structured society, with specialization of labor and with the recording of risk by specific work category in measures of injury and death and of economics, the pattern of the disparity of this risk becomes more evident. Even though the general public may be aware of it only in relation to certain more hazardous occupations, such as mining, every job, every trade, and every industry has a characteristic cost in terms of injury and death, a cost that is measured specifically by accident frequency and severity rates and by the workmen's compensation insurance ratings assigned by various governmental agencies. Although continuing effort is made to reduce the hazard, and the disparity of hazards, our society accepts the fact that underground coal mining is a hundred times as hazardous as, for example, work in the communications industry, based upon comparable injury severity rates.

In earlier years the introduction of technological developments in industry and commerce was determined almost entirely by the effectiveness in producing new or better or cheaper goods and services, with little consideration for the often unwanted and unanticipated harmful by-product effects. A changing social climate and an advancing technology have brought about corrective legislation and improved preventive programs, with the safety and health characteristics of new products or services meriting increasing consideration and importance. Many industrial processes and products essential to our present economy have had to be modified, often at considerable economic and technological cost, to reduce the harmful effects to an acceptable level. In a few instances, the cost for the necessarily stringent control measures has resulted in severe limitation or even the entire abandonment of the production and use of an otherwise desirable product.

Although much greater attention is given to the health and safety implications of new technological advances, society has not yet developed a reasonable set of guides for determining acceptability in balancing benefits vs. hazard. Each instance is dealt with in a separate and uneven manner, and the methods used, even for comparable problems, may vary widely, depending on public involvement, governmental intervention, and the experience and techniques for each new scientific discipline involved. In view of the complexity of the problems, with so many variables and uncertainties, and the recognition that any final decisions are necessarily value judgments, the present trial-and-error procedure at this stage of scientific and social development may be the most reasonable and most effective way of arriving at a determination.

Nearly every one of the important, urgent, environmental health problems—air pollution, water pollution, the increasing pervasion of pesticides, the effects of cigarette smoking—has emerged gradually through a series of epidemiological associations to public recognition of the existence of the hazard. Each of these problems is an unwanted and unforeseen by-product of goods or services which man has wanted, and the recognition of serious hazard has occurred frequently after long use and enjoyment. The early experience with ionizing radiation fitted this pattern, with the tragic examples from the radium-dial painting industry and the sporadic instances of radiation burns from the improper operation of X-ray equipment. It should be emphasized that, without exception, the hazard from air pollution, from water pollution, from pesticides, and from cigarette smoking, was unanticipated, and, although there is much uncertainty and disagreement as to the projected effect on health, in each case there is a considerable number of knowledgeable observers who feel that the real and potential injury justifies immediate and much more stringent corrective measures.

The control of the health aspects of radiation in the development of the atomic energy industry stands in marked contrast to the way our society has dealt with these other important environmental health problems. The effects of radiation on biological systems have been studied and examined to a much greater extent than has been done for any other important hazardous physical or chemical agent. The criteria of injury have been sharpened and extended beyond the biological and medical parameters usually accepted and applied in the evaluation of hazards. Although no injury was observed with the techniques accepted for determining other occupational and public health hazards, the initial conservative threshold limits for exposure were further reduced when it was shown that technology, even though difficult and costly, could maintain these lower levels. When the products and processes developed under rigid controls in the plants and laboratories of a governmentally operated atomic energy program began to move into private industry and commerce, much stricter controls governing health and safety practices were imposed than were required of many other equally hazardous materials.

There are many interesting analogies between the potential hazard from lead and that from radiation. Lead poisoning was recognized several centuries ago and became the most common form of industrial intoxication. Lead is found everywhere in man's environment—in food, in water, in air, in the home, in industry—and measurable amounts of lead are present in everyone. A wide variety of diseases and symptoms, including cancer, multiple sclerosis, vascular disease, impotence, and decreased longevity, have been attributed to lead absorption at levels considerably below those identified with overt classical lead intoxication. Investigators, as with the study of radiation, have made epidemiological comparisons of death rates for various diseases and the lead content in the soil and atmosphere.[20] There is good evidence that the amount of lead in our industrialized environment is greater than that in primitive areas and that the respective populations reflect this difference in body burdens.

While there appears to be little general concern at the present time for the hazard from current levels of lead in our environment, a few investigators are quite apprehensive about it and, particularly, about the possible increase from such sources as leaded gasoline. The problems generated by the addition of tetraethyl lead to gasoline are of interest because of certain similarities to radiation with respect to environmental health. Lead, like radiation, is ubiquitous. Although the amounts that will provoke clearly recognized lead poisoning are considerably higher than would be expected in the general environment, the uncertainty as to the possible injury at lower levels persists. When a number of deaths and serious illnesses developed in the early manufacture and use of tetraethyl lead, there was a strong public outcry against permitting the continuation of the process. The Surgeon General of the United States convened a panel of the most renowned and respected public health experts to review the matter. The dire predictions of the majority of the panel, once they had heard the limited evidence available, almost resulted in the denial to society of a very useful product. In the nearly 40 years that have elapsed, tetraethyl lead has had a remarkable record of safety in manufacture and in use.

A few years ago a second panel, on which I had the privilege to serve, was convened by the Surgeon General to consider a request from the petroleum industry to increase the permissible amount of tetraethyl lead[21] from 3 to 4 cm^3/gal. In spite of all the information that has been acquired on lead distribution in food, water, and air and on lead absorption and lead intoxication, there were no clear guidelines to help us in the decision. It seemed to me that we have much better knowledge of the effects of radiation and a more certain definition of its environmental health significance. This example merely serves to illustrate the difference in the caution applied to the control of radiation as compared to that of lead. The recent finding of small amounts of certain persistent pesticides in human fat from widely scattered geographic areas in the world is another illustration in which assessment of the hazard has developed only after the technology has been in use.

Little fault can be found with the caution shown in the development of health and safety standards during the earlier years. Additionally, the fact that we have not acquired comparable information about other hazardous agents, even though they may be equally or even more injurious, does not justify relaxing the control of radiation. We do, however, have an obligation to review our experience at reasonable intervals and to evaluate the additional evidence from research and from clinical findings in order that we may confirm or modify our earlier judgments as to the hazard. One senses a somewhat more relaxed view, among the people who are knowledgeable of radiation effects, that the criteria established to guide occupational and general population exposures are reasonable and acceptable. There is increasing evidence that the cost in terms of somatic and genetic injury is low—so low that it can be identified only with great difficulty, if at all, among the many other factors that produce the same effects.

It should be stressed that, with more than 20 years of experience and millions of man-years of exposure to radiation in the atomic energy industry and with a medical scrutiny as good as or better than that used for identifying injury from other occupational hazards, not a single instance of injurious effect has been observed in individuals whose exposure has not exceeded the recommended operating limits. Although injury from radiation has occurred, this has been found only in cases of true accident, where the levels of exposure have greatly exceeded the acceptable threshold limits because of accidental circumstances due to failure of man or machine in the same sense as an accidental chemical release or explosion. The application of more sophisticated measures of injury than are customarily used in assessing other occupational hazards, such as shortening of life-span or of genetic effect, has led to a concern for the radiation hazard which has far outstripped that for other equally potentially hazardous agents. Again, it must be emphasized that no such effects have been demonstrated where present accepted guide limits have not been exceeded. The implication is not that we should ignore the evidence of hazard from radiation, but, rather, we should place it in proper perspective in relation to other environmental factors affecting health so that we do not unduly penalize a development with such great promise of benefit.

The subject of reactor safety has been discussed so widely that repetition here is not justified. As with the health of employees in the atomic energy industry, the record of reactor operating experience is excellent. With a thousand reactor years of operation, reactor accidents have caused only six deaths.[22] The some 20 instances of accidental loss of control of reactors or critical assemblies have given a high degree of confidence that design and operating conditions are adequate to justify a wider acceptance of power reactors.

As yet the community is likely to regard an atomic energy installation with suspicion and apprehension while accepting or ignoring a chemical operation of equal or greater potential hazard. Different standards of acceptance and performance, and the confused state of the mechanisms by which society develops the judgments and takes action in balancing environmental hazards with benefits, can result in discriminatory and even capricious controls. These may ultimately deprive our society of needed and beneficial goods and services. It is essential that we view the benefits and hazards of atomic energy with the perspective of other comparable activities and their environmental hazards.

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EXPLOSION OF SOME RADIOLOGICAL MYTHS

By Merril Eisenbud

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Complex concepts can sometimes seemingly be simplified by repeated use of phrases that soon become familiar to the ears, that come right to the point, that are completely unequivocal, and that in time become insidiously convincing. Often the phrases express truths, but more often only misleading half-truths, and sometimes total untruths.

In the United States and other countries where the acceptability of nuclear energy as a source of nuclear power is being debated, adages that have come into being in the last few years are misleading the public into unnecessary apprehension about the hazards of nuclear energy. This article identifies some of these adages and discusses the reasons why they are misleading. Only a few have been selected, and these are limited to references to the normally operating reactor, as follows:

1. "We haven't had enough experience."
2. "The air and water will become radioactive."
3. "All unnecessary radiation exposure should be avoided."
4. "Very little is known about the effects of small doses of ionizing radiation."
5. "There is no such thing as a safe dose."

That "we haven't had enough experience" is a reminder of the fact that artificial release of nuclear energy has been accomplished within the present generation and that we have had only a little more than 20 years of experience with reactors. In the present state of technological development, this is a long time, particularly in view of the remarkable developments in the field of industrial safety since World War II. A spectacular case in point is the current record of the space program. Never has there been an undertaking more hazardous to an individual than the program of manned missions being conducted by the United States and the Union of Soviet Socialist Republics. It is a remarkable accomplishment that all the manned flights into outer space conducted up to the present time have been completed without loss of life. To be sure the risks will become greater with each bolder step forward, and there are undoubtedly tragedies somewhere ahead at some stage of development in the program of space exploration. However, the fact remains that man has demonstrated his ability to project an astronaut, from the top of a giant rocket containing an enormously explosive concoction of chemicals, into outer space at a velocity of 25,000 mph, to place him into an orbit, and to return him safely to a predetermined location on earth. The fact that there may be failures in the future does not detract from the wonder that man can accomplish this at all. What a contrast with the repeated failures and tragedies among the polar explorers before Peary reached the North Pole two generations ago, or among the aviators who attempted to cross the Atlantic before Lindbergh successfully flew from New York to Paris in 1927.

Modern safety derives basically from our knowledge of the characteristics of materials under various kinds of stress, from methods of quality control in manufacturing, from modern methods of educating and training people, and from the desire at every level of government and industry to keep accidents to an absolute minimum. Contemporary industrial safety records are astonishing in comparison with the experience of a generation ago. I can recall, in the mid-1930's, the feeling of real accomplishment among safety engineers when the first industrial company accumulated a million man-hours without a lost-time accident. Today this is a commonplace occurrence, and many large companies accumulate more than 20 million man-hours of experience between lost-time accidents. Modern industry knows how to do a job safely, as one can see from the spectacularly successful safety record of AEC and its contractors.[23]

The fact that reactor safety can be achieved by well-understood techniques of design and operation is illustrated by the earliest experience of the program. The Oak Ridge air-cooled natural-uranium and graphite reactor was completed in 1943 and performed well and safely throughout the years until it was finally retired, late in 1963, after 20 years of practically continuous operation. Similarly, three reactors designed to produce plutonium began operation at Hanford in 1944 at their designed initial power levels of 250 Mw. These powerful reactors, with modifications in their designs, have continued to operate to the present time. Thus it was possible to build four reactors during World War II with essentially no prior experience. The designs were based on new physical principles, and new construction materials and new techniques of fabrication were used. Moreover, these reactors were built under wartime conditions on a timetable that was accelerated to an extent that is not likely to be repeated. It is a compliment to the thoroughness of the designers that reactors of such size were built during World War II and that they have operated so successfully up to the present time. The record also suggests that perhaps to the nuclear physicists and engineers there are fewer mysteries in reactor design and operation than most people believe!

The public frequently becomes alarmed that if a proposed plant is constructed "the air and water will become radioactive." This is a hard statement to deal with because many people are unable to think quantitatively about radioactivity. They know what can happen if their neighborhood should be subjected to massive fallout from a thermonuclear bomb, and, after all, are not the radioactive substances discharged from a reactor very similar to bomb fallout? It will take another generation of education before people will differentiate between picocuries and megacuries, and in the meantime we must be patient in explaining that the presence of radioactivity of itself means nothing unless we know how much is present and what kind. The public must become better acquainted with the fact that radioactivity is one of the ubiquitous phenomena in nature and that every living cell contains radioactive substances of natural origin.

An interesting recent finding is that relatively large amounts of naturally occurring radionuclides are routinely discharged into the atmosphere by plants burning coal and oil.[24] A 1000-Mw coal-burning plant having good fly-ash control will annually discharge about 30 mc of mixed radium (^{226}Ra + ^{228}Ra) isotopes into the atmosphere. From the ratios of the maximum permissible concentrations, 1 mc of radium consisting of equal parts of ^{226}Ra and ^{228}Ra can be shown to be comparable to about 400,000 mc of ^{85}Kr and about 400 mc of ^{131}I. These two radionuclides have been selected for comparison because ^{131}I is one of the major short-lived constituents of fission products and ^{85}Kr is the principal long-lived volatile constituent. Thus the atmospheric effluents from a well-operated coal-burning power plant of 1000-Mw(e) capacity contain the "equivalent" of 10^4 curies of ^{85}Kr and 10 curies of ^{131}I. Plants that do not provide mechanical or electrical dust separation will discharge much more than this—about 1 curie of mixed radium isotopes per year, which is "equivalent" to more than 4×10^5 curies of ^{85}Kr or 400 curies of ^{131}I. An oil-burning plant of this size would discharge considerably less radium, "equivalent" to about 200 curies of ^{85}Kr and about 200 mc of ^{131}I.

Certainly no one would suggest that this amount of radium being discharged into the atmosphere of our large cities is a health hazard. In fact, only a small fraction (~0.2%) of the daily radium intake of the average person originates from this source. Most of the radium we absorb (~4 pc/day) is ingested from food in which radium is present as a trace element that has been assimilated from the soils.

From these data we conclude that electric generating stations that derive their thermal energy from fossil fuels discharge relatively greater quantities of radioactive substances in the atmosphere than power plants that derive their heat from nuclear energy. During 1961 the Yankee Nuclear Power Station at Rowe, Mass., discharged only 1.9 mc of gaseous wastes into the atmosphere; that is much less than the radioactivity that would be discharged if this 141-Mw(e) pressurized-water nuclear plant was operated with coal! Similar comparisons could be made for nuclear power plants employing direct-cycle boiling-water reactors. The number of curies of activity discharged into the atmosphere by such plants is higher than in the case of pressurized-water reactors, but the radioactivity is of far shorter half-life, with correspondingly greater maximum permissible concentrations. The liquid-waste activities are similarly minuscule, and, when the waste is mixed with large volumes of water, the activity results in insignificant environmental contamination in the vicinity of commercial reactors.

We frequently hear that "all unnecessary radiation exposure should be avoided." This is a statement with which we would not disagree, but certainly the benefit of reducing exposure should be weighed against the cost or inconvenience of reducing exposure. This is certainly the everyday attitude toward the radioactivity from nature, which contributes the largest component of the total dose received by people in most parts of the world. We receive, on the average, about 100 mr/year from this source, but the deviations from average are quite pronounced, and in normal situations the dose from natural radioactivity probably varies from 50 mr/year to about 200, depending on altitude above sea level, geological factors, the amount of radium in drinking water, and the materials from which our homes are constructed. If we accepted literally the admonition that unnecessary radiation exposure should be avoided, people would avoid living in cities like Denver, Salt Lake City, or Albuquerque, where the external radiation levels are about twice those at sea level. Hundreds of thousands of people in Illinois and Indiana would be discouraged from drinking their local water supply because the radium content is above normal. In metropolitan areas, such as New York, people would compete to live in areas that have low levels of natural radioactivity, there being a difference of almost 20 mr/year between most areas of Brooklyn and Queens and upper Manhattan Island, where the radiation level is normally higher due to the igneous rocks on which almost all of Manhattan Island is built.

It would be absurd to allow the level of natural radioactivity to influence where we live, and, so far as I know, no one has suggested that we do so. Convenience and economics dictate our choice of living place, with logical disregard of the levels of natural radiation. In respect to the 50 mr/year or more that could sometimes be avoided by altering our place or manner of habitation, the admonition "all unnecessary radiation should be avoided" is a meaningless platitude.

We are often cautioned that "very little is known about the effects of small doses of ionizing radiation." This of itself is a correct statement that can be found in proper context in most authoritative studies on the delayed effects of radiation. It will be found in the reports of the United Nations Scientific Commitee on the Effects of Atomic Radiation, the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation, and in many statements made by expert witnesses testifying before the various hearings of the Joint Congressional Committee on Atomic Energy.

As a qualitative statement it is certainly true that we know very little about the biological effects of radiation at doses of a few milliroentgens to a few hundred milligroentgens per year, but this is because the effects of small doses cannot be measured. The effects, if they occur at all, are so infrequent that it is not feasible to study them, even with the best tools available to science and with the extensive resources available for investigations of this kind.

In fact, the effects of small doses of ionizing radiation have been studied more thoroughly than the effects of any other of the noxious agents that man has introduced into his environment. The policies established after World War II by AEC, supported actively by the Joint Congressional Committee on Atomic Energy, have resulted in appropriation of public funds on a scale that has yet to be matched in other fields of environmental health. It is only in the last year or two that there has been a general awareness of the need to accelerate the investigations of the effects of possible environmental hazards such as air and water pollutions, insecticides, food additives, and tobacco smoke. As yet, however, there is little comparison in size between the AEC budget for investigating radiation effects and the budget authorized for the study of the effects of chemical pollutants.

If people are told we know nothing about the effects of small doses, they will understandingly oppose *any* exposure to man-made radiation. They are told that radiation can produce cancer, genetic changes, and a general reduction in life-span, and, since so little is known about the effects of small doses, their children might be injured if a nuclear reactor were built near their home. However, the implications of the statement that we know little about the effects of small doses of radiation are considerably less ominous when it is added that this is because the effects occur so infrequently that they cannot be observed in either humans or populations of experimental animals.

Most people would say that the dose is safe if the effect is so small it cannot be observed. Yet, we are told that for radiation "there is no such thing as a safe dose." This is another way of saying that "all radiation exposure is bad," which is a concept that is used all too frequently to counter statements that a proposed installation will be operated safely and that people in the environs will be exposed to only a fraction of the permissible dose. The idea that there is no such thing as a safe dose of ionizing radiation derives from the hypothesis that there is no threshold for some radiation effects. This assumption is commonly accepted for genetic effects, and, on the basis of data obtained with experimental animals, it is sometimes applied to the carcinogenic and life-shortening effects of ionizing radiation, although these data are far more equivocal. Actually a strong case can be made for a threshold hypothesis in the case of the carcinogenic effects that have been studied in experimental animals.

For the purpose of this discussion, we can accept the "no threshold" hypothesis and consider the effect of this assumption on the proposition that there is no such thing as a safe dose of ionizing radiation. To a considerable extent, this involves quibbling about the absolute meaning of the word "safe." Most parents believe that their children are safe in the home, although the statistics of the National Safety Council would disagree with this in the absolute sense. As is well known, many children die in accidents in the home. In almost all uses of the word "safe," we mean "reasonably safe" rather than safe in the absolute sense. We normally say that something is safe when the risk of injury is so small that the person has a feeling of security and is heedless of the very small but finite danger. It was perhaps first in connection with the potential dangers of ionizing-radiation exposure that the word "safe" was required by some to have an absolute meaning. More recently the same restriction has been placed on the purported safety of insecticides and food additives.

There are a number of reasons for the recent concern with absolute safety. The very nature of the times demands that we be more prudent in our evaluation of environmental risk than has been true in past generations. There is a new public consciousness concerning environmental risks of all kinds, a development that is desirable and which everyone should encourage, although we may wish sometimes for less extremism and fewer appeals to emotions.

It is only comparatively recently that man's activities have resulted in contamination of the environment on a national or even global scale. It is no longer only the people living in less cultured areas of industrial communities that are exposed to the environmental contaminants. Air pollution is now a metropolitan problem; food additives and pesticides expose people on a national scale; and the radioactive debris from weapons tests can be detected all over the world in all forms of life from single-celled organisms to man.

A small probability of injury may be an acceptable risk to an individual and may be of minor concern to a population of small size. However, the same probability of injury may be totally unacceptable when it is applied to the total population of the world. As a matter of fact, it was this difference that was at the basis of the fallout controversies of the late 1950's in which scientists seemed to disagree about the risks inherent in the atmospheric testing of nuclear weapons. The difference was primarily the basis for estimating the risk. Some scientists considered the risk on an individual basis and, after concluding that the probability that a given individual would develop leukemia was of the order of 10^{-6}, decided that the risk was "negligible." However, others took note that the population of the world was 3×10^{9} and that, if such a population were exposed to a risk of 10^{-6}, there would be 3000 cases of leukemia! Thus we see that what may be safe for an individual may nevertheless be a risk of sufficient magnitude, when the entire population is considered, to justify a further reduction in exposure or, if possible, elimination of exposure entirely.

Industrial atomic-energy installations expose a very few people in the immediate environs of the plant to a very small fraction of the permissible doses established by AEC regulations. If there is a threshold dose that must be exceeded before deleterious effects are produced, there may be no effects at all. If there is no threshold, the effects produced by the levels of permissible exposure would occur at such a low frequency that the effect could not be measured. If we make certain conservative assumptions that (1) there is no threshold, (2) the effect is independent of dose rate, and (3) the effect is linearly proportional to dose, we can calculate the probability of injury. These calculated values will be maximal figures, with the true value being somewhere between zero and the calculated values. By these methods it has been concluded that the risk of developing leukemia from ionizing-radiation exposure is about one case per million per rad for each year at risk. A person exposed to the Federal Radiation Council maximum permissible dose of 0.5 rad/year would have 1 chance in 2 million of developing leukemia. However, the exposure of people in the vicinity of nuclear reactors is far less than 0.5 rad/year and, even in the case of reactors built in the center of populated areas, need be no more than 10% of this value or 0.05 r/year. In this case the maximum risk of developing leukemia could be as high as 1 in 20 million, but the actual risk might be as low as zero. Certainly we can tell an individual living in the community that the plant is safe so far as he and his family are concerned and that in all probability he is much better off living near a nuclear plant, since, at a cost of a few milliroentgens per year, he avoids a whole spectrum of noxious agents that are of necessity introduced into the atmosphere from fossil-fuel plants.

This article has been concerned with some of the fallacies underlying five frequently quoted reasons why nuclear reactors should not be built near population centers. These are not all the reasons why people object to construction of these plants, but the analysis does serve to illustrate the way in which these statements contribute to the morass of misunderstanding when they are taken out of context and repeated over and over again in public discussions.

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EFFECT OF LOW-INTENSITY RADIATION ON MAN

By F. J. Jankowski

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The ratio of radiation-dose-rate threshold for somatic damage to the normal background dose rate is of the order of a few hundred (100 to 500). This is in the range of the ratio of harmful concentration of several chemicals to the amount needed or believed to be needed for health. This observation raises the question as to whether all radiation is harmful, a question which has been raised before and which is under investigation. It also suggests further experiments at low or very low (below background) dose rates.

An analogy applied to phenomena not well understood can be useful in suggesting new approaches to a problem and in providing new insight into the nature of a problem. An analogy is drawn here between the biological effects of inorganic chemicals and the effects of radiation. As a result of this analogy, suggestions are made for future work.

Little is known at the present time about the effects of small radiation doses. There is no firm basis for interpolating or extrapolating radiation effects to small exposures, and many data[8-10] seem to show effects opposite to those predicted; i.e., they show a lengthening of lifespan rather than a shortening, or they show an ability of the body to tolerate the radiation where deleterious effects might be expected. A need for information on the effects of low radiation doses is recognized, and projects currently under way or proposed can help to fill this need.[11,12] A further insight into radiation effects will be sought through the analogy drawn below.

Large doses of most chemicals are injurious to the body, but, from studies and observations of nutrition, we find that many chemical elements are essential in small quantities to maintain health. This suggests comparison with radiation effects.

Such a comparison cannot be made to a high degree of accuracy. Quantitative data needed on nutrition, toxicology, and radiation effects are not generally available and, when available, are frequently expressed as ranges of values rather than as single fixed values. Thus only "ball-park" values can be expected in making the comparison.

The comparisons are made between the somatic effects of radiation and the effects of chemicals, both on adults. Genetic effects are not considered, nor are the effects on children, who appear to be much more sensitive both to chemicals and to radiation.

Three sources of information on nutritional amounts of chemical elements are available. The first, and most accurate, is the compilation of the U. S. Food and Drug Administration laws contained in the *Code of Federal Regulations*.[13] The amounts given are based on recommendations of the National Research Council. In addition, there are other elements that have been found or suspected to be needed by the body but for which agreement as to amount or certainty as to need are lacking. Here it is assumed that pharmaceutical companies have made a search of this field and that their conclusions are reflected by the mineral content of their vitamin-mineral tablets. This is taken as a second source of nutrition requirements. A third source is provided by reports on daily intakes by the body of certain elements. These intakes often vary over a large range; further, there is the possibility that the average intake exceeds the average need. However, intake values provide some information where information is generally scarce.

The amount of a chemical that constitutes a hazard is just as difficult to specify quantitatively as is the nutritional amount. Data on poisoning by ingestion are very scarce. Poisoning by inhalation is a much more probable occurrence in industry and has been studied more. An excellent review and summary of known information on inhalation hazards has been assembled in an industrial hygiene handbook edited by Patty.[14] The threshold values used below were all obtained from this volume. In most cases these are limits set by the American Conference of Governmental Hygienists, but, where such limits are absent, the thresholds are ones proposed by investigators in the field. The thresholds set for inhalation hazards are given in milligrams per cubic meter. These were changed to daily intake by multiplying by an assumed breathing rate of 20 m^3/24 hr.

A daily need has not been established for radiation; it is generally believed, but not proven, that the need is zero. However, the daily intake is known quite well. It varies over the earth's surface and depends on altitude and local concentrations of radioactive materials. A general average is 0.6 mrad/24-hr day.

The acute radiation dose that produces somatic damage is generally taken to be approximately 100 rads. However, to make a comparison with chemical poisoning, the threshold for chronic-exposure damage is required. This is less well understood. Taylor[15] reports that radiation effects have not been demonstrated in cases where exposures of 50 to 500 times background have existed for years. Thus 500 times background might be taken as a limit on the threshold for chronic-exposure hazard. Another measure of a threshold value is the daily permissible dose of 500 mr/week suggested by the International Commission on Radiological Protection (ICRP) during the early days (1936) of handling radioactive materials before concern over genetic damage developed strongly. Adjusting this tolerance to a continuous level gives a value of 120 times background as a measure of the lower limit for the threshold for damage from chronic exposure.

The data discussed above are summarized in Table I-1. In the last column of the table, a ratio of threshold to need (or threshold to intake) is given for each element and for radiation. The relations are shown more clearly by a plot of the data in Fig. I-1. Where a range is given, the extremes of the range are linked by a dashed line. The points may be identified by reference to Table I-1.

It is not improbable that an intake of 1 g/day, or a substantial fraction of a gram, continued over an extended period would be injurious, even if the element was not chemically poisonous. Therefore we might expect a bulk, or volume, effect in addition to any chemical poisoning effect. This would tend to place an upper bound on the threshold curve.

Table I-1 SUMMARY OF NUTRITION, TOXICOLOGY, AND RADIATION-EFFECTS DATA GIVING A COMPARISON OF CHEMICAL AND RADIATION EFFECTS ON MAN

Element	Source of information	Need or intake, mg/day	Threshold for chronic-exposure damage, mg/day	Ratio of threshold to intake values
Iron	CFR*	10	300	30
Iodine	CFR	0.1	20	200
Aluminum	Intake	10 to 100	300	3 to 30
Copper	V-M†	1	2 to 60	2 to 60
Copper	Intake	2	2 to 60	1 to 30
Mercury	Intake	0.005 to 0.020	2	100 to 400
Mercury	V-M	1	300	300
Manganese	V-M	1.5	120	80
Manganese	Intake	3 to 6	120	20 to 40
Zinc	V-M	1.4	300	210
Zinc	Intake	10 to 15	300	20 to 30
Radiation		0.6 mr/day		500‡
Radiation		0.6 mr/day	70 mr/day	120

Code of Federal Regulations (see Ref. 13).
†Vitamin-mineral tablets.
‡From Ref. 15.

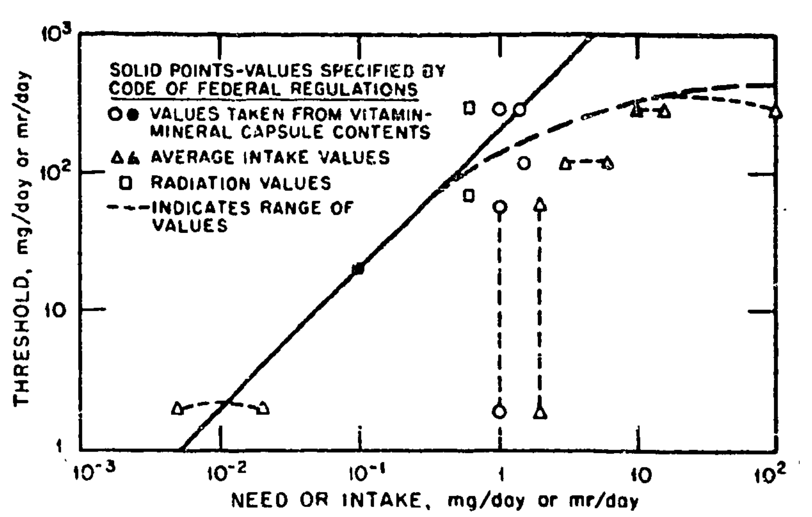

Fig. I-1 Threshold for chronic-exposure damage vs need or intake of chemical elements and of radiation.

In Fig. I-1 the heavy dashed line (showing the volume effect) joining the lower solid line (a constant ratio) was placed through the points representing iron and iodine (CFR data[13]) to produce a reasonable fit. These results appear to indicate some validity to a common value for the poison-to-nutrition ratio for a chemical element.

Points representing the radiation believed to represent the lower limit of the threshold for somatic damage relative to that absorbed from background (the intake) are also plotted in Fig. I-1. These points may be seen to correlate quite well with the chemical data. This observation raises the question of whether all radiation is indeed harmful to biological systems or might radiation perform some useful function in the operations of these systems, as do the chemicals.

The nature of the analogy made is such that conclusions are not justified, but questions and experiments are suggested. The principal suggestion is to attack the radiation-effects problem by using the principles of chemical-effects experiments. Here the experiment important to chemical nutrition but untried in radiation effects is to withhold the affecting agent from the biological system.

To withhold radiation would require a reduction of the various sources of normal radiation dose, which include cosmic rays, terrestrial sources, and radiation in food, primarily ^{40}K. These sources each contribute approximately one-third of the total dose.

The cosmic-ray contribution could be reduced to a negligibly small amount by performing the experiments in a cave or mine. At a depth of 1000 m, the cosmic-ray intensity would be reduced by a factor of approximately 10,000 from the sea-level value.[16] The reduction of terrestrial radiation would require some attention and effort. The intensity of the surrounding sources would largely determine the effort required, and selection of the location might be the single largest factor in reducing this component. Shielded rooms with low-activity wall materials would likely be used. Low-activity steel plates and water have been used.[17] Also, control of the airborne activity, primarily radon, might be necessary and would depend on the surroundings. The radioactivity entering the body via food might also have to be controlled, as it would be the largest single contributor once radiation from cosmic-ray and terrestrial sources had been reduced.

In this low-radiation environment, several generations of animals, plants, and insects would be raised. The use of control groups might or might not be required and would depend on the environmental control possible. The subjects would be examined for growth, health, intelligence (in animals), and any other factors that might be significant. An initial experimental group comparable in size to that which would be used for nutrition studies is suggested.

Continuing the analogy to chemical nutrition studies brings further suggestions which may be fruitful (or which may be under way at some laboratories). With radiation the initial studies were on whole-body radiation, and these were followed by radiation-effects studies on individual organs. It may prove profitable to investigate the microscopic effects of radiation on cell biology. Such studies would take note of all effects of radiation known or suspected, determine their probable magnitude, and ascertain their effect on specific life processes.

Many other ideas follow from the reasoning presented here. One of the more intriguing ones comes from theories proposed by biologists. It has been suggested that the ratios, and perhaps even the concentrations, of inorganic components of the blood are the same as those existing in seawater at the start of the Cambrian period, when life on earth was just beginning. Perhaps the radiation ratios reported in Table I-1 and Fig. I-1 should be based on the radiation background existing at the beginning of the Cambrian period. If radiation is found to be beneficial, this may be the optimum value (perhaps the value leading to the maximum life-span, if the experiments indicating lengthening of life-span should be confirmed).

In conclusion, the need for further data on effects of small doses of radiation is generally acknowledged. Performing experiments in which radiation is withheld could contribute significantly to this need.

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ATOMIC ENERGY FOR SOCIETY AND THE BALANCE BETWEEN HAZARD AND GAIN

By J. H. Sterner

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Health problems created by the peaceful uses of atomic energy are not significantly different, quantitatively or qualitatively, from many of the other environmental health problems confronting society. It is only that inordinate concern by the general public tends to overemphasize the highly publicized hazards inherent in the use of atomic energy without appropriate consideration for the gains which may be derived therefrom. Society may thus be deprived of the substantial profits that can accrue from orderly development of the industry.

The experience of some thousand nuclear reactor years has developed a performance record for the industry which is excellent in comparison with that of other major industries. No injury has been identified in individuals or groups exposed to allowable opera-

tional levels of radiation, based on the same kind of risk assessment as has been applied in the evaluation of other occupational and environmental health hazards.

Present criteria that have been established for the control of radiation hazards appear to be prudent and acceptable. These hazards, however, should be viewed in proper perspective in relation with those of other comparable accident and environmental conditions.

The concern for the radiation hazard is exemplified in the system of control established with atomic-energy legislation in the United States and the interpretive response of AEC in promulgating a licensing and inspection mechanism that excludes or excepts only inconsequential amounts and uses of radioactive materials. When legislation was enacted that permitted the transfer of surveillance responsibility to the states which gave evidence of ability to perform the licensing and inspection function, these states applied the same strict interpretation. Further, they added all other sources of radiation to the fissionable-materials sources for which AEC had exclusive responsibility, including X-ray equipment and radium. Thus, for an industry to obtain and use a relatively small source of radiation, such as a beta-ray thickness gauge or an alpha-emitting static eliminator, a license must be obtained. To do this requires the submission of evidence that competent personnel will supervise the installation and use of the source and that operation will continue to meet strict safety criteria. By contrast, toxic or explosive chemicals, in tank-car amounts and manyfold more hazardous, can be handled and used without a comparable demonstration of technical competence and evidence of the existence of detailed operating procedures. It is true that, in certain states, approval of any ventilating or industrial hygiene control equipment is required, but, if such equipment is not judged to be necessary, no notification to an official industrial hygiene agency is made. To critical and experienced occupational-health personnel, this disparate emphasis on the hazard of the radiation source—largely because radiation hazards as a class are viewed by the public as of greater concern—imposes an imbalance with respect to the true hazard and the usefulness and application of radiation-emitting equipment and materials.

The benefits of nuclear energy have been widely proclaimed and accepted. The applications to medicine and to research have firm and increasing acceptance by physicians and scientists, and, of all the various beneficial uses, the applications to medicine probably have the most ready approval by the general public. Yet, at one period when there was widespread public debate involving the threat from fallout from weapons testing and from nuclear war, the fear of radiation spilled over into the health applications. A considerable number of individuals expressed great apprehension, and some refused to have chest X-ray examinations, even though there were medically convincing reasons why such an examination was needed. Here the balance between gain in terms of identifying an early disease of the lung with the prospect of favorable therapy far outweighs the risk in terms of somatic or genetic injury from the minimal radiation. Fortunately this particular apprehension apparently has subsided, but the occurrence reflects an underlying fearfulness of radiation that extends into consideration of other uses of nuclear energy.

As general industrial experience has demonstrated that nuclear energy can perform unique and more efficient functions, the applications have expanded rapidly. In spite of the more rigorous safety criteria associated with the use of radiation sources, the number of registered industrial installations and the number of registered sources have increased greatly in the past few years. In 1962, New York State alone reported some 700 registered industrial installations involving more than 4000 sources and 118,000 curies of radioactive materials, the latter chiefly in large sealed sources.[18] The wide diversity and expansion of applications, in the face of a strict control program that requires greater effort and costs for the control of a radiation hazard than for a comparable or even greater nonradiation risk, attest to the value and usefulness of nuclear energy in common industrial operations.

It is in the matter of acceptance of nuclear reactors by the general public that the greatest reluctance and confusion are shown. The problem is well exemplified by the difficulties encountered, with great public controversy, in the instances of the Enrico Fermi reactor at Lagoona Beach, Mich., and the proposed Ravenswood reactor in the Borough of Queens, N. Y. Although questions were raised as to the hazard to the surrounding community from the regular and routine operation of these reactors, the chief point of contention was the hazard from a majc accident. Many of the expressions of concern, and of fear, ignored or denied the considerable body of experience and knowledge accrued over the 20 years of reactor operation and the extreme caution and careful and competent consideration that precedes and follows closely the siting, the construction, and the operation of a nuclear reactor.

A good example of the complexity of the whole problem is the strong position opposing the siting of these reactors by individuals who presumably had a substantial background and identification with the positive development of atomic energy and with the changing directions of our industrial technology. In spite of the appreciable resistance encountered with each new proposal for the establishment of a power reactor, there has been a progressive advance in placement from the initially isolated locations to areas in closer proximity to larger and larger communities with increasing population size and concentration. This graduated progress in the siting of reactors, essentially on a trial-and-error basis so far as local acceptance is concerned, has involved much greater public scrutiny and participation than has occurred with many other technological operations that have associated serious hazards. It has been pointed out that the maximum credible accident with a large nuclear reactor is much greater than the equivalent potential accident with other present industrial operations. However, a comparison solely on this basis, which ignores the safeguards applied to reduce the hazard to a reasonably "probable" level, is unrealistic. In discriminating unduly against the development of nuclear energy, it may deprive society of goods and services it needs and wants.

As technology has advanced in our increasingly industrialized society, the magnitude of many hazardous operations has increased tremendously. Although various aspects of such operations are under the control of governmental agencies, the general public usually is unaware of the increasing risk until an accident occurs. The shipment of tank-car and barge amounts of highly hazardous materials through populated areas is now an accepted practice and an essential element of our industrial economy. As greater amounts of ever more reactive substances are required, larger accumulations of materials in storage, in shipment, and in use become standard practice. The hazards in some instances are approaching the magnitude of a nuclear reactor accident hazard, but, even when the public is apprised of the situation, the concern generated seems less insistent and less emotional.

In the 15-year period 1941 to 1955, catastrophic accidents (involving five or more deaths in a single accident) took about 20,000 lives[19] in the United States. The most serious, in terms of the number killed, was of industrial origin, although it involved the adjacent residential areas of the community. This was the Texas City disaster in 1947, which resulted in 561 deaths. There is no record of the many situations where serious accidents were just averted, but an instance of this that might have resulted in thousands of fatalities may add to our perspective and merits retelling.

In March 1961 a barge upbound on the Mississippi River carrying four steel tanks containing 2,200,000 lb of liquid chlorine, in relatively clear weather, shipped water, broke its towline, and sank.[20] The accident occurred near the small city of Natchez. The total population of the threatened area, which included portions of Louisiana and Mississippi, was 80,000. Experts of the U. S. Army Chemical Center estimated that release of the chlorine could result in 40,000 to 50,000 casualties within a 30-mile radius, with 10,000 to 25,000 fatalities. Ultimately the tanks were located and safely removed from the riverbed, but the whole area was alerted and placed on an emergency status during the recovery operation. Some 550 chronically ill or handicapped persons were evacuated from the hazard area.

The chlorine tanks were on a 1900-mile trip up the Mississippi and Ohio Rivers and were to pass such highly populated areas as Memphis (metropolitan-area population of 627,000), St. Louis (2,060,000), Cincinnati (1,070,000), and Louisville (725,000). In such a trip the possibility of collision of the chlorine barge and the many barges containing petroleum products, with the additional hazard of fire and explosion and the increased likelihood of release of the chlorine, must be considered.

In this accident no lives were lost, no one was seriously injured, and no property was damaged by the chemical, although the cost for the mobilization of the community and removal of the chlorine amounted to nearly $3 million. This example is cited solely to put in perspective the risks our present technology is incurring. Apparently our society is willing to accept such risks for the gains in products, services, and employment. In contrast to the difficulties involved in gaining acceptance for the building and operation of a nuclear reactor, with the emotional overlay of the fear of radiation, there has been little or no public awareness or concern for the increasing potential of catastrophic accidents associated with our expanding technology.

There have been a number of thoughtful and imaginative discussions on the evaluation of reactor hazards, some of which have attempted to measure the relative risk in terms of injury, death, and economics and to make comparisons with other hazardous operations.[21,22] With respect to nuclear reactor safety, many of the evaluations include impressive calculations for assigning numerical values to the various elements of risk, an exercise that seems to be peculiar to the nuclear energy field. In discussing one of these proposals, Beck[23] summarizes effectively the limitations of this approach.

> The idea that in principle a balance between risk and other factors can be struck and a quantitative measure of adequate safeguards calculated is intuitively attractive. On the other hand, it is difficult to see how the procedures suggested here can in practice lead to quantitatively better decisions than those now arrived at by present, largely subjective judgments. The basic difficulty arises from the extraordinarily wide range of possible values existing for all the parameters that would go into the equations one would set up in making the calculations outlined. When such essential ingredients of the calculations are so uncertain, it is not possible to obtain a confident answer.

An increasingly important and reassuring factor in these judgments is the record of performance. The record of nuclear reactor operation, with more than 20 years of experience and a thousand reactor-years of operation is excellent.[24] The some 20 instances of accidental loss of control of reactors or critical assemblies have given a high degree of confidence that design and operating conditions are adequate to justify wider acceptance. Even the earliest reactors, the Oak Ridge air-cooled natural-uranium reactor, completed in 1943, and the Hanford reactors designed to produce plutonium and to operate at power levels of 250 Mw, completed in 1944, have had excellent safety performance. This good record is all the more remarkable since there was no body of experience with respect to design or materials, and the urgency of the wartime situation limited the time and opportunity for the experimentation and redesign that usually characterize such an important undertaking. The development and operation of a variety of experimental reactors and of reactors for military purposes have added much to our confidence in the safety of these devices. In the United States, 14 civilian power-generating nuclear reactors are now operating, another eight are under construction, and seven more are in the planning stage.[25] The loss of only six lives in nuclear reactor or critical-assembly accidents in the whole 21-year period and in an operation of this magnitude and complexity is an achievement almost without parallel in the history of industrial technology.

In the matter of routine day-to-day operation of nuclear reactors and of other operations involving the peaceful uses of atomic energy, the record of health and safety has been outstanding. It should be stressed that, with more than 20 years of experience and some millions of man-years of exposure to radiation in the atomic-energy industry, and with medical scrutiny as good as or better than that used for identifying injury from other occupational hazards, not a single instance of injurious effect has been observed in individuals whose exposure has not exceeded the recommended operating limits. Although injury from radiation has occurred, this has been found only in cases of true accident where the levels of exposure have greatly exceeded the acceptable threshold limits because of accidental circumstances due to failure of man or machine in the same sense as an accidental chemical release or explosion. The application of more sophisticated measures of injury than are customarily used in assessing other occupational hazards, such as shortening of life-span or of genetic effect, shows that the concern for the radiation hazard has far outstripped the concern for other equally potentially hazardous agents. Again, it must be emphasized that no such effects—decreased longevity, increased incidence of leukemia or other malignancies, or increased genetic or birth abnormalities—have been demonstrated where present accepted guide limits have not been exceeded. The implication is not that we should ignore the evidence of the hazard of radiation; rather we should place it in proper perspective in relation to other environmental factors affecting health so that we do not unduly penalize a development with such great promise of benefit.

The well-documented safety record of employees of AEC and its contractors has been consistently much better than that of U. S. industry in general; for example, in 1962, the injury rate was less than one-third the rate for all industry. Of the seven accidental deaths during the year, none was due to radiation. In 1962, of the 128,000 employees monitored, i.e., those with any occupational radiation exposure, 99.9% received less than 5 rem and 95.5% received 1 rem or less.[26] In the last five-year period, 99.6% of the employees monitored received less than an annual dose of 5 rem.

There have been no injuries to the general public from the routine civilian activities of the AEC. Direct radiation from establishments to the surrounding community is controlled by shielding, distance, good operating practices, and the requirement that levels in the plant be acceptable for employee exposure. Extensive and repeated surveys of the radiation levels in areas around atomic-energy establishments show that the increases over background radiation are insignificant.

To emphasize one element of safety from the routine operation of a nuclear power reactor, Eisenbud and Petrow[27] have shown that, when the physical and biological properties of the various radionuclides are taken into consideration, conventional coal-fired power plants discharge relatively greater quantities of radioactive materials (^{226}Ra and ^{228}Ra) into the atmosphere than nuclear power plants (chiefly ^{85}Kr and ^{131}I) of comparable size. The merits of nuclear power generation are further stressed by noting the elimination of the discharge of smoke, dust, and sulfur dioxide, elements that are recognized as increasingly serious factors in the air-pollution problem.

This discussion is primarily concerned with the effects of the peaceful uses of atomic energy on the health and safety of man, but, when the balance between hazard and gain is dealt with, consideration must be given also to effects on other goods and services that man wants and needs. The industry which is most sensitive to effects of radiation and which has had to make the greatest adaptation to a nuclear age is the photographic industry. Levels of radiation, far below those of concern to health, can and have caused serious and costly damage to photographic products vital to the nation's security and medical and economic needs. Thus, when benefit vs. hazard is weighed, considerations extend beyond matters of health.

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FACT AND FICTION CONCERNING NUCLEAR POWER SAFETY

By Henry B. Piper

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Not every criticism that appears in print concerning an industry is worthy of comment, but it is interesting to examine the kinds of criticism that have been leveled at the nuclear power industry. In this article a small sampling of material will be made from three sources: the nontechnical writer, the syndicated columnist, and the technically oriented writer, none of whom have any apparent conflict of interest with nuclear development. But in all the examples cited here, sensational treatment of the potential hazards associated with nuclear power is the common thread, and the criticisms and implications seem, to this author, to be unjustified in view of the recorded facts. The general public depends on various media for information in all areas of life —including the nuclear industry. If something that is untrue or frightening is stated or implied in an article or editorial, it is frequently almost impossible to remove that view from a person's mind.

Nontechnical Approach

Let us first examine some articles that have been carried in recent years in widely circulated magazines—for example, Man's Magazine, Popular Science, and Bluebook.

> Baffled and frightened motorists braked sharply on the two-lane concrete ribbon of highway winding alongside the SL-1 nuclear reactor site near Idaho Falls, Idaho. Only seconds before, the brilliance of moonlight and the glittering of stars had illuminated the lonely wastelands, dotted with KEEP OUT signs at the approachways to the top-secret testing site. Now, at 9:01 p.m. on this subzero evening of January 3, 1961, the sky—these motorists noted—suddenly turned dark as a hangman's smile.
>
> Even as the drivers jammed down on their brake pedals, an invisible wave of shock thudded against doors and wheels.

These are the introductory sentences from an article[1] that appeared in Man's Magazine. There is, in fact, no indication that any darkening cloud resulted from the SL-1 accident. There was certainly no shock wave in air associated with it. In fact, there is no evidence that anything out of the ordinary could have been observed by the passing motorist.[2,7]

Farther on in this same article the author related his version of the Canadian NRX accident of December 12, 1952:

> On a 10,000-acre wilderness, not too far from Pembroke, Ontario (population 13,000), a thunderous explosion flung scores of some 1,800 workers to the ground.

The official account[8,9] of that accident reveals no indication of an explosion that would throw an individual to the ground. Actually, the only visible or

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audible events associated with the incident were: (1) a flood of cooling water that was dumped into the lower header room below the reactor,[8] (2) a rumble and a spurt of water from the top of the reactor, [8] as reported by an operator, and "a thud or 'poof' inside the shielding . . ." [9] These events were so isolated that they were observed by only a few who were inside the reactor building; other personnel were notified that something was amiss by the sounding of assorted alarm bells, etc. This was certainly upsetting to the people in the immediate vicinity of the reactor, but no cataclysmic event such as a "thunderous explosion" was recorded.

Although both of these accidents (and others as well) were indeed serious and expensive, and at SL-1 the three members of the operating crew lost their lives, no member of the general public was harmed.

The article was written with some basis in fact—the SL-1 accident did occur and so did the one at NRX—but it appears that the treatment given the facts served to sensationalize these events. (The author did say in the last paragraph that nuclear scientists are dedicated to keeping the atom safe.)

"Atomic Death Factories in Your Backyard," which appeared[10] in the magazine Bluebook, presents the nuclear community as an irresponsible group more interested in making profit than in the health and safety of the general public. The article contains many distortions—for example:

> . . . The frightful hazard of nuclear accident, of whole cities and states contaminated and populations wiped out!
>
> Impossible! say the nuclear power advocates, but they fail to mention Idaho Falls [SL-1 accident mentioned above] and the long list of other nuclear accidents that have already occurred. To name only a few . . .

The author then lists nine other incidents (making a total of 10) involving the nuclear industry, which he apparently considered to be the most significant. None of these occurred in a central station power plant. Of the seven accidents that occurred in the United States, six happened in national laboratories that were specifically established to do experimental and developmental work in the nuclear field. The seventh happened at a privately owned, though AEC-licensed, materials-recovery plant at Wood River Junction, R.I., and resulted in the death of one worker, as will be mentioned later.

Only one of the ten accidents involved significant contamination beyond the boundary of the plant, and that one occurred in 1957 at the Windscale Atomic Reactor No. 1 in Windscale, England. Radioactive contamination in the form of iodine-131 was released[11] to the surroundings, and the effect on produce from nearby farms was determined. An official report reads as follows:[11]

> Health Physics Manager advised Works General Manager that distribution of milk from farms in immediate vicinity should be stopped, [Milk deliveries were stopped from a coastal strip 30 miles long and approximately 8 miles wide.] Other possible sources of ingestion hazard were examined, including vegetables, eggs, meat, and water supplies. A thyroid iodine survey has been made among local inhabitants around the works. Measurements have also been made establishing that there was no danger from strontium-89 or 90, nor from caesium.

Furthermore, in a letter to the editor of Nuclear Safety, H. J. Dunster of the UKAEA Health and Safety Branch, reported that doses arising from the accident were within established limits. An excerpt reads as follows:[13]

> The Windscale accident was followed by countermeasures which successfully limited the dose to the thyroids of even the most highly exposed children to substantially less than the figure of 25 rads recommended as an emergency reference level by the

> British Medical Research Council. This emergency reference level is a term of fairly recent origin, and is closely analogous to the protective action guides of the Federal Radiation Council. The FRC recommendation for thyroid dose is 30 rads.
>
> The countermeasures took the form of replacing contaminated milk by clean supplies within the existing framework of commercial distribution; this caused no inconvenience, let alone damage, to members of the public. Indeed, the Medical Research Council were able to say in their report, "It is in the highest degree unlikely that any harm has been done to the health of anybody, whether a worker in the Windscale plant or a member of the general public."

This accident is well documented [7, 14, 15] and was highly publicized. It is significant to note, however, that only ten years after that incident Great Britain has 24 power reactors[16] in operation with a total capacity of 4048 Mwe and is strongly committed to nuclear power for her future.

The article[10] in Bluebook further states:

> They are dumping them [nuclear plants] next door to you and millions of other Americans like you—without proper safeguard, without proper research, without any regard for the safety of a whole living generation or of generations yet to come!

According to a compilation [17] completed in 1966, there were at that time more than 500 active programs under contract to perform research and development in the general area of nuclear safety. Of this number about 400 were on the subject of biological and ecological behavior of radionuclides and radiation effects on human beings. Furthermore, the nuclear industry is constrained by law in the Atomic Energy Act [18] of 1954 to protect the health and safety of the public. Implementation of this law with regard to safety was carried out, first, by the establishment of the Advisory Committee on Reactor Safeguards (SCRS), which is a technical committee charged with the review of nuclear facilities with respect to safety of the public at large; second, by AEC programming, which sets aside a substantial budget for reactor safety research (e.g., $23.2 million in fiscal year 1965, $24.9 million in 1966, and $32.8 million in 1967); and third, by a general cognizance of the need for public safety in all areas of effort.

Power of Suggestion

Popular Science published an article[19] which began with a rather dramatic description of the July 24, 1964 criticality accident at the Wood River Junction, R. I. fuel-processing plant in which one death occurred. The author continued by giving information concerning other accidents and the locations of reactors, processing plants, waste disposal sites, etc., which he implied may be public hazards. The article itself, in general, gives a good layman's description of the fission process and some of the hazards involved with it. But the very disturbing features as (1) the title, "Is Atomic Industry Risking Your Life?" (this question is not answered in the article) and (2) the illustration on the first page which depicts a community being permeated by "radiation" emanating from a nuclear plant in the distance. The illustration seems to imply an affirmative answer to the title question, even though no member of the American public has been harmed by a nuclear accident.

Syndicated Columnist

The general public is quite dependent on newspapers for information. This places a great responsibility on writers in this medium to report the important developments clearly and objectively. However, during 1967, articles appeared in newspapers across the country that were severe in their attack on the nuclear community. For example, columnist Ralph deToledano and free-lance public relations man Malcolm Kildale wrote on the subject of a "hot whale." It appears that deToledano has used an earlier Kildale release [20] as a source of information for the following statement: [21]

> One example of the effects of this deadly atomic waste pollution which pours into the Pacific Ocean from the Columbia River is the report of the "hot whale" caught off the coast of Oregon. When the whale was analyzed it was found to be emanating gamma rays from its vital organs. Scientists believe that this "hot whale" became contaminated by eating plankton from the polluted Columbia River.

An investigation of this report disclosed the following facts, which show that describing the whale as "hot" was certainly a misleading exaggeration. Three investigators from the Department of Oceanography of Oregon State University [22] studied a male fin whale, 55 feet in length, that was captured in the Pacific Ocean just west of Depoe Bay, Ore. on September 14, 1963. The radionuclide zinc-65 (a neutron activation product) was found to be the most prominent gamma emitter; small amounts of potassium-40 (naturally occurring) and some very small contribution from nuclides resulting from weapons test fallout were also found. The greatest concentration of the zinc-65 (7.4 pc/g (7.4 X $10^{-6}\mu/g$)) was found in the whale's liver. According to the National Committee on Radiation Protection (NCRP) [23] any member of the general public may drink water containing 100 pc/g of zinc-65 at the normal consumption rate indefinitely. Thus, the "hottest" portion of the whale was about 13 times "cooler" than the level that would be acceptable in drinking water.

In another case, Mr. deToledano referred in September to a 1963 radiation release from which a child supposedly died. The article [24] stated:

> Malcolm Kildale, in his campaign to alert the public, has pinpointed the death of a child in Washington State as a result of an "inadvertent release" of poisonous radioactive iodine gas from the AEC's Hanford Separation Plant.

This was quite a shocking statement, so an investigation of the occurrence was begun. Inspection of press releases by Mr. Kildale produced the following: [25]

> What happened to a small child, the victim of an "inadvertent release" from a Hanford Separation plant stack in September 1963, is documented as follows [the following is an excerpt from a Hanford document*]:
>
> . . . Plant operations were shut down as soon as the abnormal release was detected, and a comprehensive program of environmental surveillance was undertaken to define the extent and magnitude of the 131-I (radioactive iodine gas) deposition . . . a child was residing at the small farm where the maximum 131-I concentrations in milk were measured. The estimated maximum total thyroid dose to the child of 0.035 rem was supported by direct measurement of the thyroid burden made in the Hanford Whole Body Monitor. For comparison, the Radiation Protection Guide published by the Federal Radiation Council for individuals is 1.5 rem per year to the thyroid. The results of the surveillance program also supported previously derived parameters for the behavior of 131-I in various media in the Hanford environs and provided guidance for rapid evaluation of future accidental releases."

In Mr. Kildale's column a quote from the original Hanford document indicates that this "victim" received a total thyroid dose of 35 mrem, which is only about 30 percent of the yearly dose *from natural background* (about

* J. K. Soldat, Environmental Evaluation of an Acute Release of I-131 to the Atmosphere, USAEC Report HW-SA-3338, General Electric Company, Hanford Atomic Products Operation, Richland, Wash., June 10, 1964.

120 mrem). Upon further investigation it was found that the Hanford document describing the incident [26] concluded that

> "... the inadvertent release of 60 curies of 131-I from the Hanford Purex facility in September, 1963, *did not result in any significant radiation exposure* [emphasis supplied] to persons residing in the Hanford environs. The maximum off-site exposure was deemed to be that received by a small child residing at the farm where the maximum 131-I concentrations in milk were measured. The radiation dose to the 4-gram thyroid of this child was calculated to be ~0.035 rem compared to the FRC Radiation Protection Guide of 1.5 rem per year for an individual member of the public."

But getting back to Mr. Kildale's penetrating question, "What happened to a small child, the victim. . .," what did happen? In a letter received recently from J. K. Soldat, [27] author of the Hanford document in question, it was stated "that the child referred to in my paper is indeed alive and attending a local public school as of November, 1967." The accumulated dose to the thyroid was so small that the incident has no continuing interest so far as radiation effects studies are concerned. So it appears that, from an off-site dose to a child that was considered inconsequential in expert opinion, this story grew to a "victim" and finally to a "death."

Technical Approach

So far only work by nontechnical authors has been cited and, even though much of this writing indicates a lack of familiarity with the subject matter, it can have a serious and damaging effect on the public image of the nuclear industry. But men who are technically trained can have an even more severe effect; after all, these men *should* know what they are talking about. This makes particularly great their responsibility to criticize constructively, but it also makes even greater their responsibility not to distort or mislead. Their views and opinions may appear in articles in technical or quasi-technical journals, they may be presented in papers at professional meetings, and they may infrequently be carried in widely circulated magazines. A few of our colleagues in the technical community have chosen to oppose nuclear development. Often the zeal and emotion with which an argument is presented produces implications that will not bear close scrutiny.

Let us look at an article [28] which appeared in a recent issue of the magazine Scientist and Citizen. In this article the author, Sheldon Novick, built a case against the development of nuclear resources; in so doing, he made some statements which subliminally inject fear into the context. For example:

> The $120 million Enrico Fermi Atomic Power Plant, built in spite of eleven years of bitter opposition and litigation which went all the way to the Supreme Court, and plagued by a series of technical failures, has suffered an accident that might have just missed being a disaster to nearby Detroit.

and further on the author cites "Fermi's near disastrous failure. . ." What does it mean to say "might have just missed being" or "near disastrous"? What kind of reporting allows drawing conclusions of this sort? And then Mr. Novick equates a reactor to the bomb:

> The long thin fuel rods of the Fermi core contained about half a ton of uranium 235—enough to make forty Hiroshima-sized atom bombs.

This statement is true from a chemical point of view; but the inference could be drawn that the reactor could explode like an "atom bomb," and this is *not* true. But the most important single fact concerning that accident is pointed out in the same article:

> The only visible signs of the [Fermi] accident were the abnormal meter readings in the con-

trol room and the automatic radiation alarms. High radiation levels were occurring in the plant vuildings, but their cause was not known. *Later investigation showed* [emphasis added] that small quantities of radioactive gases had been released to the air outside the buildings.

So here was an accident which, although it was expensive to the utility company concerned and disappointing to those involved in the operation of this experiment, not only rendered no harm to the general public but did not harm any employees. Even so, it was made to appear very ominous to a reader of this article.

Adolph J. Ackerman, a member of the engineering profession with long experience in the civil engineering field, has chosen to oppose nuclear power development on the related premises that it is unsafe, it is proceeding too rapidly, it is not economical, and it is not sound. All of these add up to accusing the nuclear industry of imprudence, where prudence is one faculty that the industry *must* exercise. Are these accusations fair and accurate in view of the facts? We will investigate three sources of material through which this writer expresses his opinion: a paper [29] presented at the 1965 American Power Conference, testimony submitted to the JCAE [30] (Ref. 29 as well as other material by this author were written into the Congressional Record as appendices of this testimony), and an article [31] published in The Rotarian magazine.

In the three sources cited the same general theme seems to be carried out: There is general lack of safety and an abdication of traditional responsibility. He also implies that the Price-Anderson Insurance Act (which provides partial Federal subsidization of insurance liability payments in case of a large-scale nuclear accident) replaces the ethical duty of the scientists and engineers with regard to public safety. For example, the following is stated in the Rotarian article:

. . . the Indemnity Act has spawned a whole new set of evils by breaking down the traditional system of engineering, legal corporate and actuarial disciplines and responsibilities. The situation is one of grotesque exploitation of public confidence in the engineering profession.

It presents, also, a terrifying breakdown in the ethical commitment of the engineer to serve the public interest above all others.

I find that it is difficult to deal with the reasoning of Mr. Ackerman because more often than not his accusations are quite generalized. For example, when talking about the imagined evils leading to the enactment of Price-Anderson indemnification, he states: [29]

Instead of promoting greater safety by sound engineering design and location of atomic power plants, with whatever increase in cost this might entail, they promoted a terrifying idea. [Price-Anderson indemnification]

Insurance doesn't operate on the basis of "sound engineering," but on the basis of actuarial data. Data is generated only by experience, and until experience is obtained, no risk can be evaluated. As was pointed out by W. D. Manly, [32] when chairman of ACRS, ". . . (this) country cannot accept in atomic energy the occasional major accidents that have punctuated engineering progress in other fields. . ." In spite of the enviable safety record of this industry, it may be many years before reliable risk statistics can be generated. So, in the interim, the ability to recover from an incident is underwritten by Price-Anderson indemnification. But Mr. Ackerman further states:

When the insurance companies were confronted with this new risk of unprecedented magnitude, they eventually offered a maximum of $60 million in third party liability insurance on the type of design then proposed. But this was

> recognized to be only a small fraction of the potential property damage.

He states here that the degree of coverage by the insurance industry was based on "the type of design," but there is no basis in fact for this allusion. Lack of statistics limited their participation. It is interesting to point out that the Price-Anderson Act specified a total coverage of $560 million for any accident, with $60 million being provided originally by the insurance industry and the remainder guaranteed by the Government; in 1967, after about 10 years of experience, the industry has increased its degree of responsibility to $74 million and thus reduced the Government participation to $486 million. In a recent speech Senator Pastore made this observation: [33]

> The Price-Anderson protection scheme has now been in operation for 10 years. One might ask —how much money has the Government had to spend on this 'subsidy' to the nuclear power industry? My answer is that not a dollar—nay, not even a red penny—of Government funds has ever been expended under the Act to indemnify an AEC licensee. Meanwhile, the Commission through June 30, 1966, has collected more than a half million dollars in indemnity fees [equivalent to insurance premiums] from operators of nuclear facilities. The annual income to the AEC from these fees is expected to swell to nearly $5 million by 1973.

Mr. Ackerman suggests that safety in operating nuclear power plants is very poor, and he cites plant performance records to prove his claim. He lists the operating histories through late 1964 of seven "first-generation" power reactors and shows that on several occasions lengthy shutdowns were necessitated to make repairs and careful investigation of suspected and actual trouble. This, he says, indicated poor design and inherent lack of reliability. But one could equally argue that this indicates that in power demonstration experiments such as these, unplanned shutdowns are expected so that careful and systematic investigation of troubles and suspected troubles may be carried out in order that similar difficulties will be minimized or eliminated in subsequent plants. After all, these are prototype plants that were built and operated for the purpose of investigating useful, rather large-scale applications of nuclear energy. It is significant to point out that one of the plants chosen to show the impracticality of nuclear power was "Yankee," which produced electricity at an average cost[34] of 9.0 mills/kwh in 1964 and 9.8 mills/kwh in 1965, with a capacity factor and availability in 1965 of 65% and 75%, respectively. These figures are very close to comparable figures for a conventional coal or oil-fired plant and are therefore very impressive credentials for a first-generation nuclear power plant. The more advanced and higher-capacity plants now being built are expected to produce power for about half this amount.

Mr. Ackerman further suggests that cancellation of plans to construct certain nuclear plants indicates a lack of confidence in nuclear safety considerations. But in this industry, as in any other heavy industry, plants that are proposed will occasionally be cancelled; and the cancellation may be for any of a number of reasons. For example, the Rochester Gas and Electric Company discontinued its effort to build a high-temperature gas-cooled reactor (HTGR) at its Brookwood site. Mr. Ackerman had the following words to say about this cancellation of contractual negotiations after he had visited with a member of the board of that company in October 1964:

> It was reassuring to find that at the top management level there was a strong sense of public service and a firm determination to refrain from doing anything that would jeopardize the position of the company or that might create an undue public hazard. It was also apparent that some of the

important matters under discussion had not previously come to this Director's attention.

On February 12, 1965, the utility company suddenly announced cancellation of its plans for the new reactor. A brief press release stated that "one of the major reasons for the breakdown in negotiations was the unwillingness of General Dynamics Corp. to provide assurances that the proposed nuclear plant would be available to supply power to our customers by the fall of 1972, and we cannot gamble when our customer's welfare is at stake."

And later, in the Rotarian article, he said:

In another case plans for a 260,000 kw atomic power plant near Rochester, N. Y., were cancelled in February, 1965, after the selected builder declined to guarantee the plant's dependability.

Since these comments were written into the Congressional Record during hearings concerned with the extension of Price-Anderson indemnification, Robert E. Ginna, chairman of the board of the Rochester Gas and Electric Company, felt compelled to contest this implication in a letter that also appears in the Congressional Record.

The entire connotation of the Rochester Section [that part of Ref. 31 relative to the Brookwood HTGR] is that the company broke off negotiations with General Atomic because of "safety considerations." Nothing could be further from the fact.

Quoting Mr. Ackerman's concluding sentence of item 3, paragraph 2, page 18, where he recounts a personal conference with one of the directors of the power company, he states, "It was also apparent that some of the important matters under discussion had not previously come to this director's attention." Mr. Ackerman came to my office in October, 1964, and requested a meeting with me. I can assure you that nothing Mr. Ackerman divulged in that meeting had any effect whatsoever on the company's decision not to go forward with the HTGR nor did he provide any pertinent information that I was not already aware of . . .

At no time was the safety of the HTGR concept an issue and whether Mr. Ackerman intended to leave such an impression or not is beside the point. The impression is certainly there. Had there been such a doubt in our minds after 6 years of study of the HTGR concept, or any other reactor concept, we would not have progressed to the stage of attempting to negotiate a formal contract with General Dynamics Corp.—nor would we be requesting bids for a water type reactor today to produce commercial power by June 2, 1969. Rochester, as well as every other responsible utility in the country, is very conscious of the health and safety of its employees and the public. It is nonsense to claim otherwise.

Conclusion

Many accusations of disregard for safety by the nuclear industry have been made. In this article a very small number of these are investigated. It is not difficult to defend the nuclear industry, the facts speak for themselves. During the 22-year history of this industry through 1964 there have been only seven deaths [37] attributable to nuclear causes and 33 non-lethal overdoses of radiation, 11 of which showed no clinical evidence of injury. In the main, these injuries and fatalities occurred in the area of research and development with only one of the deaths being associated with the power industry. We must thank a very prudent approach to our problems for the existing situation; but this industry is barely out of its infancy, and to maintain the safety record of which we are so proud, we must put forth greater effort. No one has to remind us that progress means larger reactors with higher power densities and ever-increasing numbers of such reactor power plants. With progress comes a greater potential hazard, and this must be met with ever-increasing emphasis on public safety. It has cost a lot of time, money, and effort to come this far; the future holds the vision of progress in meeting rapidly growing power needs, reasonably priced electric power in future decades, and, of course, dividends for the stockholders of the companies making up the nuclear community. For this to come to fruition we must continue to be sensitive and receptive to the public that we serve, we must efficiently utilize this energy source, and we must ethically, prudently, effectively, and responsibly meet the problems that will arise.

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RADIATION IN PERSPECTIVE — THE ROLE OF NUCLEAR ENERGY IN THE CONTROL OF AIR POLLUTION

By B. R. Fish

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Abstract: *Nuclear energy can play a critically important role in combating the growing assault on the purity of our atmosphere by supplanting fossil-fuel energy for most of the power plants to be built late in the century. Even then the same tight control that is currently exercised over the nuclear industry must come into being for other industries that are actual and/or potential polluters of the atmosphere. Several air-pollution disasters of the past emphasize the potential for future disasters.*

Man is a consumer of energy and of space-time. The mere fact of his occupation of space and time is a problem of increasing concern to the population dynamicists and to the other social scientists. At the same time the so-called "population explosion" creates problems for the technologists who are concerned with providing the energy necessary to sustain each man during his existence.

With our present knowledge, there is little we can do to remedy the problems of man's occupation of space–time except to prevent them, as is being attempted through various birth-control efforts or, failing that, eventually through the brutality of war. However, since man's use of energy can be accomplished in a variety of modes, it continues to be our fond hope to find new ways or to change the old ones so as continually to better our position as consumers.

Nuclear energy offers a basis for hope in this regard through its promise as an essentially clean source of power. A review of the reported experiences of operating nuclear facilities in the United States, although brief and incomplete, indicates that the routine operation of nuclear electric plants does not lead to significant release of pollution to the atmosphere. Because of its potential for the release of vast amounts of radioactivity to the environment, however, the nuclear energy industry has grown to the threshold of maturity with a unique burden of strict review and control at every step. Nevertheless, this feature which has appeared to be a handicap may well become the industry's greatest asset at a time when effective control of atmospheric pollution is rapidly becoming an absolute imperative. It is suggested that all levels of government interested in pollution control should examine the impressive achievement records of the various review boards and control agencies within the U. S. Atomic Energy Commission and consider adoption of comparable methods for controlling other actual and potential polluters.

Basic to our utilization of energy are our requirements for the intake of food, water, and air. In order to survive, some animals must take in food practically continuously. Others must live in the water to maintain a constant liquid intake. Of these three components, however, the only item of continuous obligatory consumption for man, even when asleep, is air.

Amount of Air Required

First, it may be instructive to review briefly some measurements made by Silverman and his associates[1] on the intake of air by average, healthy, adult males while exercising at known work rates. Table 1 represents a selection of work rates taken from a much larger table of data in Ref. 1. Column headings have been modified to translate the original work rates in kilograms per meter per minute to approximate easily recognized levels of effort.

Such measurements form the basis of the air-intake values assumed by the International Commission on Radiological Protection (ICRP) Committee II on Internal Radiation and are used in the computation of maximum permissible concentrations of radionuclides in the air.[2-4] Thus the ICRP calculations are based on

At work: 10^7 cm^3 in 8 working hours = 20.8 liters/min

Away from work: 10^7 cm^3 in 16 rest hours = 10.4 liters/min

With very little juggling of numbers, it is seen that a normal, healthy adult male easily can take in an average of nearly 54 lb of air per day (assuming complete rest 2 days in 7). This represents about an order of magnitude greater intake of air by weight than the combined intake of food and water.

One further comparison may serve to emphasize the relative position of air in the hierarchy of intake

Table 1 Mean Respiratory Air-Flow Measurements: Healthy Young Men*

	Work rate, kg/(m)(min^{-1})				
	~0 (rest, watching TV)	>0 (light work, slow walk)	208 (average work)	622 (heavy work, slow run)	1660 (maximum effort)
Respirations per minute	14.6	19.6	21.2	23.0	47.6
Minute volume, liters	10.3	14.2	20.8	37.3	113.8
Tidal volume, ml/breath	705	725	981	1620	2390

*Adapted from Silverman et al.[1]

requirements. Consider the expected survival time of man if completely deprived of all intake. Man can live on the order of 5 weeks without intake of food and perhaps 5 days without water, but, if his air intake is restricted for 5 min, he is in serious trouble.

Deposition of Pollutants in the Respiratory System

We might look upon the lung as a processing plant, small by industry standards, but specialized and performing an indispensable service. The lung processes just under 10 tons of raw air per year for a total of about 600 tons per lifetime (women average perhaps 80% of these amounts). As in any well-designed system required to process raw materials of variable quality, there are features of the respiratory system which serve to prevent or reduce the intake and retention of many of the noxious substances that might be admixed with the air we breathe. An excellent introduction to the subject of inhalation of particulate aerosols is given in a book by Hatch and Gross.[5]

In 1964, ICRP Committee II created a special Task Group on lung dynamics (P. E. Morrow, Chairman) to review the so-called ICRP-lung model[2] and to suggest changes where appropriate. The Task Group report[6] includes much detail on the estimation of particle deposition and clearance in the respiratory tract. One of the significant features of the report is that, within fairly narrow limits, it is only necessary to know the mass median aerodynamic diameter* (MMAD) of a particle size distribution in order to estimate the fraction of the inhaled mass deposited in the three major divisions of the respiratory system—the nasal-pharyngeal region (N–P), the tracheobronchial region (T–B), and the pulmonary region (P). Estimates of particle deposition given in Table 2 are based on a gross interpolation of data given in the Task Group report[6] and should be considered of qualitative significance only. Although the tabulated values refer to the mass fraction deposited and the mass median size, the words *count* (particle number), *area* (surface), or *radioactivity* may be substituted for *mass* in the table.

*As defined in the Task Group report: "Diameter of a unit density sphere with the same settling velocity as the particle in question."

Table 2 Estimates of Particle Deposition and Clearance in the Respiratory System

Mass median aerodynamic diameter, μ	Mass fraction deposited			
	N–P	T–B	P	Exhaled*
0.01	0.01	0.18	0.70	0.05
0.1	0.02	0.08	0.55	0.35
1	0.25	0.05	0.25	0.45
10	0.85	0.05	0.09	0.01
100	0.95	0	0	0.05
Clearance rate	Minutes	Minutes to hours	Days to years	

*Includes particles too large to be inhaled efficiently.

It should not be supposed that the lung model for particle inhalation is a closed question. There are numerous features of the lung model that require clarification. Nevertheless, there is a serviceable model that yields predictions not grossly at variance with experimental data. Unfortunately, there is no comparable model that may be used to predict the site of deposition for partially soluble or reactive gases and vapors in the lungs.

Effects of Air Pollution on People

The undesirable direct effects of air pollution on man may be classified according to the mode or site of attack on the sensitive tissue of primary concern. Thus specific pollutants may attack the surface of the body, e.g., acrolein or sulfuric acid mist in the eyes or large-particle fallout from nuclear weapons tests falling onto unprotected skin.

Respirable pollutants, including all gases and vapors, as well as particles of less than 300- to 400-μ aerodynamic diameter, may affect various regions of the body. In the first place, for a very soluble particle or vapor, whose effect is not local, it matters little at what site it is deposited; the important factor is the total quantity absorbed into the bloodstream. This is true of systemic poisons, such as arsine or carbon monoxide, and materials that concentrate in a specific organ, as ^{131}I in the thyroid. On the other hand, local irritants, as represented by sulfur dioxide, or short half-lived radionuclides such as radon and its radioactive daughters, may be expected to produce the greatest damage at the intake site where the tissue sustains the greatest exposure (= concentration × time). Obviously, the significance of local exposure cannot be independent of tissue sensitivity and of the importance of the tissue to the well-being of the individual. This may be illustrated qualitatively by referring to sulfur dioxide, which is moderately soluble in lung fluids. Inhalation of a few parts per million of SO_2 can produce local irritation in the nose and throat because of the corrosive action on tissues exposed to the sulfuric acid formed at the sorption site. Continued exposure to somewhat elevated concentrations or short-term exposure to very high levels can result in the extension of the damaged region further into the lungs and possibly alter the caliber of the airways through a bronchoconstrictive reaction. If the high concentration of SO_2 is carried far enough into the lungs to involve the functional gas-exchange tissues of the pulmonary region, the otherwise irritant reaction may become a fatal reaction as the body loses vitally needed respiratory tissues. In the widely reported[7] air-pollution disasters of the Meuse Valley in Belgium (1930), of Donora, Pa. (1948), and of London (1952), there are indications that the pollution levels did not vastly exceed previously experienced levels; however, there are suggestions of a possible synergism between particles, possibly fog droplets and SO_2, whereby a portion of the gas, which normally would become an irritant in the nose, throat, or tracheobronchial region, may have been delivered to the vital pulmonary tissues via sorption on particles penetrating through the airways.

It is possible to undergo exposure to the gastrointestinal (GI) tract by inhalation. Referring to the report[6] of the ICRP Committee II Task Group on Lung Dynamics (or taking roughly the numbers given in Table 2), we can see that essentially all particles having an aerodynamic diameter exceeding 10 μ will be deposited in the nasal–pharyngeal or the tracheobronchial regions. From these regions undissolved particles are cleared rather quickly to the esophagus and thus directly to the GI tract. It should be kept in mind that a single 100-μ-diameter particle contains the same mass as a million 1-μ particles of the same density; hence an inhaled, soluble systemic poison may enter the body in larger quantities through the GI tract than through the lungs. Furthermore, if the action of the strong acids in the stomach is such as to increase the solubility or the toxicity of an inhaled pollutant, the significance of the GI tract as an entry portal may become equal to or greater than that of the lungs.

Air-Pollution Disasters

Usually one thinks of a disaster as something that occurs suddenly, perhaps explosively, such as an earthquake, a tornado, or a fire. The classic air-pollution disasters are of an entirely different character. Except for such sudden releases as that which occurred in Poza Rica, Mexico, in 1950, the quantities of the pollutants released to the atmosphere during the most significant episodes were not unusual.[7] Thus no breakdown in equipment or normal operating procedure nor a process accident could be blamed. Rather, the pollutants were routinely being released in disaster quantities; it was only necessary to wait until weather conditions prevented the adequate dispersion and dilution of the noxious effluents.

Meuse Valley, Belgium, 1930 (modified from Ref. 7). On Monday, Dec. 1, 1930, the narrow valley of the Meuse River in Belgium experienced an unusual and widespread weather condition that persisted the remainder of the week. In this river valley, 15 miles long with hills about 300 ft high on either side, a thermal inversion confined emitted pollutants to the limited air volume contained in the valley. There were many industries in the valley, including coke ovens, blast furnaces, steel mills, glass factories, a zinc smelter, and sulfuric acid plants. On the third day many people became ill with respiratory-tract complaints, and, before the week was over, 60 had died. In addition, there were deaths in cattle. Older persons with previously known diseases of the heart and lungs had the greatest mortality; however, illness affected persons of all ages and was best described as an irritation of all exposed membranes of the body, especially those of the respiratory tract. Chest pain, cough, shortness of breath, and eye and nasal irritation were the most common symptoms. Fatalities occurred on both December 4 and December 5, although frequency of symptoms decreased strikingly on December 5. Autopsy examinations showed only congestion and irritation of the tracheal mucosa and large bronchi. However, there was some black particulate matter in the lungs, mostly within the phagocytes.

The chemical substances responsible for the illness and fatalities have been disputed. In the original report on the episode, it was estimated (since no measurements had been made during the event) that the sulfur dioxide content of the atmosphere was from 9.6 to 38.4 ppm. Assuming complete oxidation of the sulfur dioxide, even though unlikely, sulfuric acid mist concentrations of 38 to 152 mg/m^3 might theoretically have resulted. It is generally thought that a combination of several pollutants may have been associated with this, as well as with other community disasters. Certainly, strong suspicion attaches to sulfur dioxide, but it is more likely that this substance, when dissolved or otherwise combined with water droplets, and in the presence of other pollutants, oxidizes to sulfuric acid mist with a particle size sufficiently small to penetrate deeply into the lungs.

Donora, Pa., 1948 (modified from Ref. 7). The impact of the Donora disaster has been eloquently described by Rouéché.[8] "The fog closed over Donora on the morning of Tuesday, October 26th. The weather was raw, cloudy, and dead calm, and it stayed that way as the fog piled up all that day and the next. By Thursday, it had stiffened adhesively into a motionless clot of smoke. That afternoon it was just possible to see across the street, and except for the stacks, the mills had vanished. The air began to have a sickening smell, almost a taste. It was the bittersweet reek of sulfur dioxide. Everyone who was out that day remarked on it, but no one was much concerned. The smell of sulfur dioxide, a scratchy gas given off by burning coal and melting ore, is a normal concomitant of any durable fog in Donora. This time it merely seemed more penetrating than usual." During this period, temperature inversion and foggy weather affected a wide area. Donora is located on the inside of a horseshoe-shaped valley of the Monongahela River about 30 miles from Pittsburgh. The city contains a large steel mill, a sulfuric acid plant, and a large zinc production plant, among other industries. The hills on either side of the valley are steep, rising to several hundred feet. At the time there were about 14 thousand people living in the valley. A meticulous health survey of the population was made within a few months of the episode.[9] The investigation was directed at the health effects that occurred among people and animals, the nature of the contaminants, and the meteorological conditions. Interviews were obtained with persons who were ill and from physicians in the community. Roentgenograms and blood tests were taken; and teeth, bone, and urine samples were studied to determine whether fluorides might have been involved. These studies indicated that 43% of the population was made ill during the episode. Curiously, a large number of the persons who were not ill were unaware of the extent of ill health. Cough was the most prominent symptom, but all of the respiratory tract and the eyes, nose, and throat were irritated. Many complained of chest constriction, headache, vomiting, and nausea. There was a relation observed between the frequency and severity of illness and the age of the population. Most of those who became ill did so on the second day of the episode; of the 20 deaths, most occurred on the third day. Among the fatalities, preexisting cardiac or respiratory-system disease was common. From examinations made for fluorides, it was felt that fluorine was probably not involved. Retrospective examination of mortality indicated that a similar event might have occurred in April 1945. Autopsy examinations from the 1948 fatalities were nonspecific, but there was abundant evidence of respiratory-tract irritation. Environmental measurements had not been made during the episode, but it was inferred that sulfur dioxide had ranged between 0.5 and 2.0 ppm. Particulate matter was undoubtedly present. The calls for medical assistance in Donora ceased rather abruptly on Saturday evening despite the fact that the fog remained quite dense. This suggests that some change in the physical nature of the fog droplets may have occurred; for example, the particles may have increased sufficiently in size so that they were deposited in the upper airway instead of penetrating deeply into the lung.

London, England, 1952 (modified from Ref. 7). From Dec. 5 through Dec. 9, 1952, most of the British Isles were covered by a fog and a temperature inversion. One of the areas most severely affected was London, which is located in the broad valley of the Thames. During this period an unusually large number of deaths occurred, and many more persons were ill. The illnesses were usually sudden in onset and tended to occur on the third and fourth days of the episode.[10] Shortness of breath, cyanosis, some fever, and rales were observed. Most of those seriously ill were in the older age groups. Admissions to hospitals for the treatment of respiratory diseases increased markedly, but so did admissions for heart disease. An increase in mortality among all ages was observed. However, the very old, those in the seventh and eighth decades, had the highest increment. The most frequent causes to which deaths were ascribed were chronic bronchitis, bronchopneumonia, and heart disease. Of particular interest was the fact that mortality remained elevated for several weeks after the weather had improved. The total excess was between 3500 and 4000 deaths. Measurements were available for the amount of suspended smoke and sulfur dioxide. The highest values reported were 4.46 mg/m^3 of smoke and 1.34 ppm of sulfur dioxide. Autopsy examination did not reveal any characteristic mode of death other than evidence of respiratory-tract irritation. Search of the past records of meteorology and mortality indicated that periods of excessive mortality had occurred previously. Three hundred excess deaths occurred in the winter of 1948; detectable increases in mortality associated with fog were found in December 1873, January 1880, February 1882, December 1891, and December 1892. A subsequent episode occurred[11] in 1959. None of the other episodes, however, was quite as severe as the one in 1952.

Poza Rica, Mexico, 1950 (modified from Ref. 7). Another type of community disaster resulting from the sudden discharge of a toxic gas from a single source occurred in the small town of Poza Rica, Mexico.[12] Here a new plant for the recovery of sulfur from natural gas put a portion of its equipment into operation on the night of Nov. 21, 1950. One of the steps in the process was the removal of hydrogen sulfide from natural gas. In order to do this, the hydrogen sulfide was concentrated in a system in which it was intended to be burned. During the night of November 23 and 24, the flow of gas into and through the plant was increased. The weather was foggy, with weak winds and a low inversion layer, and, between 4:45 a.m. and 5:10 a.m. of November 24, hydrogen sulfide was released inadvertently and spread into the adjacent portion of the town. Most of the nearby residents were either in bed or had just arisen; many were afflicted promptly with respiratory and central nervous system symptoms. Three hundred and twenty were hospitalized, and 22 died. The characteristic manner in which the hydrogen sulfide affected these individuals was to produce loss of sense of smell and severe respiratory-tract irritation. Most of the deaths occurred in persons who had such central nervous system attack symptoms as unconsciousness and vertigo. A number of the affected individuals also had pulmonary edema. Persons of all ages were affected, and preexisting disease did not seem to have much influence on which persons were afflicted.

Future Air-Pollution Disasters

The title of this section may appear to be gloomy indeed. To some extent it does presume that the reckless dumping of gaseous and particulate wastes to our atmosphere will continue to be dominated by a philosophy better suited to the frontier days than to our increasingly urbanized world. Until quite recently, and still very much in evidence, the prevailing attitude toward water pollution, for example, has been for the user to treat it at the point of use *if it needs treatment.* The air-pollution equivalent is the suggestion that we should build domed cities and clean the air at the city intakes.[13,14] This clearly presumes two things: (1) the priority of man as a polluter over man as a breather with respect to their rights to use the atmosphere; (2) it assumes that we are willing to give up the vegetative cover of the space between domed cities.

A more optimistic approach to predicting the future emissions of SO_2 was made by Rohrman, Steigerwald, and Ludwig.[15] Figure 1 was taken from their paper and represents their best estimates of SO_2 control and emission per year in the United States. In preparing this figure the authors assumed "that no new fossil-fuel power plants will be built after 1995, and that in the year 2000 approximately half of all electricity will be generated by nuclear power." Thus going *all nuclear* late in this century will not of itself prevent a threefold increase in SO_2 emissions. Clearly the alternative to going nuclear, without severely restricting the fossil-fuel-plant effluents, would be an increase over present levels of about an order of magnitude.

The authors described the assumptions used in obtaining the prediction curves labeled Case 1 and Case 2 as follows:

Case 1

The control assumptions for Case 1 are severe but realistic. They do not assume early development and universal use of highly effective SO_2 gas cleaning methods for power plants nor the rapid application of available methods of fuel desulfurization.

1. Beginning in 1970, 1-percent control [i.e., reduction] is applied to existing power plants, increasing 1-percent each year; and 5 percent control yearly to new power plants, starting in 1975, to a maximum of 80 percent control for new plants put on stream in 1990. After the initial year, control of these new plants increases 1-percent per year, the same as existing plants. This assumes some increased use of fuel desulfurization, selection of fuels with lower sulfur content, miscellaneous uses of fuel additives, improved design of plants, and eventually perfection of processes to remove SO_2 from power-plant stacks [effluents].

2. One-percent control of all non-power-plant emissions in 1965, increasing 1-percent each year.

Case 2

The control assumptions for Case 2 are very severe and probably represent the maximum that can be achieved technically. They will require an immediate and vigorous program of research and pilot plant efforts on power-plant gas cleaning methods, fuel desulfurization, and forced application of control methods as they become available.

1. Seventy-five percent control of SO_2 emission from new power plants put into operation in 1975, including replacements or expansion of existing plants. This 75 percent control in 1975 is increased 1-percent each year after 1975 to a maximum of 90 percent in 1990. Since there is a minimum of 5 years lag time between initial design of power plants and the time the unit is put on stream, the initiation of control by 1975 requires that proven designs must be available in 1970. Achieving this

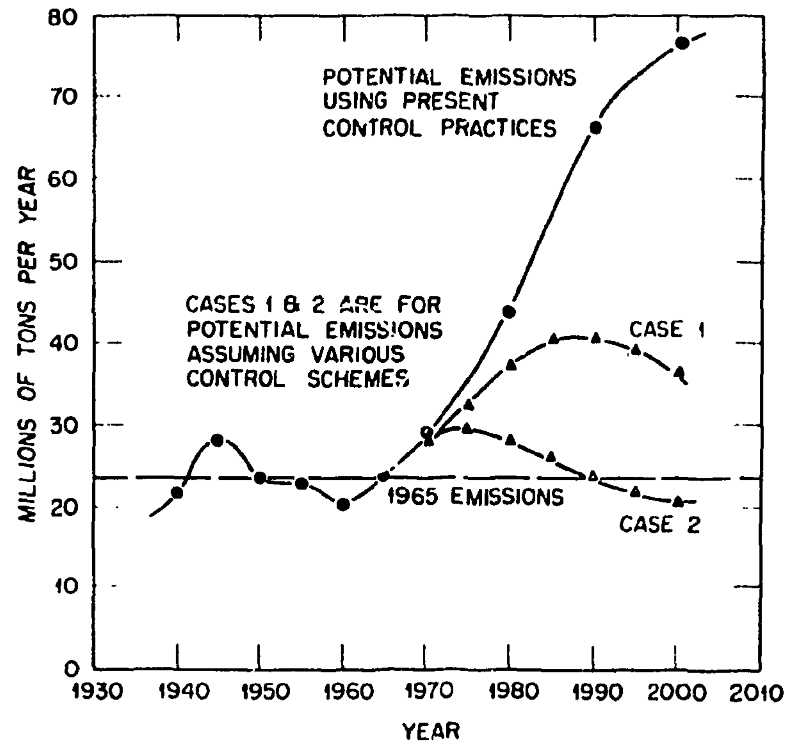

Fig. 1. Potential SO_2 emissions in the United States. (From Ref. 15.)

goal will require extensive development in the next 5 years, since most of the methods for control of SO_2 in power plants are only in the bench-test stage and effective coal desulfurization methods are not now available for 75 percent removal. The increase of average removal efficiency by 1-percent per year to 90 percent maximum is in keeping with expected improvements in technology.

2. Two-percent control of SO_2 from all coal and oil combustion beginning in 1970, increasing by 2 percent per year to a maximum of 50 percent control in 1994 (excluding new power plants after 1975, which are covered in the preceding paragraph). This assumption requires increased use of available techniques for fuel desulfurization, selection of fuels with lower sulfur content, and miscellaneous schemes for control of SO_2, such as use of fuel additives.

3. One-percent control for all noncombustion sources in 1965, increasing by 1-percent each year to 35 percent in the year 2000.

The Roles of Nuclear Energy

First the role of nuclear energy as a source of air pollution should be considered. This requires that a clear distinction be made between potential releases of pollution under accident conditions, such as at Poza Rica, Mexico, and the continuous real release of pollutants to the atmosphere.

With respect to accidents, most of us will agree with Sporn's[16] comment in his presentation to the National Conference on Air Pollution "... on the basis of safety all fuels—and this includes nuclear power—represent potential hazards." He also expressed the opinion that "... nuclear power continues to make progress and will substitute for an increasing share of the new power generation plants to be built. Undoubtedly its rate of substitution is being moderated by the cost burden of responsible conservatism in design and construction to assure safety and surely it must continue to be, for a long time, part of AEC, and in this case, national policy, to promote by every practical means absolute assurance of the safety of our nuclear power installations." Although many of us will agree with continuing and strengthening this responsible conservatism in design and construction, a growing number of people are beginning to wonder if a comparable quality might not be desirable in the design, site selection, construction, and operation of other types of facilities. This might prevent, or at least reduce, the occurrence of incidents such as the hydrogen sulfide release (and the 22 deaths) at Poza Rica, gas pipeline explosions, tank-car accidents releasing poisonous gases and vapors, pier explosions (e.g., the Texas City disaster of 1947), and numerous other potentially hazardous operations that are currently subject to the loosest review, if any at all, by responsible public officials.

Apart from potential accidents, the central problem of this section is the role of nuclear energy in air pollution. A synopsis of the views of the AEC was given by Chairman Glenn T. Seaborg[17] to the National Conference on Air Pollution:

> With reference to the primary focus of this conference—air pollution—nuclear power plants offer decided advantages over fossil fueled plants. The main advantage stems from their control of waste. In a nuclear reactor the split atoms, "fission products" as they are called, remain essentially within the fuel cladding until such time as the reactor is refueled. Then the used fuel elements are removed, stored under water for a cooling off period, after which they are safely shipped to a reprocessing plant where unused fuel and valuable radioisotopes are extracted for future use. The remaining waste products are then safely disposed of in storage tanks at underground burial sites. The extremely minute amount of radioactivity produced auxiliary to the operations can be held and released in such tiny amounts, and under such favorable atmospheric conditions, that it poses no health hazard whatsoever. Or it can be packaged for safe disposal in other ways. In fact, a nuclear plant can be built without any stack at all, and such a plant is under construction today in the Rochester, N. Y., area.

Similar comments were made by Grob[18] in his paper given at the 1967 Annual Meeting of the Air Pollution Control Association:

> It should be noted, however, that continuous release is not required in nuclear plant operation. The radioactive noble gases produced during reactor operations may be stored and released during favorable meteorological periods.
>
> Radioactivity released to the atmosphere by nuclear power plant operations is no greater than radioactivity released to the environment by conventional power plant operations. Both of these sources of radioactivity are insignificant compared to natural radioactivity, natural radiation fields, and man's non-nuclear and non-power generation activities. Discharges from our Company's (Consolidated Edison Company of New York) nuclear plant, Indian Point Unit No. 1, have been less than 0.01% of what the plant's license permits. The limits imposed by the license are such that they prevent achieving the legal limits set forth in 10CFR20 by orders of magnitude. The legal limits of 10CFR20 themselves have safety factors, which amount to orders of magnitude.

In his recent book on the technology of nuclear power facilities, Wills[19] includes a tabulation of typical radioactive wastes and disposal methods (his Table 29). Table 3 includes the airborne wastes mentioned by Wills.

Table 3 Typical Airborne Radioactive Wastes Related to Nuclear Power*

Type of waste radioactivity	Source of waste	Form of waste	Typical isotopes	Type of radiation	Disposal methods
Natural activity	Mining of uranium ores	Gases, dusts	^{222}Rn	α	Ventilate mine
	Fuel-fabrication plants	Dusts	^{238}U ^{235}U	α,γ	Ventilate, filter, and disperse to air
Fission-product activity	Fuel irradiation and processing	Gases	^{131}I	β,γ	React with chemicals to bind in solid, e.g., silver iodide
			^{85}Kr	β,γ	Disperse to air
Activation-product activity	Reactor materials unavoidably irradiated during operation	Gases	^{16}N	β,γ	Hold for decay (very short life); then disperse to air

*Modified from Table 29, Ref. 19.

Wills also commented on the relative amounts of radioactivity released from nuclear energy plants and from coal-burning plants, although he did not cite the source of his numbers nor did he identify the specific radionuclides which are, in fact, dispersed from a coal-fired plant:

> Gaseous Wastes—The gaseous effluent from a nuclear plant, which may occur from dissociation of the coolant, is removed to holdup tanks to permit decay of short-lived isotopes. The remaining gases are monitored and diluted with air and discharged through a tall stack when meteorological conditions are suitable for dispersion high into the atmosphere. This discharge is controlled in compliance with AEC regulations (activity limited to 10^{-9} $\mu c/cm^3$ of air), which are based on the annual radiation exposure that might be received by persons living at the plant exclusion-area boundary.
>
> Actually, a pressurized-water-moderated nuclear plant with a 150 MWe rating will in a year's operation disperse 2 mc of noble gases (Kr and I [*sic*]) into the atmosphere, whereas a coal-burning plant of equal capacity will disperse 20,000 mc of mixed nuclides into the atmosphere with other pollutants.
>
> Radiation levels inside and outside the plant exclusion area are constantly monitored to ensure that proper environmental conditions are maintained. Recently, a spokesman of the AEC's Division of Compliance summarized experience in the United States in years 1960 through 1963 as follows: "There has been no detectable increase in the amount of radioactivity, which could be attributed to the existence of the nuclear installation, in the environment of any reactor plant. This conclusion is based on the results of pre- and post-operation environmental surveys, which include sampling of the air, soil, water, vegetation, aquatic life, and milk in the vicinity of the reactor site."

The most thorough comparison of the environmental pollution levels from nuclear and conventional power plants was given recently by Terrill, Harward, and Leggett.[20] They point out the inherent difficulties in making such a comparison. One basic problem is the lack of accepted standards for permissible concentrations of nonradioactive pollutants in the environment in contrast to the well-established standards for radioactivity. A number of interesting points are given in the original paper, but only two will be treated here. First, the authors' discussion of the release of radioactivity from fossil-fueled plants and from nuclear energy facilities:

> Due to the presence of trace quantities of two naturally occurring radioactive materials in coal (1.1 ppm of ^{238}U and 2.0 ppm of ^{232}Th), the released fly ash would contain 10.8 mCi of ^{228}Ra and 17.2 mCi of ^{226}Ra per year, which are daughter products of ^{232}Th and ^{238}U. Thus, the question is raised: Do fossil fuel plants discharge significant quantities of radioactivity and how do they compare with releases of radioactivity from nuclear plants?
>
> On the basis of the AEC's regulations covering exposure to airborne radioactive materials, Eisenbud[21] states that this total of 28 mCi per year of mixed radium isotopes is approximately equivalent to 10^4 Ci of ^{85}Kr or 10 Ci of ^{131}I. Krypton-85 and ^{131}I were chosen for comparison, since they represent two of the principal gaseous radionuclides of concern in reactor stack effluents. Associated with the particulate emission from oil-fired plants will be approximately 0.5 mCi of radium per year (^{226}Ra and ^{228}Ra), which is roughly equivalent to 200 Ci of ^{85}Kr or 200 mCi of ^{131}I.
>
> A recent joint study[22] of natural gas from northwestern New Mexico and southwestern Colorado by the U. S. Public Health Service and the El Paso Natural Gas

Company shows that ^{222}Rn, a daughter of ^{226}Ra, is present in natural gas at concentrations ranging from 0.2 pCi/liter to 158.8 pCi/liter. There is a lack of data concerning concentration of ^{222}Rn in the stack effluent of natural gas power plants, but it can be assumed minimal due to the 3.8 day half-life of ^{222}Rn and the transit and/or storage times from well to plant which are involved. There will be some activity from the longer-lived daughter products of radon, but since these are particulates and therefore subject to many removal forces about which there is a lack of data, it is difficult to determine the amount of activity emitted.

Operating data is presently lacking for large nuclear power plants in the range of 500 to 1,100 MWe, because they are still in the construction or planning stage. However, published data are available from several smaller plants. For example, the Shippingport Atomic Power Station, located in Shippingport, Pennsylvania, and operated for the AEC by Duquesne Light Co., has been operating since 1957. This is a 100 MWe pressurized water reactor, and has generated a total of nearly 2,400,000 MWh as of May 1966.[23] During the five-year period, 1961–1965, this plant's annual average releases were 0.217 Ci of liquid radioactive waste (excluding tritium), 4.5 Ci of tritium in the liquid waste, and 0.57 Ci of noble gases (primarily ^{133}Xe).[24] These actual releases have been a small fraction of design discharge quantities and all releases have been well within the limits specified for the plant by the AEC and the liquid waste discharge permit issued by the State of Pennsylvania.

Another pressurized water plant, the Yankee Nuclear Power Station, near Rowe, Massachusetts, has been operating since 1960 and its present power level is 185 MWe. As of May 1, 1966, it has generated over 5,500,000 MWh.[23] During the calendar year of 1965, this plant released 0.067 Ci of liquid waste (exclusive of tritium—published tritium data not available at time of this writing) and 1.66 Ci of gaseous waste to the environment.[25] All releases were within limits established by the AEC regulations as contained in 10CFR20.

The authors chose plausible values for the permissible concentrations of SO_2 and NO_2 from the literature and compared the various types of plants on the basis of the amount of air per year required to dilute the emitted pollutants to stated standard concentrations. Table 4 appeared as Table V in the article cited in Ref. 20.

In all these comparisons nuclear energy comes out well ahead of fossil-fueled plants in terms of its minimal direct contribution to noxious airborne pollution. Furthermore, to whatever extent carbon dioxide (CO_2) may be detrimental in connection with the heat balance of the atmosphere, as has been suggested,[26] nuclear power again has the advantage in that it does not result in CO_2 production. However, normal operation presupposes that the fission products remain essentially within the fuel cladding. The critical point is reached when the cladding is breached in the fuel-reprocessing operation. According to Mawson[27] the "gases evolved from fuel-reprocessing plants are usually heavily contaminated with such chemicals as nitric acid and organic solvents, as well as with fission products, but the chemical contaminants can be removed by conventional scrubbing systems." Obviously, the chemical composition of the airborne effluents from a fuel-reprocessing facility depends upon the particular process employed.[28] Perhaps the only general comment warranted is that, in the absence of established standards for nonradioactive air pollutants, reactor fuel-reprocessing plants are not likely to institute significantly stricter control than is the practice of similar, nonradioactive, chemical-processing facilities. Nevertheless, fuel reprocessors operate under the control of their licensing provisions for the limitation of radioactivity release, and, in treating effluent gases to remove minute quantities of radioactive materials, they must remove many of the nonradioactive components as well. An order-of-magnitude comparison might be gained by considering the relative "acceptable" levels of SO_2 and radioactive ^{131}I. At a level of 0.3 ppm SO_2, as assumed by Terrill, Harward, and Leggett[20] (see Table 4), 1 μg of SO_2 would be dispersed in each liter of air, whereas 1 μg of ^{131}I would have to be dispersed in approximately 0.1 cu mile of air to equal the maximum permissible concentration in air for the general population.[2,3] Thus it would seem difficult indeed to remove the micrograms of radioactivity without, at the same time, significantly reducing the pounds of vapors and acid mists.

Unfortunately, the foregoing references do not tell the complete story in that they all pertain only to pressurized-water reactors (PWR's). The boiling-water reactors (BWR's) also represent a major type of power reactor which must be considered. In two recent reviews, one by Blomeke and Harrington[29] and one by Goldman,[30] the BWR's have been shown to release a very much larger fraction of the radioactivity produced in the fission process than is released in the operation of the PWR's. Release rates that may be compared with those given in Table 4 can be derived from data summarized by Goldman.[30] Thus the Dresden BWR (Commonwealth Edison Company) released about 4.3 $\times 10^9$ μc/Mw(e)-hr (noble gas) during the period 1963–1967, averaging about 2.4% of the limit imposed in the license; the Big Rock Point BWR (Consumers Power Company) released 23.8 $\times 10^9$ μc/Mw(e)-year ($>$ 99% noble gas) from May 1965 through April 1968, averaging 1.7% of the license limit; and the Humboldt Bay BWR (Pacific Gas & Electric Company) released

Table 4 Dilution Air Required To Meet Concentration Standards for Various Power-Plant Pollutants*

Type of plant	Critical pollutant	Exposure vector	Concentration standards†	Discharge quantities per Mw(e)-year	Yearly volume of air required for dilution, m^3/Mw(e)
Coal	SO_2	Air–SO_3–lungs Air–lungs	0.3 ppm	306×10^3 lb	1.77×10^{11}
	Fly ash ^{226}Ra	Air–lungs	1.0×10^{-13} $\mu c/cm^3$	17.2 μc	1.72×10^8
	^{228}Ra	Air–lungs	3.0×10^{-13} $\mu c/cm^3$	10.8 μc	3.6×10^7
Oil	SO_2	Air–lungs	0.3 ppm	116×10^3 lb	6.75×10^{10}
	NO_2	Air–lungs Air–O_3–smog–irritants of lungs and eyes	2 ppm Unknown	47×10^3 lb	5.77×10^9
	Fly ash ^{226}Ra	Air–lungs	1.0×10^{-13} $\mu c/cm^3$	0.15 μc	1.5×10^6
	^{228}Ra	Air–lungs	3.0×10^{-13} $\mu c/cm^3$	0.35 μc	1.2×10^6
Gas	SO_2	Air–lungs	0.3 ppm	0.027×10^3 lb	1.5×10^7
	NO_2	Air–lungs	2 ppm	26.6×10^3 lb	3.22×10^9
	Particulates—radon daughters	Air–lungs	Unknown	Unknown	
Nuclear	Radioactive noble gases ^{85}Kr + ^{133}Xe	External	1×10^{-7} $\mu c/cm^3$	5.7×10^3 μc	5.7×10^4 (Shippingport 5-year average)
				9.5×10^3 μc	9.5×10^4 (Yankee 1965)
	^{131}I	Air–lungs–thyroid	1×10^{-10} $\mu c/cm^3$	No detectable levels reported in available literature	No detectable levels reported in available literature
		Air–grass–milk–thyroid	1.6×10^{-13} $\mu c/cm^3$		

*Table V of Ref. 20.

†In the case of radioactive materials, they are based on AEC regulatory concentration standards (10CFR20), and in the case of chemical pollutants from combustion of fossil fuel, they are based on recommended permissible concentrations in the available literature.

22.5×10^9 μc/Mw(e)-year (noble and activation gases) from February 1963 through February 1968, which, however, averaged about 23% of the limit (the Humboldt Bay limit is a factor of 20 lower than the limit for Big Rock Point).

To bring the values given in Table 4 further up to date, one would have to modify the limit assumed for SO_2. More recent air-quality criteria for SO_2 suggest 0.015 ppm instead of 0.3 as estimated by Terrill.[20] Applying this factor of 20 to the yearly dilution volume indicated for SO_2 in Table 4, we see that on the order of 3.5×10^{12} m^3 of air are needed to dilute the flue gas produced in generating each megawatt of electricity in a coal-fired plant. The average discharge rate of radioactive noble gases from the three BWR's discussed by Goldman[30] was 10^{10} μc/Mw-year which would require dilution by 10^{11} m^3 of air per megawatt, a factor of 35 less.

The high release rates from the BWR's occurred during periods of operation with defective stainless-steel-clad fuel elements in the cores.[29] For example, the release rate per megawatt for the Humboldt Bay reactor was a factor of 340 less during the 18-month period February 1963 through August 1964 than it was from February 1965 through February 1968. The replacement of defective elements may be expected to reduce the average release rate by at least an order of magnitude. In any case, present experience indicates that continuous release of gaseous wastes from either the PWR's or the BWR's presents a lower order of hazard than that of coal-fired plants.

Nuclear Energy To Control Air Pollution

In addition to its role as an essentially clean source of power, nuclear energy has contributed heavily to society through the way it has fired the imagination of creative technologists in many fields. The field of air-pollution control is not lacking in this respect.

The massive technological effort of the national laboratory approach has impressed many scientists and engineers with its records of accomplishment. A number of comments were recorded in the biweekly newsletter *Environmental Technology and Economics*[31] for Apr. 13, 1967:

> Dr. Rene Dubos (Rockefeller Un.) said that what this country needs is a "Brookhaven applied to biology." He further said air pollution could be conquered if the country devoted the effort to it that it has given to probing the atom. Benn Jesser (M. W. Kellogg), speaking at the AIChE Workshop in NYC, suggested that process engineering concerns be given responsibility for running the pollution control R&D program just as the AEC gave responsibility for running its facilities to a number of concerns (UCC, duPont, Dow, Monsanto, GE, etc.). R. N. Rickles (Celanese), speaking at Rice Un., seconded Mr. Jesser's idea and further suggested the establishment of an ESC (Environmental Science Comm.) on the model of the AEC, to handle the development of new waste management techniques.

Use of nuclear energy to produce substitute fuels was discussed recently by Green.[32] He mentions the possible use of nuclear power to produce cheap ammonia for use as a fuel for internal combustion engines, and he points out the possibility of using nuclear energy as a clean source of process heat to convert coal and shale into gas to supplement our dwindling supplies of natural gas.

The use of chemonuclear reactors for the production of ozone to be used in odor control has been proposed by Steinberg.[33] Ozone could be produced for \$47.00 per ton in a single-purpose, 600 ton/day plant costing \$38 million. Such systems also could produce ozone for water treatment.

Beyond whatever secondary spinoff that may have come from nuclear energy programs, there have been extensive contributions in fields basic to air-pollution control. Fundamental and practical work in meteorology, air-cleaning technology, aerosol physics, inhalation physiology, process dynamics, ecology, and numerous other important areas have been supported by the AEC since its inception. It is impossible to look far in the literature of these fields without encountering many important contributions initiated by the nuclear program. In return, support of research in these areas has made it possible to provide the competent experts, hardware, and sound technological base which have enabled the nuclear industry to apply its "responsible conservatism in design and construction."

Summary and Conclusions

Nuclear energy has a critically important role in combating the growing assault on our atmosphere. Still, even with nuclear energy completely supplanting fossil fuels for new plants built late in this century, much more must be done. What then can the nuclear energy industry do to aid our fight for clean air? The answer is implicit in the very advantages claimed by nuclear power. Unquestionably, the potential for massive pollution exists in the fission products produced by a nuclear reactor; in the absence of effective control to restrict the emission of radioactivity, the nuclear program could have become a leading contributor to atmospheric pollution. The key word is control. Essentially every phase of design, site selection, construction, and operation of a nuclear power plant is under the strict surveillance and control of responsible and technically competent review boards. The same tight control is overdue for other actual and potential polluters and must surely come into being, hopefully soon.

What then are the technological problems for continued control of nuclear air pollution and for mounting a successful attack on nonradioactive pollution? There are at least two major stumbling blocks. First, providing the technically qualified people to man the review boards for the nuclear program alone is difficult at present and may eventually become the major bottleneck to the orderly advance of nuclear energy. Without question, if responsible review is to become a factor in the fight against conventional air pollution, the availability of technically competent hazards analysts is a basic prerequisite in this field. Thus those persons on local, state, and federal levels who are serious in their desire to combat air pollution had better begin now the structure of the necessary review boards by supporting graduate education in environmental hazards analysis. On the other hand, technically competent reviewers would wield an empty control if air-cleaning and fuel-treatment methods are not available to implement the control requirements. Thus a continuing pressure must be maintained on the problems of gaseous waste disposal from conventional power and other processing operations.

In view of our mounting needs for energy, it is not in the best interest of our society to proscribe the use of any important source of energy, such as the fossil fuels. Nevertheless, without the rapid institution of responsible control, we may well face a curtailment in the use of energy as our society reaches and fails to penetrate the coming air barrier to our continued existence. It is the clear duty of both government and private enterprise to look closely at the record of the nuclear energy program and to adopt those features of control which have worked so effectively. Two questions remain—will we do it, and is there time?

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RADIATION STANDARDS AND PUBLIC HEALTH

By Merril Eisenbud

[*Nucl. Safety*, 12(1): 1–8 (Jan.–Feb. 1971)]

Abstract: *The radiation-safety record of the AEC has been good, but changes in the present regulatory system are needed to reconcile differences between public attitudes and the AEC. AEC regulations are based on the recommendations of the ICRP and the NCRP, and the standards contain extensive built-in conservatism. However, the emphasis on the maximum permissible concentrations of radionuclides in air and drinking water should be changed to specify the maximum permissible daily intake from all sources to take into consideration multiple sources and ecological factors. Further, the dual responsibility of the AEC for the development of nuclear power and the protection of the public has contributed to lack of public confidence in the AEC. Accordingly it is recommended that responsibilities for setting radiation limits be shifted to another agency of the federal government. The same agency, in cooperation with the states, should assume responsibility for environmental monitoring in the vicinity of AEC-licensed facilities.*

The AEC has relied from the beginning of its existence on the National Council on Radiation Protection and Measurements (NCRP) and the International Commission on Radiation Protection (ICRP) to recommend the basic numerical values of permissible radiation exposure. The AEC has assumed for its part the role of translating the recommendations of the non-AEC independent expert groups into administrative language that lends itself to use by regulatory authorities.

The NCRP was founded about 40 years ago and until recently had its headquarters in the Bureau of Standards. In 1964 NCRP was granted a congressional charter and now operates as an independent organization financed by voluntary contributions from government, scientific societies, and manufacturing associations. The 65 members of this council and about 175 members of the 18 NCRP scientific committees have the responsibility for developing the technical reports of the organization.

In 1928, 1 year before NCRP was formed, the International Society of Radiology sponsored formation of the International Commission on Radiation Protection. This group has operated in close cooperation with NCRP and receives support from the World Health Organization. It is essential to this discussion of standards of permissible radiation exposure to understand that AEC standards originate in the work of these national and international bodies among whom there is total harmony and whose recommendations are based on objective evaluation of existing information that is motivated by a common interest in the public health.

ROLE OF U. S. ATOMIC ENERGY COMMISSION

When the U. S. Congress passed the 1946 Atomic Energy Act that established the AEC, it gave the AEC responsibility for assuring the safety of atomic energy workers and the public at large. The unusual step of vesting this responsibility in a federal agency rather than the states was taken for a variety of reasons, among which were that (1) much of the required technical knowledge was then highly classified, (2) the specialists who had this knowledge were, for the most part, located in a few large laboratories owned by the federal government, and (3) the potential risks of this new industry were not necessarily limited to state jurisdictions.

The record of the AEC to date with respect to radiation safety can be easily summarized. There have been no known radiation injuries to any member of the public resulting from any of the civilian activities of the AEC. Among the approximately 200,000 employees of the AEC and its contractors, there have been six fatal injuries due to nuclear accidents, all of which occurred in the course of experimental research. There was one additional death in a privately operated industrial company licensed by the AEC. Further, among this large population of industrial workers, there are no known injuries from the cumulative effects of exposure. During the same period, 1946 to the present, there have been 276 on-the-job accidental deaths from all causes, such as vehicle accidents, falls, etc. This indicates that the safety record of the AEC is very good, with the occupational fatality rate being about 25% of the average for all industry.[1] The excellent occupational safety record is cited to illustrate that the AEC has demonstrated a high degree of concern for protection of its personnel. It has exercised similar concern for public safety.

Because of a technicality in the Atomic Energy Act, responsibility for the health of uranium miners was not preempted by the AEC but, rather, has continued to reside with the states. The radiation-safety record in the mines has been far less satisfactory, and more than 100 deaths from lung cancer have resulted from the cumulative exposure to the radioactivity of the mine atmospheres.[2] It is regrettable that federal preemption of health and safety matters in the atomic energy program did not include the mining industry, because this tragic record would have been avoided had the AEC standards of permissible occupational exposure been enforced.

Another governmental agency concerned with radiation protection is the Federal Radiation Council, which consists of representatives of several federal departments and agencies. It was established by the President about 10 years ago to assure a consistent governmental approach to radiation protection matters. The Council has promulgated a number of radiation protection guides to assist in evaluation of hazards from nuclear weapons testing and, more recently, for control of radiation exposure in uranium mines.

RADIATION STANDARDS

The recommendations of ICRP and NCRP were originally intended for protection of workers exposed to ionizing radiation. Prior to World War II, there was so little use of these radiations that the need for standards to protect the public had not yet arisen.

The pre-World War II students of radiation protection did not have the benefits of governmental grants that were later available, nor did they have the sophisticated laboratory equipment now used in research. However, the tragic misuses of ionizing radiations during that period provided an all too ample research resource from which to devise protection measures. Although before World War II there were relatively few X-ray machines and the radioactive material to which people were exposed was some part of the approximately 2 lb of radium that had by that time been extracted from the earth's crust, hundreds of deaths and many injuries resulted from inadequate understanding of the principles of radiation hygiene. Fortunately the effects of the misuses of these sources of ionizing radiation were studied with such extraordinary diligence and perception by our colleagues of a generation ago that much of the basic information needed for protecting the employees of the atomic energy program was already on hand when it was needed during World War II. Two very basic recommendations were already available that pertained to the upper limit of permissible exposure to external X-rays and gamma radiation and to the maximum permissible body burden of radium. The recommendation that the permissible body burden of ^{226}Ra be limited to 0.1 μCi has not been changed since it was first established early in World War II. This yardstick has had a strong influence in setting the permissible body burdens of other bone-seeking radionuclides.

The maximum permissible dose of external radiation exposure permitted before and during World War II was 0.1 R/day, based on the scanty information available up to that time, and was equivalent to 20 R/year. If we allow for the difference between roentgens and rads and for the fact that the radiations now encountered in the atomic energy program are more penetrating than the 75- to 125-kV X-rays that were the principal source of radiation before World War II, we find that the permissible dose for occupational exposure recommended by NCRP as long as 30 years ago is within a factor or 2 of the tissue dose permitted today for occupational exposure.

The problem of setting standards for protection of the general public is much more complex for several reasons. Because radiation workers comprise a relatively small fraction of the total population and because the genetic effects are related to the per capita gonadal dose of the population, genetic effects are less important than somatic effects, insofar as occupational exposure is concerned. The probability of somatic injury at a given level of exposure in the general population is increased by the fact that children and fetuses are involved. Additionally, it is necessary to become more conservative as the size of the exposed population increases, and in this country the general population is about one thousand times the population industrially exposed.

Leukemia and genetic mutations are believed to be the effects of ionizing radiation exposure that should be of greatest concern relative to the general population, and the following discussion of AEC standards focuses on these. An increased incidence of leukemia[3] has been reported among several groups of humans exposed to relatively high doses of ionizing radiation. These may include such groups as Japanese survivors of the atom bombings of Hiroshima and Nagasaki, patients irradiated for ankylosing spondylitis, radiologists exposed to ionizing radiation in the course of their work, and children irradiated *in utero* in the course of pelvic X-ray examinations. This epidemiological experience involves mainly single or multiple exposures at high dose rates compared with those permitted by existing standards. To estimate the expected effect of doses of a fraction of a rad delivered in small bits, we must extrapolate from these epidemiological data. In the interest of maximum safety, this is done by assuming that there is no threshold and that the biological response is proportional to the dose and independent of the dose rate. Both the United Nations Scientific Committee on the Effects of Radiation[3] and the ICRP[4] have emphasized that the estimates made in this way represent an upper limit of risk and that the actual risk may in fact be very much less. Subject to these conservative assumptions, the epidemiological evidence suggests that a dose of 1 rad delivered to 1 million people may produce a maximum of about 20 extra cases of leukemia during the lifetime of the population. The incidence of leukemia in the normal population is about 70 cases per million per year.

Insofar as genetic effects are concerned, there are no epidemiological data on which to draw. However, extensive research has been done with lower animals which suggests that there is no threshold for genetic effects and that the frequency of mutation is directly proportional to dose but the relation is not independent of dose rate.[5] According to these data a per capita dose of about 10 rads per generation, delivered to successive generations, will eventually cause the spontaneous mutation rate to double. It has recently been shown,[6] however, that, when the dose is fractionated, the genetic effect is less by a factor of about 6. Thus for continuous exposure a dose of 60 rads per generation, delivered to many successive generations, might be expected to cause the spontaneous mutation rate to double. For a reproductive span of 30 years, the doubling dose would thus be about 2 rads/year.

The basic criterion for the upper limit of permissible occupational exposure is that an employee should not accumulate more than $5(N - 18)$ rads, where N is the employee's age in years.[4,7] Stated another way, the employee should not work with ionizing radiation until he is 18 years old and then should not be exposed to more than an average of 5 rads/year.

When internal radiation exposure is involved, the ICRP methodology introduces the concept of the "critical organ," which is the organ in which a given radionuclide tends to accumulate and give the highest radiation dose and/or most significant effect.[8] For example, the critical organ for radioiodine is the thyroid, and for ^{90}Sr, it is the skeleton. With a few exceptions, exposure to internal emitters is controlled by limiting the quantity of radionuclides that may be absorbed by ingestion or inhalation to that amount which will result in exposure of the critical organ to less than 5 rads/year. The ideal, of course, in every case is to hold the absorption to as little as possible consistent with the activity.

The maximum permissible mean dose to the gonads or blood-forming organs, according to AEC regulations, is one-thirtieth of the permissible occupational dose. The regulations are based on this average not being exceeded if the individual with the highest exposure in a given population is not exposed to more than one-tenth of the permissible occupational dose. In short, the mean exposure of a given population should not exceed 0.17 rad, and the maximum individual exposure should not exceed 0.5 rad.

NATURALLY OCCURRING SOURCES OF IONIZING RADIATION

It is helpful to review what is known about the radioactivity of the natural environment[9] so that we may have a yardstick with which to compare the AEC standards. An appreciation of the kinds and amounts of ionizing radiation exposure due to natural sources is relevant to this discussion of the significance of reactor-produced radiation.

Radioactive substances are naturally present in the air we breathe, the water we drink, and the food we eat. These substances become incorporated into our tissues in such amounts that on the average our body tissues are literally disintegrating at a rate of about 500,000 atoms/min due to radioactive decay.

The total-body irradiation received by man in most parts of the world is about 0.1 rad/year. This figure varies somewhat from place to place, with an addition of about 0.028 rad/year for each 1500 m of altitude above sea level. Further deviations from the norm occur in places where the thorium or uranium content of the rocks and soils is above normal. In one village in Brazil, some people can be exposed to as much as 12 rads/year.

The lung and skeleton are selectively exposed over and above the dose received by the body as a whole. A large component of the dose to lungs is due to the presence of atmospheric radon, the concentration of which varies from about 10^{-11} μCi/ml to about 2×10^{-10} μCi/ml in different parts of the world. A concentration of 10^{-10} μCi/ml will deliver a dose of about 1.3 Rems/year to the basal cells of the bronchial epithelium, which is the tissue of the lung known to be particularly radiosensitive.[3] Doses as high as 10 times this value are possible indoors, particularly when the building is made of materials having a high radium content.

Radon-222, which has a half-life of 3.8 days, decays progressively through several shorter lived progeny to ^{210}Pb, which has a half-life of 22 years, and this radioactive substance ultimately deposits on the earth's surface. Only in the last few years have we begun to appreciate that mankind has always been subject to this form of natural fallout and that broad-leafed plants in particular have relatively high concentrations of this isotope because of foliar deposition of ^{210}Pb. According to one investigator this phenomenon contributes an additional 41 mRems/year to the lungs of individuals smoking one pack of cigarettes per day.[10]

Two naturally occurring nuclides, ^{226}Ra and ^{228}Ra, which are chemically similar to calcium, enter our bodies through the foods we eat, and they deposit with calcium in our skeletons. The daily radium ingestion of individuals in this country is about 5 pCi/day, approximately equally divided between the two nuclides. Studies of food and water in various parts of the world have shown that there are wide variations from these mean values. In certain parts of the Middle West, the radium intake is elevated owing to the presence of abnormally high amounts of radium in the drinking water, and the dose to the skeleton is thereby increased by about 0.06 Rem/year. Considerably higher doses have been reported from Brazil and India, where there are radioactive anomalies of the type mentioned earlier.[11]

Thus we can conclude that the whole-body dose from natural radioactivity in most parts of the world is about 0.1 Rem/year. The lung receives a greater dose due to the superimposed radiation from atmospheric radon, as does the skeleton in certain geographical areas where the radium content of food and water is elevated above normal.

EXTERNAL RADIATION

The actual external radiation exposure to the general population from nuclear power plants does not approach the so-called permissible dose rates because of certain inherent factors. For example, the heavy shielding required to protect men working around the reactor in the normal course of their activities gives assurance that the external radiation dose to the public will not be detectable. I [illegible] of no case in which radiation from the plant [illegible] has caused a perceptible change in the levels of radiation exposure beyond the property boundary.

In the case of a boiling-water reactor, the principal way in which the general population would be exposed to external radiation would be by direct irradiation from the passage of radioactive gases discharged from the stack of the plant, but, if the maximum exposed individual received no more than 0.5 rad, the per capita exposure would be very much less than 0.17 rad. For example, consider a hypothetical situation in which a boiling-water reactor stack is located 100 m from a 360° fence at which the dose is assumed to be 500 mrads/year. In this situation, people living right on the fence would receive no more than the AEC maximum permissible dose to individuals. From known rates of diffusion of gaseous effluents from point sources, it can be calculated that the dose rate beyond the fence would, on the average, diminish inversely with the 1.8 power of distance from the stack. The per capita doses have been calculated for populations of 10^5, 10^6, and 10^7 people uniformly distributed around the fence at a density of 1000 people/km^2. The annual per capita doses for the three populations turn out to be 1.9 mrads, 0.28 mrad, and 0.04 mrad, respectively. We must recognize that this, in fact, overestimates the per capita dose because a dose of 500 mrads would occur only in the downwind sector, which would be perhaps one-eighth of the plant fence circumference. For seven-eighths of the plant circumference, the dose would be very much less than 500 mrads/year. We now begin to see the kind of built-in conservatism that exists in the AEC regulations and that, even under the worst conceivable conditions, 10 million people distributed around a boiling-water reactor would receive no more than a total of 400 man-rads instead of the 1.7 million man-rads permitted under a literal interpretation of current regulations.

As mentioned earlier, 10^6 man-rads may produce 20 cases of leukemia in the lifetime of the exposed population. Four hundred man-rads may on this basis cause 0.008 case per million exposed people. Assuming the mean sensitive life-span to be 60 years, 400 man-rads/year could produce 0.5 case per million people per generation of 60 years. As explained earlier, this is an upper limit of risk, and the true risk is somewhere between zero and this upper estimate. Since the incidence of leukemia in the general population is about 64 cases per million per year, the 0.5 case in 60 years would occur against a normal background of 4200 cases.

With respect to genetic effects, if the doubling dose for spontaneous mutations is a per capita exposure of 2 rads/year, 0.17 rad/year delivered over many generations would result in about an 8% increase in the spontaneous mutation rate. However, since the man at the fence can receive no more than 0.5 rad, the external radiation dose from the plume would, at the limit of permissible exposure, result in a per capita annual dose of 0.04 mrad in a population of 10 million people, as previously shown. On the improbable assumption that these 10 million people constitute a closed breeding population for as many generations as it takes to reach equilibrium, the spontaneous mutation rate would eventually be raised by about 0.05%. This rise is equivalent to the change in radiation exposure that might be expected from living at a difference of about 10 ft in altitude.

To place all this in further perspective, note not only the well-established fact that increased temperature, like ionizing radiation, can cause genetic mutations but also the suggestion that as many as 50% of the mutations that occur normally in contemporary man might be due to the increase in testicular temperature caused by the male practice of wearing trousers. Although this observation on the effect of trousers appeared in the literature in 1957, I am unaware of any subsequent popular movement to prescribe kilts in place of the more mutagenic habit of dress of the American male.[12]

STANDARDS PERTAINING TO ENVIRONMENTAL CONTAMINATION

The ICRP and NCRP standards for permissible human exposure to radioactive substances are based on the assumption that the permissible amount of radioactive substances accumulated within the body or in the critical organ should not cause the permissible annual dose to be exceeded. These figures are then translated into maximum permissible concentrations of each radionuclide in air or water by using a set of physiological parameters that describe the movement of each element to the critical organ and the daily rate at which the contaminants are inhaled or ingested. In the case of ingestion, the AEC regulations give only the maximum permissible concentrations in drinking water. This is a defect since ingestion may be by way of food or water. The Federal Radiation Council approach is different and more logical since their recommendations, which they call radiation protection guides, focus on the permissible daily intake of a given nuclide, regardless of the source.

Where several nuclides are present, the AEC regulations provide a method for weighing the effects of each in relation to the others in such a way that the maximum permissible radioactivity of the mixture of nuclides takes into consideration the contribution of the individual nuclides. In this case the method errs on the side of safety. For example, if ^{131}I and ^{90}Sr are present in drinking water, the maximum permissible concentration of the mixture might allow 50% of the ^{131}I permissible concentration and 50% of the ^{90}Sr permissible concentration despite the fact that one nuclide irradiates the thyroid, the other irradiates the skeleton, and the effects are not thought to be additive.

Another safety factor exists insofar as the long-lived radionuclides are concerned because the maximum permissible concentration is taken as that concentration which will result in accumulation of the lifetime permissible body burden in 50 years. It can be shown from the mathematics of ^{90}Sr accretion in the skeleton that this provides a significant additional safety factor.

Since the AEC regulations are stated in terms of the maximum permissible concentrations of radionuclides in air and water, the regulations implied for many years that, if the maximum permissible concentration is not exceeded at the point of discharge to the environment, the dose to humans will not be exceeded anywhere beyond the site boundaries. In most cases this is an enormously conservative assumption since dilution up to several orders of magnitude can and does take place beyond the point of release. However, it is also possible for physical or biological concentration to take place, and when this occurs the risk can be correspondingly increased.

Within the past few years, the AEC standards have been modified to allow for biological concentration. In the case of ^{131}I, the maximum permissible concentration in air has been reduced by a factor of 700 to allow for the fact that exposure to man is increased by the tendency of iodine to deposit on forage and eventually pass to cow's milk. In addition, the regulations have been modified to require the licensee to demonstrate that accumulations in the food chain are not taking place. The discharges to the environment are considered to be excessive if the radionuclides ingested by a sample of the population by any route of exposure exceed one-third the annual intake permitted for water and air.

It should be noted that the Commission has always had the right to place upon the prospective licensee the responsibility of demonstrating that such concentration will not take place, and, although the AEC regulations were formerly silent on this point, no one who has followed the course of reactor licensing procedures over the years has ever doubted that the AEC has meticulously probed into questions of biological concentration beyond the point of discharge. Under the AEC regulations a licensee can discharge radioactive waste to the environment in concentrations greater than those permissible for immediate inhalation or ingestion if he can demonstrate the extent to which dilution takes place.

The AEC requires the licensee to conduct monitoring programs in the vicinity of the reactor. This provides information about the concentration of radioactive substances in air and water and also in whatever food products may be grown in the vicinity. Thus the question of human safety is not left to conjecture but is based on actual measurement of samples collected from the environment. Some of the AEC facilities, such as Oak Ridge and Hanford, have been collecting data for more than a quarter of a century, and experience at these places has produced valuable information that in many cases is directly applicable to civilian power reactors.

For several years many of us in the field of public health and environmental protection have argued that, on the balance, electrical generating stations powered by nuclear fuels make better neighbors than those using coal or oil. It is true that nuclear plants of the current generation discharge more heat to the environment than do the newest fossil plants. This places more stringent limitations on the use of water for condenser cooling, but regulations dealing with this problem are being promulgated in the various states for application to both nuclear- and fossil-fueled stations.

Much has been said about the ecological effects of radioactivity discharged to the environment, but there is no evidence that this occurs at or above the levels of radioactivity permitted by AEC. Putting it more strongly, there is a considerable body of scientific data that demonstrates that such effects do not take place. In contrast, we do know that certain vegetation is adversely affected by traces of sulfur dioxide and possibly other components of the combustion products of coal and oil.[13] There have been millions of dollars spent investigating the ecological effects of low levels of ionizing-radiation exposure, but there have been comparatively few studies of the ecological effects of the chemicals in fossil-fuel effluents, despite the fact that we know these effects take place and can be observed.

In most parts of the country, fossil fuels are the only practical alternative to nuclear fuels. We know, beyond any doubt, that sulfur dioxide discharged to the environment by plants burning fossil fuels has been responsible for many deaths in the general population, particularly during periods of meteorological stagnation. Even the innocent gas, carbon dioxide, produced by combustion of fossil fuels, is accumulating in the earth's atmosphere and is regarded as a long-range threat to the world's heat balance, with the possibility of eventual climatic changes on a disastrous scale.[14] Finally, it is a curious fact that, because radium and other radioactive substances are normally present in fossil fuels, the radioactive atmospheric emissions from fossil-fueled plants are not insignificant compared with those from many nuclear plants.[15,16] These are among the reasons that some of us are convinced that nuclear reactors make good neighbors.

Additional reasons are to be found in the actual operating experience of the civilian power-producing reactors. The atmospheric and liquid effluents are in most cases less than 1% of the amounts permitted by AEC standards, and the public-health risks, though finite, are so small as to be more than offset by even the most modest of the benefits of increasing man's available electrical resources.

CONCLUSIONS

From the foregoing it is possible to draw certain conclusions which constitute the thesis of this presentation and which indicate that, although the record of the AEC has been a good one from the point of view of the public-health official, changes in the present regulatory system are being demanded to continue to lessen differences between public attitudes and the AEC that are still not completely resolved after 15 years of almost continuous debate.

The AEC regulations are substantially compatible with the recommendations of ICRP and NCRP. Moreover, they are both scientifically and philosophically compatible with evaluations of the state of our knowledge of radiation effects that have been undertaken from time to time by other national and international bodies, including the United Nations Scientific Committee on the Effects of Atomic Radiation, our National Academy of Sciences,[5] and the British Medical Research Council.[17]

The AEC regulations have resulted in a safety record that is unsurpassed for any major industry. In the 27 years that have passed since the first reactor went critical in December 1942, there has been ample time to evaluate the basic adequacy of the systems of control that have been derived.

Although there are ambiguities, inconsistencies, and perhaps even deficiencies in the AEC regulations for permissible discharges to the environment, they are adequate to protect the public health. The standards contain enormous built-in conservatism.

The present system of AEC regulation, which puts major emphasis on the maximum permissible concentrations of radionuclides in air and drinking water, should be changed in favor of specifying the maximum permissible daily intake from all sources. This is the method used by the Federal Radiation Council and is preferable because it automatically takes into consideration such factors as multiple sources of exposure and ecological factors.

Although neither NCRP nor AEC is sacrosanct, considerable weight must be given to the fact that the ponderous procedures of these organizations have produced a set of regulations that are workable and that have successfully protected the public health for more than a quarter of a century.

An examination of 27 years of experience would seem to indicate that the AEC has been fully prudent in discharging the responsibilities Congress bestowed on it in the health and safety field. However, it is clear that this judgment is not shared by many people. For reasons probably related to factors other than the excellent safety record it has achieved in the nuclear power field, the AEC does not have the high degree of public confidence that is necessary for smooth development of the electrical generating industry. There remains a credibility gap that has not been closed after more than 15 years of debate.

A significant factor in the credibility gap is the unusual dual responsibility of the AEC for both development of civilian nuclear power and protection of the public health. Although I personally believe that the AEC has an excellent record of accomplishment in both areas and has retained a high degree of objectivity in facing its responsibilities for health and safety, the public is not fully convinced that this is so. For this reason I believe it would be in the public interest to begin active consideration of the means by which the regulatory responsibilities of the AEC can be transferred to some other agency of government or shared with them. Only in this way can we hope to assure the public that the present apparent conflict of missions is not operating to its detriment. However, a transfer of regulatory responsibility cannot be accomplished easily. The AEC has well-developed regulatory machinery of a type that does not exist in any other branch of government. Although in theory it would be possible to transfer this organization *in toto* to another agency, this would not be wise because interagency transfers are always disruptive of morale and working efficiency.

As a compromise the newly created Environmental Protection Administration (EPA) should be given a more prominent role in the regulatory program. The EPA rather than the AEC should promulgate the numerical standards of permissible exposure. The AEC, with its highly developed capability to evaluate reactor designs, should continue to consider applications for new reactors and should continue to monitor construction and operation to assure compliance with the terms of the license. However, the EPA, in collaboration with the states, should undertake the responsibility of effluent monitoring and ecological surveillance. By sharing its present statutory regulatory authority with the EPA in this way, the credibility gap that now exists between AEC and many segments of the public can hopefully be closed.

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RADIATION IN PERSPECTIVE: SOME COMPARISONS OF THE ENVIRONMENTAL RISKS FROM NUCLEAR- AND FOSSIL-FUELED POWER PLANTS

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Abstract: *Fossil- and nuclear-fueled steam plants seem the practical means for meeting immediate power needs. The use of nuclear-fueled plants is being restricted in several instances because reactor-related hazards have been exaggerated. Ninety power reactors, in the United States and abroad, have generated 2.5 × 10^{11} kWh over 650 reactor-years without serious incidents. Comparison of routine discharges of hazardous agents from different types of steam power plants shows that nuclear-fueled plants produce the lowest concentrations of such agents relative to protection standards. Radioactive releases associated with the Brookhaven Graphite Research Reactor are comparable to the upper amounts anticipated from 1000-MW(e) reactors, and the measured Brookhaven external radiation levels, deposition, and aquatic concentrations suggest that the radiation level in the vicinity of large power reactors should be insignificant. The calculated risk (~10^{-7}/year) of fatal injury from the anticipated maximum exposures of a few millirems per year above natural background is small compared with that of other accepted hazards of everyday living.*

The safety of nuclear power reactors and the routine release of radioactivity from these plants has become a matter of widespread public concern. Much of this concern stems from conjecture and speculation that is due in part to the technical nature of the data and the nontechnical nature of the public.

Brookhaven National Laboratory (BNL) was established on Long Island 20 years ago, and the air-cooled Brookhaven Graphite Research Reactor (BGRR) was operated as one of its major research facilities from 1951 to 1968. The establishment of BNL preceded the adoption of uniform national radiation protection standards by the AEC, and at that time less was known about environmental radioactivity than is the case today. Conservative practices were adopted with regard to release of reactor air and liquid from the BGRR to the environment, and the releases turned out to be similar to those anticipated from the large nuclear power plants now under construction at many locations in the United States.

As part of its mission to obtain scientific information, BNL has maintained a more extensive environmental monitoring program than that which would be required in the vicinity of a nuclear power reactor to establish compliance with radiation protection standards. The experience to date with nuclear reactors, in addition to the data developed at Brookhaven, led to the conclusion that nuclear reactors possess a high degree of safety and that the environmental radiation risk associated with the operation of nuclear power reactors should be small compared with that from conventional fossil-fueled plants.

ASSUMPTIONS

The *potential* risks of nuclear power plants can be considered sensibly only in the context of the alternate choices. Three underlying assumptions are basic to this discussion.

1. Electricity is a basic necessity to a technological civilization. A review of recent electrical power statistics and a projection of future requirements to the year 2000 are presented in Table 1, which was adapted from information on the environmental effects of producing power and recently published for use of the Joint Committee on Atomic Energy.[1] Apparently the nation's generating capacity will have to be doubled about every decade to meet the anticipated demand, and, even with the anticipated introduction of nuclear power, a substantial increase in conventional fossil-fueled generating capacity will also be required to meet the total projected needs for electric power.

2. All human interventions related to the extraction and consumption of energy have the potential for both cost and benefit. Some concrete instances are suggested in Table 2 with regard to the present alternatives for electric-power generation.

3. For most areas of the United States, fossil- or nuclear-fueled power plants offer the only practicable means of meeting the near-future electric-energy demand. Various other methods for producing electricity, such as the magnetic-hydrodynamic topping cycle, the fuel cell, and the fusion reactor, are under development. However, none is sufficiently advanced to be applied "off the shelf" in meeting immediate needs for power.

It follows from these assumptions that the real issue before the public is which technology, fossil or nuclear, will yield the greatest overall benefit-to-risk ratio. In contrast to most technological innovations (including that of the use of fossil fuels), this sort of consideration has been uppermost from the outset in the development and employment of nuclear power reactors. In his annual report for 1969 to the United Nations, Dr. Sigvard Eklund, Director General at the International Atomic Energy Agency (IAEA), stated, in part, "From the start the utmost care has been exercised to control the release of artificial radioactivity into the environment, indeed far more care has been taken with, and far more rigid legislation and standards are applied to nuclear energy than to any other potential source of environmental contamination. Far from being a major contributor to the pollution of the environment, nuclear energy can be a factor which will diminish pollution if it is used as a substitute for other sources of electric power such as coal and oil."[2]

Table 1 Use and Projected Demand for Electric Power in the United States*

	Year			
	1950	1968	1980	2000
U. S. population, millions	152	202	235	320
Electricity generating capacity, 10^3 MW				
Total	85	290	600	1352
Conventional (hydro-electric, fossil)	85	287	450	411
Nuclear	0	3	150	941

*Based on data from Ref. 1.

MALFUNCTIONS AND CATASTROPHES

Although a balanced assessment of the adverse effects of power-plant effluents on the environment should be devoted primarily to those released during routine operations, some considerations of the probability of catastrophic accidents seem appropriate in the present context. Even with conventional technologies, the dramatic nature of catastrophes is such that they are often given far more attention than routine mishaps, even though it may be shown that the latter are, in the aggregate, far more costly per capita. This is, for example, evident in the relative amounts of attention given and resources devoted respectively to air and to highway safety.

With regard to catastrophes, the *public safety first* approach of the atomic industry has included an assessment of the potential consequences of catastrophic events in what is known as a "safety analysis." In this analysis it must be convincingly established that, for the most serious plausible simultaneous occurrence of malfunctions and failures, the so-called DBA (design basis accident), the release of radioactivity would be sufficiently limited so that no person in the environs would be seriously affected now or in the future. Some unwarranted apprehension about the inherent safety of reactors has been created by a

Table 2 Risks and Benefits from the Generation and Distribution of Electricity

Type of plant	Risks	Benefits
Hydroelectric	Alteration of stream flow; destruction of habitats and scenery, such as by reservoirs and long transmission lines	Energy; employment; flood control; recreation
Gas-fired	Destruction of scenery, such as by pipelines and plant stacks; air pollution with many substances; alteration of local ecology by thermal waste	Energy; employment; by-products
Oil-fired	Destruction of scenery, such as by pipelines, storage tanks, plant stacks, and ash-disposal areas; water pollution; air pollution with many substances; alteration of local ecology by thermal waste	Energy; employment; by-products
Coal-fired	Destruction of scenery, such as by strip mining, transport and storage facilities, plants, stacks, and ash-disposal areas; stream pollution (from mining refuse); air pollution with many substances; alteration of local ecology by thermal waste	Energy; employment; by-products
Nuclear	Destruction of scenery, such as by mining and processing facilities, plants, and stacks; minimal routine air and water pollution with radioactive ash; possible leakage during the long-term confinement of high-level radioactive wastes from fuel-reprocessing facilities; possible accidental release of significant quantities of radioactivity due to a reactor malfunction; alteration of local ecology by thermal waste	Energy; employment; by-products (i.e., isotopes useful in medicine, industry, research, etc.)

favored device of some reactor critics; they quote from the consequences portions of the safety analyses, out of context, with little or no indication of the exceeding improbability of the postulated events.

To inject a consideration of probability into this presentation, note that over 300 civilian and military nuclear reactors are now operating or have been operated in the United States.[3] A few have been functioning for as long as two decades, and a total of well over 2000 reactor-years of experience has been accumulated. A malfunction leading to the release of a significant, let alone a catastrophic, amount of radioactivity to the environment has yet to occur in this nation in connection with reactor operation. Perhaps more pertinent, it was recently indicated at an IAEA symposium on nuclear power-reactor components that the 90 power reactors now in operation throughout the world have generated 250 billion kWh of electricity and have accumulated 650 years of experience, all without serious incidents.[4]

A study of the possibilities and consequences of some hypothetical, but highly improbable, catastrophic reactor accidents was made at BNL almost 15 years ago, when the Price–Anderson Act (AEC indemnity legislation) was first proposed. This report[5], generally referred to as WASH-740, has frequently been cited in the continuing debate about reactor safety. Starr[6] has since calculated that the probability of the incident the authors envisioned is about comparable to that of a jet transport crashing into an occupied sports stadium, that is, about 1 : 300,000,000. Starr commented that no one has suggested, on the basis of this probability, that we should abandon either spectator sports or airline service. In reaffirming the applicability of the

Brookhaven study, when the extension of Price–Anderson was under consideration in 1965, AEC Chairman Seaborg indicated that, although the consequences of a major accident could be greater, the likelihood of a major accident was still more remote than originally suggested.[7]

Perhaps because we are accustomed to them, we are sometimes forgetful of the catastrophes and near-catastrophes that are at least in part attributable to the uses of fossil fuels, such as mine explosions,[8] floods related to strip mining,[9] oil leakage from tanker wrecks,[10] and urban air-pollution incidents[11] in which excess mortality over normal rates has been documented.

The favorable safety record of nuclear reactors is a result of the conscious provision of several successive layers of protection in their design and operation. These include:

1. *Careful training and practices.* Operators are trained for licensing as though the entire safety of the reactor depended solely on their actions.

2. *Electronic safety monitors.* These automatic backup devices continuously sense the condition of the reactor and associated equipment. They react much faster than a human operator could to shut down a reactor in the event that any significant indication exceeds preset operating limits.

3. *Self-limiting behavior.* The arrangement of the fuel and the inherent characteristics of a nuclear reactor are such that most imaginable accidents would tend to be self-limiting if the many control devices ever failed to operate.

4. *Fuel cladding.* The fissionable material is "canned" to minimize the possible escape of fission products from the fuel.

5. *Primary-system enclosure.* The entire nuclear "furnace," or reactor, including the canned fuel, is located inside a pressure vessel to minimize release of fission products that might escape from the fuel.

6. *Building containment and engineered safety features.* These are provided to further minimize the release of fission products to the environment if they should escape from the primary system that is within the containment building.

It seems appropriate in concluding this consideration of catastrophes to suggest that the public welfare would be much enhanced if the degree of attention to safety and the employment of many backup devices comparable to those now routinely provided for nuclear reactors were applied to other large-scale technologies with a view to promoting the same kind of conservative design and review prior to their application or extension.

ROUTINE EFFLUENT RELEASES

When the situation with regard to the effluents produced by the routine operation of power facilities is examined, it appears that in principle the hazardous agents from both fossil- and nuclear-fueled plants are controllable at almost any level which those responsible deem advisable or which the public insists upon. However, the closer to zero this level is set, the greater is the economic cost ultimately passed on to the consumer. In practice, effluent control seems largely governed by the state of the available technology and the economic cost of its application. From both standpoints, nuclear plants appear to have an advantage; that is, the technology for the control of radioactive emission is more developed and, as suggested by Lane,[12] will probably be less costly than that for the comparable control of the several conventional pollutants emitted from fossil-fueled plants, particularly for advanced types of reactors.

What this means is suggested by the comparison of the respective fuel requirements and of the principal types and amounts of atmospheric pollutants released from various 1000-MW(e) plants using coal, oil, gas, or nuclear fuel, as shown in Table 3. The data for fossil-fueled plants are calculated from those published by Terrill, Harward, and Leggett[13] and, for nuclear plants, from those reported for 1969 by the Division of Compliance of the AEC.[14] The data for radioactive noble gases are from Ref. 15. As originally suggested by Eisenbud and Petrow, on the basis of the much greater health significance of radium nuclides, the amounts of radioactivity released from conventional plants are biologically comparable to those released from nuclear plants.[16] It is apparent from Table 3 that to meet projected power needs with fossil-fueled plants would require releasing millions of pounds of obnoxious agents, including some radioactivity, to the environment for years to come during the operational lifetime of these plants.

The clean-air advantages of nuclear plants are clearly shown in Table 4, which is also partly from Ref. 13 and partly from Ref. 14. Table 4 shows the volume of air required to dilute the yearly amount of released air effluents to suggested conventional-pollutant concentration standards or to established radiation protection standards.

It should be noted that a plant stack release limit for radioactive noble gases is based on ground-level

Table 3 Effluents from 1000-MW(e) Electric-Power Stations

	Type of Fuel			
	Coal	Oil	Gas	Nuclear
Annual fuel consumption	2.3×10^6 tons	460×10^6 barrels	6800×10^6 ft^3	2500 lb*
Annual release of pollutants,† millions of pounds				
Oxides of sulfur	306	116	0.03	0
Oxides of nitrogen	46	48	27	0
Carbon monoxide	1.15	0.02		0
Hydrocarbons	0.46	1.47		0
Aldehydes	0.12	0.26	0.07	0
Fly ash (97.5% removed)	9.9	1.6	1.0	0
Annual release of nuclides, Ci				
1620-year ^{226}Ra	0.0172	0.00015		0
5.7-year ^{228}Ra	0.0108	0.00035		0
10.8-year ^{85}Kr + 5.3-day ^{133}Xe	0	0	0	
Radioactive noble gases‡				
PWR §				600
BWR §				1.11×10^6
^{131}I	0	0	0	
PWR §				0
BWR §				0.85

* From a fuel reserve of approximately 27,500 tons.
† From Ref. 13.
‡ For a PWR with greater than 1 month gas holdup, these gases would be 10.8-year ^{85}Kr and 5.3-day ^{133}Xe. The typical 30-min-holdup and diffusion mixture from a BWR is composed primarily of 1.3-hr ^{87}Kr, 2.8-hr ^{88}Kr, 9.2-hr ^{175}Xe, and 17-min ^{178}Xe (from Ref. 15).
§ Calculated from average of releases during 1969 as reported in Ref. 14; yearly totals estimated for those plants with less than 9 months of full-power availability.

dose and not the concentration per se. However, the Table 3 comparison remains valid insofar as the dose is closely related to the ambient radioactive gas concentration at and beyond most plant-site boundaries. One way of interpreting the generally smaller dilution volume of nuclear reactor plants is to say that, on the average, they release lower average concentrations of deleterious agents relative to accepted protection standards than do fossil-fueled plants.

The air pollutants from fossil-fueled plants are perhaps reason for greater concern when seen in the context of the total emission from all conventional air-pollution sources, as tabulated below:[13]

Total	~125×10^6 tons
Source or pollutant	
Carbon monoxide	65×10^6 tons
Sulfur oxides	23×10^6 tons
Hydrocarbons	15×10^6 tons
Nitrogen oxides	8×10^6 tons
Particulates	1.2×10^6 tons
Electricity generation	12.5% of total, including most of the sulfur oxide emission

A National Research Council committee on pollution has calculated that the total cost attributable to these air pollutants is $13,000,000,000, or $65 per capita.[17] Starr has calculated that these air pollutants result in about 20,000 deaths per year.[6]

As shown in Tables 3 and 4, the principal air effluents from nuclear reactors, in particular the boiling-water (BWR) type, are the fission-product noble gases, xenon and krypton. Although they are not retained in the body, the short-lived nuclides of these gases are of concern insofar as they may contribute to a noncumulative increase in the external radiation background in the local vicinity while a reactor emitting them is in operation. The increases in background attributable to these gases in the vicinity of power reactors have been in general too small to be measurable. Although the increases in external radiation levels in the vicinity of BNL during the years in which the air-cooled Brookhaven Graphite Research Reactor (BGRR) was in operation were well within radiation standards, they were large enough to have

Table 4 Volume of Air Required To Meet Concentration Standards for Yearly Emission from a 1000-MW(e) Plant

Type of plant	Pollutant	Standard*	Discharge quantity*	Dilution volume required to meet standard, 10^9 m^3
Coal†	Sulfur dioxide	0.1 ppM‡	306×10^6 lb	531,000
		0.025 ppM§		2,120,000
	Fly ash (97.5% removal)			
	^{226}Ra	0.1 pCi/m^3	0.0172 Ci	172
	^{228}Ra	0.3 pCi/m^3	0.0108 Ci	36
Oil†	Sulfur dioxide	0.1 ppM‡	116×10^6 lb	202,000
		0.025 ppM§		810,000
	Nitrogen dioxide	2 ppM	48×10^6 lb	5,770
	Fly ash (97.5% removal)			
	^{226}Ra	0.1 pCi/m^3	0.0015 Ci	1.5
	^{228}Ra	0.3 pCi/m^3	0.0035 Ci	1.2
Gas†	Sulfur dioxide	0.1 ppM‡	0.03×10^6 lb	45
		0.025 ppM§		180
	Nitrogen dioxide	2 ppM	27×10^6 lb	3,220
Nuclear¶	$^{85}Kr + ^{133}Xe$	300,000 pCi/m^3	PWR, 600 Ci	2.0
	Short-lived noble gases + $^{85}Kr + ^{133}Xe$	330,000 pCi/m^3	BWR, 1,110,000 Ci	3,360
	^{131}I	100 pCi/m^3 for inhalation	PWR, 0	0
			BWR, 0.85 Ci	8.5
		0.2 pCi/m^3 for air, grass, and milk	PWR, 0	0
			BWR, 0.85 Ci	4,250

*1 ppM = 1 part per million = 1/1,000,000.
1 pCi = 2.2 radioactive events per minute.
1 Ci = 2,200,000,000,000 radioactive events per minute.
†Calculations based on Ref. 13.
‡1-hr exposure.
§Long-term average exposure.
¶Calculated from average of releases during 1969 as reported in Ref. 14; yearly totals estimated for those plants with less than 9 months of full-power availability.

been measurable and are therefore useful as a basis from which to estimate the upper limits that may be anticipated from operation of the large nuclear power reactors now coming on line. Since the air used to cool the BGRR was briefly subjected to the neutron flux in the reactor, some of its constituent elements were activated, with the principal product being ^{41}Ar (which has a half-life of 110 min). Its yearly emission rate[18] was about 4,350,000 Ci. This rate was comparable to the release of about twice as many curies of fission-product noble gases since the latter have a lower effective radioactive energy (about one-half that of ^{41}Ar).

To date the radioactive gaseous releases from power reactors have been much smaller than those from the BGRR. In 1969 the largest reported release was 800,000 Ci (4,000 Ci/MW) from the Dresden Nuclear Power Station.[14] This was comparable on an energy basis to about one-tenth of the annual release rate of ^{41}Ar from the BGRR. Other reported releases from BWRs during 1969 were Humboldt Bay Power Plant, 490,000 Ci (7,150 Ci/MW); Big Rock Point

Nuclear Plant, 200,000 Ci (2,850 Ci/MW); Oyster Creek Nuclear Power Plant, 7000 Ci (130 Ci/MW*); La Crosse Boiling Water Reactor, 480 Ci (9.6 Ci/MW); and Nine Mile Point Nuclear Station, 55 Ci (4.6 Ci/MW*). The release rates from BWRs with a brief history are much less than those from older plants such as Humboldt Bay and Big Rock Point. The releases from the latter were indicated by Blomeke and Harrington[19] to have been abnormally high owing to the presence of defective stainless-steel-clad fuel elements in their cores. During 1969 the average gaseous radioactive release from pressurized-water reactors (PWRs) was 175 Ci (0.6 Ci/MW).

The increases in ambient gamma radiation when the BGRR was operated at 20 MW are shown in Fig. 1. At the distance to the BNL perimeter, about 1 mile, the average level was 0.055 rem/year. This was equal to about 50% of the measured natural background and was one-tenth of the applicable AEC radiation protection standard for individuals in the general population. At a distance of 2 miles the increase averaged 0.018 rem/year; at 3 miles, 0.007 rem/year.

If the average 1969 release rate of noble gases from BWRs is accepted as typical, an estimated yearly release of 1,110,000 Ci of fission gases would be contained in the air effluent from a 1000-MW(e) BWR. If we assume that conditions of stack height, prevailing winds, and terrain are similar to those which prevailed at the well-ventilated BGRR site, increases in background about one-seventh of those observed at BNL would be anticipated in the vicinity of this plant.

The 2.5 Ci/year of ^{131}I released from the stack during operation of the BGRR may be compared with an estimated 0.85 Ci/year from a 1000-MW(e) plant. The latter was calculated from the average of reported releases for 1969 adjusted for power level.[14] The average ground-level concentration of iodine 1 mile from the BGRR stack was about 0.005 pCi/m^3, or 1/20,000 of the applicable radiation protection standard. Comparable or lower concentrations may be anticipated in the vicinity of power reactors. At no time has ^{131}I or any of the particulate radionuclides released from the BGRR stack in somewhat smaller concentrations been present in detectable concentrations in vegetation or milk collected from nearby dairy farms (between 3 and 5 miles from the stack). There has also been no measurable long-term increase in external background radiation levels over those

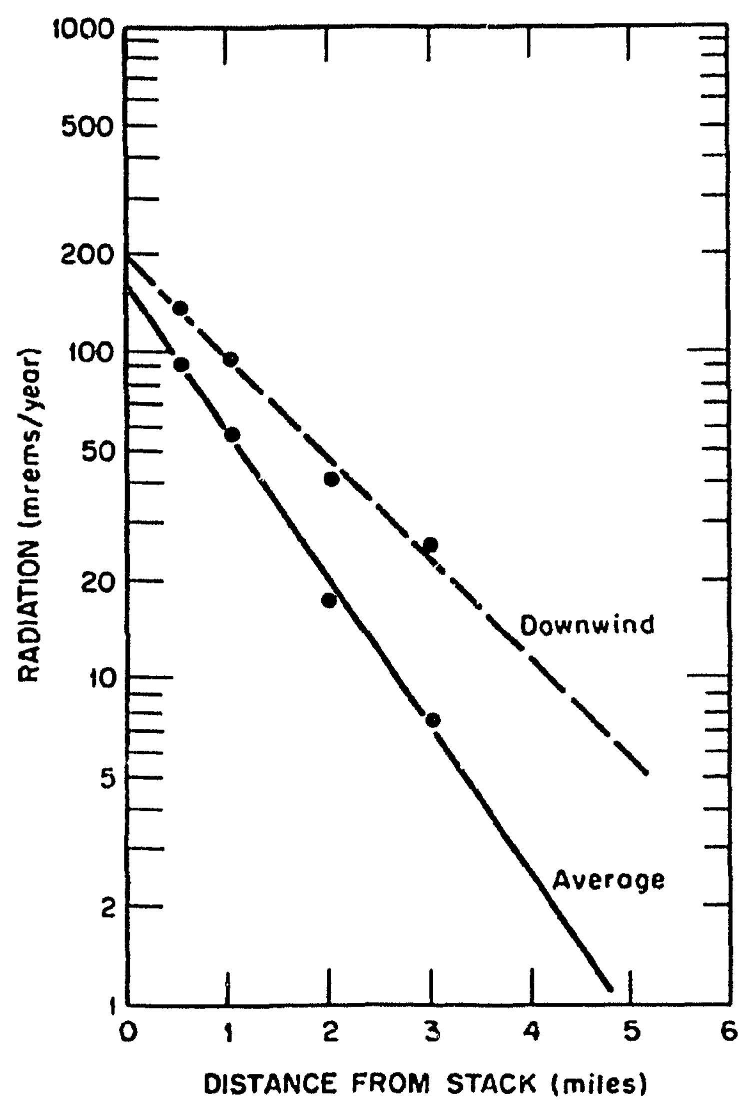

Fig. 1 Downwind and average gamma radiation in the vicinity of the BGRR when operated at 20 MW.

measured prior to the startup at the BGRR, which suggests that the accumulated deposition of long-lived stack effluent nuclides has been negligible. As also indicated by a recent U. S. Public Health Service survey around the Dresden plant,[20] no measurable deposition of long-lived nuclides would be anticipated in the vicinity of power reactors.

Principally in connection with releases from fuel-reprocessing facilities, concern has been expressed about the worldwide buildup of ^{85}Kr (which has a half-life of 10.4 years) and of tritium (which has a half-life of 12.3 years). Projections made by Cowser, Boegley, and Jacobs[21] of the worldwide accumulations of these nuclides through the year 2000 and of the accompanying increases in dose rates are shown in Table 5. The data for ^{85}Kr were derived from its radiation protection standard and were based on a calculated external dose of 500 mrems/year to the skin of an individual submerged in a semi-infinite cloud of this gas. Dunster recently pointed out that this standard is overly conservative since the accompanying

*Estimated from release data for a partial year of operation.

Table 5 Calculated ^{85}Kr and Tritium Production and Dose Rates*

Year	Accumulated ^{85}Kr, 10^6 Ci	Sea-level body-surface dose rate, mrem/year	Accumulated tritium, 10^6 Ci	Body-tissue dose rate, mrem/year
1970	13	0.008	0.32	0.000008
1980	210	0.13	6.3	0.00015
1990	1100	0.65	32	0.00071
2000	3150	1.8	96	0.0021

*From Ref. 21.

genetic dose for a given concentration of ^{85}Kr would be only 1% of the external skin dose.[22]

Conventional power plants apparently have not contributed materially to the pollution of many of the rivers and lakes in the United States. There is no reason to suppose that nuclear plants will differ in this regard. The amounts of activity release that may be anticipated from a 1000-MW(e) PWR and from a BWR of similar capacity are shown in Table 6. These values are based on the average of the amounts of radioactive mixed fission and corrosion products and of tritium reported to have been released to liquid wastes from power reactors during 1969 (Ref. 14). In general, the amounts of tritium released from PWRs exceed those released from BWRs. The amounts of water required to dilute this released radioactivity to radiation protection standards appear to be small, when compared with the flow of a major river (such as the Hudson, 2.92×10^{12} gal/year) or to the volume of the large bodies of water (such as Long Island Sound, 16×10^{12} gal inventory and 5.5×10^{12} gal yearly inflow) that are suitable for power-reactor siting. The calculations for Long Island Sound suggest that the released amounts may also be small compared with the amounts of natural long-lived activity already present in many rivers, lakes, and bays receiving reactor effluents. The amount of tritium released, in the order of 10^2 Ci/year from a 1000-MW(e) BWR, and 10^4 Ci/year from a

Table 6 Calculated Radioactivity in Liquid Effluents from 1000-MW(e) Power Reactors

	Type of activity	
	Mixed fission and corrosion products	Tritium
PWR		
Amount of activity in effluent, Ci	26.5	7.7×10^3
Volume of water required to dilute to radiation standard,* gal	70×10^9	675×10^6
BWR		
Amount of activity in effluent, Ci	27.5	50
Volume of water required to dilute to radiation standard,* gal	72.5×10^9	4.5×10^6
Long Island Sound natural background radioactivity, Ci		
Inventory	600†	3×10^4‡
Yearly inflow	105†	1×10^4‡

*Applicable radiation protection standard = 1×10^{-7} μCi/ml; does not require analysis for individual nuclides.

†Calculated from measured gross beta concentrations, which are assumed to reflect those of ^{40}K but not those of tritium.

‡Calculated; based on one-seventieth of tritium concentration of 500 pCi/liter, as reported by Wrenn.[23]

1000-MW(e) PWR, should be viewed in the context of a reported cosmic-ray production of 4,000,000 to 8,000,000 Ci/year.[24]

The low-level radioactive liquid-waste experience at BNL is not directly relevant to that of a power reactor situated on a large body of water, since the Laboratory is located on the headwaters of the Peconic River, the flow of which is small by comparison with the volume of water required for cooling by a power reactor. However, the release and nearby downstream concentrations of the BNL liquid effluents as shown in Fig. 2, have been comparable to those from power reactors. At the point of release the effluent has been found[25] to contain about 50% ^{137}Cs, 10% ^{90}Sr, and about 10% ^{60}Co. There has been, if anything, a greater opportunity for reconcentration of these nuclides in the locally limited aquatic environment than would usually be the case. As shown in Fig. 3, in the routine downstream surveillance on the Peconic, small amounts of some of the longer lived radionuclides, such as ^{60}Co and ^{137}Cs, known to be present in the BNL effluent, have also been found in plants. Similar concentrations have been found[25] in fish, turtles, and other biota obtained within a few miles below the site boundary. Calculations based on the most generous assumptions about dietary habits suggest that even the most avid angler or watercress fancier could not have ingested more than

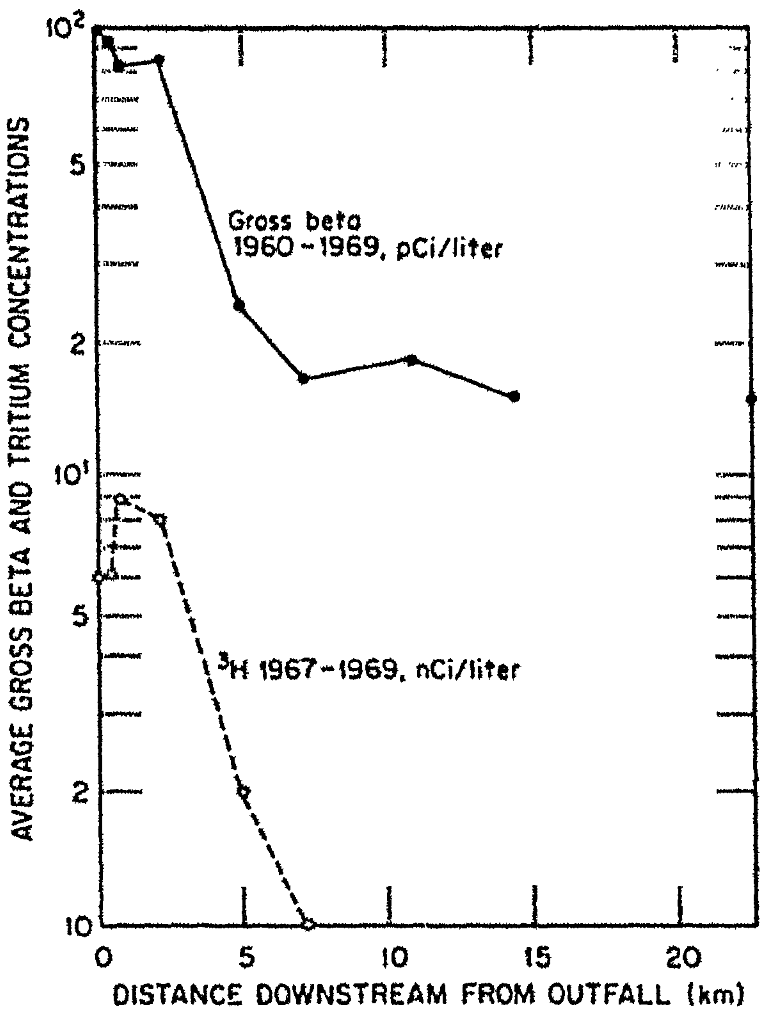

Fig. 2 Average gross beta and ^3H concentrations in Peconic River monthly samples.

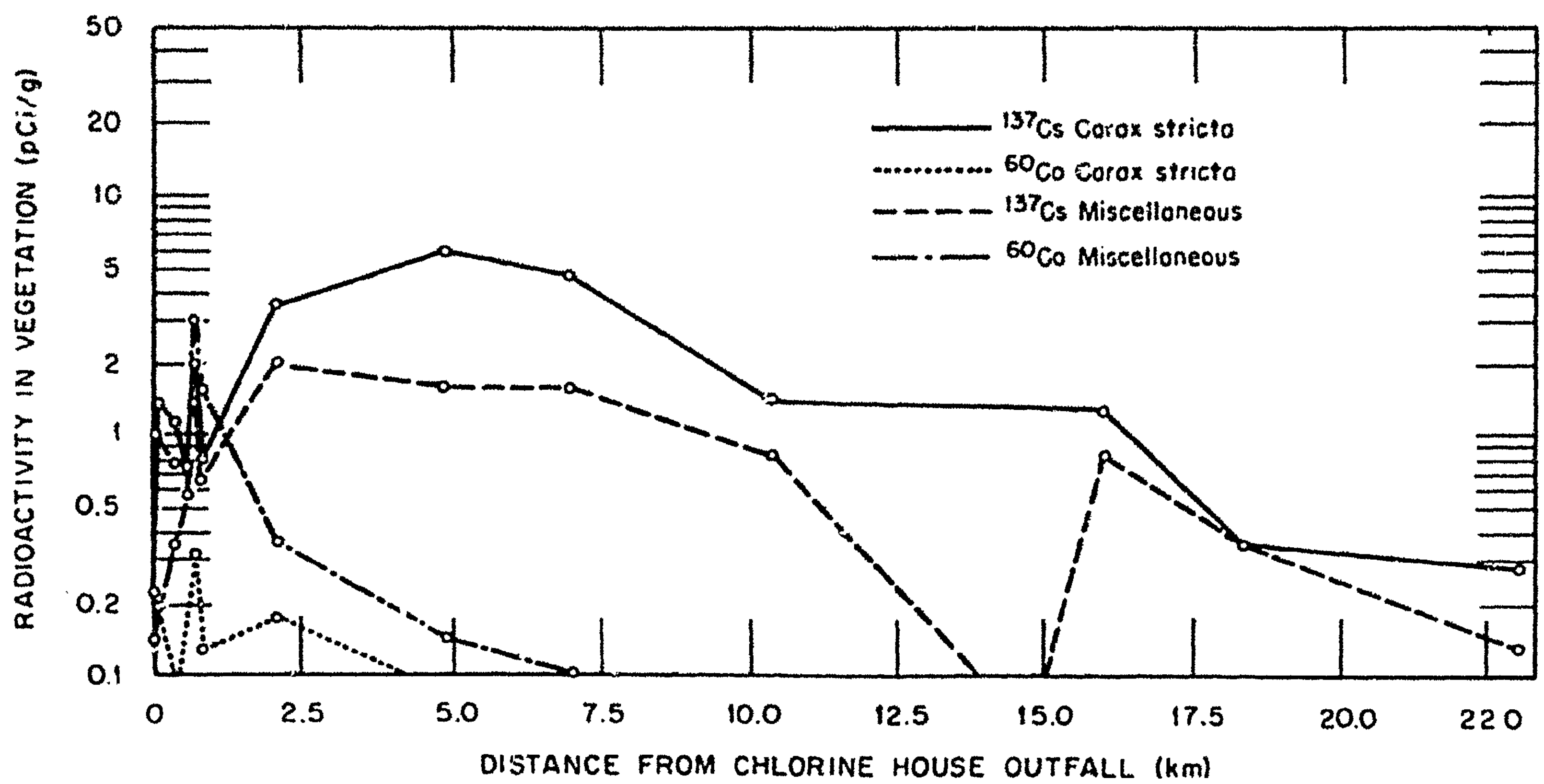

Fig. 3 Radioactivity in Peconic River vegetation in 1969.

25% of the allowable daily intake of these nuclides derived from their radiation protection standards. More reasonable assumptions suggest that the amounts of nuclides actually consumed have been less than 1% of those allowable.

The operating experiences at six power reactors with regard to both gaseous- and liquid-waste discharges were reviewed in 1968 by Blomeke and Harrington.[19] Their study indicated that power-reactor liquid effluents are generally being controlled at a small percentage of release limits, which are based on the radiation protection standard in the receiving body of water. The BNL experience suggests that the accumulation of radioactivity in the aquatic environments of power reactors would be radiologically insignificant. The nuclide of greatest interest, in terms of the anticipated discharge quantities, appears to be tritium. Calculations by way of example can show that, if ten 1000-MW(e) PWRs each discharged 3000 Ci/year of tritium to Long Island Sound, a person obtaining his entire food supply from aquatic animals and plants from the sound would receive a dose increment of 0.07 mrem/year.

RISK ESTIMATES

Some quantitative estimates of these and other risks in terms of the probability of fatal injury or effect per year to an exposed individual are shown in Table 7. The value for 1 mrem/year of radiation was inferred from data published by the International Commission on Radiological Protection (ICRP) that are based on the conservative assumption that effects observed at high dose (in the order of 100 rems) are linear with decreasing dose and dose rate.[26,27] The other estimates are based on Starr's calculations from observed mortality data.[16,28] The risk from the highest radiation levels of a few millirems per year to an individual living adjacent to the boundary of a nuclear reactor site seems trivial in comparison with the many other risks seldom taken into consideration by the populace.

Design options are now available that could reduce the amounts of radioactivity per megawatt of capacity in the effluents of future BWRs and PWRs by one or two orders of magnitude below those now prevailing and used for the comparisons made herein. In view of the already minimal risk connected with the routine release of effluents from plants of current design operated with current practices, significant expenditures or reductions in power-plant reliability to reduce these releases seem difficult to justify. The clamor from political quarters for more restrictive limits on reactor effluents seems especially ironic when the attendant risks are compared with those from firearms and when the difficulties of passage of gun-control legislation are considered.

Table 7 Annual Probability of Fatal Injury from Radiation and Other Causes

	Individual probability of fatal injury or effect per year of exposure	Refs.
Radiation at 1 mrem/year*	1×10^{-7}	26, 27
Natural disasters	2×10^{-6}	28
Fossil-fueled power plants	4×10^{-6}	28
Electricity	2×10^{-5}	28
Firearms	2×10^{-5}	28
Air pollution†	1×10^{-4}	6
Smoking‡	5×10^{-4}	28
Automobiles	1×10^{-2}	28
All diseases	1×10^{-2}	28

*Estimated from ICRP data, which are based on the conservative assumption that effects observed at higher levels (100 rems) are linear with decreasing dose and dose rate.

†Based on entire population exposed 100% of the time.

‡Based on smoking at a continuous rate.

THERMAL EFFECTS

Although it has come to public attention in connection with the releases of steam-condenser cooling water from nuclear power stations, the so-called thermal pollution is neither new nor unique to nuclear facilities. It has to do more with the growth in numbers and size of steam-turbine generating plants because most suitable hydroelectric sites have already been used. Unfortunately, owing to the inherent nature of the steam cycle, neither fossil- nor nuclear-fueled steam plants use anywhere near all the heat energy released by their fuel to produce electricity, and the unutilized heat is discharged to the environment. The average thermal efficiency is about 33% for fossil-fueled plants,[29] and the ceiling for thermal efficiency is about 40% for a modern fossil-fueled plant. The current light-water-moderated reactor plants are reported to operate at about 32% thermal efficiency.[30] Since essentially none of its heat goes up a stack, this means that a nuclear plant may reject up to 60% more to its steam-condenser cooling water than a modern fossil-fueled station. However, the next generation of nuclear power reactors promises to reach an efficiency of 40% or better.

If there is minimal mixing of the heated-discharge plume, most of the heat released in condenser cooling water is lost to the atmosphere by evaporation within a relatively small zone near each plant. In a recent review of thermal effects, Jaske[31] indicated that impact areas (within which the temperature change is measurable, about 0.75°F minimum increase) of from 2500 acres (~4 square miles) to 3500 acres (~5.5 square miles) should be considered for a nuclear plant. By way of example, the total surface area of Long Island Sound is 939 square miles. If their local thermal effects can be kept within acceptable limits, there should be room for a number of power plants on the Sound and other similarly large bodies of water before alternates for the waste-heat release, such as holding reservoirs or evaporation cooling towers, have to be considered.

SUMMARY

From the evidence to date, the hazard potential of nuclear plants has been greatly overexaggerated by adversaries of such plants. The risks that do exist have been guarded against to a degree that is unparallelled. With regard to routine effluents, nuclear plants produce less air pollution, relative to applicable standards, than do their fossil-fueled cousins. The concentrations of radioactivity in the liquid effluents from nuclear reactor plants are controllable at levels well below radiation protection standards and pose little threat to the environment. Contemporary nuclear plants are somewhat less thermally efficient than modern fossil-fueled plants (although *more* efficient than the average fossil-fueled plant), but the immediate waste-heat problem would seem to be manageable without causing serious environmental problems in large bodies of water. The next generation of nuclear plants, now being designed and tested, promises to be at least as efficient as the best fossil-fueled plants. The AEC and others responsible for the utilization of nuclear plants have been proceeding in a manner that has the public safety and welfare as prime considerations. To date, despite many recent allegations, there is little hard evidence on which to question the judgments of such parties.

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NUCLEAR POWER IN PERSPECTIVE: THE PLIGHT OF THE BENIGN GIANT

By D. N. Hess

[*Nucl. Safety*, 12(4): 283–290 (July–August 1971)]

Abstract: *Premised on the assumption that the public press is both a molder of opinion and a reflector of public interest and critique, nearly 800 items in the daily and periodical press pertaining to the nuclear industry and covering a period of about 1 year were examined for their philosophical and psychological impact on the reader. Accordingly this survey is a retrospective assessment in order of priority of the principal controversial issues confronting the nuclear community. The hope is that, from this work, nuclear advocates and allied interests may find a firmer sense of direction and significant areas where special attention can be most profitably devoted to afford the public the reassurances it needs to feel at ease in the presence of the* energy giant.

Today our country faces an imminent electric-power crisis, and nuclear energy stands ready to accept the challenge. The projected needs for electricity within the next few decades are enormous, and, at this moment in time, nuclear power has the opportunity to fulfill its destiny by being the source of this power for which it is so eminently suited and capable.

Until the late 1960s, nuclear power reactors had been installed and operated with relatively few plaudits or complaints. Considering the successes this energy giant had achieved without encountering any major disquieting reactions from the public, the nuclear industry had little reason to anticipate any opposition. Thus it was that electric-utility companies blithely contemplated utilizing this new technology to meet the energy requirements it foresaw and announced the construction of numerous large nuclear power stations around the country. Suddenly, outcries and rebuffs beset the industry, and its optimism was replaced by bewilderment and chagrin. On the one hand, the utilities offer unlimited nuclear power to the people as the panacea for their future problems concerning well-being, comfort, and economic growth. On the other, voices were raised against the nuclear community which accused it of hidden motives and an assortment of hypothetical ills. The numerous questions posed asked how the installation and utilization of this vast resource will affect our institutions, our society, our health, our environment, and our very destiny and ultimate human existence. These questions have such profound, all-encompassing implications that the nuclear community has been sorely tried to respond. In being challenged on so many fronts, it is faced with the quandary of what issues are most in need of attention and rebuttal.

This attack and rash of denunciations came, not much more than 2 years ago, with considerable unexpectedness. One may aptly wonder at this precipitate concern over the atomic giant, but a probable explanation may have recent origins. Emotions today are apparently most stirred over the concept of *pollution of the environment.* This may be the root of much of the confusion and distrust of the atom and its promises of a viable future. This may have been the wellspring from which all the other quarrels with the industry derived. Many sensitive persons are genuinely concerned with the fate of our planet. Their concern for it and what their offspring will inherit has, no doubt, caused them to feel revulsion for the destruction that man has inflicted upon it, and they feel a compelling desire to thwart any further indignities that would jeopardize conditions on earth even more than they are jeopardized today.

Such concerned people are certainly deserving of admiration and attention. Some people have self-serving interests, many have economic interests, and some are completely disinterested. None can be discounted, but it is to the truly concerned individual that so much is owed in the form of tangible reassurances. Thus it is necessary to learn what problems to them are most worrisome. Even the severest critics of nuclear power submit that the world is facing crisis and find some good in nuclear power, with reservations. It is the side effects of nuclear power and the urgent immediacy of its implementation that apparently are the controversial aspects. On the other hand, the nuclear community concedes that the criticism leveled at it is a healthy thing since it points up the areas where corrective actions might be applied or scientific principles invoked to correct any alleged deficiencies. Then through a declaration of sound assurances, the real or conjectured fear can be allayed or set to rest.

EVALUATION OF THE NEWS MEDIA

What follows is an attempt to provide to the nuclear community and nuclear proponents a weathervane that will indicate the directions of public acceptance and apprehension on nuclear matters. The indicator chosen was the published news. To learn and assess just how well or how badly nuclear power has fared with the public, a meaningful concept of the status of the industry should be attainable by evaluating the situation as seen by the journalist. Thus the frequency with which a given nuclear topic was reported in the press was considered to be indicative of the relative importance of each topic to the public (or, at least, what newsmen believe to be important). Furthermore, the ratio of adverse articles to the total pro-and-con articles was taken as a measure of the magnitude (seriousness) of concern over the issues by "opinionated" people. In other words, this approach takes into account not simply the numerical *popularity* of a subject in the strict sense of the word but also articles that tend to lead the reader to some definite conclusions or convictions on these nuclear-associated topics. These were the two sets of data derived as a basis for recognition of priorities.

Seven hundred and sixty-two articles in newspapers, popular periodicals, and semitechnical magazines published within the past year were surveyed. The articles varied broadly in scope, and the review encompassed sources such as the following: news accounts of speeches by nuclear proponents (AEC Commissioners, utilities' spokesmen, academicians, legislators, and laymen) and of its opponents (conservationists, protest organizations, etc.); general discussions of their contentions; editorials; letters to the editor; and reviews of a particular reactor, or reactors, or the nuclear industry in general. As an integral part of this examination, general-interest articles were also included, e.g., discussions of power brownouts, economics of nuclear power plants, uses of isotopes in industry, warm-water irrigation, and the implications of thermal and radioactive effluents. No articles devoted to "Plowshare" and its adverse or beneficial characteristics were considered, even though nuclear opponents frequently use this project to dramatize the dangers of nuclide release to the environment. Similarly, articles concerned with weapons testing (Alaska and Nevada) or weapons production (Rocky Flats) projects were eliminated, in spite of their popularity with the critics as demonstrations of the "reckless abuses" associated with the atomic energy program. On the other hand, articles devoted to the pros and cons of nuclide waste disposal (e.g., Snake River aquifer) were considered valid, since waste management is an inevitable ramification of nuclear power.

The articles were assigned to a series of 12 categories, selected to reflect the many-faceted aspects of this complex arena, ranging from the real, technological implications to the hypothetical, philosophical idiosyncrasies:

1. Nuclides and wastes
2. Nuclear safety and reactor accidents
3. Insurance and subsidy
4. Safeguards
5. Thermal pollution
6. Siting
7. Environment
8. AEC regulation
9. Antitrust and monopoly
10. Legalistics, law, and legislation
11. Esthetics
12. General

THE SURVEY METHOD

In order to set up more or less well-established criteria on which to base the survey so that in the course of evaluation there would be little likelihood of deviating from the norm, a system of ground rules was established and the category subjects were defined.

Ground Rules

1. An article could be assigned to one or more categories. At extremes, a lengthy review article on thermal pollution would be weighted only once, whereas a simple news release reporting on some organization protesting the placing of power reactors along the shores of a body of water and asserting their potential for thermally and radioactively polluting the water would be listed under three of the categories.

2. Each article was evaluated and assigned an *A* (against), *N* (neutral), or *F* (for) rating according to how the article treated the growing use of nuclear energy for the generation of electricity or other beneficial uses. Generalized descriptions of these assignments are given below:

A. An article reporting the remarks of a nuclear-industry critic or one emphasizing some adverse aspect(s) of nuclear power reactors.

N. An article presenting both sides of some controversial issue associated with the technology. The opposing theses of academicians on the effects of thermal effluents from electric-power plants on the fishes in a body of water are an example.

F. An article setting forth the position of an industry proponent or one giving impetus to the promises, prospects, and benefits of the technology and its innovations.

3. Articles in periodical literature were to be reviewed. Articles in *Newsweek, Fortune, Look, Popular Science, Business Week, Natural History, National Parks Magazine, Scientific American,* and news items in *Construction Digest, Power News, Industrial Research, Electrical World, Product Engineering, Scientist and Citizen,* and *Chemical and Engineering News* are examples of the scope of sources in this area. Such articles are representative of in-depth appraisals, as contrasted to news items, but articles in these media are quite infrequent compared with newspaper items and hence comprised probably only about 5% of the total bulk of the data. Newspaper articles comprised the remaining 95% of the source material. Obviously they were the most abundantly available. Moreover, they were considered to be the most significant criterion of public opinion and reaction to a nuclear-oriented society.

4. Numerous nuclear-oriented publications, technical and otherwise, are supported, subsidized, or simply partial to the nuclear industry. Accordingly, none of these were included in the survey—nor were any official AEC press releases.

Categories

Most of the subject titles are self-explanatory. Thus the obvious will not be covered in the following definitions. Rather, examples are cited that are indicative of the more anomalous situations.

1. *Nuclides and Wastes.* A mayor volunteers to provide an area in or near his community for the establishment of a nuclear-waste burial ground. The issue here is not siting (see below); rather the mayor and his citizenry are showing their disdain for those people who express fear over the presence of nuclides.

2. *Nuclear Safety and Reactor Accidents.* When the statistical likelihood of an actual nuclear accident is given and compared with the chances of other catastrophes, even though stated to be one in one billion per reactor, the critics claim that *one* such accident can happen at any time and that the consequences could be incalculable. Other examples might be the possibility of an accident during radioactive-waste transportation; the locating of a power reactor next to a strategic missile base; and the concern over what precautions are in effect to prevent disaster from sabotage, civil disobedience, maniacal action, or falling aircraft.

3. *Insurance and Subsidy.* Insurance is best illustrated by the contention of nuclear opponents that nuclear power would be economically infeasible for the utilities if it were not for the Price-Anderson Act that provides for partial federal risk assumption. Subsidy would be exemplified by the setting up of a state-supported agency to encourage the progressive development of nuclear technology through tax incentives and the selling, distribution, and control of nuclear fuel elements or the fuel itself.

4. *Safeguards.* The subjects in the *safeguards* category include such topics as the potential for diverting fissile substances into the manufacture of weapons (i.e., nuclear blackmail), the maintenance of correct inventory accounts, and the possible actions of organized crime (i.e., hijacking) due to the high value of the fissile materials.

5. *Thermal Pollution.* Articles devoted to the consequences of utilizing cooling towers in association with a nuclear power plant (e.g., their effect on the weather in the locale) or the use of the thermal effluent to prevent frost damage or to provide warm-

water irrigation were included in the *thermal pollution* category. Another article described the predicted shortened lifetime of one of the Great Lakes if all the power reactors planned for it were installed.

6. *Siting.* An article describing the opposition to man-made islands on Long Island Sound for nuclear-power-plant siting was surveyed. Another survey item was a news account of a poll taken by a utility in which it asked the public whether they objected to having a power plant situated on some stream and, if so, would they be willing to relinquish the use of their air conditioners.

7. *Environment.* In instances where a concern for the *environment* was expressed, there was no alternative but to set up a category covering this broad scope. Moreover, sometimes the effects of nuclide releases and thermal pollution were questioned in the context of their total effect on an ecosystem (e.g., contamination and eutrophication of an estuary). Such an article was categorized under *thermal pollution* and *nuclides and wastes*, as well as *environment.*

8. *AEC Regulation.* The *regulation* category pertains especially to the arguments over the dual role—promotion and regulation—of the AEC in its nuclear activities. Articles describing the efforts of some of the individual states to regulate (nuclides, for example) within their borders—and the stance of their counterclaimants—are included under this category and also under the *legalistics, law, and legislation* category below.

9. *Antitrust and Monopoly.* The newest controversial issues are probably antitrust and monopoly. Antitrust is best illustrated by the petitions and lawsuits instituted by small investor-owned utilities that claim discrimination in being denied participation in the corporate public utility setup of a large nuclear power plant. Monopoly pertains especially to the concern of Congress that energy-resource consortiums may be acquiring extensive holdings on the natural-fuel resources of the country and, through the buying-into or building of their own processing, enrichment, and fabrication facilities, may thereby acquire cartel-like economic power over the country's energy-production resources.

10. *Legalistics, Law, and Legislation.* Articles dealing with questions such as the following would fall under this legal category. If the Illinois Sanitary Water Board grants a permit to a utility to discharge thermal waste into Lake Michigan in conformance with the state's standards, and the Department of Interior sets more stringent standards, who has the prerogative? If the Florida Air and Water Pollution Control Department rejects the siting of a power reactor on an island because it threatens the extinction of several aquatic species, the AEC issues a provisional construction permit for the reactor, and the legalities are being fought out on the basis of the new Environmental Protection Act, what are the legal precedents and how and where will the matter be settled?

11. *Esthetics.* Examples of esthetic considerations would be opposition to locating a nuclear power plant (see *siting*) in the neighborhood of a historical structure or a national monument; or the objectionable nature of the power-generating facilities as they may affect a scenic site (e.g., Big Sur or the coast of Maine). Articles contrasting the architecture of a nuclear power plant with that of a fossil-fueled plant and its associated facilities would be pertinent to this category.

12. *General.* In this catchall category are lumped broad generalized statements and descriptions of power reactors, uses of isotopes, discussions of nuclear technology, etc. Frequently, the articles are abstract in their treatment and are devoted to the philosophical implications of a nuclear economy. The complex diversity of material categorized hereunder is exemplified by articles devoted to topics such as the impact of a nuclear installation (a fuel-fabrication plant or power plant) on the economy of a geographical area, the estimate of extra costs in mills per kilowatt-hour to the consumer for environmental-protection measures, the increase in cost of merchandising bonds that caused a utility to defer plans to build a nuclear power plant, the extrapolated reasoning that people resorted to when they voted to reject a power reactor, and the contentions of critics that the utilities use threats of brownouts as a form of "blackmail."

With these definitions of ground rules and categories, it is now no doubt apparent that the decisions were relatively arbitrary and individualistic. Nevertheless, it is the author's feeling that, in spite of shortcomings and unintentional prejudices, what follows provides some insight into the major areas of concern associated with nuclear energy.

SURVEY RESULTS

Each article was read and given one or more appropriate category assignments. Then I endeavored to envision the reader's probable reaction to the topic being reported and assigned an *A*, *N*, or *F* under the appropriate category(ies). It was this latter judgment that most often presented problems because of its inherent subjectivity. Category assignments, except in the general category, were not so difficult because the articles were most frequently unambiguous.

One Approach—The "Popularity Poll." The results were totaled and are presented in Table 1, where the categories are arranged in order of most entries.

Table 1 Articles Devoted to Subject Categories Associated with Nuclear Technology and an Evaluation of the Expressed Attitude or Inferred Impact on Public Opinion

Category	Evaluation			
	Against	Neutral	For	Total
Nuclides and wastes	142	98	71	311
Thermal pollution	95	68	66	229
Environment	66	72	68	206
Siting	82	63	38	183
Nuclear safety and reactor accidents	55	31	26	112
Legalistics, law, and legislation	63	27	7	97
AEC regulation	32	9	8	49
Insurance and subsidy	24	4	2	30
Esthetics	6	6	10	22
Antitrust and monopoly	13	5	1	19
Safeguards	5	3	0	8
Subtotal	583	386	297	1266
General	93	106	228	427
Grand Total	676	492	525	1693

The order indicates the subjects written about most frequently and what the news media consider the public is most interested in or concerned with. Of course, the *general* category has the most entries; but this is separated from the rest of the table, because it is obviously not amenable to consideration in the same light as the other topics. Based on the *grand total* of all category assignments (1693) and the total of all the articles (762), an average of slightly more than two topics (2.2, to be exact) was discussed per article. From the *subtotal* data it is readily apparent that articles devoted to the subject categories are predominantly critical; the opposite is true when nuclear energy is reported in *general*, with favorable articles being dominant. Nevertheless, it is noteworthy that a comparison of *neutral* articles in the subject categories and in the *general* category shows reasonable agreement: 30% (386/1266) vs. 25% (106/427).

A Second Approach—Poll of the "Opinionated." A second approach is to consider the data from the standpoint of individuals with formalized opinions or those writers who take a definitive stand on a category. Thus, if the number of articles expressing adverse opinions of these nuclear-technology-associated categories are divided by the total of articles, both for and against, the values obtained should give a relative indication as to what concerns these writers most. Data of this type are given in Table 2.

Table 2 An Assessment of Relative Antipathy Toward Controversial Problems Associated with Nuclear Technology

Category	Biased articles			Relative antipathy quotients			Derogatory disposition ratio, Against : For
				$A/A+F$	Uncertainty* (%)		
	Against	For	Total	(%)	Σ	Δ	
Safeguards	5	0	5	100	48–100	52	
Antitrust and monopoly	13	1	14	93	66–100	34	13 : 1
Insurance and subsidy	24	2	26	92	75–99	24	12 : 1
Legalistics, law, and legislation	63	7	70	90	80–96	16	9 : 1
AEC regulation	32	8	40	80	64–91	27	4 : 1
Siting	82	38	120	68	58–76	18	2.2 : 1
Nuclear safety and reactor accidents	55	26	81	68	56–78	22	2.1 : 1
Nuclides and wastes	142	71	213	67	61–73	12	2.1 : 1
Thermal pollution	95	66	161	59	50–67	17	1.4 : 1
Environment	66	68	134	49	41–59	18	1.1 : 1
Esthetics	6	10	16	38	15–65	50	0.6 : 1
General	93	228	321	29	25–36	11	0.4 : 1

*From A. Hald, *Statistical Tables and Formulas, Two-Sided 95% Confidence Limits for the Probability θ of a Binomial Distribution*, p. 66, John Wiley & Sons, Inc., New York; courtesy of Forest L. Miller, Statistics Department, Mathematics Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

The numbers resulting from the manipulation were termed "relative antipathy quotients." Another treatment of the data might be interpreted as showing how many adverse articles were written for every one that was complimentary. These are called "derogatory disposition ratios."

Table 2 shows that in some instances the statistics are extremely poor in that some of the controversial topics have not been written about to any great extent. Thus, in order not to attach too much significance to these poor data, another column shows the extent of this uncertainty. The data are plotted in Fig. 1, along with the uncertainties. At the bottom again is the *general* material, which must be discussed in a separate context as before.

AN ASSESSMENT OF THE QUANDARY

A "Popularity Poll" of the Categories (Table 1). What subjects are written about most frequently? The number of these should be indicative of those topics of most interest and concern to people. From the number of times (311) the subject of *nuclides and wastes* appeared, it is inferred that people want most to be informed on how their health, longevity, and progeny will be affected by the radioactive materials from a nuclear-power-oriented economy. It follows that the people's predilection for no change in their immediate environs (*thermal pollution* and *environment* categories) is the next most important issue, as is borne out by the order in the table.

That *siting* assumes only fourth order of significance might be attributed to "intellectual maturity" on the part of the press and the public. In other words, as a result of having become more conversant and articulate on atomic matters, more precise terminology is being invoked with words such as ecology, mutation, nuclides, biological concentration, and thermal effect. In this light it would no longer be expected that complaints would be on the general basis of siting, except where the term connotes its exact meaning. It is somewhat surprising to observe that *nuclear safety and reactor accidents* are not higher than fifth on the list. This too may be the result of maturity. It appears that

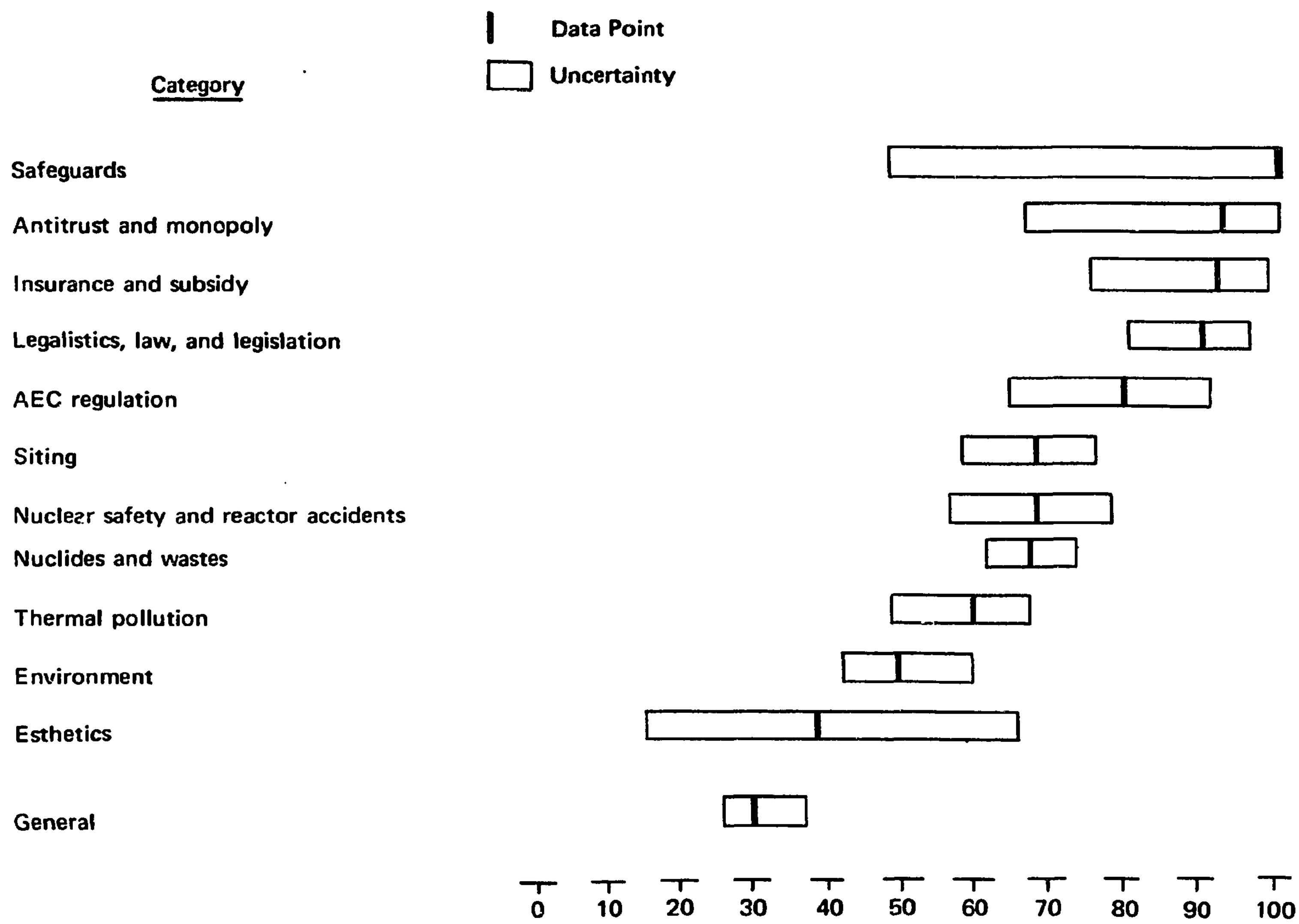

Fig. 1 Relative antipathy quotients from Table 2 and the 95% uncertainty limits associated with the data.

the public is sufficiently informed on nuclear power reactors to not be fearful of a disaster occurring during routine operation. In fact, it is my impression that possible actions of psychopaths or the accidental breaching of the reactor containment structure through "acts of God" are the most speculative qualms. *Legalistics, law, and legislation* (sixth place) pertain almost exclusively to the prerogatives of the states in regulating nuclear reactors and all their associated ramifications. The controversial dual role of the *Atomic Energy Commission* in regulation and promotion falls next in line (seventh) to the states' rights issue. That one more or less complements the other is a happy coincidence and can be regarded as corroboration of their respective priorities. The subject of the government providing an *insurance* subsidy (eighth) is not especially conspicuous in the news. Perhaps the people expect Congress or the states to settle this aspect in the courts; or, since subsidies are provided to so many vested interests, it may be that this assistance is not thought to be particularly unusual.

It should be noted that the critical articles far outweigh the favorable, by 583 to 297; however, this will be discussed in detail in the context of Table 2. Since the last three subject categories (*esthetics, antitrust and monopoly,* and *safeguards*) fall so low in the list, any attempt to associate their location with respect to the uppermost categories, with regard to priorities, would have little significance.

Finally, it may be seen from the number of articles in the *general* category that the press is not lax or remiss in giving publicity to nuclear technology.

Poll of the Opinionated (Table 2). The data given in Table 2 and plotted in Fig. 1 are the bases for the "Poll of the Opinionated." In some respects it is unfortunate that more adverse articles were not found for some of the categories, since the statistics leave much to be desired. Nevertheless, in conjunction with the numbers in Table 1, some inferences can be made. Although five articles written on the matter of *safeguards* indicated a need for dire concern (Table 2, 100%), the topic was broached only eight times in the course of 1693 entries (Table 1). So the most that can be said concerning this is that, at least for the moment, it is not a very topical subject, but when it *is* brought up, most of the authors find it an area where much needs to be done. From Table 2 and Fig. 1, the evidence indicates a marked difference in priorities from Table 1. Some of the data are relatively tenuous, but at least two categories are statistically well represented and hence have real significance. These are *legalistics, law, and legislation,* and *siting*. Concerning the former it is inferred that, among writers with a bias, 90% (80 to 96%) favor the position taken by the states. Is it because most of the reporters are hometown boys who are writing what their audience wants to read, or do they really want their state governments to take over the AEC's responsibilities? At least in looking at Table 2 under *AEC regulation*, the percentage drops to 80 and could be as low as 64, meaning that certain of the AEC regulatory prerogatives are not seen in quite so bad a light as Table 1 would indicate. Furthermore, the *AEC regulation* category also often included arguments against AEC regulatory activities.

In contrast to the situation in Table 1, where it placed fourth, *siting* and the environment are uppermost in people's minds (items 6 to 11, Table 2). To explain the new prominence attached to siting under this approach, it is essential to note that the articles are devoted to the debates over locating specific reactors at specific sites, such as Chesapeake Bay, Lake Cuyuga, Lake Michigan, or Eugene, Oreg., for example. In other words, these critiques comprise the bulk of the articles assigned to this category and accordingly resulted in this new significance being attached to the subject of *siting*.

It is interesting to note that in both lists of data, the *nuclear safety and reactor accidents* category follows (or is practically equal to) *siting*. Although this arrangement is retained in Table 2, both supersede the topmost issues in Table 1; i.e., *nuclides and wastes, thermal pollution,* and *environment,* which are in the same order in Table 2 as in Table 1, but they are lower in priority.

There also appears to be a high order of concern about *antitrust and monopoly, insurance and subsidy,* and *AEC regulation*. Even when the "uncertainty" in the numbers is taken into account (and the lowest "antipathy quotients" are assumed to apply), it may be seen that these three categories hold the seeds of more controversy than the categories relating to the environment and to people's health and welfare.

Finally, there are the categories with poor statistical quality. Considering this, not much can be said definitively, except that, of the few articles devoted to *safeguards*, all pointed up deficiencies in the present surveillance and control of fissile materials. With regard to *esthetics*, there is no particular controversy; only 38% of the articles was devoted to criticism, and this value is not far from the *average* of the "uncertainty," namely 40%.

The Lessons Learned

So where does this leave the *nuclear giant*? What have we learned to help in this enigmatic dilemma? It can almost be predicted that when a site for some power reactor is announced writers will focus on it. Some will tout the benefits to be derived from the facility, and others will deplore it and debate the hazards of living in the proximity thereof in the event of a nuclear calamity, since this is the most sensational aspect to attract public attention. Once the public is apprised of the situation, they will initiate questions concerning those subject areas that involve their well-being, with nuclear effluents, thermal pollution, and the effect of the reactor on their environs being considered, in this order. Accordingly it behooves the nuclear industry or utility to approach the public with these factors in mind. However, as the number of reactors grows, the subjects in the statistically poor categories that seem to be of low priority may assume increasing significance. To date they have been largely confined to Congress and the courts, and the press has duly reported on the proceedings. Thus, although the public may become accustomed to and feel more comfortable in the presence of the nuclear giant, the questions regarding these more "nebulous" political, socioeconomic considerations will persist.

At the present time the disputes over specific reactors are being publicized, with the remarks of the opposition being dominant. But much has already been done to provide the general public with representation and the opportunity to participate in planning and decision-making deliberations prior to application to the AEC for facility licensing. For instance, even before the National Environmental Policy Act of 1969 and the AEC's statement[1] of general licensing policy reflecting its obligations under the Act, some utilities were inviting the public to participate in the deliberations and decisions on site selection.[2] The AEC has conducted a number of public meetings[3] to encourage this philosophy of affording the public opportunity to speak out and to promote public understanding of the whole gamut of technical considerations and sociological implications. The Commission is, in addition, considering changes[4] in its procedural process to make knowledge of impending actions, by either it or an applicant, more quickly available and thus smooth the way for early public expression. In fact, the Commission acknowledges, and is encouraged, that certain public-representing bodies have been proposed to give the people an even stronger voice in governmental agency activities, since such a body could be instrumental in expediting a consensus of accord on nuclear matters.

The nuclear industry gives appearance of having learned its lessons well. Many utilities appear to have found a quite reasonable, proper route. They are conducting intelligent advertising campaigns and are establishing rapport with the universities and community civic organizations. They are presenting the public with brief, simple, basic scientific facts that bring the problematical subjects into perspective.

Of course, it would be too much to expect the pathway to total acceptance to be without obstacle. Some misunderstandings are going to persist in the minds of certain individuals. Nevertheless, as ever-mounting numbers of persons become better informed through surmounting the scientific language barrier, it can be anticipated that this majority will become more tractable and amenable to nuclear technology than one that is forced to accept predestined plants under threats of brownouts or blackouts.

CONCLUSION

I do not purport to have any new, striking panacea to offer the industry. I do, however, hope to have given some direction to the question of priorities. A good public-relations job before the fact on the priority issues indicated would seem to be a significant answer to the nuclear community's tribulations.

In this article much attention has been directed to the criticisms leveled at the industry. A look at the number of articles under the *general* category, however, shows matters in a quite favorable perspective. Of 427 articles, 228 were favorably disposed toward nuclear power, and when those *for* and *against* are compared, the ratio is 2.5 : 1. It appears that the trend is more and more in the direction of increasing desire by the electric-utility companies to get onto the nuclear bandwagon. Furthermore, the press implies that people are getting nervous over power outages.

Public action–reaction is a very evanescent thing. Because of the changing kaleidoscope of public opinion, the data submitted here can only be considered to be indicative of current mood. If the utility industry fails to fulfill its commitments for any one or a number of reasons, a subsequent poll might reveal an entirely different complexion and climate for acceptance. In general, the prospect for a nuclear power economy appears to be very good. Moreover, the news media have been, on the whole, reasonably objective, considering the coverage and tenor of neutral and *general* articles. Nevertheless, the unfortunate fact remains that the *against* articles, although perhaps not in the majority, get and retain the public's attention. Much added effort must therefore be expended, by the utility industry and others, to promote and develop full public understanding of these complex and sensitive issues.

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NUCLEAR LIABILITY INSURANCE — A BRIEF HISTORY REFLECTING THE SUCCESS OF NUCLEAR SAFETY

By Joseph Marrone

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Abstract: *Nuclear liability insurance has been made available to the nuclear industry by American insurers through pooling arrangements that distribute the risk among many participating insurers. The liability insurance afforded by the pools has thus far been the only means employed to satisfy the financial-protection requirements imposed by the AEC on some of its licensees. The extraordinary safety record of the nuclear industry is quite visible in the pools' liability-claims experience. The most significant fact issuing from 14 years of operation is that the nuclear liability pools have never received a claim for bodily injury or property damage caused during the operation of a licensed nuclear reactor—this includes all types of licensed reactors. Critics of nuclear safety have played a role in achieving this record.*

The liability-loss experience of the nuclear industry suggests that a positive image of safety in the nuclear industry could be projected by presenting it as an example, warranting emulation, of effective control of a relatively new and serious hazard. That over 1 million persons have been killed in conventional accidents in the United States in the 10-year period 1960 to 1969 strongly suggests that much could be learned from the nuclear safety program by those who are concerned about safety in the nonnuclear area.

The function of liability insurance is to transfer to another (normally, to an insurance company) the element of risk inherent in most of our activities due to possible legal responsibility for accidental bodily injury or property damage to others. As a result of our litigious times, liability insurance has become a ubiquitous commodity generally accepted as being essential to protect our assets from possible legal liability in the course of both business and nonbusiness activities. Nuclear liability insurance is available to the nuclear industry from the nuclear liability "pools" to serve this role.

NEED FOR POOLING ARRANGEMENTS

Although the Atomic Energy Law[1] of 1954 authorized the possession and use of substantial quantities of nuclear material for commercial development, meaningful progress was deterred by developers' apprehension of the unknown dimensions of potential third-party liability claims. The maximum worldwide liability-insurance capacity generally available in 1957 was about $25 million. The Brookhaven report[2] published in 1957 essayed to measure the third-party liability consequences theoretically possible as the result of a hypothetical power-reactor accident that was based on a highly pessimistic and unrealistic set of conditions. The conclusions in the report cite the possibility of incurring billions of dollars of legal liability for bodily-injury and property-damage claims caused by such an accident. The extreme improbability of a reactor accident occurring that would cause such awesome damages was acknowledged, but for corporate directors to proceed in reactor development and, by so doing, place their corporation's existence in jeopardy (in view of the limited liability insurance available) was simply impossible. More importantly it was uncertain that those sustaining injury or damage as a result of the theoretically possible event could be assured that the person or organization causing the accident would have the liability-insurance protection or other resources necessary to respond to just claims. These considerations and the seemingly insoluble problems they entailed found their resolution in 1957 in the passage of the Price–Anderson Act,[3] which made mandatory the extension of $500 million of federal indemnity to certain activities licensed by the AEC and which provided that the extension of this indemnity be optional for other licensed activities.

Except for reactors operated by educational institutions, the government indemnity applies only to loss in excess of *underlying financial protection* required by the AEC. An important aspect of the Act is the provision made for relieving everyone of any further liability if the loss and expense caused by a nuclear accident should exceed the sum of federal indemnity and the amount of financial protection required. A significant change in the Price–Anderson Law was adopted in 1966 for the purpose of further assuring the protection of the public. The law was amended to provide that, under both the insurance offered as evidence of financial protection and the indemnity extended by the AEC, legal defenses are to be waived in the event of a serious nuclear accident.[4] The effect was to assure the prompt settlement of claims and the avoidance of wasteful litigation. The Price–Anderson Act succeeded in raising the curtain on private reactor development, although government indemnity has been extended only to AEC licensees of reactors and spent-fuel reprocessors.

NUCLEAR LIABILITY INSURANCE AND THE PRICE–ANDERSON ACT

The indemnity extended to licensees (except reactor licenses issued to educational institutions) is conditioned upon the requirement that the licensee provide underlying financial protection, which, depending on the hazard of the licensed activity, varies between $1 million and the maximum amount of liability insurance available from private sources.

All licensed power reactors are subject to an AEC indemnity agreement, and, if the reactor has a rated capacity of 100,000 kW(e) or more, the underlying layer of financial protection required is $82 million, which is presently the maximum amount of liability insurance available from private sources. Although the financial-protection requirement can be satisfied by means other than insurance, to date only insurance has been offered to the AEC by indemnified licensees.

In addition to authorizing the extension of indemnity to licensees of the AEC, the Price–Anderson Act includes authority for the AEC to extend indemnity to contractors of the AEC where there is risk of public liability for a substantial nuclear incident. The regime for extending indemnity to AEC contractors, which was introduced by the Act, was a substantial change from the prior procedures for providing indemnity to AEC contractors.[5] Although the AEC is authorized to require its indemnified contractors to *furnish financial protection* against public liability for nuclear incidents, its practice has been to not require such financial protection.[5] Thus the nuclear liability-insurance pools are not normally involved with AEC contractor activities.

It was the intent of Congress that the insurance industry provide the maximum liability-insurance capacity possible. The larger the amount of underlying financial protection required, the more remote becomes the possibility that taxpayer dollars will ever be expended in connection with indemnity extended to licensees. Greater insurance capacity decreases dependence on government indemnity and thus tends also to defuse critics of the indemnity program who assert that the extension of government indemnity is a subsidy to the nuclear power industry that confers upon it unfair advantage of competitive fuels. It should be noted that each power-reactor operator pays a fee for this indemnity. The fee is prescribed in Section 170f of the Atomic Energy Law as $30.00 per year per 1000 kW of thermal-energy capacity. Thus a large power reactor of 3000 MW(t) will pay an annual indemnity fee of $90,000.

Congress amended Section 170e of the Atomic Energy Law in 1965 to include provision for reducing the $500 million of government indemnity by the amount that the liability insurance available exceeds $60 million. Periodically the nuclear energy liability pools canvass the liability-insurance market to achieve additional insurance capacity. The total of insurance and government indemnity for power reactors will remain a constant $560 million.

FORMATION OF NUCLEAR LIABILITY POOLS—INITIAL $60 MILLION OF NUCLEAR LIABILITY-INSURANCE CAPACITY INCREASED TO $82 MILLION

The circumstances confronting liability insurers in 1957 were: (1) maximum insurance capacity was desired, (2) there was relatively no spread of risk (initially very few companies had need for the insurance), (3) small initial premium volume (although immediate rapid growth was mistakenly thought probable), (4) no meaningful experience to measure the hazard, and (5) a remote potential for catastrophic loss existed. The uncertainty these factors signaled for a liability-insurance company could not be discounted, and a pooling arrangement that enabled many individual insurers to each accept a relatively small part of the risk was the obvious instrument through which liability insurance should be made available. Thus the nuclear pools were formed in 1957 as the result of a study prepared by the Joint Casualty Committee on behalf of leading American casualty insurers.[6] At that time, stock insurance companies formed Nuclear Energy Liability Insurance Association (NELIA), and mutual insurers formed Mutual Atomic Energy Liability Underwriters (MAELU).

There are 113 American stock company insurers participating in NELIA. MAELU's membership consists of six major mutual insurance companies; however, all exposure underwritten by MAELU is totally reinsured by Mutual Atomic Energy Reinsurance Pool, which is an association of mutual-company insurers that includes the six members of MAELU and 104 additional American mutual insurance companies. In 1957 the pools' initial capacities were $46.5 million for NELIA and $13.5 million for MAELU. The two associations cooperated to offer an initial total nuclear liability-insurance capacity of $60 million. Simultaneously, stock and mutual insurers also formed separate pools to afford property insurance to nuclear facilities. The property pools also had an initial combined capacity of about $60 million. Thus, for nuclear facilities utilizing both the liability and property nuclear pools, a total of $120 million of insurance was initially placed at risk. Both the liability- and the property-insurance capacities have since been increased from the initial capacities made available so that presently the total nuclear liability and nuclear property insurance available is $166 million. Approximately one-third of the initial combined NELIA–MAELU liability capacity of $60 million was afforded by reinsurance made available from foreign insurance companies and foreign nuclear pools. In 1965 the total nuclear liability capacity available from NELIA and MAELU was increased to $74 million, and it was increased further in 1969 to $82 million. Since government indemnity is reduced to the extent that liability-insurance capacity exceeds $60 million, for those licensees required to maintain financial protection equal to the amount of insurance available from private sources, government indemnity for such licensees has been reduced from $500 million to $478 million.

There are currently 86 foreign participants reinsuring NELIA and MAELU, and they continue to account for one-third of the $82 million capacity available.[7] Nine of the foreign participants are foreign nuclear insurance pools (associations similar to NELIA and MAELU), and the remaining 77 participants are individual foreign insurance companies who have responded to our request for support. Foreign participants are domiciled in 18 countries, and the most substantial support is from Great Britain, France, Germany, and Japan.

DISTRIBUTION OF RISK WITHIN THE POOLS

Insurers in NELIA or MAELU participate for amounts that reflect their managements' views of the maximum nuclear liability loss they could sustain with some equanimity, and the amounts vary widely. For example, the largest participant in NELIA in 1970 declared a participation of $4.25 million, but many smaller insurers are participating for amounts ranging upward from $25,000. The amount represents the maximum loss a participant may sustain on a single policy issued by NELIA. Since several hundred policies are in effect, it is possible for a participant to suffer losses under two or more policies caused by unrelated accidents, with the total loss in excess of the declared dollar participation. Thus, given an adverse turn in our loss experience under several policies, a participant's loss could conceivably be a multiple of the amount declared as its maximum participation.

OPERATING EXPERIENCE

The nuclear liability pools completed 14 years of operations at the end of 1970. Early expectation of swift growth of premium volume did not materialize. Although rapid expansion has taken place in the nuclear industry since 1965, the impact on NELIA and MAELU premium volume will be delayed until the reactors under construction commence operation. The effect of the retarded growth of premium volume has been that participants in the pools continue to confront the possibility of severe loss with a continuing narrow premium base. The annual premium volume of NELIA and MAELU combined for the years 1957 to 1970 is described below:

Year	Annual standard premium of NELIA and MAELU combined (dollars)
1957	70,142
1958	357,465
1959	714,686
1960	1,167,233
1961	1,496,976
1962	1,734,817
1963	2,048,180
1964	2,085,470
1965	2,130,255
1966	2,408,842
1967	2,775,735
1968	3,053,445
1969	3,381,936
1970	4,000,000 (est.)

The premium is subject to annual refunds, which may be made to insureds pursuant to a retrospective rating system that is briefly described later in this article.

The most significant fact issuing from 14 years of pool operations is that the nuclear liability pools have never received a claim for bodily injury or property damage caused during the operation of a licensed nuclear reactor—this includes all types of licensed reactors. Additionally, claims from all types of risks have been infrequent and, in the main, have not been serious.

DIGEST OF CLAIMS HISTORY

There have been only 16 incidents, most of them minor, which have been reported to NELIA or MAELU since 1957. The reported incidents can be readily divided between transportation incidents, of which there have been nine, and the remaining seven nontransportation incidents.

Transportation Incidents

Five of the transportation incidents involved property damage caused by contamination, and the most costly totaled $3519 for loss payment and expense of investigation. The average loss and expense for these five transportation incidents was $1706. The sixth transportation incident involved minor uranium contamination of a small portion of a warehouse and a truck weigh-in station. No loss payment was necessary. The seventh incident involved alleged bodily injury from a shipment of a small quantity of depleted uranium delivered to a wrong address. Investigation determined that liability, if any, was covered by the conventional liability-insurance market. The remaining two transportation incidents each involved bodily injury alleged by a worker in the transportation industry, and, since both claims are presently in litigation, nothing more can be said concerning them at this time.

Nontransportation Incidents

Two of the nontransportation incidents involved encapsulated radioactive isotope sources that leaked and caused contamination of property of third parties. The loss and expense paid for each was about $1250. One reported incident involved possible radiation exposure to children who had stolen a radium source. Pool coverage does not extend to radium; thus coverage for potential liability would be afforded by the conventional liability-insurance market.

A fourth incident involved possible exposure to workers of a contractor employed by a pool-insured company to modify a milling machine. Depleted uranium chips were found in the machine. There was no exposure to any of the men working on the machine, and the loss expense incurred was $47 for investigation.

A fifth incident arose from a criticality accident in July 1964 at a facility processing enriched uranium in solution.[8] A worker at the facility died as a result of the accident, and a claim made against a pool-insured company was settled.

A sixth claim involved an employee of an independent contractor retained by a pool-insured company. The employee of the contractor alleged that he suffered radiation injury to chromosomes while at the insured's nuclear facility, which in turn caused his child to be born with birth defects. The claim, which had no basis in fact, was successfully defended, and the litigation was terminated with a judgment entered for the defendant.

The remaining nontransportation incident reported involves a claim made by a worker at an oil-well site, who alleges that he sustained bodily injury from exposure to a small quantity of radioactive material used at an oil-well site. This matter is presently in litigation.

As a measure of the success of nuclear safety, the loss experience of the nuclear liability pools documents a remarkable safety record with respect to the protection of the public. This experience has been important to encourage participants to continue in the pools despite the small annual premium base and the small reserve for losses accumulated in 14 years of operation. At the end of 1970, the reserve for losses of NELIA and MAELU combined was approximately $18 million. This is a small sum relative to the loss potential when it is considered that up to $82 million of nuclear liability insurance is in force for each risk written by the pools. Premium refunds made to insureds as the result of good experience are paid from the loss reserve fund.

PREMIUM REFUNDS—RETROSPECTIVE RATING PLAN

Domestic insureds of NELIA and MAELU are rated under an Industry Credit Rating Plan which, with good overall loss experience by all pool risks, provides for retrospective downward adjustment of a premium 10 years after it is received by the pools. In the years 1967 to 1970, inclusive, NELIA and MAELU paid a total of $1.55 million in premium refunds on $2.3 million premiums received in 1957 to 1960. The annual premiums for the years 1957 to 1960, the portions placed in the reserve for losses (reserve premium), and the amounts actually refunded for each year are given in Table 1.

Table 1 Annual Premiums, Reserve Premiums, and Refunds for 1957–1960

Year	Annual premium	Reserve premium	Amount of reserve-premium refund and year paid
1957	$ 70,142	$ 47,706.83	$ 46,436.22 in 1967
1958	$ 357,465	$243,479.51	$241,208.52 in 1968
1959	$ 714,686	$492,224.76	$477,869.81 in 1969
1960	$1,167,233	$813,860.42	$784,612.17 in 1970

The amounts of the premium refunds paid annually should increase. For example, if good loss experience continues, a refund of about $1 million is expected to be paid in July 1971.

The effort made by government and industry to assure the protection of the public has thus far been an extraordinary success. Exceptional engineering talent, political power, pressure from the public, and effective government regulation have been brought to bear to avoid the consequences of the theoretically possible event described by the Brookhaven report. More remarkable than the success of the program is the fact that a postulated accident based on the very darkest of possibilities that led to a hypothetical catastrophe succeeded so well in leading the private nuclear industry to develop a very profound respect for the safety of the public. Ironically, catastrophes our society actually suffers on a recurring basis do not provoke a similarly effective life-protecting response.

THE ROLE OF THE NUCLEAR CRITIC

Since private nuclear activities commenced in 1957, the safety of privately sponsored nuclear activities has been the focal point of criticism from scientists, engineers, politicians, and laymen both from within and without the nuclear community. Although it is true that some of the critics have been blatantly irresponsible in falsely or inaccurately relating what they purport to be factual information (essential "errors" to support equally irresponsible conclusions), taken in toto, the critics of nuclear safety have contributed to the success of the nuclear safety program. Although the safety of the public has always been a primary factor weighed by industry and the AEC in licensing nuclear activities, the more effective critics (which are not necessarily the more vocal) have so sensitized those responsible for the nuclear safety program that greater time and energy are expended to assure that no serious lapse develops.

It is clear that a nuclear incident which caused substantial injury to the public could retard the growth of the nuclear industry a decade or more. I believe that it is also true that the record of nuclear safety is succeeding in winning the confidence of the public. The present area of hypersensitivity relates to the environmental effects of nuclear reactors. The environmental issue is relatively new in the armaments carried by nuclear critics and, essentially, as an issue it is a small appendix to our all too real air- and water-pollution problem. The nuclear industry has not contributed to the pollution of our environment, nor is it likely to become a contributing factor because critics will prompt repeated reviews of matters previously minutely examined to the end that, if there are deficiencies regarding safeguarding our environment from the nuclear industry, they will be discovered and controlled. In several years a more complete record will have been compiled on the environmental effects of the nuclear industry, particularly the large reactors, and this record will determine the degree of public acceptance 5 years hence on the environmental issue. A continuing reasonable response by the nuclear industry on the environmental issues will effectively disarm future critics. The record will then win the day for the defense. It may be difficult to continue a reasonable response to charges and accusations that are not always reasonable, but the burden rests with the nuclear industry and its regulators to maintain such a response. This may be more readily done if, despite the heat of the exchange, there is a continuing awareness that a contribution to safety is made by responsible critics.

CONCLUSIONS

The continuing success of those in government and industry responsible for the nuclear safety program has a significance that should transcend the nuclear industry. Could a like mobilization of talent, energy, and money be as effective elsewhere in protecting the public?

The record suggests that the nuclear industry can be considered a paragon of the effective marshalling of economic and human resources to avoid injury to the public or damage to property from an unusually hazardous activity. It should be possible for those persons in industry and government responsible for nuclear safety to move from defensive positions to assert the success of their programs as evidence of what is possible in other areas of hazard to the public. There are unquestionably extensive areas of hazard that have been taking a toll of all of us. In the years 1960 to 1969, inclusive, 1.05 million people were killed in the United States by accidents of all types, and there were over 110 million nonfatal injuries in the same period.[9]

The nuclear industry would have much to gain in its relations with the public if it cast a positive image of itself as a model for action in other areas. The success of the expenditure of energy and funds in the nuclear safety program warrants emulation.

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PUBLIC OPPOSITION TO NUCLEAR POWER: AN INDUSTRY OVERVIEW

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Abstract: *The recent history of public and press attitudes toward nuclear power and its effect on the environment can be traced in the results of polls, panel meetings, debates, etc. Although opposition is not the rule, the quick response by the nuclear industry to the environmentalists' positions has helped to improve public relations. Since nuclear technology is involved in these complex problems, its leaders must do all they can to inform the public and to respond with candor to important questions so that mutual trust and understanding may prevail. Such openness may at first seem self-defeating, but in the long run it will succeed.*

The American public is demonstrating an intense concern for its environment. It is unlikely to accept any unnecessary infringements and increasingly believes that it should have a major voice in determining what infringements are in fact necessary. Moreover, there is increasing distrust of the authority of government, business, and even scientists. As this distrust grows, it diminishes the ability of science and industry to meet the growing needs of our international economy.

The new-found national awareness of our deteriorating environment and the emphasis on participating in major industrial and technological decisions are by no means directed principally at nuclear energy. Virtually every large-scale industrial activity is being questioned and criticized by some members of the public and press. In many instances, such as the U. S. Earth Day activities of Apr. 22, 1970 and 1971, nuclear power plants have received much less criticism than fossil-fueled power plants and other industrial activities. Accordingly, it is quite difficult to estimate the actual magnitude and effects of public opposition to nuclear power. Recognizing the absence of comprehensive data, I will briefly trace the recent history of public and press attitudes toward nuclear power as seen from industry's point of view.

If we were to retreat to early 1969, about 18 months in time, we would find little indication of any public opposition to nuclear power. Aside from the early and quite specialized controversies surrounding

Consolidated Edison's proposed Ravenswood plant,[1] Detroit Edison's Enrico Fermi experimental breeder,[2] and Pacific Gas & Electric's Bodega Bay plant,[3] there was little public or press concern about the rapidly expanding nuclear power industry. In 1968, utilities ordered 17 nuclear power stations with virtually no adverse public reaction. Nearly all the scant opposition in the AEC's public hearings appeared on legal or economic gounds, rather than on health or environmental aspects. A California poll taken a year earlier showed 60% favoring nuclear power, and the voters in Eugene, Oreg., approved a nuclear power plant for its municipal utility by a 4-to-1 majority.

The first indication of change in this peaceful situation came rather unexpectedly in early 1969 from an article, entitled "The Nukes are in Hot Water," in a national sports magazine.[4] That article shocked much of the nuclear industry, for it was the first story in a mass-circulation medium that attacked nuclear power on *environmental* grounds. The article proved to be only a preview of things to come. Before the end of the year, two other mass-circulation weekly magazines, several of our most prominent newspapers, and many other publications carried articles sharply critical of the environmental effects of nuclear power. Two new books rounded up every possible criticism,[5,6] including many long discredited ones, and although neither was written by a person technically qualified to examine the subject, both are still considered standard reference sources by some conservation groups and members of the press.

Throughout, 1969, the public's changing attitude was evident in a number of other developments. Several bills were introduced in Congress calling for a moratorium on nuclear power plants. A couple of planned nuclear stations in the East were postponed after being opposed by well-organized local conservationists, primarily on thermal grounds.[7,8] In response to these events, the attitudes of the AEC and the nuclear industry about public opposition began evolving. A milestone in understanding the public's view of nuclear power was made possible in late 1969 by an AEC decision to hold a public meeting in Burlington, Vt., to discuss nuclear power with local residents.[9] As it turned out, the meeting evolved into a debate between the AEC and national-laboratory scientists on one side and several professors and scientists described as "conservationists" on the other. The panel brought together prominent critics of nuclear power from the Midwest, East, South, and Southwest, and the audience included several hundred local residents. The debate and the questions from the audience were, for much of the industry and the AEC, the first direct exposure to the criticisms of nuclear power and to the misinformation and fear that surround the subject. This meeting and a later one sponsored by the University of Minnesota[9,23] indicated, by the relatively small audience turnouts, that, although worry about nuclear power was not widespread in either community, concern among many residents was quite deep. We realized more than ever that opponents of nuclear power included not only professional rabble-rousers and special-interest groups but also a number of concerned and educated citizens who had not heard all the facts about nuclear power or, having heard it, nevertheless had serious questions about its safety and environmental impact.

Many other recent developments have reflected this distrust of nuclear power or added fuel to it. Two Lawrence Radiation Laboratory scientists began telling politicians and the press that federal radiation guidelines should be made 10 times more restrictive.[10] The Minnesota Pollution Control Administration decided that the AEC's guidelines were too permissive and attempted to impose much more stringent requirements with respect to radionuclide releases from reactors within the state of Minnesota. Also, politicians from Long Island to Alaska adopted the perils of nuclear energy as a frequent subject of discussion throughout the recent election year.

These surface indications of public opposition to nuclear power bring to mind a natural question: Are they isolated developments that represent only a small minority of the public, or are they the surface indications of a great iceberg of resistance that has not yet come to light? Are the "nukes" really in hot water?

OPPOSITION NOT THE RULE

We cannot scientifically determine what percentage of the public holds what degree of opposition to nuclear power, but we do know of enough cases of disinterested parties *favoring* it to realize that opposition is by no means the rule. First, we need only to consider the large number of nuclear plants now operating, under construction, or being planned which have not received any significant public resistance. Numerous plants are now operating or under construction that have avoided any serious public criticism. Similarly, we should consider the Los Angeles area, which has outlawed fossil-fueled generating plants because of air-pollution problems. We can point to the Massachusetts Audubon Society, one of the oldest conservation organizations, which has encouraged the use of nuclear power because of its environmental advantages. Further, the California Resources Agency has reported[11] to the Governor that "nuclear energy possesses a tremendous advantage over fossil-fueled plants with respect to the effect on the environment."

Most polls on the subject also indicate that the public is by no means as opposed to nuclear power as some critics would have us believe. A Lou Harris poll[12] in Washington State in May 1970 showed 70% "not opposed" to nuclear power and 6% "strongly opposed"; only 22% were "not opposed" to fossil-fueled plants and 38% "strongly opposed." A national survey conducted for a private nuclear firm in late 1969 produced similar results. When asked what their reaction would be toward a nuclear power plant and a coal-fired plant in their area, about 65% favored nuclear-powered plants and 20% opposed such plants; 22% were "for" coal-fueled plants and 68% were "against." A nationwide poll[13] conducted for the Edison Electric Institute in 1969 showed that 50% of the U. S. population, not including Alaska, Hawaii, and areas served by public authorities, favored nuclear plants in their areas, and 27% opposed them.

Such scattered findings indicate that the opposition to nuclear power plants—often considered virtually a national characteristic—may not be nearly so widespread as some publicity makes it seem. However, this fact alone is no cause for complacency. As we have seen repeatedly in recent years, it does not take a majority of the public in opposition to an activity to significantly affect it, nor does it take a majority of the most informed technical community. A vocal minority, combined with the powers of the press and politicians, can have a major effect on nuclear power or any similar activity.

We must not ask merely whether a majority of the public opposes nuclear power but, rather, how seriously its development is being affected by that opposition, no matter what its size.

EFFECTS OF PUBLIC OPPOSITION

From a developmental point of view, there has been no serious effect from public opposition to nuclear power. The technology of nuclear power has been put into use by industry at an unprecedented pace, primarily because, as AEC Chairman Glenn Seaborg has pointed out, its development came along at the perfect time from the point of view of environment and fossil-fuel conservation. It is easy to forget how quickly nuclear power has progressed from an AEC research-and-development effort into a huge industry. As recently as 5 years ago, only eight nuclear power reactors had been built in the United States, and those eight included such prototypes as Shippingport and Dresden. Today, however, there are more than 100 nuclear reactors in operation, under construction, or on order and these reactors represent a total capital investment of some $15 billion. This phenomenal growth in the nuclear power industry seems proof enough that nothing has seriously affected its development.

A provocative survey of the nation's nuclear utilities made in February 1970 bore out this interpretation. John F. Hogerton, Executive Vice-President of The S. M. Stoller Corporation, examined 70 nuclear power projects with respect to public resistance for the Atomic Industrial Forum's Topical Conference on Nuclear Public Information. Hogerton[14] concluded that public opposition had not retarded the growth of nuclear power and had generally not been a major factor in the "slippage" of nuclear power plants. The utilities he surveyed listed labor problems, licensing delays, and late deliveries of pressure vessels as more significant contributors to the slippage of plant schedules than public opposition. Hogerton did note that in two or three cases public resistance played an important role in postponing or canceling planned projects and that this "could easily become a major factor in the future."

Although the nuclear power industry may not have been slowed significantly by public pressures, the pressures have been real and increasing, and, to the information men in the industry, they have loomed quite large. A recent survey of nuclear information specialists conducted by the Atomic Industrial Forum's Public Affairs and Information Program indicated that the nuclear information community does indeed believe that public opposition has had significant effect on the nuclear power industry.[15] When asked, "To what extent do you believe public opposition and adverse public information are affecting the nuclear industry?", 27% answered "very seriously"; 44% said "seriously"; 28% said "moderately"; and only 1% replied "hardly at all." The nuclear information specialists were also asked whether the effect of public opposition to nuclear power would become more or less serious in the next couple of years, and 66% replied "more" and 17% said "the same."

The results of these two surveys seem at first contradictory. The one says there has been no effect on the nuclear power industry from public opposition and the other that there has been a serious one, but the two are reconcilable. John Hogerton's survey concentrated on delays or cancellations of power plants caused by public opposition; the responses to the Atomic Industrial Forum poll took a broader view—that of significant effects the controversy has had on the industry, and there have been many. It may be that the activities of conservationists, the press, professors, and other groups have not threatened the further development of nuclear power, but they have certainly, as the survey asked, "affected" it. Hogerton himself pointed out that public intervention has increased governmental regulation of nuclear power plants and that public opinion reflects the weakened credibility of the nuclear power industry and the AEC.

The effects on the nuclear community from public opposition can be seen in many other ways. The public's overall concern for maintaining an environment as pure as possible—of which the concern over nuclear power is just a relatively small part—has contributed to expanded programs in research and development, environmental activities, and public affairs on the part of utilities, manufacturers, the AEC, and other organizations in the nuclear community. For example, the AEC has established a new Office of Environmental Affairs that is concerned not only with the environmental effects of the AEC's own facilities but also with expanding environmental research activities, passing the results on to industry, and informing the public about the environmental effects of nuclear power.[16] The Congressional Joint Committee on Atomic Energy conducted an unprecedentedly thorough set of hearings that has become the most valuable single source of information on the subject.[17] Many utilities have added environmental specialists to coordinate their ecological activities, and some, such as Northern States Power and Northeast Utilities, have begun new procedures for widening the public's participation in their major decisions. Westinghouse Electric Corporation has created an Environmental Systems Department, initiated environmental research programs with Consolidated Edison and Commonwealth Edison, and conducted a month-long School for Environmental Management at Colorado State University. The Atomic Industrial Forum has established a new Committee on Environmental Law and Technology, chaired by Dr. Merril Eisenbud, and has expanded its Public Affairs and Information Program to serve the information needs of the nuclear community, the media, and the public. The nation's utilities have formed the Electric Utility Industry Task Force on the Environment.

A NATIONAL PROBLEM

Even if public opposition and press attention in the past 2 years have not significantly retarded the development of the nuclear industry, they have nevertheless affected it in many other ways, some of which can be viewed as beneficial. A similar paradox is that public and press criticism of nuclear power is a national problem that does not exist in most areas of the country. This seeming contradiction can be easily explained. The principal criticism of nuclear activities has come from national magazines and television networks, national conservationists, and national special interest groups. In most local areas the opposition has not been against nuclear power in general, but rather against particular plants on particular sites, be they nuclear, fossil fueled, or hydroelectric. Nuclear opposition is thus a problem that affects the entire nuclear community, although it may not be evident on most local levels.

There are two important lessons to be drawn from this observation. For one, we can anticipate that in the next few years more and more of the national criticism will be reflected on local levels. Every critical article in the national media can be expected to sway a certain number of its audience, who may then become active against nuclear plants in local communities. The other lesson is that the organizations best equipped to meet this opposition are nationally based groups, such as the AEC, the Atomic Industrial Forum, and the American Nuclear Society. Members of the nuclear industry must not be lulled into false confidence by a lack of local opposition; every article in a national magazine can affect a community as severely as an editorial in the local newspaper. Accordingly, the industry should support and work with its national organizations, especially during this time of national interest in the environment.

THE ENVIRONMENT AND INDUSTRY

The "overview" of the public opposition to nuclear power could not be complete, of course, without mention of the over-all environmental movement of the past year. The scope and passion of the public concern have been not only national but to a considerable extent worldwide and have by no means concentrated on nuclear power. Here I will discuss briefly what this movement means for the nuclear industry.

Of course, I am qualified to discuss this only from a personal point of view based on limited observations. In general, these observations have led me to the belief that most responsible industry, including the nuclear community, has welcomed the movement and encouraged serious efforts to improve our environment. The respondents to the Atomic Industrial Forum poll[15] strongly supported this interpretation. When asked, "How should the nuclear industry react to environmental activities?", 98% replied "offer assistance"; 27% said "offer financial support"; 3% answered "respond only if properly requested"; and only 1% said, "hope they will overlook nuclear power."

The nuclear community's involvement in environmental aspects could also be seen in the Earth Day activities of Apr. 22, 1970. Hundreds of representatives of government, industry, and laboratories involved with the development of nuclear energy appeared at Earth Day meetings throughout the country, and some firms directly participated in the planning and funding of these events. These items convince me that a large part of the nuclear industry recognizes our world's very real environmental problems and is eager to help solve them. As Sherman Knapp,[18] President of the Atomic Industrial Forum, has said:

> We who are responsible for providing the nation's electricity are as shocked and saddened by our nation's befouled air and water and land as are conservationists. We are eager for our grandchildren to have open space to play in and clean water to drink. And while most conservationists can only debate and lament the problems, we are in a unique position of being able to help the situation by making the environment our number one consideration as we plan, build, and operate our plants.

Concerned though it is about the quality of our environment, the nuclear community, like much of the nation's industry, has had considerable difficulty in placing the problems and proposed solutions of the environmental crisis in a broader perspective. As Dr. Seaborg has pointed out, many ardent "environmentalists" do not seem to realize that the interrelations involving an industrial society are as complex as those comprising nature's ecology. They seem to think that industry could simply turn off a faucet marked "technology" and that all our environmental problems would end. There is more to man's environment and more to the "quality of life" than trees and air and open space, as vital as they may be. There are, for example, labor-saving technologies, without which modern man, like the U. S. frontiersman of 100 years ago, would have neither the time nor the means to enjoy his surroundings. Our natural environment must be considered in relation to our man-made one, of which electric energy is a vital part. As Dr. Seaborg[19] has said, "The environment of a city whose life's energy has been cut—whose transportation and communications are dead, in which medical and police help cannot be had, and where food spoils and people stifle or shiver while imprisoned in stalled subways or darkened skyscrapers—all this also represents a dangerous environment which we must anticipate and work hard to avoid."

The fact that environmental pollution is to some extent inevitable should not lead us to complacency about the subject; rather, it should spur us to try more vigorously to reach the most passionate conservationists with the unhappy facts about these complexities. Unless more of them begin understanding such fundamentals as the fact that all energy conversion, including that of our own bodies, unavoidably creates a certain amount of pollution, industry is in danger of being cast in the role of the villain of society. Already we can see some professional conservationists polarizing the country to the point that everyone who dispassionately discusses such complexities is forced into an antienvironment camp.

ISSUES AND THE FUTURE

The environment will no doubt remain a major issue of controversy and action in the United States for some years to come, and in this respect the nuclear industry is in a favored position. Nuclear power is the least harmful method of generating electricity now practical, and its growth will help slow the degradation of the environment. However, even if more of the public and the press begin recognizing the environmental advantages of nuclear power, the controversy around this technology is not likely to disappear soon or even diminish. The expenditures of the nuclear industry are too great and the facilities too prominent to allow it to leave the public eye. Therefore it might be useful to speculate about the principal issues of controversy that the nuclear power industry is now facing and how these issues might evolve in the near future. I realize that some of the issues are technical ones that I am not qualified to discuss in detail, but I would like to look at them briefly from a public-acceptance point of view.

Radiation Standards

The issue that now seems the most controversial is the effects of low-level radiation, in conjunction with the adequacy of federal radiation guidelines. This topic is indeed creating a great amount of heat among the press and many members of the public, but it is also an issue that could conceivably all but disappear in the near future as such eminent bodies as the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, and the Federal Radiation Council review all known data about radiation effects. Whatever radiation standards are ultimately set, I am confident that commercial nuclear power plants can operate well within them. This seems to be an issue that a strong effort to obtain public understanding could help bring to an end as a major point of contention, because much of the strong feeling has no connection with the real world of nuclear power plants. The effects on the population of the Federal Radiation Council guidelines of 170 mrems a year, whatever they could theoretically be, can hardly be associated with the localized effect of a nuclear power plant, which adds radiation of less than 5 mR/year (equivalent to a dose of 5 mrems/year) at its site boundary. When the public and the press understand this vital distinction, an issue that now seems crucial could pass from sight.

Thermal Effects

The issue of thermal effects is undoubtedly the one which will be with the nuclear industry the longest and is the most difficult to explain. Much of the public, like *Sports Illustrated*, just became aware of the potential problems associated with waste heat in the past few years, and, for many of the same reasons, the AEC and industry did not fully foresee them. From a public-understanding point of view, this issue is complicated by the facts that not only are the answers complex and technical but also are, in many cases, unknown. We simply do not know the effects of every temperature on every type of water body or the environmental effects of every type of cooling tower and pond. What we do know, however, indicates that the problems are by no means as severe as some of our critics imply with words like "fish fry" and "boiling rivers," and in some thoroughly documented cases, such as the Connecticut River, there have been no observable adverse effects.

Perhaps the most critical public-information problem involving this subject is the pressing need to put thermal discharges into perspective. In the press, in much conservationist literature, and even in material from some government agencies, the words "thermal pollution" are invariably linked with the phrase "nuclear power," as if waste heat were unique to nuclear plants. Nuclear plants are generally less efficient (about 32%) than fossil-fueled plants (about 40% for the best ones). However, the liquid-metal fast breeder reactor and the high-temperature gas-cooled reactor are fully as efficient as fossil-fueled plants, and yet in the press it is always just the "nukes" that are in "hot water."

There are a number of other issues which are not now prominent but which may become so in the near future as more and more of the nation's large nuclear power plants go on line. The reprocessing, transportation, and ultimate storage of radioactive wastes from these plants will probably undergo increasing press, public, and political scrutiny as the activities in those parts of the fuel cycle expand, and the nuclear industry and the AEC must be prepared to discuss these subjects in a concise and persuasive manner to meet the expected criticism and misinformation.

Government Indemnity

A number of other charges frequently made against the nuclear community are essentially political rather than technical. Perhaps the most frequent is that concerning the federal indemnity of the United States for large accidents involving nuclear material as legislated in the Price–Anderson Act[20,24] of 1957. One of the ironies of U. S. nuclear development is that this law, enacted to guarantee public protection, has become a major point of contention for critics of the nuclear industry. We must learn to educate the public to the fact that far from being a subsidy to the industry, this law basically assures the public's financial protection in the unlikely event of a large accident. Many critics do not seem to understand the basic fact that not a dollar of government money has been expended because of Price–Anderson and that, in fact, the Treasury Department has collected more than $1 million in fees that utilities pay the government. When this law expires in 1976, we can expect a renewed outburst of criticism of it, and we must learn to present our case, whatever it may be, logically and concisely. Although this is essentially a political question and there is a wide range of opinions, even within the nuclear community, we need to emphasize that it is not the nuclear industry that is being protected by this law so much as the public.

Credibility

Another broad issue that has always been a major factor in the criticism of the nuclear community is the public's general distrust of "the establishment" and its "credibility." The word of any official institution is viewed with distrust by many persons today, and not totally without reason. As Louis H. Roddis, Jr.,[21] President of Consolidated Edison and past President of the American Nuclear Society and the Atomic Industrial Forum, has said,

> Once assurances that carried an official seal were all that was needed in a more trusting time. But that day is over. People are less ready to believe what politicians tell them. That isn't new. But they don't believe scientists either, and they have some good examples to point to. . . So when we wave nuclear power's fine report card in the public's face, can we reasonably expect it to be believed?

If we are to be believed, we must carefully guard against any action or statement that might further erode public confidence and "credibility."

NATIONAL GROWTH RATE

One issue of controversy that seems to rival the nuclear community's credibility as most crucial in the long run is the increasingly frequent call for a slowdown in our nation's overall growth rate. The natural limits of space, land, water, energy, and other resources are being interpreted by more and more persons as meaning that the country, and the world, cannot expand its population and standard of living indefinitely. President Nixon's State of the Union address phrased it this way:

> In the next 10 years, we'll increase our wealth by 50%. The profound question is: Does this mean we'll be 50% richer in a real sense, 50% better off, 50% happier?

And, more directly related to the nuclear power field, Philip Sporn,[22] former President of the American Electric Power Company, in a review of the nuclear industry for the Joint Committee on Atomic Energy, asked:

> Why must there be an increase in electric energy production? Has a cheap and plentiful electric energy supply become a luxury our environment can no longer tolerate?

These are questions that all responsible leaders of government and industry must seriously consider. Why indeed must the United States continue its phenomenal growth?

The major part of the answer, of course, is that despite all the social movements to the contrary, our population is continuing to grow at a rate that alarms many experts. Worldwide, this is one of man's most pressing problems, with our population of 3 billion persons expected to double within 35 years. Because of its natural resources and lower birth rate, the United States, however, is not facing a problem of such magnitude. Nevertheless, during a week, the U. S. population increases by about 42,000, and by 1980 we will have added some 25 million more persons than we have today. As Sherman Knapp has said, "These 25 million in the next 10 years represent not only that many houses and automobiles and schools and jobs, but that much more pollution—no matter how we produce the goods and services and electricity that they require."

Even though many members of the nuclear industry recognize the problems connected with endless growth, there is little that they can do unilaterally to solve them. Electricity is the most democratic of all products. A single watt cannot be sold until a customer pushes a button to turn on a light, or a television, or a factory. If utilities are to fulfill their responsiblity to the public, they must provide the power whenever that switch is turned on—no matter how quickly the population is growing or how rapidly the standard of living is increasing. Otherwise, no matter how pure they may have maintained the environment, they will have failed. So even as we deplore and work to end the perilous population growth, inefficient uses of energy, and indiscriminate industrialization, we must educate members of the public to the fact that, if the nation's electricity demand is lessened, it must be *they* who turn off the switches.

THE TECHNOLOGY GAP

The problems of population growth and expanding standard of living are just two of many complexities that the nuclear community and other advanced technologies must better communicate to the nontechnical public. The gap in perspective and understanding between industry and technicians on the one hand and the public on the other widens with each new scientific or technological discovery, and if both sides do not soon begin building bridges, it may become unspannable. The public cannot be expected to put its trust in an industry as long as it does not understand the complex technology involved, nor even the complex social and political framework within which it must operate. The nuclear community must increase its efforts to inform the public not only about reactors and radiation but also, and perhaps even more importantly, about the broader perspective that to a great extent guides the industry, including such factors as energy demand, comparative environmental effects of all types of electricity generation, rising costs, increased regulation by government agencies, and critical shortage of economically available fossil fuel. Such fundamental factors as these must be appreciated by the public before it can begin to understand industry decisions and contribute to them meaningfully.

At the same time, the industry's public affairs and community participation programs must feed back the public's concerns, fears, reactions, and suggestions. They must seek not only to inform the public but also to become two-way conduits that will also inform the nuclear community. Only through this mutual understanding can we begin bridging the technological gap.

RESTORATION OF TRUST

As American industry, government, and other "establishments" move toward this more open philosophy of dealing with the public, the change will not be nearly so great for most segments of the nuclear community as for other major activities. The AEC and the nuclear industry have always operated in a uniquely open fashion, despite the cries of "secrecy" occasionally heard from some critics. Since the beginning of the private nuclear industry in the United States, every major project has undergone several open reviews by AEC staff and independent committees, at least one public hearing in the vicinity of the proposed plant, general "fishbowl" licensing and regulation procedures almost unheard of in any similar industry, and public announcements at every step of the regulatory process. The industry and the agency can be proud of their openness and willing involvement in debates. What other major federal agency has ever consented to discuss controversial issues with its most severe critics at public meetings as the AEC has done in Vermont, Minnesota, and other locations, and what other industry leaders have participated in debates and discussions with leading opponents as we have in Atomic Industrial Forum conferences, governmental public hearings, and other public meetings?

At times, of course, this openness seems to be self-defeating. It often means that the critics are given more press and public attention than they could receive without the nuclear community's recognition of their charges. However, I am convinced that in the long run this very philosophy will be one of the major factors in the resolution of the nuclear controversy. We all realize that we are dealing with a unique technology—conceived in secrecy, born in warfare, and developed in fear. It is only natural that the public's attitude toward nuclear application is more suspicious and reluctant and less logical and objective than its attitude about technologies without this dark history. Whether nuclear plants can operate safely could be completely irrelevant if public fear, justified or not, caused the public to reject them.

Public opposition to nuclear power in the United States may not have significantly slowed the development of the industry, but, as we have seen, it has affected it in a number of ways, and there is a chance that its effects could soon become much more serious as some 95 large nuclear power plants now planned and under construction complete their hearings and licensing procedures. It is a technology that represents not so much an environmental problem as a solution, and, as such, nuclear power must be supported vigorously by the governments and industries of all nations. However, because of its history and unfavorable associations, we, as representatives of this nuclear technology, must go farther than most industries in emphasizing safety, candor, and public participation in decisions. We must show that we are interested in listening to all responsible critics and seriously considering their objections. I am convinced that this method of operating may seem to further complicate our jobs in the short term but will, in the long term, lead to the public's confidence and trust.

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SOME EFFECTS OF PUBLIC INTERVENTION ON THE REACTOR LICENSING PROCESS

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Abstract: *The environmental protection movement, which has grown so strong over the last 2 to 3 years, has greatly affected the civilian power-reactor licensing process. Intervention in public licensing hearings and court action have both been widely employed, with a net result, in many cases, of significantly increasing the time required to obtain both construction and operating licenses. It is concluded that a strong effort must be made by industry if protracted delays are to be avoided.*

Today the United States is experiencing what is potentially one of the most powerful ground swells of public opinion in the history of the nation: the environmental–ecological quality-of-life movement. It is characterized by an increasing popular interest in conservation of natural resources and an increasingly active public concern about their degradation on the basis of health and safety, quality, or aesthetics. Although its antecedents have been building up over a long period of time, the overt expression of the movement has developed relatively almost overnight, and the potential impact on many of our institutions is not yet fully appreciated.

This article concerns the effect of the movement on the nuclear industry, and, in particular, how it has and possibly may influence the licensing process for nuclear power plants. Therefore the current status of the licensing process will be discussed briefly, with emphasis on the effect of public intervention to date. An attempt will be made to determine if particular patterns have emerged or if certain trends are evident. The conclusions, drawn from the foregoing, will be limited to effects on U. S. Atomic Energy Commission (AEC) hearings. The impact of states' actions, the Justice Department antitrust hearings, the various environmental agencies, etc., will not be considered owing to space limitations.

THE LICENSING PROCESS

All nuclear power reactors and other nuclear utilization and production facilities, such as irradiated-fuel-reprocessing plants, must go through two stages in the AEC licensing process: (1) the construction-permit stage, where AEC determines that there is reasonable assurance that a facility of the design and power proposed can be constructed and operated safely at the site proposed by the applicant; and (2) the operating-license stage, where the AEC determines that the construction is in conformance with the permit and where the facility is tested for safety and brought to full power.

General Chronology

At the construction-permit stage, the application for a power reactor or other nuclear facility is first reviewed by the AEC Regulatory Staff. An independent technical review is also made by the statutory Advisory Committee on Reactor Safeguards (ACRS). When these reviews are completed, an atomic safety and licensing board (ASLB), drawn from a qualified panel, conducts a public hearing in the vicinity of the proposed site. The ASLB's initial decision on issuance of a permit is subject to review by an appeal board and/or by the Commissioners before becoming final.

The AEC regulatory staff and the ACRS again conduct extensive technical reviews before a notice of intent to issue an operating license is published in the *Federal Register.* A public hearing is not mandatory at this stage, but affected persons may request a hearing or the Commission may schedule a hearing on its own initiative.

Time Scale

It is useful for our purpose here to separate the Regulatory Staff–ACRS review time and the ASLB review time. For the Regulatory Staff–ACRS review, the following is a brief recitation of statistics[1] for the years 1967 through 1970:

> For construction permits granted in 1967, the average time from filing of the application to granting of the construction permit was $10\frac{1}{2}$ months; in 1968, $13\frac{1}{4}$ months; in 1969, 19 months; and in 1970, $18\frac{1}{4}$ months. Most of these increases in time took place prior to the final ACRS reviews. The time interval for that part of the review process increased from $6\frac{3}{4}$ months in 1967 to $14\frac{1}{2}$ months in 1970. In 1967, the average staff manpower spent on a construction permit application was about 340 man-days; it increased to 392 man-days in 1968, climbed to a peak of 737 in 1969, and in 1970 has declined somewhat to 627 man-days.
>
> As for operating licenses, we do not have many data from earlier years for comparison; but, typically, they have required about 40% more manpower for review than construction permit applications.

The reasons for the increase in time required are many: greater complexity of the more-advanced-design plants, additional technical issues, incomplete applications, and understaffing of the regulatory organization. A number of efforts have been and are being made to counteract this trend, such as development of standards, USAEC Regulatory Safety Guides, and additional staff. However, the considerable time the Regulatory Staff must spend in current cases on new environmental information required by the National Environmental Policy Act of 1969 (Ref. 2) and the Water Quality Improvement Act of 1970 (Ref. 3) cannot be fully evaluated at this time. With this exception, it is not expected that the Regulatory Staff review time will increase in any significant way as a result of increased public interest in environmental protection.

The public hearings have gone somewhat differently. From 1966 to mid-1970, some 29 hearings on the 38 construction permits issued averaged only about $2\frac{1}{2}$ days each, and 7 operating licenses were issued in this period with no requests for a hearing. In 1969, however, the effects of the environmental movement on the hearings began to appear, and in 1970 the picture changed greatly. Figure 1 shows graphically the trend in strongly contested cases vs. cases in which there was little or no intervention. In the total cases in 1967, 1968, and 1969, there were 25 essentially uncontested construction-license hearings held, four of which can be considered as strongly contested. Seven uncontested operating licenses were issued, with no hearings being held. In 1970, however, along with the holding of six uncontested construction hearings and the issuance of three uncontested operating licenses, there were six strongly contested construction-license hearings and three operating-license hearings, some of which are still in progress. The figures for 1971 are not yet in, but from all available information, it appears that intervention will increase, not decrease. Pertinent information on licensing from 1967 through 1970 is presented in Tables 1 and 2.

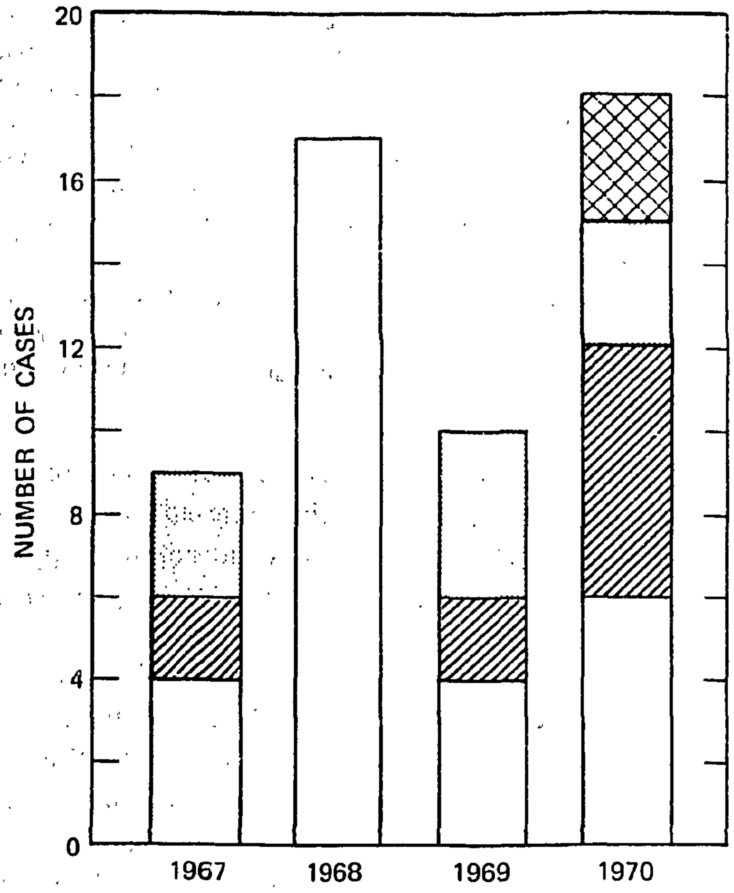

Fig. 1 Public intervention in construction and operating licenses. ▭, Construction, minimal or no contest; ▨, construction, strong contest; ▭, operating, no contest; ▩, operating, strong contest.

One aspect that Fig. 1 does not reflect is the changing character of the hearings. Only a year or two ago, the intervention was principally unorganized, local in character, and consisted in concern about possible release of radioactive materials or problems peculiar to a particular site, such as the seismic problem at the proposed Malibu plant site. The intervention today is relatively well organized and promises to become even more so, and questions covering the entire field of reactor safety as well as environmental protection are being raised. Some specific examples of these changes are discussed in the following section.

EVOLUTION OF PUBLIC INTERVENTION

As has been noted before, public hearings are mandatory for the construction permit but not for the operating license unless issuance of the license is properly contested. The two situations bring up different problems, and it is instructive to consider them separately. The role of the courts is also becoming increasingly important in the licensing process and therefore will be discussed briefly.

Construction-Permit Hearings

Until 1970 there was little public interest in construction-permit hearings, and most of that was token in nature. There were, of course, exceptions: Malibu, with its yet unresolved seismic problem; Enrico Fermi, a fast breeder that was perhaps ahead of its time; Ravenswood, which would have involved siting an advanced-design reactor in a high-population-density area and which aroused so much public opposition that its application was withdrawn prior to a construction-permit hearing. The usual problems were either economic or legalistic.

Today the situation has changed a great deal. True, some recent construction permits have been issued with little or no controversy. Trojan, for instance, required only a 3-day hearing, with no problems of significance raised. It should be noted, however, that a court action against granting the license has been filed, and the results are not yet known. However, a growing number of permits have been or are being contested strongly either at the hearings or subsequently in the courts (e.g., Shoreham, on Long Island; Davis–Besse, in Ohio; Calvert Cliffs, in Maryland).

Most of the contentions by the interveners have been based on environmental problems, and, indeed, questions concerning radiological and thermal pollution have been raised in essentially all the hearings that have been held. The issue of reactor safety per se has been raised but had not been intensively pursued until the construction-permit hearings on Shoreham. Apparently this was only the first of a series; for example, it is expected that the issue of internal reactor safety will be a significant part of the pending Midland, Mich., construction-permit hearing. The principal intervener[4] has petitioned a list of some 52 contentions, most of which have been considered in other hearings. The nuclear safety contentions, however, are fairly new, at least in their depth. It is therefore worth listing them as they appeared in the November–December 1970 issue of *Nuclear Industry*:[5]

1. There is not enough experience with reactors of this type and size to build one in such a populous area: 400,000 people within a 50-mile radius.

2. There is no reasonable assurance that the emergency core-cooling system is quick or reliable enough to prevent an uncontrolled meltdown under maximum hypothetical accident (MHA) conditions.

3. The Midland MHA does not approach the maximum that could be assumed: a meltdown of the entire fuel core.

Table 1 Construction-License Data*

Name and location	Docket No.	Application date	Start of ASLB hearing	License issued	Principal issues of hearing
1967					
Turkey Point 3 and 4, Dade County, Fla.	50-250 50-251	3/66	2/67	4/67	Enemy attack or sabotage, site criteria
Browns Ferry 1 and 2, Browns Ferry, Ala.	50-257 50-260	7/66	4/67	5/67	Not contested
Point Beach 1, Manitowoc County, Wis.	50-266	8/66	6/67	7/67	Not contested
Vermont Yankee, Brattleboro, Vt.	50-271	12/66	8/67	12/67	Thermal pollution, Sec. 104b license improper
Oconee 1, 2, and 3, Oconee County, S. C.	50-269 50-270 50-287	12/66	8/67	11/67	Sec. 104b license improper
Peach Bottom 2 and 3, York County, Pa.	50-277 50-278	2/67	12/67	1/68	Antitrust, Sec. 104b, license improper
1968					
Diablo Canyon 1, San Luis Obispo, Calif.	50-275	1/67	2/68	4/68	Health and safety of public
Three-Mile Island 1, Three Mile Island, Pa.	50-289	5/67	4/68	5/68	Not contested
Fort Calhoun, Washington County, Nebr.	50-285	4/67	4/68	6/68	Not contested
Cooper, Nemaha County, Nebr.	50-298	7/67	5/68	6/68	Not contested
Surry 1 and 2, Surry County, Va.	50-280 50-281	3/67	5/68	6/68	Not contested
Prairie Island 1 and 2, Red Wing, Minn.	50-282 50-306	4/67	5/68	6/68	Inadequate quality assurance and emergency procedures, normal release of radioactive wastes
Point Beach 2, Manitowoc County, Wis.	50-301	8/67	6/68	7/68	Not contested
Kewaunee, Carlton, Wis.	50-305	8/67	6/68	8/68	Not contested
Pilgrim, Plymouth, Mass.	50-293	6/67	6/68	8/68	Sec. 104b license improper
Browns Ferry 3, Browns Ferry, Ala.	50-296	7/67	7/68	7/68	Not contested
Fort St. Vrain, Platteville, Colo.	50-267	10/66	7/68	9/68	Prestressed concrete containment, economic dislocation to mining industry
Crystal River 3, Crystal River, Fla.	50-302	8/67	7/68	9/68	Sec. 104b license improper
Salem 1 and 2, Salem, N. J.	50-272 50-311	12/66	8/68	9/68	Not contested
Zion 1 and 2, Zion, Ill.	50-295 50-304	7/67	9/68	12/68	Not contested

*The information concerning specific cases in this article is available from the AEC Public Document Room, 1717 H St., Washington, D. C., where complete accounts of specific hearings are carried under the docket number assigned to each application. Owing to the difficulty of searching this voluminous literature, the author relied heavily upon personal communications and unpublished, condensed accounts, along with the excerpting services of NSIC, for his background material. It is for this reason that few references are made, with those generally noting a direct quotation.

Table 1 (Continued)

Name and location	Docket No.	Application date	Start of ASLB hearing	License issued	Principal issues of hearing
1968 (Continued)					
Rancho Seco, Sacramento County, Calif.	50-312	11/67	9/68	10/68	Not contested
Maine Yankee, Lincoln County, Maine	50-309	9/67	9/68	10/68	Sec. 104b license improper
Russellville, Pope County, Ark.	50-313	11/67	10/68	12/68	Not contested
1969					
Cook 1 and 2, Benton Harbor, Mich.	50-315 50-316	12/67	2/69	3/69	Not contested
Indian Point 3, Buchanan, N. Y.	50-286	4/67	3/69	8/69	Thermal pollution, 10 CFR 20 inadequacy
Calvert Cliffs 1 and 2, Lusby, Md.	50-317 50-318	1/68	5/69	7/69	Radioactive discharge, thermal pollution
Hatch 1, Baxley, Ga.	50-321	5/68	9/69	9/69	Not contested
Three Mile Island 2, Three Mile Island, Pa.	50-320	4/68	10/69	11/69	Not contested
Brunswick 1 and 2, Brunswick County, S. C.	50-324 50-325	7/68	12/69	2/70	Not contested
1970					
Diablo Canyon 2, San Luis Obispo, Calif.	50-323	6/68	1/70	12/70	Health and safety of public
Arnold, Cedar Rapids, Iowa	50-331	11/68	3/70	6/70	Not contested
Fitzpatrick, Oswego, N. Y.	50-333	12/68	3/70	5/70	Not contested
Sequoyah 1 and 2, Hamilton County, Tenn.	50-327 50-328	10/68	4/70	4/70	Not contested
Beaver Valley, Shippingport, Pa	50-334	1/69	5/70	6/70	Not contested
Hutchinson Island 1, Hutchinson Island, Fla.	50-335	1/69	5/70	7/70	Thermal pollution, ecology
Shoreham, Long Island, N. Y.	50-322	5/68	9/70		Radiological pollution, internal reactor safety (hearings in progress 4/15/71)
Millstone Point 2, Waterford, Conn.	50-336	2/69	9/70	12/70	Environmental protection, legal power of ASLB
Trojan, Columbia County, Oreg.	50-344	6/69	10/70	2/71	Environmental concern for Columbia River; seismic question
North Anna 1 and 2, Louisa County, Va.	50-338 50-339	3/69	11/70	2/71	Health and safety of the public
Davis–Besse, Ottawa County, Ohio	50-346	8/69	12/70	4/71	Public health and safety, radiation limits
Midland 1 and 2, Midland, Mich.	50-329 50-330	1/69	12/70		Hearings in continuance 4/15/71

4. The Midland MHA fails to consider the generation of large quantities of hydrogen gas within the containment after a loss-of-coolant accident.

5. The Midland MHA fails to consider the synergistic and counterproductive effects of various iodine-release control systems.

6. The Midland preliminary safety-analysis report (PSAR) fails to consider adequately problems that would be encountered if both reactors had simultaneous MHAs.

7. PSAR does not yet state a final design on many safety-related systems, some of which are still in development with no assurance of being completed in time to meet the proposed construction schedule. It is therefore impossible to determine now if the plant will be safe, and granting a permit would be illegal.

8. Exposure to radiation will lead to deterioration of many safeguard components, and there is no assurance they will retain their integrity for 40 years or that they will be adequately inspected or replaced.

9. Quality-control and quality-assurance procedures are inadequate, incomplete, and unacceptable.

10. It has not been demonstrated that economic considerations in the sale of steam to Dow Chemical will not override safety considerations if a shutdown is called for. Nor has danger in the chemical plant resulting from the sudden cutoff of steam been adequately considered.

11. Effects of accidents, leaks, etc., in the chemical plants on nuclear safety have not been adequately analyzed.

12. The MHA does not take into consideration the close proximity of a large chemical plant.

13. Interveners intend to analyze in detail the design and intended operation individually and synergistically of each system and major component. Applicant and AEC will be put to the burden of proof with respect to all legal issues and their factual underpinnings.

14. Emergency plans are inadequate.

The introduction of far-reaching contentions such as these, even if they are answerable, can obviously result in significantly protracted hearings. It should be noted that in this same Midland case a device has been introduced which purports to speed up the hearings by settling some of the issues prior to the hearing. This is the interrogatory system, in which the intervener submits a list of questions to the protagonists to be answered in writing. If the answers satisfy the intervener, there is then no need for the issue to be raised at the hearing. It might be further noted, however, that the intervener submitted 311 questions to Dow Chemical Company, 232 questions to Consumers Power Company, and 337 questions to the Regulatory Staff. It remains to be seen what the effect of this procedure will be.

Operating-License Hearings

In contrast to the construction-permit hearings, in which the applicant is only required to demonstrate that there is reasonable assurance that the plant can be built and operated in such a way that there will be no undue risk to the public, at the operating-license stage the applicant must show that he has indeed accomplished what had been promised at the construction-permit stage. This significantly reduces the options open to the applicant in answering an intervener's contentions since he can no longer defer the problem to a later stage.

Until 1970 there had been no public intervention in operating-license hearings since the previously mentioned Enrico Fermi plant hearings in 1963 and 1964. However, when hearings on the Monticello plant of Northern States Power, in Minnesota, were set for Apr. 7, 1970, intervention was made on radiological health and safety issues. A provisional license for fuel loading and low-power operation was eventually issued September 8, with a full-power operating license issued Jan. 15, 1971, a delay of almost 10 months.

Public hearings for the Palisades plant of Consumers Power Company were convened on June 15, 1970. Intervention on radiological and other safety matters was petitioned, but there has been no actual consideration of these issues as yet, since the hearings have been tied up by various legalistic questions that have required rulings by the Atomic Safety and Licensing Appeals Board. After agreement between Consumers and the interveners on radiation-release limits and installation of cooling towers, the interveners withdrew and a low-power operating license was granted in April 1971. At this time it is not possible to foresee how long the hearings might continue, since further hearings will be held when full-power operation is requested.

Other plants that have been or are being affected by intervention are Consolidated Edison's Indian Point 2 and Commonwealth Edison's Dresden 3. On the other hand, three operating licenses were uncontested in 1970: H. B. Robinson Unit 2; Point Beach Unit 1; and Millstone Unit 1. These plants are presently operating at full design power.

Table 2 Operating-License Data*

Name and location	Docket No.	Application date	Start of ASLB hearing	License issued	Principal issues at hearing
1967					
San Onofre, Camp Pendleton, Calif.	50-206	11/65	NA	3/67	Not contested
Connecticut Yankee, Haddam Neck, Conn.	50-213	7/66	NA	6/67	Not contested
LaCrosse, Genoa, Wis.	115-5	8/65	NA	7/67	Not contested
1968					
No operating licenses or hearings					
1969					
Oyster Creek 1, Oyster Creek, N. J.	50-219	1/67	NA	4/69	Not contested
Nine-Mile Point, Oswego, N. Y.	50-220	6/67	NA	8/69	Not contested
Ginna, Ontario, N. Y.	50-244	1/68	NA	9/69	Not contested
Dresden 2, Grundy County, Ill.	50-237	11/67	NA	12/69	Not contested
1970					
Robinson 2, Hartsville, S. C.	50-261	11/68	NA	7/70	Not contested
Point Beach 1, Manitowoc County, Wis.	50-266	3/69	NA	10/70	Not contested
Millstone 1, Waterford, Conn.	50-245	3/68	NA	10/70	Not contested
Monticello, Monticello, Minn.	50-263	11/68	4/70	1/71	Radiological effects, thermal pollution
Palisades, Covert Township, Mich.	50-255	11/68	6/70	3/71 (1 MW)	Environmental effects, thermal and radiation pollution, quality assurance
Indian Point 2, Buchanan, N. Y.	50-247	10/68	12/70		Radiological effects, thermal pollution

*See footnote to Table 1.

The Role of the Courts

The issuance of a construction or operating permit by the AEC is, of course, subject to federal judicial action. Litigation, introduced by private individual or group interveners and by entities, such as states and utilities, has been carried out in a number of cases involving both construction and operating licenses. Some of the results of these cases have had a significant effect on the licensing process.

For the purposes of this article, the cases can be thought of as being in one of two categories: those directed at a particular reactor system and those whose purpose is to establish or clarify a point of law. Those directed at a particular system are usually based on the contention that adequate standards (i.e., low enough) have not been set for either or both thermal and radiological releases. The effect of these has been mostly indirect; in at least one case (Dresden 3), an applicant has agreed to the imposition of more stringent standards than were required for licensing rather than risk a delay in operation of the plant. The possibility of facing such units undoubtedly is probably one of the reasons that many applicants are installing cooling towers and "zero-release" radioactive-waste systems as original plant equipment.

An outstanding example of the more comprehensive type of suit is the recent action brought against the AEC by the Calvert Cliffs Coordinating Committee, a collection of Maryland civic groups, the Sierra Club, and the National Wildlife Federation. Their contention, that the AEC was not adequately fulfilling the environmental protection role set forth for it in the National Environmental Policy Act, was sustained by the U. S. Court of Appeals for the District of Columbia Circuit.[6] No quantitative estimate of the effect of the decision can be made at this time; however, it will undoubtedly increase the AEC work load, with a good probability of lengthening the licensing process, at least in the short term.

Adequate exploration of the subject of the courts' real and potential impact on the licensing process would require a lengthy article. For the purposes of this report, suffice it to note that court action can have a significant effect and must be taken into consideration when evaluating the licensing process.

TRENDS IN CURRENT LICENSING PROBLEMS

Although the commercial licensing process has been going on for over 15 years, it has been only in the last year or so that the attitude of major segments of the public has had any appreciable direct effect on it. The scarcity of data, then, precludes the determination of any generally applicable established pattern to public intervention, although the situation is changing so rapidly that such patterns could very well be evident by the time this article is published. However, on the basis of available data, along with consideration of the general tenor of thought in the country, some emerging patterns can be identified. These trends are necessarily speculative but are firmly enough founded to require serious consideration by the industry for their future dealings with the licensing process.

First, it is evident that intervention in public hearings is increasing sharply. This seems to be taking place in a random fashion: considerations of geography, population density, the utility involved, etc., show no defensible correlation with intervention. Extrapolation of the rate would indicate that universal intervention in both construction- and operating-license proceedings is not unlikely.

Second, the character of the intervention is changing. The number of principal interveners has increased, and sufficient resources are available that adequate counsel, witnesses, background research, etc., can be obtained.

Third, the interveners themselves are changing, not only in quantity but in quality. They are now becoming organized and, probably more important, know what they want to accomplish, as witness the Dresden 3 and Monticello cases, where significant reductions in both thermal pollution and radioactive-waste release must be attributed in large measure to intervener actions.

Fourth, the tactics used by the interveners have changed. The emerging pattern appears to be to first present legalistic arguments as to ASLB jurisdiction, qualifications of the Board, etc., and next to consider the radiological, environmental, and reactor safety issues. If satisfactory results are not obtained, there is usually material enough for an appeal to the courts. These tactics do not necessarily of themselves accomplish the intervener's purpose, but it is extremely time-consuming and puts great economic pressure on the applicant to accede to the desires of the interveners.

Fifth, the questions asked by the interveners are changing. In radiological and environmental matters, they are more knowledgeable and searching. Most important for the near future, really penetrating questions on internal reactor safety are being asked for the first time, for example, in the Shoreham and proposed Midland cases pointed out previously. It might be noted that this is, as yet, mostly occurring at the construction-permit stage, where only reasonable assurance that a safe plant can be built must be established. At the operating-license stage, where it must be shown that this has indeed been accomplished, the difficulty of satisfactorily answering the questions that are sure to be raised is, of course, much greater.

CONCLUSIONS

Several conclusions can be drawn from the current situation. They are not particularly profound and have been noted, at least in part, in other presentations. They bear repetition, however, owing to their great importance to both the nuclear industry and the country at large.

First, the probability of licenses being delayed has increased to the point that this must be a major factor in the power industry's long-range planning. Whether or not there will be strong public resistance to either the construction or operation of a nuclear power plant cannot be predicted, except perhaps in the affirmative, and possession of an uncontested construction permit does not necessarily guarantee a timely operating license, as witness the Monticello and Palisades cases.

Second, the industry must work to achieve greater overall public understanding than has been done previously. Admittedly, there have been individual efforts that have been quite effective. In general, however, too much reliance has been placed on negative arguments, such as raising the specter of blackouts. This is effective only at the time it happens, and that, of course, is much too late. The conservation-minded public also seems to be little impressed with rising future per-capita or total power requirements since generally this is translated as a not-too-powerful argument for more toasters and air conditioners. Affirmative arguments that appeal to all segments of the public, such as the necessity for a clean source of electric power to minimize further environmental degeneration and, in fact, to clear up the environment that is already fouled, must be emphasized.

Third, the industry must be receptive to feedback from the public. The pressure for power plants to have minimum impact upon the environment is mounting steadily, and industry economic arguments on some aspects of plant design are losing relevance in today's antipollution-oriented climate. It is quite possible that, in some cases at least, inclusion of such design features as cooling ponds or towers and "zero release" from the outset could be less expensive than long delays in plant construction or operation or the retrofitting of such devices in already constructed plants. It might be noted that studies[7,8] of nuclear utility relations with the public have been made which could be valuable reading for any utility intent upon adding nuclear power to its system.

Last, but certainly not least in importance, is the necessity of assuring that reactor safety is on a sound technological basis. Few in industry believe that nuclear power plants are in any way unsafe. If, however, questions such as those noted previously in this article are explored in depth, the subjective nature of some of the judgments that have been made will inevitably emerge. Since safety, at best, is a moving target, a subjective approach is justifiable only for the short term while confirming facts are being obtained. It is extremely important, therefore, that the industry maintain a viable research and development program aimed toward resolving postulated problems in a responsible manner before they rightly or wrongly become public issues.

In the past the public has been content to trust the judgment of the scientists, who design and build the reactor, and the AEC staff. This is no longer true. They now demand proof that safety judgments are soundly based on tests and operational experience as well as on calculations. When the basis for the judgments has been thoroughly tested in public and agreed to be sound, the interventions should become less frequent and disrupting. What seems to be happening now is a timely challenge of the proposition that the AEC and the nuclear community know what is best for the public, what is safe enough, and what is enough protection for the environment. The reply to this challenge must be very convincing, or nuclear power is in for serious trouble during at least the next few years.

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NATURAL RADIATION IN THE URBAN ENVIRONMENT

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Abstract: *Natural radiation is the largest source of population dose and is important as a base line with which radiation-protection standards may be compared. In this article previous work on natural background radiation levels is summarized, and some new data from Boston, Mass., are reported. Gamma dose rates, corrected for cosmic radiation, were measured with large ionization chambers: dose rates inside wooden single-family dwellings were 25 to 50% lower than those outside; in masonry multiple-family dwellings, they were about 10% lower. Concentrations of radon daughters in the air were measured by predecay and postdecay alpha spectrometry: concentrations in dwellings were comparable with outdoor concentrations, but concentrations in basements were higher by a factor of about 5. Concentrations in office buildings were quite low, the radon daughters being removed by the ventilation system. Effects of building type, construction materials, and ventilation on human dose are discussed, as are possible ways of reducing population dose.*

Radiation of natural origin is widely recognized as the largest source of human exposure to ionizing radiation. Natural radiation is generally considered to contribute a dose equivalent of 80 to 200 mrems/year to people in the United States.[1] This may be compared with the genetically significant dose-equivalent average of 55 mrems/year[2] from medical radiation and of less than 5 mrems/year from all other man-made radiation sources.

[*Note Added in Proof:* A genetically significant dose from medical radiation of 36 mrems/year was reported from a 1970 survey at the 49th annual meeting of the American Congress of Radiology, Miami Beach, Fla., Apr. 6, 1972, by R. Brown, R. R. Fuchsberg, and J. N. Gitlin in "Preliminary Dose Estimates from the U. S. Public Health Service 1970 X-Ray Exposure Study."]

The natural radiation to which man is exposed in the United States has not yet been delineated in detail; however, it seems that such a description is necessary as a basis for the evaluation of the significance of man-made increments to radiation exposure. Presented in this article is a preliminary report of a study to determine the feasibility of establishing the dose of natural origin and of exploring possible methods for its reduction. Sources of natural origin include cosmic radiation, radiation from naturally occurring radionuclides in the earth or in materials in man's immediate environment, and radiation from radionuclides within the body. However, for purposes of this study, naturally occurring sources were considered only if they had not been intentionally concentrated. Thus masonry materials were included, whereas such sources as uranium mill tailings, radium dials, and medical radium sources were omitted. Also included is a review of previous measurements of natural-radiation doses supplemented by measurements of cosmic-radiation doses, terrestrial gamma doses inside and outside various buildings, and concentrations of radon-daughter products in the air.

BACKGROUND DATA

Measurements of natural background radiation have been made at numerous places throughout the world. In the United States these measurements tend to fall into three categories. First, single measurements were made at widely varying locations selected on the basis of their convenience to a given laboratory or their unusual geological characteristics. Many of these measurements were made in studies of nuclear weapons fallout.[3,4] Second, aerial surveys were conducted in the vicinity of nuclear installations, and, third, special studies were conducted to estimate background radiation dose rates to a particular group of people.[5-7] American studies of natural background radiation have not generally been concerned with the variability of the radiation background over small areas or short spaces of time. This aspect has been studied, however, by some European investigators.[8-10]

The experimental data in this article are expressed in terms of absorbed dose rate in soft tissue (muscle), usually in microrads per hour (1 μrad/hr = 8.77 mrads/year). Data from the literature, many of which were originally given in terms of exposure rates, have been expressed as absorbed dose rates, using a conversion factor of 1 R as equivalent to 0.95 rad. Where a conversion from absorbed dose to dose equivalent was desired, a quality factor of 1 has been assumed for low linear energy-transfer radiation (beta, gamma, and cosmic), so that the absorbed dose rate is the same as the dose-equivalent rate. For the neutronic component of cosmic rays and the alpha radiation from radon and its daughters, the specific quality factor used is given with the data.

Cosmic Radiation

Cosmic rays, at the altitudes where man can live, consist of an ionizing component, mainly muons (μ-mesons) and electrons, and a neutron component.[11] Estimation of the dose equivalent received from cosmic radiation has been difficult because of uncertainties as to the neutron spectrum and its associated quality factor. The dose rate from the ionizing component at sea level in middle latitudes is considered to be about 28 mrads/year (Ref. 11). The best value for the neutron dose rate, again at sea level in middle latitudes, is probably about 0.7 mrad/year (Ref. 11), as compared with a previous estimate of 2 mrads/year (Ref. 1).

The variation of exposure rate from cosmic radiation with altitude and latitude is well documented.[1,11,12] At 50° geomagnetic latitude, the cosmic-ray intensity at 5000 ft is 60% greater than at sea level; at 10,000 ft, it is more than three times the sea-level value. Variation with latitude is much less. At sea level the cosmic-ray intensity at the poles is perhaps 12% greater than at the equator. There is a somewhat greater latitude effect at higher altitudes, but even at 10,000 ft it is only about 50% greater at the poles than at the equator. Within the United States the latitude effect may be neglected for all practical purposes.

The cosmic-ray dose to people in aircraft is of some interest. O'Brien and McLaughlin[13] estimated the dose rate from cosmic radiation at 55° geomagnetic latitude to be 0.24 to 0.29 mrad/hr (0.28 to 0.38 mrem/hr) at 11 km (36,000 ft) and 0.81 to 0.93 mrad/hr (1.05 to 1.35 mrems/hr) at 20 km (65,500 ft). An International Commission on Radiological Protection task group[14] estimated the dose rates in polar latitudes to be 0.70 mrad/hr at 60,000 ft, 0.81 at 70,000 ft, and 1.34 at 80,000 ft. The corresponding dose-equivalent rates are 1.23, 1.80, and 3.10 mrems/hr. The average dose equivalent to the U. S. population from air travel can be estimated at less than 1 mrem/year from data given by Schaefer.[15]

Terrestrial Radiation

Terrestrial radiation includes beta and gamma rays from radionuclides in rock and in soil. The major contributors to terrestrial gamma-radiation dose are ^{40}K and the ^{238}U and ^{232}Th decay series, in the approximate ratio 2 : 1 : 2. A number of literature surveys of terrestrial gamma dose are available.[1,11,12,16-18]

Terrestrial gamma-radiation exposure is strongly influenced by geology.[1,12] Over large freshwater lakes, for example, there is virtually no terrestrial gamma radiation. Highest values are observed over acidic igneous rocks, such as granites, where dose rates up to 350 mrads/year have been found. In a few places, primarily monazite areas, dose rates as high as 1300 mrads/year have been observed. Radiation from terrestrial gamma sources is also affected by meteorological conditions. Probably the most important effect is shielding by snow cover and by moisture in the soil after heavy rains.[8,19]

Published data on the beta contribution to the terrestrial dose differ somewhat. At 1 m above the ground, beta radiation has been estimated to contribute from 4% (Ref. 20) to 25% (Ref. 21) of the total. More recent estimates[4,22] of the beta dose rate at 1 m above the ground are 3 to 4 μrads/hr (26 to 35 mrads/year), or about 30% of the total. The beta contribution to genetic dose is less than this because of shielding by the body.

Radon and Daughters

The naturally occurring radioactive gas radon (^{222}Rn) is a daughter of ^{226}Ra. It reaches the atmosphere by effusion from the earth. The isotope thoron (^{220}Rn), a member of the thorium decay series, reaches the atmosphere in a similar manner but to a much smaller extent since its half-life is much shorter. Both radon and thoron have a number of short-lived radioactive daughter nuclides that become attached to air particulates. Radon concentrations in the atmosphere vary from about 0.01 to 1.0 pCi/liter. Thoron concentrations outdoors vary from about 0.0001 to 0.01 pCi/liter. Concentrations of these gases and of their daughters are markedly affected by geology, by ease of diffusion from the ground, and by meteorological conditions. The daughter products become attached to dust particles and may be removed by natural aerosol clearing processes.

Radiation Within Buildings

The radiation dose within a building is affected by the nature of the building materials, which act as both a source and a shield. Since an average person (in western urbanized cultures) spends upward of 80% of his lifetime indoors, population dose estimates that disregard this fact can be very unrealistic. Exposure levels within brick, concrete, and stone buildings tend to be substantially higher than those in wooden houses or outdoors, as shown in Table 1, which gives data on measurements within buildings in various countries. It should be noted that measurements were made by

Table 1 Gamma Dose Rates Inside Buildings

Country	Exposure rate, mrads/year	Technique*
Germany (East)[10]	106; up to 1200	a
Germany (West)[23] and Switzerland	120% of outdoor	a
Japan[24]	29 to 41 (wood, Tokyo)	
	80 to 100 (wood, Kyoto)	e
	48 to 68 (concrete)	
Japan[25]	20 to 40	c
Poland[9]	84 to 106 (97 apartments, Warsaw, Lodz, Silesia)	c
Sweden[8]	48 to 57 (wood)	
	99 to 112 (brick)	a
	158 to 202 (concrete)	
United Kingdom[26]	73 to 94 (wood)	d
	87 to 122 (granite, Leeds, Aberdeen)	
United Kingdom[27]	26 to 70 (brick, concrete, London, Sutton)	d
United Kingdom[28]	145 (granite, Cornwall)	d
United States[29]	60 (wood)	b
	130 (concrete)	
United States[30]	55 to 110 (wood)	a
	60 to 120 (brick, stone)	
United States[6]	70% of outdoor, wood	a
Australia[31]	11 to 35 (wood and asbestos, coastal plain)	
	41 to 127 (brick, coastal plain)	b
	32 to 193 (brick, Darling range)	

*a = Ionization chamber, gamma + cosmic; b = ionization chamber, cosmic contribution subtracted; c = sodium iodide scintillator; d = Geiger–Mueller counter, cosmic contribution subtracted; and e = plastic scintillator.

several techniques, so that the results are not comparable. In particular, several investigators subtracted the cosmic-ray contribution, so that their data refer to terrestrial gamma contribution only, whereas others did not. Scintillation techniques, especially with sodium iodide scintillators, probably underestimate the cosmic-ray component, so that values obtained by these techniques represent dose levels between gamma only and gamma plus cosmic. Most of the results are for one- and two-story buildings. Pensko[9] and Ohlsen[10] have recently provided data for multistory buildings in Poland and East Germany, but no comparably extensive data appear to be available for the United States. The weighted average of Ohlsen's values is 101 mrads/year, but values up to 200 mrads/year were not uncommon. The two highest values were 450 and 1200 mrads/year.

A few authors[32–34] have examined building materials for their radioactive-material content. As would be expected, the dose rates were found to vary considerably depending on the origin of the building materials.

The concentrations of radon and thoron and of their daughters within buildings are of importance since, in general, the levels indoors are higher than those outdoors and are dependent on the construction materials and on the ventilation rate. Radioactive gases may be evolved readily from some building materials.[35,36] This effect may be particularly great when the materials are warmed, as occurs especially with radiant heating systems. Sievert[17] has summarized the concentrations of radon and its daughters in various types of buildings. The average level of radon in buildings has been estimated[11] as 0.5 pCi/liter, with a corresponding thoron average of 0.02 pCi/liter.

METHODS AND RESULTS

Cosmic Radiation

In the new measurements reported here, two kinds of 16-liter ionization chambers were used for gamma-plus-cosmic-ray exposures. One chamber[37] (MEC) had 6-mm muscle-equivalent walls and contained muscle-equivalent gas. The other chamber[38,39] (FFC) was filled with dry Freon-12 (dichlorodifluoromethane) containing less than 1.5% impurities. The walls of this chamber were polymethylmethacrylate (PMMA), 400 mg/cm^2.

Each chamber was connected to a Cary vibrating-reed electrometer, which in turn was coupled to a chart recorder and to a voltage-to-frequency converter and scaler. The converter–scaler combination made it possible to integrate the very small ion currents over a period of 5 min, giving results reproducible to within 2%.

The two chambers were calibrated with a 1.72-mCi ^{226}Ra standard source. The source–chamber distance was 4 m. Corrections were made for the absorption in air and in the source container and for wall scattering.

A daily calibration check of the FFC showed that the response declined with time. It was also observed that the pressure dropped from 41.7 torrs above atmosphere to 81.0 torrs below atmosphere over a period of 4 months. Both the change in response and the loss of pressure were attributed to loss of Freon-12, apparently by dissolution in the PMMA walls followed by evaporation from the outer surface of the chamber.

Cosmic radiation was measured with these instruments in a boat on Quabbin Reservoir, a large freshwater lake. Under such conditions, virtually the total ionization is due to cosmic radiation since the instruments are shielded from terrestrial radiation by the water and the long air path to shore.

Cosmic-ray physicists normally report their data in terms of I, the number of ion pairs produced per second per cubic centimeter of air. This measurement is essentially the same as the measurement of exposure rate in roentgens, one ion pair per second per cubic centimeter being equivalent to 1.7 μR/hr. Since neither the MEC nor the FFC is air filled, the I values were calculated from the ionization current by correction for the nature of the gas.

With the FFC, the ionization density I was found to be 2.18 ion pairs per cubic centimeter per second, or 2.06 when corrected to sea level.[38] This measurement compares well with reported values of 2.1 (Ref. 40) and 2.18 (Ref. 38) ion pairs per cubic centimeter per second. The measurement of I with the MEC was 2.57, corrected to sea level, or 25% higher. This discrepancy may be due to an incorrect ionization-efficiency factor for the gas (as compared with air), to response to the neutron component, or to some unknown effect. It was not due to instrument malfunction, since the exposure-rate measurements on the instruments, which are relative to radium calibrations, agreed. They were 4.27 μR/hr (37 mR/year) for the FFC and 4.43 μR/hr (39 mR/year) for the MEC, both corrected to sea level. In terms of absorbed dose, these measurements become 4.06 μrads/hr (35 mrads/year) and 4.21 μrads/hr (37 mrads/year) for the two instruments.

When these measurements were made, the air concentrations of radon daughters were not determined. Failure to correct for their contribution introduced an error into the measurements. However, this error can be estimated as about 3% from the work of Pensko,[41] in Poland, who found the contribution to gamma radiation from radon daughters to be 0.13 μrad/hr in 1964 and 0.14 μrad/hr in 1965. In spite of diurnal variations in radon content, the error is not expected to be greater than this because the readings were made during the afternoon on a clear, sunny day. Under these circumstances, radon-daughter concentrations are generally not at a maximum.

Gamma Radiation

Gamma-radiation dose was measured at 1 m above the ground or floor with the MEC and FFC chambers described previously. Use of two chambers simultaneously provided a check against spurious readings that sometimes occur in measuring extremely small currents through very high resistors. These chambers had been calibrated in roentgens, using gamma radiation from radium. The readings have been converted to absorbed dose, however, as previously described. To the extent that beta radiation can penetrate the chamber walls and produce ions, the beta dose is also included. In the actual situation, of course, the ionization in the chambers is produced by gamma radiation from the surroundings (plus beta, if any) and also by cosmic radiation. The dose from terrestrial sources is therefore obtained by subtracting the cosmic-ray dose values from the total. The values obtained at Quabbin Reservoir, corrected for the difference in altitude between Quabbin and Boston, were used for the subtraction. No correction was made for absorption of cosmic rays by building materials, since the cosmic radiation at sea level is very hard.

In these measurements the chief concern was the radiation levels within buildings. In many cases, outdoor levels were also measured for comparison.

Single-Family Dwellings. Table 2 shows the absorbed dose rates due to natural gamma radiation in seven single-family dwellings. These were wood-frame houses with poured-concrete basements. Since no significant differences were found between measurements with the MEC and the FFC, the dose readings were averaged.

Table 2 Gamma Dose Rates (μrads/hr) in Single-Family Dwellings*

Place	Outdoors	Basement	First floor	Second floor
ASG	6.2	5.3	5.0	
MWF			7.3	
FSH	9.0		6.8	
WAB	4.9	4.9	4.2	2.5
SP	8.1	6.2	4.3	4.1
FJV	5.8	6.0	4.4	
DWM	6.5	6.8	6.2	3.2

*A cosmic-ray contribution of 4.1 μrads/hr has been subtracted from all values.

It can be seen that the dose from natural gamma radiation is reduced by 25% inside on the first floor and 50% on the second floor (assuming cosmic rays are not attenuated in a wooden building). The dose rates will of course not be reduced by this large a percentage, since a constant cosmic-ray contribution of 4.1 μrads/hr must be added to all values to obtain the total dose rate.

Multiple-Family Dwellings. Measurements were made in three multifamily dwellings. These were what are normally called "brick" buildings, but details of their construction were not available. For example, it is not known whether these buildings were solid brick, brick facing on concrete block, or some other type of construction. Measurements were made in one residence in each apartment building. Each residence happened to be on the second floor. Only in one case was a corresponding outdoor measurement made. The measurements are given in Table 3.

Table 3 Gamma Dose Rates (μrads/hr) in Multiple-Family Dwellings*

Place	Outdoors	Second floor
MLC		6.2
JS		7.5
OG	7.2	5.5

*A cosmic-ray contribution of 4.1 μrads/hr has been subtracted from all values.

The average for the three apartments, 6.4 μrads/hr, is substantially greater than the average value for the three second-floor readings in single-family dwellings (Table 2). This indicates additional dose, which may be attributed to radioactive nuclides in the construction materials. In the one case where a comparison with the outdoor exposure is available, the gamma radiation is lower by 24%, showing that the terrestrial radiation is attenuated by the building materials. In this case the attenuation more than compensates for the radiation contributed by radionuclides in the construction material.

Multistory Office Buildings. Measurements were made in four office or office-plus-laboratory buildings. The most extensive series of measurements was made in the Harvard School of Public Health (HSPH) Research Building 1. This is a modern 14-story office-plus-laboratory building of reinforced-concrete construction with interior wall facings of cinder block. Measurements were made in the corridors of several floors to investigate the variation of exposure rate with height in the building (Table 4).

These measurements were made in part to test whether the attenuation of terrestrial gamma radiation on the upper floors would be greater or less than the possible attenuation of cosmic radiation on the lower floors. The data of Table 4 show a fairly constant radiation level for the first eight floors in the HSPH building and then a slight decrease. These data were supported by nonspectrometric gamma measurements with a 3- by 3-in. NaI(Tl) crystal (Fig. 1). A possible

Table 4 Gamma Dose Rates in Office Buildings

Building	Year completed	Construction	Interior walls	Height, stories	Floor	Gamma dose rate,* μrads/hr
JFK	1966	Reinforced concrete	Sheetrock partitions	23	Basement	6.7
					5	4.8
					20	4.9
					23	6.5
HC	1962	Reinforced concrete	Sheetrock partitions	10	2	9.0
SO	1917	Steel and concrete	Sheetrock partitions	12	Basement	5.5
					5	7.2
					12	7.3
HSPH†	1969	Reinforced concrete	Cinder block	14	Basement	7.3
					1	7.5
					3	7.4
					7	8.9
					9	7.8
					11	4.6
					12	6.7
					13	5.8
					14	6.8

*A cosmic-ray contribution of 4.1 μrads/hr has been subtracted from all values.
†First four floors, 1962; next 10 floors, 1969.

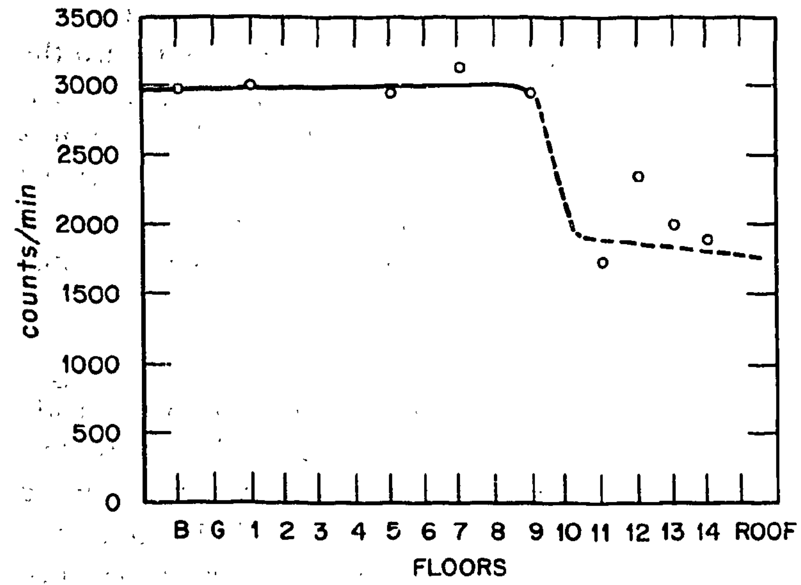

Fig. 1 **Total gamma count rates on various floors.**

explanation is shielding by heavy machinery on the 10th floor.

Measurements were also made on four floors of the John F. Kennedy Federal Building (JFK) in Government Center, Boston. This is a 23-story steel-and-concrete building that was completed in 1966. Interior walls are Sheetrock partitions. All measurements in this building were taken in office spaces. In addition, measurements were made on three levels of an older office building (SO) housing part of the Massachusetts Department of Public Health and on the second-floor level in the main building at the Holyoke Center (HC) of Harvard University. The HC building had a slightly higher dose rate than the other buildings tested. This may be attributed to differences in the radionuclide content of the concrete. The data for these three buildings are also presented in Table 4. The average gamma dose rate in these buildings was 7.3 μrads/hr, the cosmic-ray contribution having been subtracted.

The data of Table 4 fail to show any significant change with height in the buildings. It can be inferred that the gamma dose measured originates primarily in the building itself and that the cosmic-ray dose is not significantly attenuated. This is in agreement with Ohlsen,[10] who reported no change in radiation-exposure rates on various floors of multistory buildings.

Radon-Daughter Concentrations

The daughter products of ^{222}Rn are not generally present in the air in equilibrium concentrations. It was therefore necessary to measure the absolute concentration of each daughter, using a modification of Duggan's[42] method. Radon-daughter products, attached to air particulates, were collected on a membrane-filter apparatus, shown in exploded view in Fig. 2. An alpha spectrum of these particulates was taken during the 30-min sampling period and again after a 30-min decay period. Figures 3 and 4 show typical examples of these two spectra. The first is characterized by peaks at alpha energies of 6.00 and 7.68 MeV, corresponding to ^{218}Po and ^{214}Po; the second shows only the single 7.68-MeV peak. The counting rates in each peak were corrected for geometric efficiency[43] and peak overlap. Self-absorption loss was taken to be zero. At a flow rate of 15 to 20 liters/min, sensitivity was about 0.01 pCi/liter for each of the three significant short-lived daughters ^{218}Po, ^{214}Pb, and ^{214}Bi. At this level precision is poor, but the method is quite satisfactory over the range 0.1 to 100 pCi/liter. The determination does not give the concentration of ^{222}Rn itself, but this can be approximated[44] by using the ratio ^{222}Rn/^{218}Po = 1.12.

Ventilation rates, which affect the state of equilibrium of the radon daughters, were measured by injecting about 0.5 lb of CO_2 into the room from a CO_2 fire extinguisher. The CO_2 concentration was measured with Kitagawa low-range tubes after a mixing period of several minutes and again at a suitable later time. The ventilation rate (air changes per hour) was then calculated.[45]

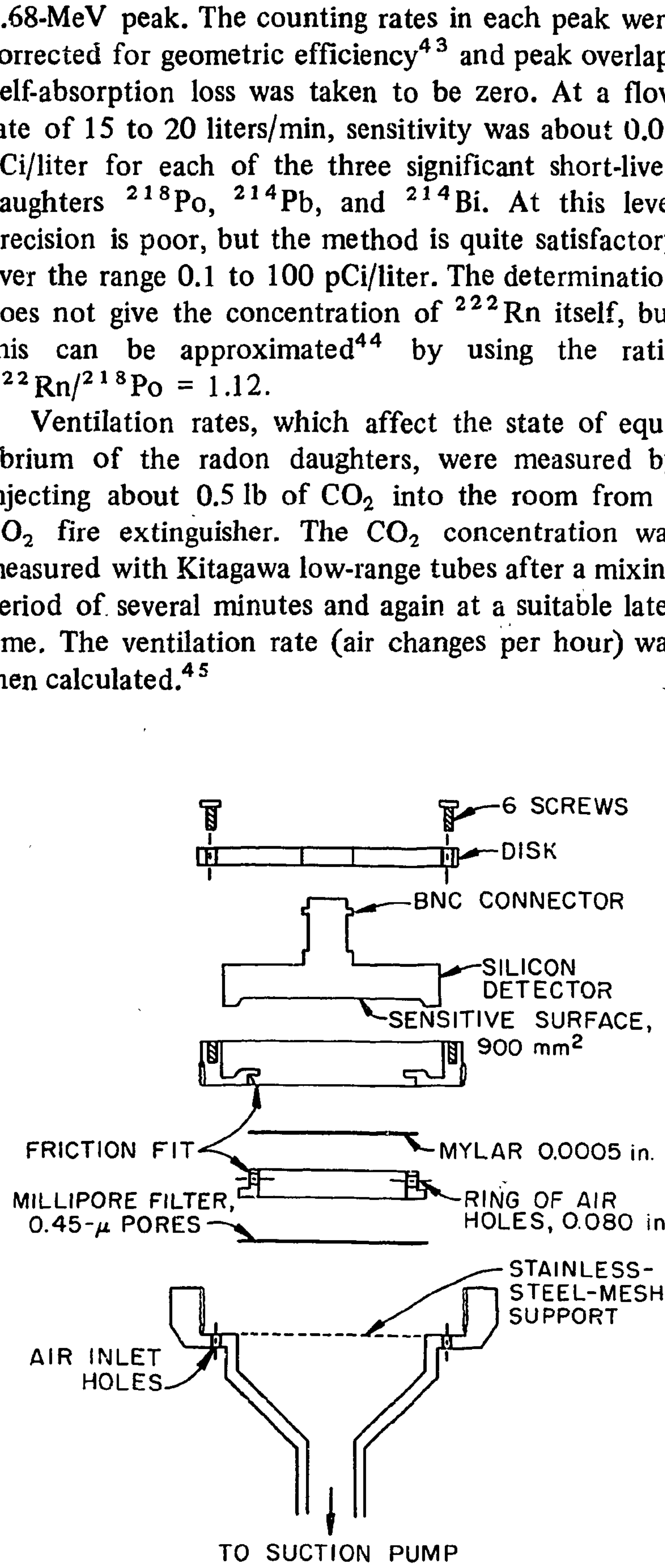

Fig. 2 **Air filter and alpha-spectrum detector (exploded view).**

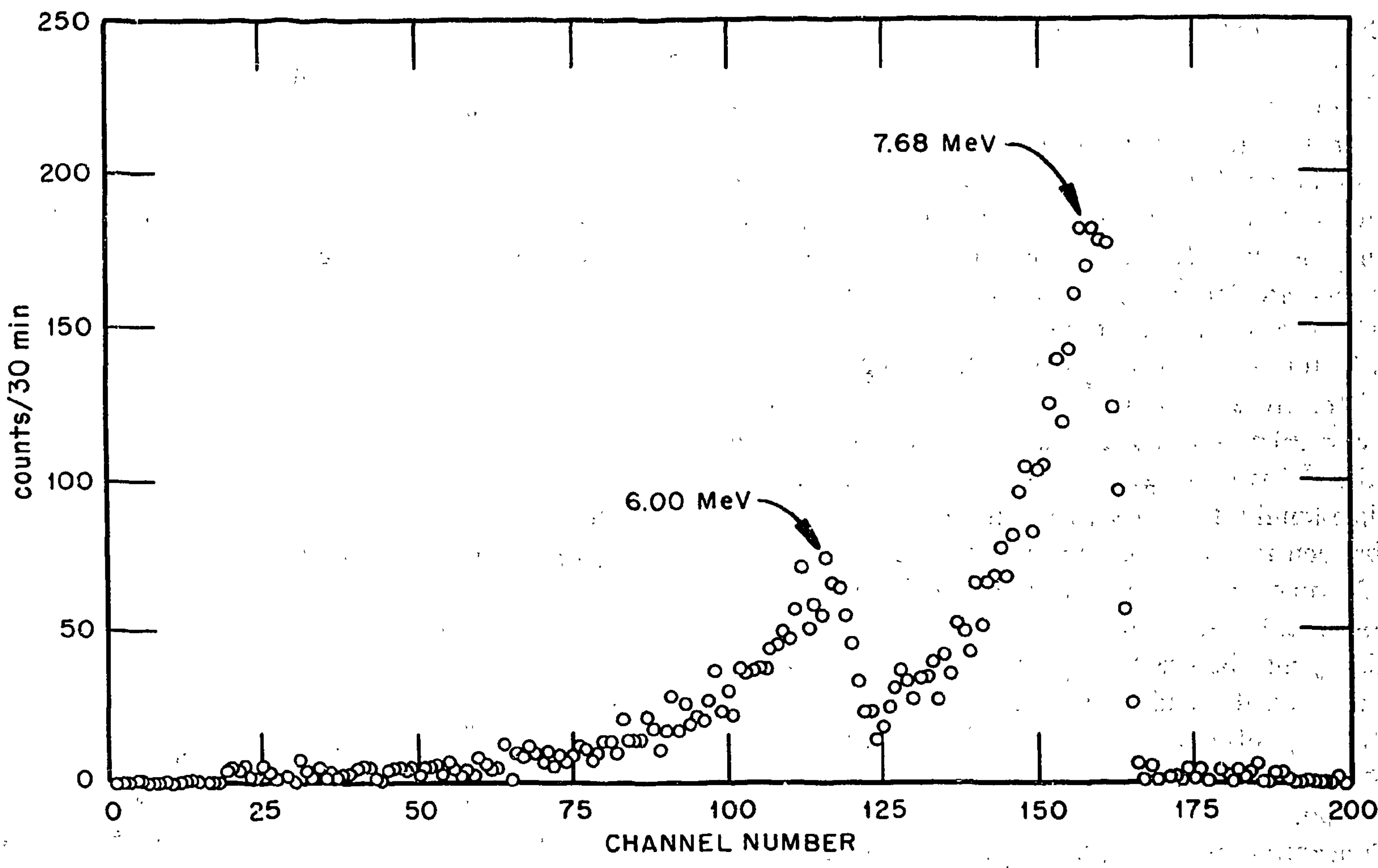

Fig. 3 Radon-daughter alpha spectrum during collection period.

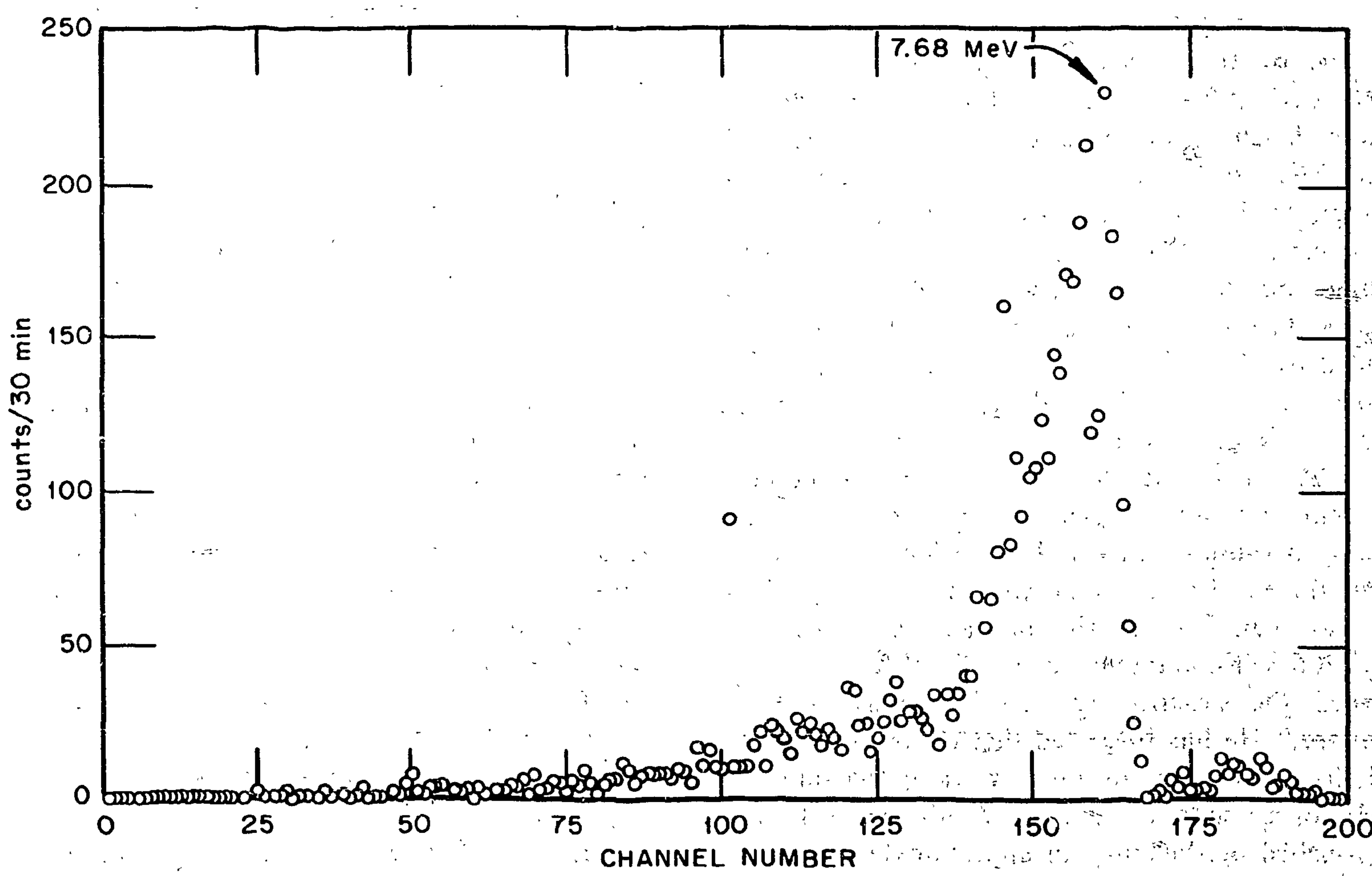

Fig. 4 Radon-daughter alpha spectrum after 30-min delay.

Because of the exchange of air between the room being measured and the remainder of the building, the ventilation rate obtained by this method may have been greater than that for the whole apartment or building in which the room was located. In some cases, however, it was not feasible to fill the whole apartment or building with an equal concentration of CO_2, so more accurate determinations were not possible.

All measurements of radon-daughter concentrations in this study were made in the summer months and therefore are limited by any seasonal effects that may exist. The concentrations of the various nuclides and the ratios of these concentrations for single- and multiple-family dwellings are summarized in Table 5. It can be seen that the concentrations in basements were 4 to 23 times those found on the first floors, with the exception of the basement of WAB, which was ventilated just before this measurement. The concentrations outside and inside wood houses are not significantly different. The low levels of concentration in apartment buildings are thought to be due to better ventilation.

Concentrations of radon daughters in the four office buildings were also quite low. All the buildings had central air conditioning except the SO building, which had a number of individual units. Most of the radon daughters in office buildings were thus removed by the filtering system and the rapid circulation of air. Table 6 shows the concentrations measured.

The data of Tables 5 and 6 show a general decline of radon-daughter concentrations with increased ventilation. The concentration of the third radioactive daughter, ^{214}Po, relative to the others, seems to be a little lower in dwellings with three or more air changes per hour, but this trend is not apparent in the office buildings (Table 6). It may be that the filtration provided by the air-conditioning systems in the office buildings removes all the daughters to an extent sufficient to hide the depletion of ^{214}Po.

Calculation of the absorbed dose and of the dose equivalent from radon daughters is not straightforward, primarily because of uneven distribution of the daughters in the respiratory tract and in the body. Much work has been done on this problem, particularly in connection with uranium miners. Parker[46] has aptly described the situation as "The Dilemma of Lung Dosimetry." He has suggested that exposure to radon daughters amounting to one "working-level-month" (WLM) corresponds to a dose of 7 rads to a portion of the bronchial epithelium. An approximate calibration for the levels observed in air in buildings may be obtained from this. The "working level" was defined[47] as that amount of radon daughters that would liberate 1.3×10^5 MeV of alpha energy per liter. This corresponds to a concentration of 100 pCi/liter of each of the three nuclides ^{218}Po, ^{214}Pb, and ^{214}Bi. The WLM is equivalent to exposure at this level for 173 hr. If these values are translated to the building situation and if exposure for 24 hr/day, 365 days/year is assumed, then a concentration of 1 pCi/liter would correspond to

$$\frac{(7000)(365)(24)}{(173)(100)} = 3500 \text{ mrads/year}$$

Quality factors of 10 to 20 have been recommended for alpha radiation, so that a concentration of 1 pCi/liter corresponds to 35 or 70 rems/year.

DISCUSSION

The data presented in this paper indicate that there can be substantial differences in the doses received from sources of natural origin, depending on the mode of life of the individual. For example, cosmic dose would be highest for those population groups living at high altitudes or latitudes, for those whose recreation involves skiing or mountain climbing, and for those whose work or pleasure includes considerable air travel. The greatest dose from terrestrial sources would be received by those population groups living on land containing high concentrations of naturally occurring radionuclides and those living in certain brick, stone, or concrete buildings. Those living in poorly ventilated homes, especially in basement apartments, or working in poorly ventilated buildings would receive the greatest dose to the lungs.

The increased doses received by some people under the above-mentioned conditions are not trivial. Based on data collected in the greater Boston area, the differences in dose rates for persons living on the second floor are as much as 35 mrads/year. These dose (rad) values are the same as dose-equivalent (rem) values since the quality factor of this beta–gamma and cosmic radiation is 1. A difference of 35 mrems/year is more than half as much as the estimated genetically significant population dose from medical uses of radiation[2] and far higher than any projections of population dose from nuclear power applications in the near future. Of course, the population or genetic significance of dose differences from various kinds of buildings depends on the fraction of the population living in each type. Relatively few people live in

Table 5 Radon-Daughter Concentrations in Dwellings

Code	Location	Concentrations, pCi/liter			Ratio	Number of air changes per hour
		^{218}Po	^{214}Pb	^{214}Po		
		Single-Family Dwellings*				
ASG	Outside	0.04	0.04	0.03	1 : 1 : 0.8	
	1st floor	<0.005				
	Basement	~0.1				
MWF	1st floor	0.04	0.04	0.02	1 : 1 : 0.5	6
FSH	Outside	0.01	0.01	0.007	1 : 1 : 0.7	
	Inside	0.06	0.06	.06	1 : 1 : 1	2
WAB	Outside					
	1st floor	0.23	0.17	0.17	1 : 0.7 : 0.7	2
	2nd floor					
	Basement	0.14	0.16	0.05	1 : 1.2 : 0.4	3
SP	Outside	0.03	0.02	0.04	1 : 0.7 : 1.3	
	1st floor	0.03	0.03	0.02	1 : 1 : 0.7	
	2nd floor	0.03	0.02	0.01	1 : 0.7 : 0.3	
	Basement	0.30	0.26	0.16	1 : 0.9 : 0.3	3
FJV	Outside	<0.01				
	1st floor	0.04	0.04	0.04	1 : 1 : 1	3
	Basement	0.94	0.97	0.84	1 : 1 : 0.9	1
DWM	Outside					
	1st floor	0.12	0.15	0.13	1 : 1.2 : 1.1	2
	2nd floor					
	Basement	0.52	0.46	0.34	1 : 0.9 : 0.6	1
		Multiple-Family Dwellings†				
MLC	2nd floor	0.01	0.01	0.01	1 : 1 : 1	
JS	2nd floor	0.07	0.07	0.03	1 : 1 : 0.4	9
OG	Outside	0.15	0.09	0.07	1 : 0.6 : 0.5	
	2nd floor	0.19	0.18	0.13		5

*All single-family dwellings were wood frame with poured-concrete basements.
†All multiple-family dwellings were brick.

Table 6 Radon-Daughter Concentrations in Office Buildings

Code	Type of building	Interior walls	Location	Concentration, pCi/liter			Number of air changes per hour
				RaA	RaB	RaC	
HSPH	Offices and laboratories	Cinder block	Basement				
			1st floor	~0.02	0.02	0.02	6
State offices	Offices	Sheetrock	5th floor	0.08	0.08	0.08	6
			12th floor	0.10	0.11	0.13	7
			Basement	0.05	0.04	0.05	
Holyoke Center	Offices	Sheetrock	2nd floor	0.05	0.04	0.04	7
JFK	Offices	Sheetrock	5th floor	0.03	0.02	0.02	12
			20th floor	0.05	0.04	0.01	5
			23rd floor	0.04	0.03	0.03	14
			Basement	0.07	0.07	0.03	

basement apartments; a much greater percentage live in brick or masonry homes.

More dramatic differences exist in the dose equivalents to lung, specifically to basal cells in small bronchi. Radon daughters are the major contributors to the dose equivalent. The concentrations of these daughters in basements with one air change per hour were from 4 to 15 times higher than those on the first floors of the same houses, with two to three air changes per hour. The average level of ^{218}Po in five basements was about 0.4 pCi/liter. Using the previously calculated relation between dose and radon-daughter concentration, this average level would correspond to a dose rate of 1400 mrads/year. Reduction of radon-daughter concentrations by a factor of 10, which is approximately the average ratio between basements and first floors, would amount to a dose reduction of 1250 mrads/year. Application of the recommended quality factor of 10 to 20 for alpha radiation would convert this to 12.5 or 25 rems/year to some basal cells in the bronchial epithelium.

Implications

Health physicists generally have paid little attention to the control of radiation exposure received by the population from natural sources. It appears probable, however, that significant reduction of radiation dose may be achieved in the design of living and working environments. The relative constancy of dose levels on various floors of masonry office buildings, noted here and by Ohlsen, suggests that most of the gamma radiation originates in construction materials rather than in the ground. Provision of better ventilation and air-filtration systems, reduction of the number of basement dwelling units, and screening of construction materials to eliminate those which emit excessive radiation would seem to be promising areas of investigation. Such reduction of population dose equivalent received from buildings may well be comparable with the projected increase from development of nuclear power.

Although definitive data are lacking, it may well be that some people, because of the nature of their environments, are experiencing unnecessarily increased exposure to radiation from sources of natural origin and that this increased exposure is greater than that expected from many man-made sources. Considering this possibility, it would seem wise that greater attention be given to obtaining data on the population dose equivalent from natural sources and the influence of man's living habits on this dose.

Prospectus

Older construction, even in central cities, was largely wood. The data for Boston[48] may be cited as an example. As of January 1968, 68.5% (96,689) of all buildings in Boston were of wood construction. The remaining 31.5% (44,546) were made up of a variety of types, the older ones being predominantly brick and the newer ones concrete or cinder block.

In the newer construction, there is a shift from predominantly single- to multiple-family-dwelling construction. The Boston building-permit records for the period 1959 to 1968 indicate that the number of single-family dwellings decreased from 95% of the total number constructed to 33% and that multifamily (three or more) dwellings increased from 1% of the number constructed to 58%. There was an increase in two-family dwelling construction from 2% in 1959 to a high of 26% in 1965, followed by a decline to 8% in 1968.

The large increase in the number of multifamily dwellings implies a large increase in the fraction of the Boston population living in masonry buildings since virtually all the new multifamily dwellings are of masonry construction. Although quantitative data are not available, observations indicate that more masonry apartment buildings are being built in the suburbs as well. It therefore appears that the urbanization and suburbanization of the population are accompanied by an increase in the fraction living in masonry construction.

To the extent that masonry construction is increasing, higher external exposure of occupants may be expected. To the extent that newer buildings include modern ventilation systems, lung exposure to radon daughters may be decreased.

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THE REGULATION OF THE ENVIRONMENTAL EFFECTS OF NUCLEAR POWER PLANTS (PART I)

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Abstract: *This is the first of a series of two articles, and it presents a survey of the regulation of environmental features of nuclear power plants. Receiving particular attention is the jurisdiction of the Atomic Energy Commission under the Atomic Energy Act of 1954, and its expansion under the National Environmental Policy Act of 1969. Several other federal agencies, including the Federal Power Commission, the Corps of Engineers, and the Environmental Protection Agency, also play important roles in this area. In addition, there have been interesting recent developments in the State regulatory picture in the field of power-plant siting.*

"[W]e are living in a high-energy civilization in which man has been freed from many physical burdens and has become productive enough to enjoy the pleasures of education, affluence, and leisure. An abundant supply of low-cost energy is the key ingredient in continuing to improve the quality of our total environment."—Dr. Lee A. DuBridge[1]

"The environment of a city whose life's energy has been cut, whose transportation and communications are dead, in which medical and police help cannot be had, and where food spoils and people stifle or shiver while imprisoned in stalled subways or darkened skyscrapers—all this also represents a dangerous environment that we must anticipate and work to avoid."—Dr. Glenn T. Seaborg[2]

Opinions differ as to whether the United States is, at this time, in an "energy crisis"[3] or will soon be in such a situation. The 1970 report on "Electric Power and The Environment" by the Energy Policy Staff of the President's Office of Science and Technology (OST Study) summarizes the status of electric-power demand today and in the immediate future.[4] As noted in the OST Study, the use of electricity in the United States has doubled approximately every 10 years for many decades, and, if prevailing growth patterns and pricing policies are continued, generating capacity may have to be tripled or quadrupled in the next 20 years. The majority of such new units would be nuclear or fossil-fueled steam power plants.

The OST Study notes that "[T]he new concern over the environment or other factors may alter this historical rate of growth and some suggest that growth rates should be reduced." However, since electricity is a "clean form of energy at the point of consumption" where pollution problems tend to be most acute, and since electric power may be increasingly utilized for environmental protection purposes like mass transit and waste recycling, it is probable that the demand for electricity will continue to increase in the foreseeable future.

The OST Study, noting the present uncoordinated federal and state provisions for preconstruction review of electric-power industry expansion projects, recommends legislation to ensure that "[n]ew public agencies and review procedures . . . take into account the positive necessity for expediting the decision-making process and avoiding undue delays in order to provide adequate electric power on reasonable schedules while protecting the environment." The unanswered questions are, of course, how much electric power is "adequate" and who is to make that determination.

ENVIRONMENTAL BENEFITS OF ELECTRIC POWER

Our society has come to take plentiful and reliable power for granted. Cities are complex ecosystems, increasingly dependent upon electric energy for propulsion, communications, indoor climate control, and other vital services. This article will focus on many of the environmental effects that accompany power-plant operations, but the reader should be aware throughout that a decrease in the amount or reliability of power supplied to our homes and industries, resulting from concern for these environmental factors, might produce other environmental consequences equally severe.

For example, if the electric motors, heating units, and similar equipment used in industry were to be replaced by local combustion sources such as steam engines, gas turbines, or diesels, we would expect an increase in local air pollution, noise, and fuel-handling accidents. The elimination of electrical space heating and air conditioning would contribute to less healthy home and work environments. Particularly in southern sections of the country, the absence of air conditioning could cause sharp decreases in productivity as well as direct adverse effects on the health of persons whose tolerance of heat stress is limited.

The health effects of an interruption of electric power to home and commercial refrigerators and freezers are obvious. The "Northeast Blackout of 1965" dramatically showed us how much we rely on electricity for transportation, both horizontal (subways) and vertical (elevators). The social implications of curtailing the use of electricity at a time of rising expectations of the urban poor are also legitimate concerns.

The reader is invited to consider the myriad applications of electricity in his own life and decide those which he would be willing to give up to preserve *environmental integrity and those of which he would* deprive his neighbor.

NUCLEAR ENERGY— A TECHNOLOGICAL TYGER

The regulation of nuclear power plants presents a unique challenge to the field of administrative law. The reactor is a technologically sophisticated device, the detailed workings of which may be fully comprehended only by experts, or rather by teams of experts, since many scientific and engineering disciplines are involved in its design and operation. The reactor utilizes an energy source, nuclear fission, which first came to public attention amidst the horrors of war. One of the major effects, nuclear radiation, is essentially undetectable by the unaided senses even at levels where it may cause acute damage. Understandably, the average citizen approaches the use of so fearful a machine with some trepidation.[5]

In recent years, public concern over the effects of nuclear power plants on the environment has led to organized opposition to proposed plants, to changes in the radiation standards and licensing procedures of the Atomic Energy Commission (AEC), and to federal and state legislation, referenda, and numerous lawsuits. Events during 1970 and 1971, the first years of what has been called the "Environmental Decade,"[6] have caused profound changes in both public awareness of the problems involved and institutional arrangements for considering the environmental aspects of power generation. Current administrative difficulties portend even greater changes in the near future. Recent power shortages in the Northeast, particularly the notorious "brownouts" during the summer of 1970, have pointed up the need for the construction of new plants to meet the increasing demand. In addition, concern with problems of meeting air-pollution standards as well as shortages of fossil fuels has resulted in the decision by many utilities to "go nuclear."

This article reviews the significance placed on the environmental factors in nuclear plant licensing during the last decade, first considering the effect of recent legislation and the status of current controversies, and then briefly discussing proposals for legislation and developments that can be expected in the near future.

Three major types of environmental effects[7] will be considered separately: radiological effects that are specific to nuclear plants, effects of thermal and chemical effluents which are similar to those to be expected from all types of power plants, and effects of the physical presence of the nuclear plant which are similar to those resulting from the presence of any large industrial facility. Each of these effects will be discussed in turn, and some of the major controversies involved in their regulation will be considered. More specifically, with regard to radiological effects, the question of standards setting, the role of the states in regulation, and the placement of responsibility for risk–benefit analysis will be examined. The questions of AEC jurisdiction and the scope of responsibility of other agencies will follow in a study of effluent effects. And finally, the question of regulation of aesthetic features, the role of local jurisdictions in regulating plant location, and the responsibility for land use planning will be considered in relation to physical presence effects.

Before these problems are presented, however, the current regulatory scheme of nuclear plant licensing will be surveyed to provide the reader with a basic understanding of the complexities of the field.

THE ATOMIC ENERGY COMMISSION

At present there is no overall federal program for licensing power plants, although legislation to set up such a system has been proposed. Nuclear power plants, however, are subject to regulation by the AEC. Until passage of the National Environmental Policy Act (NEPA) of 1968 (Ref. 2), the jurisdiction of the Commission was limited to matters of radiological health and safety and the common defense and security. NEPA expanded this jurisdiction to permit the AEC to consider all environmental matters. However, the AEC does not have the sole responsibility for environmental regulation. There are myriad state, local, regional, and federal agencies with power to issue licenses, orders, permits, and variances based on consideration of specific environmental effects. The jurisdictions of the major federal and state agencies in the field are the subject of the following discussion.

The Atomic Energy Act

The Atomic Energy Act of 1954 (Ref. 9) authorizes the AEC to issue licenses for "utilization or production facilit[ies]," a category that includes power reactors. The procedures and criteria that have been developed and are currently in use are set forth in Title 10 of the *Code of Federal Regulations*, and modifications are published in the *Federal Register* as part of the rule-making process [and are reported in each issue of *Nuclear Safety*—Ed.].

At present the licensing of nuclear power plants by the AEC is a two-step process. Before plant construction can start (except for preliminary site preparation), a construction permit must be issued. Then, before the completed plant can operate, an operating license must be obtained. The procedures followed in the two steps are similar, the major difference being that at the *construction-permit* stage for the acquisition of the license a public hearing is mandatory, whereas at the *operating-license* stage such a hearing will be held only if someone petitions to intervene and requests a hearing or if the Commission directs that a hearing be held because there is a question of "substantial" public interest involved.

With respect to the considerations of radiological health and safety and the common defense and security which the Commission is mandated to oversee, the licensing procedure begins with the submission of an application by the utility to the AEC regulatory staff, although this step is often preceded by informal review of the site by the AEC staff. As a major part of the application, the company files a preliminary safety-analysis report (PSAR). The PSAR presents the preliminary design and safety features of the proposed reactor as well as comprehensive data on the proposed site. It discusses various accident situations and the safety features that will be provided to prevent accidents or, if they occur, to prevent overexposure of the public and employees to radiation. The AEC furnishes copies of the application to state and local officials in the geographical area concerned, federal agencies with jurisdiction over or expertise in various environmental aspects of the plant, and the Commission's Advisory Committee on Reactor Safeguards (ACRS).

The independent review by the ACRS proceeds in parallel with that of the Commission's staff.[10] This committee, made up of experts from outside the AEC, is required by law to review and report on each major power-reactor application. Utility representatives meet with the committee to present their case and respond to questioning. The ACRS, by letter to the Commission which is made public, then comments upon the safety of the project, spells out areas of technical concern, and makes recommendations for research and development efforts in those areas. Most such letters are carried in the Current Events section of *Nuclear Safety*. AEC staff review includes consideration of all the radiation-safety aspects of the proposed reactor as well as the applicant's technical and financial qualifications; at the end of its review, which includes detailed questioning of the applicant, the AEC staff issues its own safety-analysis report, which is also made available to the public and is sent to state and local officials and news media in the plant area.

The next step in the licensing process is a public hearing to consider issuance of the construction permit. Public notice of the hearing date and location is published in advance in the *Federal Register* and in an AEC announcement sent to the news media in the vicinity of the site. The Commission's Rules of Practice permit persons whose interests may be affected by the proceedings to intervene as parties. Persons who wish only to make a statement of their views concerning the project may be permitted to make a "limited appearance."

The hearing is conducted before a three-member Atomic Safety and Licensing Board appointed by the Commission from a panel of qualified persons. Two of the members are technical experts; one is a lawyer who serves as chairman. In a hearing on an uncontested application, the Licensing Board determines (1) whether the application and the record contain sufficient information and (2) whether review by the AEC staff has been adequate to support the findings proposed to be made by the Director of Regulation. If the application is contested, i.e., if there is controversy between the staff and the applicant concerning the issuance of the permit or any of its terms or conditions, or if the application is opposed by an intervening party, the Licensing Board will consider any matters in controversy. Upon completion of the hearing, the Board issues its decision, and, if that decision so authorizes, a construction permit is issued. The decision and the permit are subject to review by the Commission (in most cases by the Atomic Safety and Licensing Appeal Board) upon its own motion. The decision is likewise subject to judicial review.

The steps in obtaining an operating license are similar to those steps described above for a construction permit and will not be described in further detail.

Expansion of AEC Jurisdiction: NEPA and the Calvert Cliffs Decision

The National Environmental Policy Act of 1969 (Ref. 8) requires the federal government to use all practicable means, consistent with other essential considerations of national policy, to improve and coordinate federal plans, functions, programs, and resources to foster environmental protection. Federal agencies are required to include, in every recommendation on "major federal actions significantly affecting the quality of the human environment," a detailed discussion of the basic short-term and long-term environmental consequences of the proposed action, and to "utilize a systematic, interdisciplinary approach which will insure the integrated use of the natural and social sciences . . . in decision making which may have an impact on man's environment. . . ." They must also develop appropriate alternatives to recommended courses of action in any proposal involving alternative uses of available resources. The Act also established the Council of Environmental Quality (CEQ) which reports to the President and which is charged with reviewing the activities of the government in light of NEPA and recommending national policies to foster environmental quality. NEPA expanded the AEC's regulatory jurisdiction into the area of nonradiological environmental effects of nuclear power plants. The AEC regulations implementing NEPA and challenges to their sufficiency are discussed below.

The scope of NEPA covers not only nuclear power plants licensed by the AEC, but also hydroelectric plants licensed by the Federal Power Commission (FPC) and all plants, both nuclear and nonnuclear, for which a permit from the Corps of Engineers is required under the Rivers and Harbors Act. Controversies over the interpretation of the language of NEPA have already resulted in litigation in the federal courts,[11] and a great many more may be expected because of the broad wording of the Act and the absence of specific procedural guidance.

NEPA became effective on Jan. 1, 1970. In March the CEQ was established, and in April the Water Quality Improvement Act of 1970 (WQIA)[12] became effective. On Apr. 2, 1970, the AEC published general policies and procedures[13] applicable to the issuance of construction permits and operating licenses for nuclear power reactors which the AEC determined would significantly affect the quality of the environment. These AEC regulations, designed to satisfy the provisions of NEPA, enlarged the scope of the nonradiological issues that might be raised in licensing proceedings and imposed new environmental requirements on holders of nuclear power-reactor licenses already issued by the Commission.[14]

On July 23, 1971, the U. S. Court of Appeals for the District of Columbia decided *Calvert Cliffs Coordinating Committee, Inc.* vs. *Atomic Energy Commission.*[15] Plaintiffs, interested environmentalists, had challenged several of the AEC regulations for implementing NEPA provisions. Two of the provisions, applicable to plants already in the licensing process, will not be discussed because of their transitory nature.

Two other provisions, which are of general applicability to all future licensing procedures under NEPA, are discussed below.

Plaintiffs contended that the AEC regulations being challenged provided for no mandatory consideration of environmental factors by licensing boards. They argued:

> Although environmental factors must be considered by the agency's regulatory staff under the rules, such factors need not be considered by the hearing board conducting an independent review of staff recommendations, unless affirmatively raised by outside parties or staff members.[16]

In its decision the court noted:

> NEPA makes only one specific reference to consideration of environmental values in agency review processes. Section 102(2)(c) provides that copies of the staff's "detailed statement" and comments thereon "shall accompany the proposal through the existing agency review processes." The Atomic Energy Commission's rules may seem in technical compliance with the letter of that provision. They state:
>
> . . . 13. When no party to a proceeding . . . raises any [environmental issue] . . . such issues will not be considered by the atomic safety and licensing board. Under such circumstances, although the Applicant's Environmental Report, comments thereon, and the Detailed Statement will accompany the application through the Commission's review processes, they will not be received in evidence, and the Commission's responsibilities under the National Environmental Policy Act of 1969 will be carried out in toto outside the hearing process."
>
> The question here is whether the Commission is correct in thinking that its NEPA responsibilities may "be carried out in toto outside the hearing process"—whether it is enough that environmental data and evaluations merely "accompany" an application through the review process, but receive no consideration whatever from the hearing board.[17]

The court considered the AEC's "crabbed interpretation . . . [to make] a mockery"[17] of NEPA:

> The word "accompany" in Section 102(2)(c) must not be read so narrowly as to make the Act ludicrous. It must, rather, be read to indicate a congressional intent that environmental factors, as compiled in the "detailed statement," be considered through agency review processes.[18]

The court noted that since it is "unrealistic to assume that there will always be an intervenor" with the resources to challenge a staff recommendation, the AEC must "take the initiative" of considering the environment at every stage of the licensing process. This means that hearing boards must independently review and balance conflicting factors:

> The Commission's regulations provide that in an uncontested proceeding the hearing board shall on its own "determine whether the application and the record of the proceeding contain sufficient information, and the review of the application by the Commission's regulatory staff has been adequate, to support affirmative findings on" various nonenvironmental factors. NEPA requires at least as much automatic consideration of environmental factors. In uncontested hearings, the board need not necessarily go over the same ground covered in the "detailed statement." But it must at least examine the statement carefully to determine whether "the review . . . by the Commission's regulatory staff has been adequate." And it must independently consider the final balance among conflicting factors that is struck in the staff's recommendation.[19]

Using a figure of speech that had been used before in a landmark environmental case, the court pronounced that the responsibility of the Commission

> . . . is not simply to sit back, like an umpire, and resolve adversary contentions at the hearing stage. Rather, it must itself take the initiative of considering environmental values at every distinctive and comprehensive stage of the process beyond the staff's evaluation and recommendation.[20]

Although the Calvert Cliffs decision calls attention to the need for consideration of environmental factors by the AEC, it does not interpret NEPA as setting environmental protection as an absolute, but rather as one element in a delicate balance:

> "Environmental amenities" will often be in conflict with "economic and technical consideration." To "consider" the former "along with" the latter must involve a balancing process. In some instances environmental costs may outweigh economic and technical benefits, and in other instances they may not. But NEPA mandates a rather finely tuned and "systematic" balancing analysis in each instance.[21]

As a result of the Calvert Cliffs decision, which the AEC decided not to appeal, the licensing regulations for nuclear reactors have been changed to reflect the court's requirements, as the Commission interprets them.[22] In addition to the discussion of direct environmental effects of a facility, the Commission now requires applicants to submit with their environmental report a discussion of the effects of possible accidents, transporting radioactive matter, and building transmission lines, a discussion of alternatives to the proposed action, a "cost–benefit analysis," quantified "to the fullest extent possible," and a discussion of all factors with respect to water quality, whether or not certification from the appropriate authority has been obtained.

The Water Quality Improvement Act of 1970

The Water Quality Improvement Act of 1970 (Ref. 12) amended the existing Federal Water Pollution Control Act that established a framework of state–federal cooperation under which the states were given the opportunity to set water-quality standards for interstate waters. Under the 1970 amendments the AEC and other federal agencies that issue permits or licenses for electric-power plants must now receive from the utility applicant, before the license may be granted, a certification that there is "reasonable assurance" of compliance with the applicable water-quality standards. The certification must come from the state where the discharge originates or, in some circumstances, from interstate agencies or the federal government.

Until Calvert Cliffs the AEC had interpreted its duties under the WQIA as superseding those of NEPA in the field of water quality. Thus, in its pre-Calvert Cliffs regulations on NEPA review, the AEC stated:[23]

> With respect to those aspects of environmental quality for which environmental quality standards and requirements have been established by authorized federal, state, and regional agencies, *proof that the applicant is equipped to observe and agrees to observe such standards and requirements will be considered a satisfactory showing* that there will not be a significant, adverse effect on the environment. *Certification by the appropriate agency* that there is reasonable assurance that the applicant for the permit or license will observe such standards and requirements *will be considered dispositive for this purpose.*

The Calvert Cliffs court, discussing the "plain language" of Section 104 of NEPA, and WQIA, found[24] that the Commission's rule was in fundamental conflict with the basic purpose of NEPA:

> Obedience to water quality certifications under WQIA is not mutually exclusive with the NEPA procedures. It does not preclude performance of the NEPA duties. Water quality certifications essentially establish a *minimum condition* for the granting of a license. But they need not end the matter. The Commission can then go on to perform the very different operation of *balancing the overall benefits and costs of a particular proposed project, and consider alterations (above and beyond the applicable water quality standards) which would further reduce environmental damage. Because the Commission can still conduct the NEPA balancing analysis, consistent with WQIA, Section 104 does not exempt it from doing so.* and it, therefore, *must* conduct the obligatory analysis under the prescribed procedures.

The AEC was directed to change its rules in this respect[25] and has done so. Representatives of several of the federal environmental agencies have since stated their disagreement with this part of the Calvert Cliffs decision, which, in effect, has returned all decisions on water quality to a case-by-case basis, and legislative reform is probable.

Clean Air Act Amendments of 1970

Under the Clean Air Act,[26] the federal government had the authority to set air-quality criteria for certain pollutants but could not regulate the emission of such matter into the air. The 1970 amendments, *inter alia:*

> . . . provided for federal establishment of national primary ambient air quality standards (to protect health) and national secondary ambient air quality standards (more stringent standards to protect the public welfare), and an opportunity for adoption by the states of implementation and enforcement plans for such standards.

The federal government may now itself establish emission standards for new stationary sources and may also promulgate emission standards for hazardous air pollutants from all stationary sources, new or existing.

> The provisions relating to new stationary sources have particular relevance for electric power plants—particularly fossil-fuel plants which release oxides of sulphur and nitrogen. As to nuclear power plants, the legislative history of the amendments indicates that the responsibilities of the AEC with respect to radiological health and safety aspects of nuclear facilities were to remain unchanged by enactment of the amendments.

FEDERAL POWER COMMISSION

At the present time, the FPC[27] regulates the electrical industry in three ways: (1) by licensing the use of hydropower sites on navigable rivers under the federal jurisdiction; (2) by regulating the wholesale rates of power sold for resale in interstate commerce; and (3) by encouraging the interconnection and coordination of power systems. It also serves as an information collection agency.

In contrast to the limited regulatory mandate of the Atomic Energy Act of 1954, the Federal Power Act provides the basis for comprehensive consideration and control of the environmental effects of hydroelectric generating stations. For example, the FPC, as part of its authority to license the construction of hydroelectric projects, even before the passage of NEPA, could condition such licenses to limit thermal discharges from fossil and nuclear plants located on water impoundments under FPC license. However, like other federal agencies, the FPC is now also subject to the provisions of NEPA and WQIA.

CORPS OF ENGINEERS, DEPARTMENT OF THE ARMY

The jurisdiction of the Corps of Engineers over fossil and nuclear power plants encompasses the uses that such plants may make of the navigable waterways of the United States. Under the Rivers and Harbors Act[28] of 1899, the placement of a structure in a navigable waterway, other than a dam, dike, causeway, or bridge, requires a permit from the Corps of Engineers. The operators of a nuclear or fossil plant, who propose to use such waters for cooling purposes by inserting water intake and outlet structures into navigable waterways, first must apply for, and be granted, such a permit.

Within the past few years, another provision of the Rivers and Harbors Act of 1899, referred to as the Refuse Act, has been given new life. This statute makes it unlawful to discharge "refuse matter" into navigable waters without a permit from the Corps.* Until recently, implementation of the 1899 Act had been directed toward protection of navigation, but it now also serves the end of environmental protection. The comprehensive regulatory program currently being developed under this Act may significantly affect the design and operation of power plants, particularly fossil-fueled plants, heretofore generally unregulated by federal authorities. For nuclear plants it is expected that the actions of the Corps will be coordinated with those of the AEC as well as the Environmental Protection Agency (EPA). Of course, the Corps is also subject to provisions of NEPA and WQIA.

ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency (EPA), formally established by Reorganization Plan No. 3 of 1970 which became effective[29] on Dec. 2, 1970, consolidated several environmental agencies of the executive department. The functions transferred to the EPA included administration of the Federal Water Pollution Control Act and the Clean Air Act. In the radiological field the new agency took over part of the AEC's Division of Radiation Protection and part of the Bureau of Radiological Health from the Public Health Service of the Department of Health, Education, and Welfare. The staff and functions of the Federal Radiation Council were also transferred to the EPA. The EPA is now responsible for establishing generally applicable standards for the protection of the environment from radioactive materials.

OTHER FEDERAL AGENCIES AND STATUTES

Other significant federal statutes that relate to environmental matters which may be involved in nuclear plant licensing include the Fish and Wildlife Coordination Act,[30] requiring federal agencies to take into account the conservation of fish and wildlife resources in connection with certain activities; the Wild and Scenic Rivers Act[31] designed to preserve scenic rivers in their free-flowing condition; the National Historic Preservation Act,[32] requiring federal licensing agencies to take into account the effect of a licensed undertaking on historical sites that are included in the National Register; the Resource Recovery Act[33] of 1970 authorizing the expenditure of federal funds for research and development in the recycling and disposal of solid wastes; and the Federal Aviation Act[34] of 1958 which requires anyone proposing to construct certain structures to give notice to the Federal Aviation Administration which may then evaluate the hazards posed by the structure.

STATE REGULATION OF POWER-PLANT SITING AND CONSTRUCTION

State regulatory commissions having jurisdiction over electric utilities vary widely in their authority and the extent to which they exercise jurisdiction over siting, construction, and the environmental effects of power plants and transmission lines. A study[7] published in 1969 indicated that, with respect to the continental United States, "28 of the state regulatory commissions at that time exercised no jurisdiction in the matter of licensing or power plant site selection and the remaining . . . commissions were vested with varying degrees of licensing authority."

According to the recent report of the President's OST, "[i] ncreasing public concern for the quality of the environment is evident in the actions of state legislatures in recent years [strengthening] the role of the state regulatory commissions and other state agencies in controlling environmental effects of electric power facilities."[4] The majority of states whose commission possess a degree of licensing authority permit public hearings on licensing applications, and

*Under the new Federal Water Pollution Control Act, jurisdiction for the discharge-permit program has been moved from the Corps of Engineers to the Environmental Protection Agency.

most of these, 19 out of 29, take environmental impact factors into consideration; in 17 of the 29, data and advice on matters involving these environmental considerations are available to the state regulatory body.

Although detailed discussion is beyond the scope of this report, it should be noted that several states (Arizona, California, Connecticut, Maine, Maryland, Nevada, New Hampshire, New York, Oregon, South Carolina, Vermont, and Washington) have recently adopted a variety of approaches to the problem of power-plant siting.

* * *

An early issue of *Nuclear Safety* will carry Part II of this article. It will discuss some cases and controversies concerning the environmental effects of producing nuclear power, as well as possible improvements that could be effected through proposed federal legislation and proposed changes in regulatory procedures.

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THE REGULATION OF THE ENVIRONMENTAL EFFECTS OF NUCLEAR POWER PLANTS (PART II)

By Joyce P. Davis

[*Nucl. Safety*, 14(3): 165–181 (May–June 1973)]

Abstract: *Part one of this two-part article (see* Nuclear Safety *for January–February 1973) discussed U. S. needs for electric power and the role of nuclear energy in meeting these needs. The major portion of the article reviewed the regulatory process that is currently required for nuclear power plants. Part two discusses the radiological and nonradiological effects of nuclear power generation on the environment and the means for their regulation along with some related cases and controversies. Proposals for improvements through changes in procedures and new legislation are also examined.*

RADIOLOGICAL EFFECTS

During normal operation of nuclear power plants, all potential sources of external radiation are shielded to protect plant workers from exposure to radiation in excess of occupational dose limits. Such limits, however, are generally less severe[1] than those applicable to the general public outside of the "exclusion area."[2] This environmental hazard of direct radiation is controlled to meet the applicable safety criteria of the U. S. Atomic Energy Commission (AEC). The plants are designed to ensure that, even under the conditions of the most serious "credible accident" possible, the effect on the environs of direct radiation from materials within the high-integrity containment building is minimal. Once such direct radiation has been reduced to negligible levels, through intervening distances and shielding material, the major source of radiation of environmental interest is radioactive material that in some manner is released or escapes from the containment building or other plant areas. Regulation of such radioactive "effluents" will be briefly discussed.

Gaseous Effluents

The commercial nuclear plants currently in use in the majority of nuclear installations in the United States utilize a boiling-water reactor (BWR) or a pressurized-water reactor (PWR) as a heat source for producing steam. Radioactive gases are produced in both types of reactors by activation of such materials as nitrogen, oxygen, and argon and by the release of some of the gaseous products of the fission process, such as xenon, krypton, and iodine, from the fuel element into the primary reactor coolant stream. The amount of the latter materials present in the coolant water depends on the integrity of the fuel elements. If the metal cladding that covers the uranium oxide fuel material is intact, little of the fission-product gas will escape; however, as time goes by, the clad elements may develop pinhole leaks.

The plants are designed to operate with fuel-element leakage of up to about 1%. This design, in turn, sets the criteria for the design of systems to handle the radioactive gaseous effluents that will maintain releases to the environment within prescribed limits.

In the BWR the gases released in the primary coolant are carried to the turbine and the condenser, along with the steam produced by boiling. Steam is condensed back to water in the condenser, but the noncondensable gases, including the very small volume of radioactive gases, are vented to a cleanup system, which provides some holdup time for radioactive decay. In currently operating units the gases are then filtered and released through a stack to the environment. Longer holdup times and more extensive systems for gas treatment are being incorporated into the design of many future units to reduce the activity level of such releases.

In the PWR, most of the gases remain in the reactor coolant water in a system that is sealed during normal operation. The water in this system is not permitted to boil. When the temperature and pressure are lowered and the system is opened during reactor shutdown for maintenance or refueling, the gases are vented to a cleanup system, from which they may be released to the atmosphere. A small amount of gaseous activity may also be released continuously during operation.

In currently operating reactors the activity released by a BWR is greater, on an instantaneous basis, than that released by a PWR of comparable size. However, in the BWR, most of the activity is short-lived and decays within a short time to nonradioactive matter. The long-term potential hazard from both types of plants is of similar magnitude and is caused by ^{85}Kr, which has a half-life of 11 years. Given the present design of gaseous-waste systems, essentially all the krypton that escapes from the fuel will eventually be released to the atmosphere. Because it is a nonreacting noble gas, krypton does not present a biological hazard at today's concentrations.

Liquid Effluents

During reactor operation, radioactive materials are present in the reactor cooling water. Some of these come from activation of elements in the water itself—the naturally occurring trace elements. Others include soluble and insoluble products of the corrosion of metals in the system (which are activated by neutrons in their passage through the reactor) and a variety of fission products which may leak from defective fuel elements. In addition, tritium, an isotope of hydrogen, is produced. Tritium, with a 12-year half-life, is a unique radiological contaminant, because, in the form of tritiated water, it is not separable from ordinary water by any practical chemical or physical processes.

Liquids leaking into and recovered from various plant systems are collected and sent through a special liquid-waste system. The processes used in liquid-waste treatment are designed to concentrate on the radioactive material and to put it into a form that will permit it to be safely shipped to AEC-licensed radioactive-waste-storage areas. Reductions in radioactivity levels are also achieved by storing material for a period of time to permit decay of short-lived activity and by diluting effluents containing low levels of radioactivity to reduce the concentration of radioactive matter below the designated limits for release into the environment.

After the processing, the effluent liquids, from which most of the radioactive matter has been removed, are collected in monitoring tanks. After these liquids are checked for radioactivity, they may be released at a controlled rate to the plant's condenser cooling-water discharge or recycled for use in the plant. The concentrated radioactive matter that has been removed in the liquid-waste system is treated as solid waste.

Solid Wastes

Solid radioactive wastes consist mainly of concentrated wastes from the radioactive-waste system, contaminated tools and equipment, and filters and demineralizers that have concentrated the radioactive matter removed from air and water. Such solids are generally stored for a time to allow for decay of all but the longest-lived isotopes, for example, ^{60}Co and ^{90}Sr.

Solid wastes are then shipped off-site in shielded casks to licensed waste-storage areas. Also removed from the plant periodically are the spent fuel elements that have been in the reactor for 3 to 5 years. After on-site storage for a few months to allow for decay of short-lived activities, these elements are shipped in heavily shielded casks to a fuel-reprocessing plant, where unused fuel material is recovered for recycling to the reactor, and fission products and other wastes are converted to forms amenable to long-term storage and stored indefinitely.

REGULATION OF RADIOACTIVE EFFLUENTS*

Under the 1970 reorganization,[3] the Environmental Protection Agency (EPA) has the responsibility to set standards[4-10] that govern public exposure to radiation and radioactive materials in the environment from nuclear power plants and from those artificial radioactive materials within the scope of the Atomic Energy Act of 1954 (Ref. 11). The EPA has also been given the advisory functions of the Federal Radiation Council (FRC), which was formed in 1959 to provide "guidance for all federal agencies in the formulation of radiation standards."[12] No federal agency, however, has the authority to enforce standards for *exposure* to radiation from sources not under AEC control, such as that from X-ray and similar electronic machines, from radium and other naturally occurring radioactive materials, and from materials made radioactive in accelerators.

Direct knowledge of the effects of radiation on human beings is based on studies of Japanese survivors of bombings, Marshall Islanders exposed during weapons tests, radiologists, children X-rayed in utero, patients treated by radiation, radium watch-dial painters, uranium miners, and victims of radiation accidents. The value of such studies depends on the size of the population studied, the ability to estimate dose, and the availability of control groups.[8]

The recorded human-exposure data are not directly applicable to the effects of long-term exposure to the much lower levels of radiation or concentrations of radioactive materials permitted by AEC regulations. The effects of these low levels of exposure must be inferred by various methods of estimation that are frequently little more than scientific conjecture.

The standards-setting agencies have issued numerous reports containing a variety of numerical standards and guidelines.[5,13-16] One standard which has stirred major controversy sets the limit of 0.17 rem/year for the general population.[15]

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*This article was prepared before the enactment of the comprehensive Federal Water Pollution Control Act Amendments of 1972, which replaced the previous language of the Federal Water Pollution Control Act (first passed in 1956) and its subsequent amendments. The Amendments of 1972 will be discussed by Joyce Davis in an article to appear in *Nuclear Safety* later this year.

A recent review[9] of the history of these standards states:

> . . . In the mid-1950's, both the ICRP [International Commission on Radiological Protection] and the NCRP [National Council on Radiation Protection and Measurements] concluded that 5 rem per year should be the maximum permissible dose for occupational exposure, and that the general population should receive no more than one-tenth this amount. The FRC divided this latter value by 3 in order to allow for variations of exposure to individuals within the population.
>
> In 1956, geneticists on the NAS [National Academy of Sciences] Committee recommended that the contribution of man-made radiation to the human body not exceed 10 rem per generation (30 years). At that time they estimated that exposure from medical uses of radiation already accounted for about one-half this value. The remaining 5 rem, when divided by 30 years, again gave a figure of 0.17 rem per year.

The review[9] comments that, in theory, the setting of standards requires a careful balancing of the benefits to be derived from radiation-producing processes against the expected risks. Determination of benefits—such as military preparedness or abundant electric power—is entirely a social problem; but even the determination of risk can, at best, be only partially scientific.

Reactor Licensing

Within the framework of FRC, NCRP, and ICRP recommendations, the AEC has developed regulatory standards and set criteria to control release of radioactivity at the source, prior to its reaching the environment, by placing limits on concentrations and quantities of radioactivity that may be released into the air and water by AEC licensees.[17] These limits, set forth in Part 20 of the regulations, are designed to ensure that public exposure to environmental contamination is well within FRC radiation-protection guides.[18]

Until recently, in applying these Part 20 standards to reactor water effluents, the AEC generally limited concentrations of radioactivity in undiluted effluents leaving a plant site so that a person using the water effluent as his sole source of drinking water throughout his lifetime would not exceed FRC guidelines for individual exposure.[19] In addition to Part 20 concentration limits,[20] the AEC regulatory program now includes various restrictions on plant design and on operation in individual operating licenses.[21] In controlling effluents from nuclear reactors, one provision in the AEC regulations[22] considers both the possible effect of multiple units in one geographic area and adverse reconcentration effects of radioactive materials in fish, wildlife, or man's food chain. This provision states that *quantity* as well as *concentration* limits may be imposed to ensure that the total radioactivity released to the environment from all sources does not result in radiation doses to humans in excess of FRC guides.

During the AEC staff review phase of licensing, both the site and the plant design are studied thoroughly to ensure that exposure standards can be met. Environmental monitoring is also required, both before the plant starts operation (to form a base line) and after operations have started (to detect any effects on the environment). In addition to the licensee and the AEC, other agencies are active in performing environmental surveys. These may include the state health or conservation department or similar state agencies and the EPA.

Challenges in Licensing Proceedings

In recent years the adequacy of AEC standards has been challenged. Owing in part to the pressure resulting from public concern with these matters, the AEC has taken steps to clarify its regulations on radioactive effluents from light-water-cooled nuclear power reactors.[23]

On Mar. 28, 1970, the AEC announced its intention of adding to the statement of purpose of Part 20 a statement of the licensee's obligation to "make every reasonable effort to maintain radiation exposures and releases of radioactive materials in effluents to unrestricted areas as far below the limits specified in this part as practicable."[24] This is a reflection of a similar statement in the FRC guides.[25] In addition, a Part 50 amendment[26] proposed adding Section 50.34a, designed to "give appropriate regulatory effect, with respect to radioactivity in effluents . . . to the guidance of the FRC that radiation doses should be kept as far below the radiation protection guides as practicable." These amendments became effective on Dec. 3, 1970. They did not modify the Part 20 limits on radiation exposure, which "will continue to be based on the recommendations of the FRC. . . ."[27] Subsequently the AEC proposed adding a new Appendix I to Part 50, to "provide numerical guides for design objectives and technical specification requirements for limiting"[28] operating conditions of light-water reactors to keep levels of "radioactivity in effluents as low as practicable." These proposed regulations are the subject of one of the AEC's first rule-making hearings,[29] convened in January 1972.

The Calvert Cliffs Case

An intervenor at a hearing concerning the Calvert Cliffs nuclear power plant[30] (construction proposed in

Calvert County, Md.) challenged the adequacy of AEC Part 20 standards. As the Atomic Safety and Licensing Board (ASLB) noted in its initial decision authorizing the issuance of a construction permit,[31] "[t]he intervenor does not question that the proposed reactor will comply satisfactorily with the limits of Part 20. The focus of its attack seems to be on the validity of Part 20 itself." The ASLB concluded[30] that:

> Both the Applicant and the staff argue that it is beyond the Board's function to inquire into the validity of the standards established by Part 20. . . . *[I]t seems to the Board that there may be cases in which the evidence introduced is such as to draw into question the validity of those regulations themselves.* In such a case, the Board might not be able to rely upon Part 20 as establishing the outer limits of acceptable risk. In this case, however, although questions are raised as to the underlying assumptions of Part 20, there is no evidence upon which the Board could base a refusal to accept Part 20. [Emphasis added.]

In a memorandum that supported the issuance of the permit, the AEC Commissioners took issue with that statement of the ASLB.[32] The Commissioners said:

> [The] Commission's licensing regulations established the standards for reactor construction permit determinations; and . . . the findings in proceedings such as the instant one must be made in accordance with those regulations. . . . *[O]ur licensing regulations . . . are not subject to amendment by boards in individual adjudicatory proceedings.* [Emphasis added.]

It should be noted that this decision was made in the context of the AEC's health and safety review. Under the later Calvert Cliffs court of appeals decision[33] and the new AEC regulations[34] implementing the National Environmental Policy Act of 1969 (NEPA),[35] the ASLB, in its "risk–benefit" evaluation of *environmental* factors, may have the power to consider challenges to AEC standards.

The Project Rulison Case

An interesting case[36] decided in early 1970 considered the problem of radiation standards in detail. Although the challenged AEC action (Project Rulison, an experiment in the application of nuclear explosives to the exploitation of natural-gas resources) did not involve a nuclear reactor, the AEC and FRC standards in question were basically the same as those applicable to reactor effluents.

The court asked whether the "FRC and AEC radiation-protection standards [are] reasonably adequate to protect life, health and property" and answered in the affirmative:[36]

> Radiation protection standards are established . . . through a complex process. . . . The setting of exposure standards at a given level requires the weighing of . . . risks and benefits to be derived therefrom. The weighing requires a value judgement as well as a measuring, and thus the standards are not scientific numbers below which no danger exists. The value judgement embodies complex social and political considerations, for atomic energy has a potential that suggests unlimited benefits to entire nations and presents a risk to entire populations of people, and perhaps their progeny.

The court found that the standards, as presently established, "*do* embody this risk–benefit evaluation" and concluded that the court need not determine the risk–benefit question for this project:[36]

> [T]he decision of the extent and nature of government participation in development of energy sources is a political question. . . . *It is for Congress, in making these decisions, to weigh the risks presented by the use of atomic energy in such projects. Our task here is to ensure that the AEC has not exceeded Congressional standards* established to protect the public in utilization of atomic energy which Congress has authorized, presumably after having evaluated the risk–benefit equation presented by the Rulison project. [Emphasis added.]

The court determined that, although the plaintiffs introduced "impressive evidence of new developments in the field of radiation biology," there was no evidence that justified an alteration of standards:[36]

> [T]hey did not establish an adequate correlation between this information and radiation exposure at low dose levels [and] they did not refute equally new and impressive evidence of repair of the biological damage from radiation at low dose rates and levels.

The court recognized that the field of radiation protection is constantly changing with the continuing development of new scientific information on the biological effects of ionizing radiation:[36]

> Careful decisions must be made in the context of contemporaneous knowledge. Such decisions cannot be indefinitely postponed if the potentials of atomic energy are to be fully realized. *All that is required to establish reasonableness of the decision setting a standard* under the statutory directive to protect the public health and safety *is that it be made carefully in light of the best available scientific knowledge.* [Emphasis added.]

The court recognized that in the setting of standards "*[a]bsolute certainty is neither required nor possible.*"[36] (Emphasis added.)

State Jurisdiction[37]

Between the passage[11] of the Atomic Energy Act of 1954 and the 1959 state "turnover" amendment,[38] and for a time thereafter, several legal studies were made of the problem of state–federal relations in the regulation of nuclear materials and the question of federal preemption of regulation of materials covered in the Atomic Energy Act. Recently the question has been raised again and considered in *Northern States Power Company vs. Minnesota.*[39]

The AEC contends that Congress has preempted the entire field of regulation of radioactive effluents from licensed nuclear power plants to the exclusion of the states. In the opinion of Congress, the only way that the states can exercise any power over materials subject to the Atomic Energy Act is to enter into a "turnover agreement" with the AEC. Since the section of the Act which authorizes such agreements specifically excludes delegation to the states of any regulatory power over reactors, the states are effectively barred from regulating radioactive effluents from reactors to protect radiological health and safety.

Most legal analyses have concluded that Congress did intend, and had the power, to give the AEC some jurisdiction over the new aspects of nuclear energy, a technology that was "born" as a government monopoly. Although the Act uses the term "health and safety"[11] without qualification, the AEC has interpreted this, with judicial concurrence, to mean only *radiological* health and safety.[40]

It is also apparent that not *all* radiological health and safety is under AEC jurisdiction. As previously mentioned, regulation of X-ray equipment and of such naturally occurring sources as radium was not covered by the Atomic Energy Act. Before the passage of this federal legislation, some states had exercised jurisdiction over such sources, and they continue to do so.[41] Thus it appears that, absent a federal statute, the states have the right to act in the field of radiological health and safety as part of their inherent police powers.

It can be contended that some of this power was taken from the states, assuming it was constitutional to do so, and given to the AEC in the 1954 Act or the predecessor 1946 statute. The question is whether Congress intended the AEC to take over the field of radiological health and safety completely with respect to sources covered in its Act or whether states were to be allowed concurrent power. Most authorities who have considered this question have concluded that the federal regulations preempt the field.

The Monticello Case[42]

In early 1966 Northern States Power Company announced plans for the 550-MW Monticello nuclear generating plant to be built in Minnesota and submitted an application to the AEC for a construction permit and an operating license.[43] The AEC hearing on the application for a construction permit, held in May 1967, was an uncontested proceeding. After receiving the construction permit, the utility filed an application with the state's Water Pollution Control Commission (WPCC) for a permit to discharge plant effluent, excluding radioactive wastes that would be covered by AEC license. In an unrelated action the state abolished the WPCC and set up a new agency, the Minnesota Pollution Control Agency (MPCA), which took over the permit application.

In early 1968 the MPCA raised the question of radioactive effluents and retained a nuclear consultant to develop the radiological standards to be applied in the permit. The consultant drafted a permit, and the MPCA submitted a copy to the AEC for information and review. The permit set effluent standards for the Monticello plant and required certain other steps to be taken to minimize these effluents. The standards set were, for the most part, considerably more stringent than those set by the AEC.

In a letter to Governor Le Vander, the AEC stated its objections,[44] asserting, for example, that standards "more restrictive" than AEC standards did not necessarily indicate a corresponding increase in public health and safety; furthermore,

> [T]he permit reflects an "ad hoc" approach to the regulation of nuclear power plants which, in our view, cannot and should not be made the basis for a fair and effective regulatory program. The approach taken by MPCA is that each nuclear plant should be regarded as an individual case . . . but the MPCA has no definitive criteria or standards for determining on a case-by-case basis what concentrations should be permitted.

In August 1969 the utility filed a complaint in the federal district court of Minnesota,[45] initiating an action ". . . to determine whether the state of Minnesota, acting through the Pollution Control Agency, has jurisdiction over nuclear power plants or the discharge of radioactive effluents therefrom or whether the Federal Government, acting through the Atomic Energy Commission, has sole and exclusive jurisdiction over these matters."[46] A companion suit was brought in a Minnesota state court challenging specific provisions of the permit as unreasonable. This action was held in abeyance, awaiting the ruling of the federal court.

On Dec. 22, 1970, the U. S. district court, per Devitt, Chief Judge, stated:[47]

> The question here is whether Congress has preempted the field of regulation of radioactive releases by nuclear power plants. In my view it has, and Minnesota is without authority to enforce its regulations in this field.

The court was[47]

> . . . satisfied from an examination of the statutes and of the congressional reports which accompanied their enactment that the Congress has expressly and effectively manifested its intent to preempt the disputed field of regulation; and in light of practical construction afforded the administration of the law, the interpretation it has received from official legal authorities, the evaluation of the issue by legal scholars, and the inference to be drawn from previous decisions of the Supreme Court in those cases where it established standards for determining the implied intent of the Congress to preempt a field of regulation that, if called upon to do so, the Supreme Court of the United States would hold that the Atomic Energy Commission's authority to regulate radioactive releases by nuclear power plants is exclusive.

On appeal the U. S. Court of Appeals for the Eighth Circuit, in a 2–1 decision, affirmed the district court's decision.[48] The court declared that Congress had the *power* to preempt the field, but, since in framing the statute Congress did not *expressly state* such an intent, the court must "determine whether Congress has nevertheless manifested an intent to displace concurrent state regulations in this field." Considering the legislative history of the atomic energy acts and amendments, the AEC's construction of its statute, and the pervasiveness of the licensing scheme set up by Congress, the court of appeals reached the same conclusion as the district court. The Eighth Circuit, however, emphasized:[48]

> Congress vested the AEC with the authority to resolve the proper balance between desired industrial progress and adequate health and safety standards. Only through the application and enforcement of uniform standards promulgated by a national agency will these dual objectives be assured. Were the states allowed to impose stricter standards on the level of radioactive waste releases discharged from nuclear power plants, they might conceivably be so overprotective in the area of health and safety as to unnecessarily stultify the industrial development and use of atomic energy for the production of electric power.

Thus the court seems to have held that Congress has delegated the risk–benefit analysis of nuclear power to the AEC alone. Therefore, as the district court had stated, "[i]f the exercise of federal authority in this field is inadequate or unwise, recourse lies with the AEC to raise its standards or with the Congress to relinquish its authority to the states."[47]

It should be noted that, although the utility challenged the state agency in court, it did eventually agree to comply with many aspects of the contested state-permit requirements. Before the trial began in October 1970, Northern States Power Company had agreed to install four 48-hr off-gas holdup tanks to reduce emissions,[49] and its Chairman of the Board had stated:

> *We will conform to any regulations imposed by the State of Minnesota whether or not they are more restrictive than AEC* [sic], *provided:* (1) That the regulations are compatible with the Atomic Energy Commission's regulations with which we are legally obligated to comply, (2) That the regulations are based on a comprehensive program supported by adequate, competent, technical staff. [Ref. 50.]

On Apr. 3, 1972, in a memorandum decision, the Supreme Court, with two justices dissenting, affirmed the court of appeals.[51] The federal government, which had not previously taken a position in the case, submitted a memorandum in response to the Supreme Court's invitation for an expression of the government's view. The Justice Department memorandum supported federal preemption.[52]

NONRADIOLOGICAL EFFECTS[53]

During the 1960s, intervenors in several AEC licensing proceedings tried to require licensing boards to take thermal effects into consideration. The AEC contended that Congress had not given it jurisdiction over any but radiological effects on environmental health and safety. In a 1969 judicial decision, discussed below, the AEC's view was upheld. Events since then, however, have changed this situation dramatically with respect not only to thermal effects but also to other nonradiological effects.

In 1969, construction of the Vermont Yankee plant on the Connecticut River was proposed.[54] In its initial decision favorable to the construction of the plant,[55] the ASLB noted that the Board had refused to consider the proffered evidence on thermal effects. Of the three intervening states, Massachusetts, Vermont, and New Hampshire, only the last excepted to the initial decision. The AEC's subsequent memorandum and order[56] states the questions raised by New Hampshire as follows:

> (a) Whether the Atomic Energy Act of 1954, as amended, vests in the Commission jurisdiction to consider, in the licensing and regulation of nuclear facilities, health and safety matters other than those relating to radiological health and safety, and (b) Whether the provisions of the Federal Water Pollution Control Act, as amended by the Water Quality Act of 1965, and Executive Order 11288, enlarge the Commission's regulatory jurisdiction.

The Commission resolved both of these issues against the position taken by New Hampshire.

New Hampshire appealed the AEC's decision to the U. S. Court of Appeals for the First Circuit. The court concluded that "in enacting the Atomic Energy Acts of 1946 and 1954, in overseeing its administration, and in considering amendments, the Congress has viewed the responsibility of the Commission as being confined to scrutiny of and protection against *hazards from radiation.*"[39] The court also found that the 1965 amendments to the Federal Water Pollution Control Act (FWPCA)[57] were intended to encompass only installations owned by, and operated for, the government, rather than those subject to the government's regulatory powers, and thus did not expand the AEC's jurisdiction. In conclusion the court found that the ASLB and the Commission had properly refused to consider the evidence on thermal effects,[54] saying:

> We do so with regret that the Congress has not yet established procedures requiring timely and comprehensive consideration of nonradiological pollution effects in the planning of installations to be privately owned and operated. But the very fact that complex questions of jurisdiction among federal agencies, of federal–state relations, of procedure, and even of specialized staff and appropriations must be reserved indicates the inappropriateness of any judicial fiat—particularly when the legislative branch is actively seised of the problem.

Within a year Congress did act. The enactment of NEPA[58] and the Water Quality Improvement Act (WQIA)[57] have rendered this decision moot. In future licensing actions, thermal effects, as well as other areas of environmental impact, must be considered by AEC licensing boards.

A current example of the complexities of the thermal-effects regulation picture is the controversy in connection with the Turkey Point power plants. Florida Power & Light Company (FP&L) has, since 1967, operated two fossil-fueled power plants at its Turkey Point site on Biscayne Bay in Dade County, Fla. Two nuclear plants, under construction at the same site in an area of ecological interest, are scheduled to start full-power operation in 1973.

On Oct. 18, 1968, Congress enacted a law that authorized the Secretary of the Interior to establish the Biscayne National Monument, "[i]n order to preserve and protect for the education, inspiration, recreation, and enjoyment of present and future generations, a rare combination of terrestrial, marine, and amphibious life in a tropical setting of great natural beauty. . . ."[59]

The two oil-fueled generating plants of FP&L discharge approximately 10,000 gal of condenser cooling water per second, at 10 to 15° above the ambient temperature, into the waters of Biscayne Bay. The natural temperature of water in Biscayne Bay averages about 85° for much of the year; however, temperatures in excess of 100° have been observed. In June 1969, water temperature rose to 103° and caused a substantial fish kill.[60]

The pollution-control office of Dade County had set a 95° limit for effluents discharged into the waters of the bay. Existing plants have been operating under a series of variances granted by local pollution-control authorities.[61] Under these variances, the utility had been given until July 1971 to complete a cooling canal to Card Sound,[62] a contiguous waterway outside the Biscayne National Monument, at which point the 95° limit could be met.[61]

Acting under the FWPCA, the governor of Florida, which state had not yet developed numerical standards, requested a state–federal conference,[63] subsequently held on Feb. 24 and 25, 1970. The resulting standards determined that the effluents could raise the maximum monthly mean temperatures[64] of the bay water no more than 1.5° in summer or 4° in winter and limited the discharge temperature to less than 90°. The conference also ruled that the canal to Card Sound was not acceptable as a solution because the discharged water would not be sufficiently cooled. FP&L was given 60 days to propose an alternate system that would meet the standards. The conference considered a letter from Interior Secretary Hickel, in which the department insisted that the utility promise to stop building the Card Sound Canal or face suit. FP&L declined to make such a promise.

On Mar. 16, 1970, a complaint was filed by the Justice Department in the District Court for the Southern District of Florida.[65] The suit alleged violation of the act that established the Biscayne National Monument, nuisances against property owned by the United States, and violation of the Rivers and Harbors Act of 1899. The relief sought included a preliminary injunction ordering FP&L:

> 1. Immediately to cease all activities in the operation of its existing fossil-fuel plants which result in the discharge into Biscayne Bay or waters of such temperature or quality as to adversely affect the marine life . . . to the extent such can be done consistently with the public interest in the continued operation of such plants.
>
> 2. To submit to [the] court, within 45 days . . . a plan for the operation of its existing . . . plants . . . to eliminate the destruction of the plankton and other marine life in the waters of Biscayne Bay . . .
>
> 3. Immediately to cease construction of any canal . . . designed to be operated or used for the discharge into Biscayne Bay or Card Sound of water of temperature higher than . . . natural conditions. . . . [Ref. 66.]

At a hearing in March 1970, Judge Atkins refused to issue the preliminary injunction requested, calling any damage caused by the Turkey Point plants "minimal and retrievable."[67]

In December 1970, in further action on the Justice Department's suit, Judge Atkins ruled that the company's two existing fossil plants were a common-law nuisance to federal property now owned or to be acquired for Biscayne National Monument.[68] The court also ruled that discharge of heated water "saturated with dead organisms" into the bay was a violation of the Refuse Act. The question of whether *heated water* is "refuse" under the Act was certified to the U. S. Court of Appeals for the Fifth Circuit,[68] which remanded the question to the district court without ruling on it.[69]

In July 1971, before the Justice Department's suit for a permanent injunction against operation of the plants had been set for trial, FP&L filed suit in the U. S. district court in Miami against the federal government, seeking an injunction against having to obtain a permit for discharging heated water into Biscayne Bay under the Refuse Act permit program. The utility contended that heated water is not "refuse" under the 1899 Act. The complaint also attacked the permit program on the grounds that the statute was applicable only to discharges that obstructed navigation and that the Executive Order creating the permit program in December 1970 exceeded the scope of authority of the statutes it purported to implement.[69]

In a compromise settlement approved by Judge Atkins in September 1971, it was agreed that "[i]n return for a loosening of the discharge standards for the next four years, Florida Power [shall] drop its suit questioning the applicability of the 1899 Refuse Act to heated water discharge."[70]

Under the agreement, "the company will spend $30 million on a 5000-acre system of cooling canals and lakes."[71] The government will "permit the company to discharge water at temperatures up to 95° into the bay for five years." In the interim period, FP&L will be allowed to discharge heated water through an existing canal and a second canal to be completed in the near future. To keep discharge temperatures at 95°, the company's power plants on the site will be operated below capacity. After the new cooling facilities are ready in 1976, the discharge limit would be cut to 90°. Apparently the company agreed not to challenge the government's use of the 1899 Act in a suit brought after this 5-year period.

All discharges require Corps of Engineers and state approval, and such approval has been obtained. The AEC must also evaluate the plants' environmental impact (including thermal effects) in carrying out the NEPA review as part of its licensing process. On Oct. 30, 1971, the AEC published notice that it was considering issuance of operating licenses for the two nuclear units.[72] An operating license for the first nuclear unit has been issued.[73]

Thermal Effluents

The heat-disposal problem is not unique to nuclear plants; it has a thermodynamic effect that is common to all steam–electric power plants. In the United States today, the majority of electricity-generating plants use fresh water as a coolant and discharge it into nearby surface waters. In 1970, less than 8% of installed electrical capacity used cooling ponds and about 13% used cooling towers.[73]

The temperature and quantity of the heated effluent varies from plant to plant. Current light-water-cooled nuclear power plants in operation or under construction, however, will discharge up to 50% more heat in cooling water, per electrical unit generated, than new plants using fossil fuels, owing mainly to the generally higher thermal efficiency of the large modern fossil-fueled units. This, however, does not consider the stack heat losses in fossil-fueled units, which amount to about 10%.

The excess heat generated in steam–electric power-plant operation must be removed from the facility in some manner. Typically a system is used in which flowing water takes the heat produced in steam condensation and transfers it to air or water in the external environment. Two major types of cooling systems exist: (1) "once-through," or "open-cycle," where the cooling water is taken from a suitable source, passed through the condenser, and returned to the source body of water; and (2) "closed-cycle," where water is recirculated through the condenser after it has been cooled in some manner; this cooling may be provided by an evaporative cooling tower, a dry cooling tower where the heat is dissipated to the air through heat exchangers, or a cooling pond.

The effects of increased water temperatures may be beneficial or detrimental.[75] At the present time, research is being carried on to understand these effects in various ecosystems and bodies of water and to develop constructive uses for the waste heat.

It is possible to use an air-cooled condenser and thus completely bypass the water-cooling problem. Now, however, these units are available only for relatively small-sized plants.[76]

Gaseous Effluents

Nuclear plants do not produce heated combustion gases like those released from the stacks of fossil-fueled power plants. If cooling towers or other evaporative cooling methods are used for the rejection of waste heat, however, the introduction of warm water vapor and droplets into the atmosphere may itself create environmental problems, such as changes in precipitation, humidity, wetting and icing, temperature, concentration of pollutants, and wind.[77]

A major concern in connection with the possible use of saltwater cooling towers at a seaside site is the small amount of water carried out of the wet towers into the air as a fine spray or mist. This "drift" or "carry-over" contains salt that, when deposited, could cause damage to plant components and neighboring property.[78]

The use of large air-cooled condensers or dry cooling towers, with the resultant production of hot air, could affect the local meteorology.

Chemical Effluents

The chemical effluents that may be expected to create environmental problems are generally released with plant liquid wastes. Chemicals that might be released from nuclear plants include boric acid or other boron compounds used for reactivity control in the reactor coolant and detergents, chelating agents, acids, and other substances used in decontamination operations. Chemicals used for plant cleanup, *p*H control, and regeneration of ion-exchange demineralizer resins may be expected from all types of power plants. In addition, in the open-circuit or wet cooling systems, one or more chemicals are generally used to inhibit biological growth, corrosion, and deposit of salts in the water, on the condenser tubes, or in the cooling towers.[79] Although not a plant effluent, other potentially toxic chemicals may be used along rights-of-way or for treating power poles.

Mechanical and Electrical Effects

A power plant is a collection of mechanical equipment and structures that may have an effect on animals or fish that come into contact with it. Structures that may extend many hundreds of feet into the air include stacks and cooling towers as well as the plant buildings and electrical transmission towers. These might be considered a potential hazard to birds and, if there is an airport in the vicinity, to planes. Outside plant equipment, if not adequately protected, can be dangerous to small animals and attractive to children, although access to a nuclear plant's "exclusion area" is generally well controlled. However, the hazard to fish and other aquatic life posed by the plant's water-intake facilities can be substantial, and fish kills due to such mechanical effects have been reported.[80] Smaller aquatic organisms may be affected by mechanical as well as thermal phenomena. Noise may also be a problem where such equipment as mechanical draft cooling towers is used. The hazards of traffic in the vicinity of the plant, the use of heavy construction and materials-handling equipment, and similar problems are analogous to the safety problems of any large industrial facility.

A central station generates large amounts of electricity, which is usually transmitted at high voltage over uninsulated wires carried on tall transmission towers, although the use of underground transmission by insulated cable is possible in certain cases. The care taken in the design and operation of these facilities minimizes the electrical hazards. Our society considers a death rate of about a thousand persons a year accidentally electrocuted as an acceptable risk when balanced against the benefit of electrified homes, farms, and industries.[81]

Aesthetic Effects

In the past, aesthetics have not been an important factor in power-plant design. However, in the future, the presence of such plant features as high stacks, mammoth cooling towers, power-plant structure, switchyards, and transmission lines may well preclude the use of certain sites. At other sites careful consideration of landscaping and architectural treatment of buildings and facilities will be necessary. The problem is compounded when the site is in an area of particular scenic or historic interest:[79]

> Power plants and transmission facilities are not welcomed, to say the least, in a natural or historic setting. While proper design and architectural treatment can make a difference there is nothing, short perhaps of undergrounding the facilities, which could eliminate the adverse encroachment of a generating station upon an important historic setting.

As a positive step toward improving the human environment, a number of utilities are associating recreational facilities and real-estate development with their nuclear power plants. For example, the Trojan nuclear power plant will have an extensive public recreational area. A strip of land along the Columbia River will be preserved, as will a large marsh area used as a wintering ground by whistling swans. Another marsh area will be redefined for recreational swimming and boating. Areas for picnicking, fishing, nature trails, and playgrounds will be provided. Fish-rearing ponds for Chinook salmon and steelhead will be heated by warm water effluent from the plant.

The use of transmission rights-of-way for wildlife purposes has been considered extensively, particularly for game management through habitat improvement. Recently, however, similar consideration has been given to use for outdoor recreation, including hiking, bicycling, horseback riding, and motorcycling. In an urban setting, power-line rights-of-way may serve a beneficial use for parking purposes. Such use may thereby free additional land for recreational use.

REGULATION OF NONRADIOLOGICAL EFFECTS

As the court in the Vermont Yankee[82] case stated: "The Atomic Energy Act itself is replete with many references to the 'health and safety of the public.' But in its section on definitions . . . any attempt to delimit 'health' and 'safety' of the public is singularly in absentia." The AEC has interpreted its statute to give it jurisdiction only over the *radiological* aspects of public health and safety.

In 1961 the Pacific Gas & Electric Company proposed to build a nuclear plant at Bodega Bay, Calif.[83] Pursuant to California law, the utility filed an application for a Certificate of Public Convenience and Necessity with the State Utilities Commission. After several years of proceedings and a decision favorable to the utility, the Northern California Association To Preserve Bodega Head and Harbor, Inc., petitioned the Supreme Court of California to review the decision denying a hearing.[84]

One of the questions presented to the court was: "Has the federal government preempted the question of safety of the location of atomic reactors?"[84] (Emphasis deleted.) The court cited Section 274 of the Atomic Energy Act[11] and found that the California Commission

> . . . unquestionably has authority to inquire into safety questions apart from radiation hazards. Accordingly, since the location of an atomic reactor at or near an active earthquake fault zone involves safety considerations in addition to radiation hazards, it is clear that the federal government has not preempted the field, at least with respect to the phase of protecting the public from hazards . . . other than radiation hazards. . . .

The court concluded that "the *states' powers* in determining the locations of atomic reactors are *not limited to matters of zoning or similar local interests* other than safety."[84] (Emphasis added.)

Land Use and Zoning

Land-use policy has not been considered a federal responsibility in the United States;[85] in fact, even the states have exercised very little control over land use, having delegated zoning and planning to municipalities, counties, and other local governments. Recently, however, the need for a national land-use policy and regional or national planning has been acknowledged. Proposed legislation on land use is under consideration by Congress.

To some extent the problems of zoning for nuclear power plants are aspects of the preemption question. However, the AEC Regulatory Staff, emphasizing that the responsibility of the AEC "to assure protection of the public health and safety . . . is limited to radiation hazards," has stated that it considers other zoning problems to be "outside the Commission's jurisdiction."[86]

If *radiation safety* cannot be considered by local regulatory authorities because of federal preemption, other aspects of zoning authority may be applied to nuclear power facilities. These include "provision of adequate light and air, control of traffic, avoidance of undue population concentration, conservation and improvement of property values and promotion of desirable land uses" and aesthetics.[87]

Three approaches are offered to the problems of zoning for nuclear energy uses.[88] The first is to ban these facilities outright. Such a ban was proposed in Huntington, N. Y., in 1963 but was never adopted. "At the opposite extreme from total prohibition, a community can permit 'atomic' uses wherever it permits their 'nonatomic' counterparts. . . . Perhaps unintentionally, many cities are apparently taking this permissive approach—by listing . . . power plants as a permitted use and failing to mention the nuclear aspect."[88] However, as Professor Joseph F. Zimmerman noted in his 1964 article, the question of federal preemption was as yet undecided, and there existed the "possibility that local governments have no legal *power* to prohibit an 'atomic' use at a location where they permit comparable nonatomic uses."[88]

Another solution is to require special permits for reactor facilities. In Pittsburgh, for example, the zoning ordinance requires that "atomic reactors" comply with the following standards:[88]

> (a) It shall be demonstrated by qualified experts that such use may be safely located on the concerned site and will not adversely affect existing or potential adjacent uses.

(b) Suitable measures are to be taken for the disposal of waste without adversely affecting adjacent areas.

Such a permit scheme was proposed for New York City as an alternative to an outright ban.[89] However, it should be noted that the AEC termed this proposal "unnecessary" and emphasized its detailed procedure for evaluating a license application.[90]

Local interests may also challenge the environmental impact of a power plant in judicial review of the utility's exercise of the power of eminent domain. The utility may be required to show that it has complied or will be able to comply with local, state, and federal environmental-protection requirements before it can condemn property for use as a power-generating or -transmission facility site.[91] For example, a suit has been filed against Commonwealth Edison and the AEC by local property owners near the site for the La Salle station. The suit asks that proceedings for condemnation of land for cooling ponds be stopped until environmental reviews are complete.

Aesthetic Considerations

In 1967 the Niagara Mohawk Power Corporation applied to the AEC for a permit to construct a nuclear power plant at Easton, N. Y., on the upper Hudson River. However, following a year of delays because of objections to aesthetic effects on historic landmarks, as well as ecological effects on the Hudson River, the corporation withdrew its application.[92] The project has been reviewed by the Hudson River Valley Commission, which mentioned a number of problem areas in its findings of March 1968, including visual relation of the plant to the Saratoga National Historical Park. Because of the Commission's objections, the utility had previously rejected the use of giant cooling towers; prompted by the Commission findings, Niagara Mohawk began a "reevaluation" of its plant design.[93]

Another agency that opposed the plant was the President's Advisory Council on Historic Preservation.[94] Responding to a request from the AEC for comments, a part of the licensing review, the Council emphasized the significance of the Saratoga National Historical Park and stressed that, as designed, construction of the facility on a site across the river "would materially detract from interpretation, understanding, and appreciation of the events and locale of a significant battle of the American Revolution. . . .[95] It recommended that

[T]he Atomic Energy Commission should not issue a construction permit which requires the use of the proposed Niagara Mohawk Power Corporation site on the Hudson River and opposite the Saratoga National Historical Park unless:

1. There is no feasible and prudent alternative to the use of the proposed site; and
2. Such use includes all possible planning to minimize the adverse effect to the Saratoga National Historical Park resulting from the use.

In this case as in several others[96,97] where, after the application was filed, it became evident that there would be sizable opposition to the plant, the utility chose to withdraw or suspend the application rather than face the possibility of further delay and controversy. Because of the need for advanced planning for required system additions, utilities are particularly sensitive to delays and threats of delays in their construction schedules. Given their ability to arouse public interest and prolong the review schedule, the power of advisory bodies without direct licensing jurisdiction may be far greater than might otherwise be thought.

In 1969 Public Service Electric & Gas Company of New Jersey proposed to build a two-unit nuclear power plant (Newbold Island 1 and 2) on an island in the Delaware River. Cooling towers are required to meet thermal-release guidelines of the Delaware River Basin Commission. Several agencies, including the Delaware Regional Commission and the Pennsylvania Historical and Museum Commission, expressed concern that the plant, particularly the tall hyperbolic cooling towers proposed, would adversely affect Pennsbury Manor, a landmark in the area. In its required review, the Advisory Council on Historic Preservation also criticized the proposed plans.[99]

Pennsbury Manor is owned by the state of Pennsylvania, and, although not a national park like the Saratoga battlefield, it is listed in the National Register[100] and thus comes under the review jurisdiction of the Council.[101] Pennsbury Manor is the recreated country estate of William Penn and is operated as a state historical park. As the Council described it:[99]

The Manor, its outbuildings, gardens, and grounds present an appearance that today would be familiar to Penn himself. . . . The area is largely pastoral in nature, and it is in a region which is generally industrial in character.

Considering the proposed plant in that setting, the report stated:

The . . . facility . . . as proposed, will rise to a height of 400 feet, approximately 1000 feet from Pennsbury Manor, thereby altering the historical and natural character of the area and creating an unacceptable adverse visual intrusion.

The Council, however, recognized that failure to build the power plant on the island would create the possibility of construction of a "smelter, refinery or some other less desirable industrial neighbor not subject to federal licensing. . . ."[102] Since the size, design, and location of the cooling towers were the major cause for concern, the Council recommended their relocation and redesign, and the utility complied with the recommendations.[103]

Transmission Lines

The consideration of aesthetic factors in transmission-line location has been receiving greater attention in recent years.[104] Potential aesthetic problems exist:

> [Transmission lines] require clearing of the natural vegetation on the right-of-way, construction of large steel towers and access and maintenance roads which so change the natural character of the landscape that scenic and other resources can be virtually destroyed. And even undergrounding is not a complete solution, aside from the cost, because clearing of the vegetation and access roads would still be required. [Ref. 79.]

In a recent case in Massachusetts, the court considered a statute that allowed electric companies to cross streets with their lines, provided that such lines "shall not incommode the public use of public ways."[105] The court held that there was nothing wrong in the town's Board of Selectmen determining "that such annoyances [the court's interpretation of 'incommode'] may involve aesthetics. The presence of power lines across a public way can, in our view, disturb natural beauty sufficiently to create real annoyance to the public users of the way, particularly in a day when such beauty seems to be a rapidly diminishing public asset."[105]

Guidelines that will minimize the impact of transmission facilities on the environment have been prepared for the protection of natural, historic, scenic, and recreational values in the design and location of rights-of-way and transmission facilities.[106] The Federal Power Commission (FPC),[107] the Department of the Interior,[108] and state commissions[109] with jurisdiction over transmission facilities have begun to consider environmental factors in their reviews.

PROPOSALS FOR IMPROVEMENT

In the past several years, many parties, both governmental and nongovernmental, have proposed changes in the AEC's regulatory procedures for the licensing of nuclear plants. Legislation to effect certain changes was considered in the first session of the Ninety-second Congress (1971), and hearings were held on the proposals.[110] The Joint Committee on Atomic Energy (JCAE) decided not to submit any bill to the Congress in that session. However, it is suggested that the Commission could make appropriate changes through its rule-making powers.[111]

In late November 1971 the then-new AEC Chairman, Dr. James R. Schlesinger, announced that the AEC was considering changes in its licensing rules "to achieve more effective public participation in the licensing process, and to increase efficiency in the conduct of public hearings."[112] Such hearings[113] include the "legislative-type" rule-making hearings, the first two of which were convened in January 1972.

Because of court decisions interpreting NEPA and the Refuse Act Permit Program, the AEC and other agencies proposed early in 1972 that NEPA and the Atomic Energy Act be amended to facilitate licensing of power plants during the "energy crisis" of the next year or two.[114]

Transfer of Regulation

Legislation has been proposed which would transfer the regulation of commercial uses of nuclear power to, for example, the Secretary of Health, Education, and Welfare, subject in certain cases to disapproval by the FPC or the Secretary of the Interior.[115] The Nixon administration has opposed these bills. Edward E. David, Jr., the President's science advisor, stated:[116]

> We recognize the criticisms which are made from time to time regarding the location of nuclear development and nuclear regulatory functions in the same agency. However, the recent transfer to the Environmental Protection Agency of the responsibility to fix the basic standards for radiation protection of the general environment tends to overcome some of this problem. There is now an independent agency which fixes the basic standards and AEC's task is implementing and enforcing those standards through its licensing authority.
>
> In the longer term we would not rule out the possibility of separating AEC's regulatory functions from the other functions of that agency. Developments may make such a move desirable at some appropriate time in the future.

Dr. David noted that, in view of pending reorganization plans,[117] consideration of the possible transfer of AEC's regulatory functions would be best left to some later date.

State Jurisdiction

During hearings in 1971 by the JCAE,[110] several bills were discussed which would permit individual states to set standards more restrictive than those of the AEC for discharge of effluents for nuclear power plants. These bills would amend Section 274(d) of the Atomic Energy Act to prohibit the AEC from refusing to enter into an agreement with a state under that section because the state's program for controlling the discharge or disposal of radioactive materials into navigable waters is more restrictive than the Commission's standards.

The Justice Department, in its review of this legislation for JCAE, noted:[110]

> We would like to call attention to two technical matters: (1) Section 274b limits the scope of agreements with the States to certain materials which apparently do not include effluents, a subject of prime interest to States, and (2) we have reservations as to whether it is technically possible to establish standards for the discharge of effluents from nuclear utilization facilities which do not affect construction and operation of such facilities, matters not subject to agreements under §274(c)(1) (42 USC 2021(c)(1)). It is not entirely clear that the bills obviate the later difficulty by their amendment of Section 274d.

The AEC has opposed the establishment of such a scheme of "dual regulation." The Department of Justice refused to recommend that the legislation be adopted because it involves "policy considerations."[110]

Power-Plant Siting

In October 1970 a task force that had studied the problem of power-plant siting issued a report on "Electric Power and the Environment."[118] On the basis of the recommendations of this group, the Office of Science and Technology developed a proposal for implementing legislation. The bill that was introduced in the Congress would:[119]

> (1) Require this Nation's electric utilities to engage in long-range planning and to publish general plans for their system expansions at least ten years in advance of construction; (2) provide that each State or region may establish a decision-making body that will review alternatives in order to assure that optimum sites for power plants and large transmission lines are selected, and that adequate environmental protection features will be employed; (3) provide for Federal Government review and approval responsibility until such time as a decision-making body is established on a State or regional level. . . . (4) require proposed power plant sites and general locations of transmission line routes to be disclosed and that public hearings on the plant sites be held at least five years prior to construction; (5) require that detailed applications be filed and another public hearing held at least two years in advance of construction; and (6) provide that the decision of the State or regional power plant siting body shall be conclusive on all matters of State or local law, thus consolidating the various approvals now required at the State and local level.

Among the other bills introduced in the first session of the Ninety-second Congress are at least seven others dealing with power-plant siting and environmental protection. The main features of these bills, as well as the administration's proposal, were discussed[120] in the subcommittee hearings held in May 1971.

Other proposed legislation would develop and declare a national energy policy or take other steps to meet the "energy crisis."[121]

CONCLUSION

This article has not addressed itself to the question of whether nuclear power plants *should* be built; rather it has assumed that, as in the past, they *will* be built and that they will be regulated. The threshold question is that of where major regulatory responsibility should be placed. Despite continuing pressure to give a concurrent responsibility to the states, notwithstanding the decision in *Northern States Power Company vs. Minnesota,* it appears likely that such regulation will remain a federal function; in fact, in the foreseeable future, fossil-fueled plants will probably also be subject to federal, or at least regional, regulation.

The first questions facing regulators in the environmental field involve the relative weight to be given to ecological, economic, and other considerations in balancing the benefits and costs of electricity in general and each proposed new plant in particular. An additional set of questions concerns who is to speak for each of these interests. Those who call themselves environmentalists may claim to represent an interest as broad as saving the earth's ecosystem or as narrow as ensuring the continuing productivity of a localized one-species sport fishery. These environmentalists may demand the preservation of a pristine wilderness or its opening up to public recreational uses. On the other side, consumers of electricity include such diverse groups as large industrial users trying to remain competitive in world markets, small storekeepers whose refrigerated inventories (and consequently their businesses) may be wiped out by extended interruptions of power supply, and the urban poor who aspire to share in the air-conditioned comfort of their countrymen during long hot summers.

Other questions include how best to design procedures to ensure that each of the many interests can make itself felt in the regulatory process without that process becoming so unwieldy that nothing can be done. In this field, as in others, *inaction* is an action with direct consequences. The respective roles of administrative agencies, the legislatures, the courts, private "attorneys general," and private interests must be spelled out. Perhaps procedural innovation will provide part of the answer. Such things as "counsel for the environment" (consumer ombudsmen) standing for natural objects (such as mountains) to be represented in proceedings,[122] an energy commission, and a technology-assessment arm of Congress are among recently suggested additions to our store of regulatory tools.

In the past the small number of nuclear power plants proposed for licensing allowed the process of determining their suitability to proceed with some success, despite inadequate procedures and insufficient opportunity for the plethora of interests potentially involved to be heard. Even though not specifically considered by the AEC before NEPA, major environmental factors were generally taken into account either at the federal level or in one of the many local agency reviews. But such a sporadic system is ill-adapted to an era of practical and multitudinous nuclear plants, a near-crisis in energy availability, and a raised consciousness of environmental values.

NEPA may not have solved all the problems, but it has certainly forced us to face many important questions head on. Although today's procedures are not yet optimum, the development of the regulation of nuclear power plants is a pioneering effort in evolving procedures for allowing a democratic society to utilize the benefits of advanced technology and at the same time to ensure that the concomitant environmental risks are minimized and that the public interest is served.

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PUBLIC HEALTH RISKS OF THERMAL POWER PLANTS

By Chauncey Starr and M. A. Greenfield

[*Nucl. Safety*, 14(4): 267–274 (July–August 1973)]

Abstract: *The results of a study comparing nuclear power plants with oil-fired plants are reviewed and assessed in terms of public-health risks. The study was undertaken as a basic contribution to the state of California's long-range planning on how best to meet the power needs of its growing population. Based on an 8-month evaluation of oil-fired and nuclear plants in urban settings, the authors conclude that the public-health risk from either type of plant is roughly comparable to the hazards to which the public is exposed by uncontrollable natural events—lightning, insect or snake bites, etc. Such*

deaths occur at an annual rate of approximately one per million of population. A comparison of the risk factors in routine operation of different types of power plants showed that public-health risks from nuclear plants averaged less than one-tenth of the risks from oil-fired plants.

This article summarizes the results of a comprehensive study[1] comparing nuclear and oil-fired power plants that took a broad view of pollutants and their effects on health. Topics considered in the study included pollutant pathways, risks from steady-state effluents, transient releases, resistance to earthquakes, transportation of nuclear fuels, and acceptable levels of public risk—how safe is safe enough? The work was done for the state of California based on a 1965 policy[2] that "seeks to ensure that the location and operation of thermal power plants will enhance the public benefits and protect against or minimize adverse effects on the public, on the ecology of the land and its wildlife, and on the ecology of state waters and their aquatic life." It is also the policy of the state of California to encourage the use of nuclear energy because such use has the potential of providing direct economic benefit to the public, of helping to conserve limited fossil-fuel resources, and of promoting air cleanliness.

The California State Resources Agency sponsored this study by faculty members of the University of California to provide a factual basis for comparing the public-health risks from fossil fuels and nuclear fuels. The analysis was restricted to oil-fired and nuclear power plants and their associated activities in an urban environment. Gas and coal were not considered, since they are not competitive economic modes for future power expansion in California.

COMPARISON SUMMARY

With both oil-fired and nuclear plants in a typical urban setting, public risks of continuous operation at regulatory limits are in the range of those due to other activities of man which have general societal acceptance. For 1000-MW(e) plants, the risks are in the "low" part of this socially acceptable range for the oil-fired plant (60 deaths per year in a population of 10 million) and in the "negligible" part of the range for the nuclear plant (1 death per year in a population of 10 million).

In both cases the integrated accident risk (averaged over time and all episodic events) is about a hundred-thousandth of the continuous exposure for either the nuclear plant or the oil-fired plant. For the analyzed accidents with equal estimated probability of occurrence, the impact on public health from the oil-fired plant is substantially worse than that from the nuclear plant. For example, the one event in a million years for the oil-fired plant would lead to approximately 700 respiratory deaths in a population center (such as Los Angeles County) of 10 million people, and the one event in a million years for the nuclear plant would result in approximately one death in the same population.

In the worst hypothetical nuclear accident, which has an estimated probability of occurring once in 100 million years, we can assign a maximum consequence of about 5000 cancer deaths per 10 million population (about one-third of the normal annual cancer death rate). Since most of the fatalities resulting from such radiation exposure would be spread over very many years, the effect of such a nuclear-plant accident on public health is unlikely to have much general visibility. It would only be possible to measure the full impact by maintaining lifetime statistics of the exposed population.

For the oil-fired plant, sufficient data are not available to estimate the worst hypothetical case. It is generally known that respiratory ailments can be increased by the synergistic interaction of various "insults" to the system. An extraordinary and rare hypothetical combination of a variety of airborne pollutants, respiratory epidemics (such as influenza), and chronic irritants (including asthmogenic allergens) might substantially increase regional fatalities. Since all these impacts are focused on the respiratory system, it is quite possible that the oil-fired-plant maximum hypothetical accident could cause as many fatalities as the maximum hypothetical nuclear-plant accident—with a probability of occurrence equally low. Omitted from this estimate is the synergistic effect of pollutants from the oil-fired plant other than sulfur dioxide—such as nitrogen oxide, heavy metals (lead, mercury, cadmium, nickel), radioactive elements, carbon monoxide, and carcinogenic compounds. Nitrogen oxide, in particular, may be a serious hazard, but so far little is known about its quantitative health effects. Insufficient data on respiratory effects are available to evaluate the full impact of all the multiple synergistic combinations that might possibly occur.

SCOPE OF THE STUDY

The total public-health risks from electric power should include public injuries and deaths that might arise from the construction and operation of power plants; from the use of electricity; from mining, transportation, and processing of fuel; from disposal of waste products; and from accidents associated with any of these activities. However, this study assumes that the demands for electricity in California will be met; thus it is not an evaluation of the public risks and benefits from electricity nor of the consequences of meeting the demand for it. Also, this study does not consider other areas of social cost, such as thermal discharges, esthetics, utilization of resources, and recreation.

The public-health factors considered include both the risk to an individual (or small groups of individuals) and the risk to the total population. The total (or average) risk must be socially acceptable, with consideration being given to both large- and small-group exposures.

The technology considered in this article is that which can be expected to be available in the near future (next 15 to 20 years) at reasonable costs. Therefore it must either be available now or be operating on a small scale now with reasonable capability of expansion to meet near-term needs.

At the outset, it must be stated that today's coal-fired electric-power plants cannot meet the air-quality requirements of the state and that the technology of pollution control for such plants is not sufficiently developed to assure meeting the needs of the state in the time scale required. Furthermore, it is assumed that California cannot continue to import substantial energy by locating coal-fired power stations out of the state. Natural gas is already in short supply. Accordingly it is necessary to focus attention on oil-fired plants and on nuclear reactors, particularly pressurized- and boiling-water reactors, high-temperature gas-cooled reactors, and fast breeders.

THE EFFECT OF POLLUTANTS ON HEALTH—A PERSPECTIVE

Information on steady-state releases to the atmosphere and to bodies of water is plentiful and is well established for both fossil-fueled and nuclear power plants. However, estimation of the frequency and magnitude of transient or accidental releases is less firm. In either case the correlation of levels of pollutants and public-health risks is primarily based on epidemiological studies, which characteristically represent small samples of the population with many variables that are not as easily controlled as in a laboratory study. Experiments on animals in controlled situations are numerous, but extrapolations to humans do not generally rest on a proven model. Hence the correlation of public-health risks with pollutant levels is on a much less firm basis than the correlation of pollutant emissions with plant size or type.

The central difficulty in comparing the health effects of power plants using different fuels arises from the problem of comparing pollutants with totally different effects on humans. For example, the somatic risks due to sulfur dioxide or radioactive iodine depend not only on the relative quantities involved but also on the nature and severity of their effects on humans. Considering an oil-fired plant alone, the types of pollutants released may change significantly with different fuel supplies.

Despite the lack of precision in our knowledge, some perspective on the relative effects of important pollutants is possible. There are data and known lethal levels that can be used as bench marks for radiation, sulfur dioxide, and nitrogen dioxide. Because of the uncertain data for large populations, the transition from medically perceivable effects to disability and lethality can usefully be indicated as three approximate ranges: natural background, medically perceivable, and lethal. Ranges of medically perceivable effects are about 10 times lower than lethal levels for radiation and sulfur dioxide and about 100 times lower for nitrogen dioxide. "Medically perceivable," as used here, means in vivo clinical measurements on man, in contrast to studies on other forms of life. For all three pollutants the natural background levels are about 100 times lower than the ranges of medically perceivable effects.

There are regulatory limits governing radiation, sulfur dioxide, and nitrogen oxide, each of which applies to an average level to which large populations might be exposed on a continuing basis. However, these are not all implemented in the same way. The limit for average radiation dose to large populations is based on continuous monitoring of reactor-site-boundary effluents. For fossil-fuel pollutants, criteria are focused on off-site ambient levels, which are usually the result of contributions from power plants and other sources, for example, fuel combustion for such other purposes as industrial plants and transportation.

Noting that the AEC limit[3] on reactor-emission levels is the only regulation that is below natural background, it is enlightening to calculate the percent of background permitted by the various regulations. The values are 1, 10,000, and 400% for radiation, sulfur dioxide, and nitrogen dioxide, respectively. Interestingly, much greater excursions above background levels are allowed for pollutants that are less well understood than radiation with respect to their medical implications. This statement is especially true for sulfur dioxide and nitrogen dioxide when information on their possible carcinogenic (cancer-causing) or genetic (altering mutation rate) effects is compared with such information on radiation. This suggests that federal regulations are not consistently or solely determined by the available medical data or public-health criteria. As noted previously, it is relatively easy to compare pollutant levels on a simple stack-effluent basis, for example, but it is more difficult to correlate the various effluents with risks to public health. (Appendixes I and VI of Ref. 1 review this issue in detail.)

The cellular effects of pollutants (stable chemicals as well as radioactive) must also be investigated, and a brief review of the problem will suffice to indicate the ramifications.

Chemical attack on deoxyribonucleic acid (DNA), the genetic material of living cells, can produce mutations—changes in the structure of DNA which are inherited by succeeding cell generations. When the DNA is in a germ cell, the mutation becomes part of our load of mutations; it may result in an increased frequency of occurrence in children with such major afflictions as cystic fibrosis, sickle-cell anemia, hemophilia, phenylketonuria, or one of the innumerable minor genetic disabilities that are "the differential cause of the death or failure to reproduce of between one-fifth and two-thirds of the persons who escape being killed before reproduction or being prevented from reproducing, by other, purely extrinsic causes."[4] When the DNA is in the developing fetus, the mutation may result in fetal wastage or in one or another of the congenital birth defects that afflict some 6 to 8% of the newborn. The percentage of congenital anomalies varies widely according to the criteria used and ranges from 1 to 14% as reported in a variety of studies.[5-9] When the DNA is in a somatic cell of a child or an adult, the mutation may transform the normal cell to a malignant cell and thus induce a potentially lethal cancer.

At the molecular level, mutations can result from the reaction of a single molecule with a molecule of DNA. Therefore single ionizations can produce mutations or activate latent viruses in individual living cells.

With respect to the cellular effects of pollutants, a general statement that can be made about the magnitude of the hazards associated with environmental agents is that the hazards increase with the level of the agent and the duration of exposure of the population. A more specific statement must be based on detailed data about the action of each agent.

One of the principal modes of action of ionizing radiations on living cells is through the production of free radicals in the water within the cell. These free radicals, chemical species with an odd number of electrons, are highly reactive and attack DNA at many sites. However, radiations are not unique in their ability to initiate free radicals within cells; ozone, for example, when dissolved in water, decomposes to form free radicals. The normal amount of ozone at sea level, 0.02 ppM, if entirely converted to free radicals in the body, would produce about 4000 times more free radicals than are produced by the natural-background radiation levels of about 0.1 rad/year.[10-11] Ozone contents of 0.02 to 0.2 ppM are not uncommon in the Los Angeles basin, and the "alert level" of ozone in smog in Los Angeles is 0.50 ppM. Oxygen is also converted in the body to free radicals by normal metabolic processes. Thus the action of radiation is not qualitatively different from that of other environmental agents, and the risk of increasing radiation levels by the operation of nuclear power stations must be weighed against the qualitatively similar risk of increasing ozone and other pollutants in the atmosphere by the operation of fossil-fuel power plants.

POLLUTANT PATHWAYS

Although little can be said in this brief article about the pathways of pollutants to the public, some of the highlights of the risk-evaluation process can be indicated. Both nuclear and fossil-fueled plants release pollutants to the atmosphere as well as to liquid effluents. Minimization of these releases is common practice, but to expect zero release is unrealistic, even in the future. Thus it is imperative to determine the transport characteristics associated with site meteorology, hydrology, and food chains so that the quantities of pollutants reaching the population can be established.

Meteorological transport is the most important pathway for both particulate and gaseous pollutants from power plants to the population. Such transport leads directly to exposure through inhalation and less directly by ground deposition. Accumulation of detailed meteorological information for a prospective site is a necessary first step. This information includes wind speed and direction, vertical temperature variation (mixing layer thickness), stability class (Pasquill), and their variations with time. Such data acquisitions are already available for the San Onofre, Rancho Seco, and Humboldt Bay nuclear plant sites in California.

The hydrology of the area must be examined from both the standpoint of direct reception of pollutants contained in liquid effluents and also as another link in the chains beginning with meteorology and leading to man. The relative importance of hydrologic transport is strongly dependent on the chemical nature of pollutants and their radioactive or chemical half-lives.

Possible entry of pollutants into food chains or webs can be examined by surveys of the local biogeography and of remote biosystems which could be reached via atmospheric or hydrologic transport. Pollutants of greatest concern are heavy metals and long-lived radioisotopes because other species will not enter food chains or will not maintain their toxicity at the end of food chains, which generally are slow transport paths. This leads to a simplification because relatively few pollutant species need to be followed very far. (Appendix II of Ref. 1 contains a detailed analysis of this subject.)

RISKS FROM STEADY-STATE EFFLUENTS

For a given basis with a fixed volume of air, the question of relative public-health risk attributed to various types of power plants can be posed as follows: How many plants of a given type can be operated without reaching a pollutant concentration level having public-health significance? Quantitative answers to this question can be arrived at in terms of the critical pollutants SO_2, NO_2, and radioactive gases.

Meteorological stagnation of several days' duration is not an uncommon event in several areas of the state. It is a historical fact that air-quality standards are exceeded regularly in some areas and that these occurrences coincide with meteorological stagnation. Increased mortality data for these occurrences are impossible to glean from the public-health data unless the meteorological conditions are extremely adverse and of long duration, resulting in substantial mortality and morbidity, such as the New York, Donora, or London episodes. Nevertheless, lesser occurrences should not be assumed to have no impact.

According to the assumptions used for the study, Los Angeles County can tolerate under current practices 10 oil-fired plants (SO_2), 23 plants fired by natural gas (NO_2), or 160,000 nuclear plants (radioactive gases). Here, each power plant operates at full capacity for 1 day, and no washout or other depletion mechanisms are operative to clean the air during that day. It is notable that 160,000 nuclear power plants of 1000 MW(e) each could operate for 1 day without exceeding an average concentration in the air-basin volume corresponding to legislated limits.

TRANSIENT RELEASES

If the public-health risk of any technological system is to be determined, the frequency and consequences of accidents must be considered. For a well-established system, such as a fossil-fueled power plant, the frequency and magnitude of public-risk accidents can be estimated from historical records. However, since the history of nuclear power plants is short, and there are relatively few such plants, more information is needed to estimate the frequency and magnitude of their releases.

The probabilistic approach to quantifying risk has not been the historical approach to power-plant safety—either fossil fueled or nuclear. Three basic approaches to safety analysis can, however, be identified. The most common is the empirical (or inductive) study of actual performance history to estimate the level of risk of various events. The second is the judgmental (or intuitive) review by experienced professionals to determine if adequate design precautions have been taken. The third, a deductive process, is the estimation of system risk as derived from the reliability of individual components and their interaction. Only the first (empirical) and the third (deductive) approaches provide quantitative results. In the absence of a substantial operating history, nuclear plants have typically been studied by the second (or judgmental) approach. However, the third (deductive) method was used to make a meaningful comparison between oil-fired and nuclear plants. (Appendix III of Ref. 1 discusses this approach in greater detail, with specific calculations for a typical fast breeder nuclear reactor.)

SEISMIC SAFETY OF POWER PLANTS

The methodology used in assessing the seismic safety of power plants (Appendix IV, Ref. 1) provides a basis for determining when typical power-plant designs may be expected to safely withstand the vibratory ground motion to be expected within the state of California. The problems of fault slippage occurring beneath a plant and of tsunamis (seismic sea waves) are not considered here, although they are important considerations in the siting of power plants. Typical nuclear power plants were considered in this evaluation, but the methods could be applied to any type of power plant. This methodology is intended to provide a general basis for preliminary site evaluations. For nuclear power plants, such a study should precede, but cannot replace, the detailed review procedures adopted by the U. S. Atomic Energy Commission.

Results of the seismic analyses indicate that, with reasonable care and attention to detail, satisfactory reactor-containment structures can be designed and built to withstand the earthquake ground motion to be expected at most California sites.

The study also indicates that, in nuclear plants, internal equipment comprising the primary coolant loop (particularly large-diameter interconnecting piping under typical design pressures of 1000 to 2000 psi and temperatures of 600°F) is considerably more sensitive to seismic loading than are containment structures. These systems will require careful analysis, design, and testing for satisfactory performance. For fossil-fueled plants, internal equipment, piping, and fuel-storage tanks are also expected to be critical elements.

Since detailed analytical models of reactor pressure vessels, cores, and control rods are not generally available, no evaluation was attempted during this study. They are potentially critical elements in the dynamic response of nuclear reactor systems and require detailed dynamic analysis. Plant designers and constructors must be prepared to apply new methods of dynamic analysis and to increase the efforts given to experimental verification of power-plant seismic design and construction.

TRANSPORTATION OF NUCLEAR FUELS

A conservative projection was made for the year 2000 (Appendix V, Ref. 1) by choosing the greatest average transportation distance from among the three postulated reprocessing plants in the study, and assuming that every accident that leads to a radioactive release to the environment is a maximum credible accident (all fission gases in the shipping-container plenum are released). The number of serious injuries in the state was found to be less than one in 1000 years for the projected fuel-logistics requirements. This conclusion was based on an average population density and would change in proportion to the actual population density on any chosen route. Two generalizations may be derived from this result:

1. Transportation of spent nuclear fuel does not measurably add to the public-health risks of the power plant.

2. Siting of nuclear power plants does not depend on the location of reprocessing plants, because the two can be decoupled with little or no change in the total risk.

ACCEPTABLE LEVELS OF PUBLIC RISK: HOW SAFE IS SAFE?

Risk, as used in this study, means the quantitative probability of injury (that is, the chance of some specified personal damage occurring in a specified time interval). Public risk is the averaging of individual risks over a large population. The injuries involved may vary from minor annoyances and discomfort (not enough to prevent normal activities), to disabilities that cause reduction in normal productivity (morbidity rate), and to loss of life (mortality rate). Because of the dramatically visible nature of death, public risk is usually conceived of in terms of fatalities or mortality rate. However, the importance to the public welfare of the less visible morbidity rate (disabilities) may be much greater in terms of humanistic, economic, and social values. For example, the annual number of deaths in the United States due to automobile accidents is often quoted with alarm, but one rarely hears of the disabling injuries, hundreds of times as many, which may have an equal or greater social importance.

Since mortality data are most readily available, the quantitative power-plant comparisons presented in the study dealt with the public risk of fatalities, recognizing that this is only indicative of the total risk and that the social cost should include a multiplier to account for associated disabilities. Similarly, a usually neglected but important factor from low-level exposures is the time required for physiologic impairment to develop. If the time for the effects of exposure to develop is long, then only the younger members of the population may have their later life affected (as with smoking). These factors of degree of morbidity, age, and duration of exposure, changing social value as a function of age, and other similar public-health parameters should theoretically be included in any complete study. Unfortunately, basic physiologic and technical data in the air-pollution field are generally so uncertain quantitatively that such a refined analysis is only occasionally justified. Order-of-magnitude answers (that is, within a factor of 10) are usually all that can be expected in such areas of public risk.

A study of the public acceptance of mortality risk arising from involuntary exposure to sociotechnical systems, such as motor-vehicle transportation, indicates that our society has accepted a range of risk exposures as a normal aspect of our life.[12] Figure 1 shows the relation between the per capita benefits of a system and the acceptable risk as expressed in deaths per exposure year (i.e., time of exposure in units of a year). The highest level of acceptable risks which may be regarded as a reference level is determined by the normal U. S. death rate from disease (about one death per year per 100 people). The lowest level for reference is set by the risk of death from natural events—lightning, flood, earthquakes, insect and snake bites, etc. (one death per year per million people).

In between these two bounds, the public is apparently willing to accept "involuntary" exposures (i.e., risks imposed by societal systems and not easily modified by the individual) in relation to the benefits derived from the operations of such systems. The position of electric power plants is well within the acceptable risk range.

PRINCIPAL CONCLUSIONS

If currently available technology is used to protect the public health and safety, the following can be concluded from the study:

The public-health risk from routine operations of electricity-generating plants using nuclear fuel or oil is in the range of the very low hazards to which the public is exposed by uncontrollable events of nature, such as being struck by lightning or bitten by a venomous animal or insect (about one death per year in a million population).

Routine operation of a nuclear plant presents a significantly smaller public-health risk than the routine operation of an oil-fired plant, typically by a factor of 10 to 100.

The public-health risks due to accidental releases from either a nuclear or an oil-fired plant are both of the same magnitude and are about 100,000 times smaller than the risk from routine operation of the plants.

The maximum hypothetical accidents associated with either plant type are not likely to be sufficiently large to have a significant public-health impact when compared with the normal incidence of disease.

Both oil-fired-plant and nuclear-plant structures should be designed to meet the earthquake forces expected at a particular site, and a basis for such a design does exist.

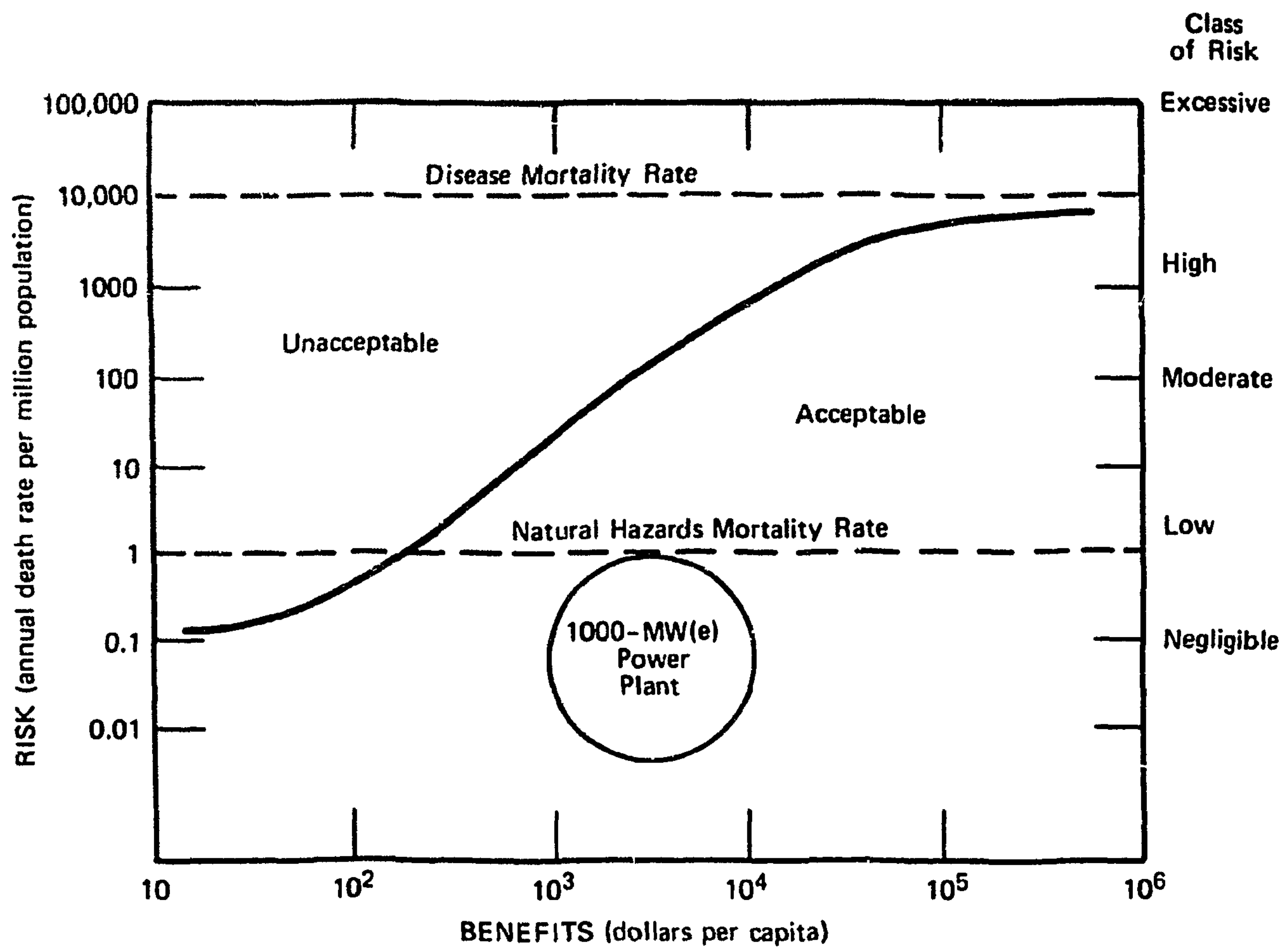

Fig. 1 **Benefit–risk pattern for involuntary exposure.**

The risk associated with transporting spent nuclear fuel can be made small enough so that the location of the associated fuel-reprocessing installations is a separable factor in siting nuclear power plants.

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Item		Price per copy (including U. S. postage)
Basic Report		$2.25
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Appendix IV	Seismic Safety of Power Plants	$4.00
Appendix V	Transportation of Nuclear Fuel	$4.50
Appendix VI	Approximate Mortality Risk from SO_2 and Particulates	$2.00

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HEALTH EFFECTS OF ELECTRICITY GENERATION FROM COAL, OIL, AND NUCLEAR FUEL

By L. B. Lave and L. C. Freeburg

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[Editor's Note: This is another in the continuing series of *Nuclear Safety* articles on nuclear power and radiation in perspective. Our complex industrial society is fraught with hazards at every turn—automobiles, polluted air, insecticides, electricity, gases, chemicals, and nuclear radiation—to mention a few. One of the purposes of this series is to portray the impact of radiation in our society in its true perspective.

In this very interesting article on the health hazards associated with electricity generation using various fuels, the authors studied the public-health risks from uranium, low-sulfur oil, and coal power plants. The conclusions they reached regarding the risks associated with each fuel were based on multiple regression analysis in much the same way as other investigators have associated lung cancer with cigarette smoking. However, the editors would like to caution the readers that, although regression analysis is a useful tool that is frequently used in instances involving many interrelated parameters, causation is not proved by such correlations. Rather, the correlations are suggestive of a possible cause–effect relation that must be proven by other means.

Other facts that the reader should bear in mind are: (1) the relatively limited operating experience with nuclear reactors

has been so good that no experience has been accumulated regarding the consequences of low-probability accidents (although this relation is being evaluated by the Rasmussen Study, AEC Press Release R-252, June 25, 1973); and (2) effluent releases in both nuclear- and fossil-fueled plants are being cleaned up as a result of recent environmental legislation, and experience with the improving effluent-cleanup technology is limited.

Despite these qualifications, the editors believe that this article brings together such significant information that is needed for such a study, and, given the reservations and assumptions noted, the conclusions are justified.]

Abstract: *Occupational- and public-health effects of generating electricity from coal, uranium, and oil are compared, with particular attention given to accident and chronic-disease rates for fuel extraction and airborne emissions from power and reprocessing plants. It is concluded that uranium offers less of a health hazard as a fuel than coal. The analysis is based on current operating practice; however, advances in technology can be expected to reduce both the occupational- and public-health risks from these fuels.*

The threat of black lung and other respiratory diseases to coal miners, the health effects of air pollution, and the radioactive releases of nuclear reactors have received national publicity in recent years. Each is, to a considerable extent, a consequence of electricity generation. This article focuses on the health effects of generating electricity from three fuels, with particular attention given to light-water reactors (LWRs) and steam plants fueled by coal and to a lesser extent by oil. Since experience with other types of reactors is much more limited, they will not be considered here. Natural gas is excluded from the analysis and oil is only partially treated because they are not likely to be important sources of fuel in the future. Hydroelectric sites are largely used up and thus are of little future incremental consequence. A major topic not analyzed in this article is the optimal growth rate of the demand for electricity.

Coal miners experience accidents as well as pneumoconiosis (black lung) and other chronic respiratory diseases. Accidents also occur in transporting coal from the mine to the generating plant, and, at the plant, additional accidents, such as boiler explosions or the release of noxious fumes, can harm workers. Finally, the normal effluents of the burning—heat, SO_2, NO_x, CO, particulates, and some radioactive substances—pose a threat to surrounding residents.[1,2]

Uranium miners are also threatened by accidents and by disability resulting from inhalation of dust and radioactive particles. Although much smaller volumes of material are transported, there are still potential hazards from transportation accidents. Persons engaged in the milling and fuel-preparation processes are subject to normal industrial accidents and to the risk of radiation exposure (especially from breathing radioactive dust). Nuclear reactors contain large quantities of radioactive substances, a very small proportion of which is released to the environment during routine operation of the power plant. The effluent normally consists of heat, noble gases, tritium, and other radioactive wastes and contributes little to the level of background radiation. There is also a small, but finite, potential for accidental release of more substantial amounts of radioactivity from the power plant. Finally, reprocessing the fuel releases radioactive substances and thus produces additional radiation hazards.

Oil extraction carries the risk of drilling and pumping accidents. The transportation of oil has a small accident rate. The refining operation is susceptible to explosion and fire, as well as to the normal release of air pollutants; for example, petroleum refineries are responsible for a significant amount of CO, SO_2, and hydrocarbons.[3] Finally, there are generation accidents and normal effluents similar to those associated with coal, although the quantity of emissions is lower per megawatt-hour of electricity.

Morgan,[4] Starr,[5] and Sowby[6] approached the problem of evaluating risks from generating electricity by calculating the probabilities of various accidents or other adverse consequences and comparing these with other activities that people pursue. Some of these calculations are informative but are subject to great reservations since there is no good way of estimating such low-probability events as major nuclear-generator disasters. This is especially true when an attempt is made to incorporate events that are believed to have probabilities of 10^{-3} to 10^{-6} per reactor per year.

The primary approach of this article is (1) to compare the documented occupational-health effects of "extracting" fuel in the forms of coal, uranium, and petroleum, with respect to both accidents and chronic diseases (in terms of disability days per million megawatt-hours of electricity generated), and (2) to compare the calculated public-health effects of the normal operation of power plants fueled with coal, uranium, and oil (both in terms of the dilution volumes required for emissions to meet public-health standards and in terms of estimated dose–response relations for chemical and radioactive emissions). In general, the health effects of spent-fuel transport, radioactive-waste storage, and other radioactive releases associated with the nuclear cycle are treated only qualitatively; insufficient data for quantitative analysis have been accumulated in the short history of many of these operations.

The total analysis results in the conclusion that electricity generation from uranium offers less of a public-health hazard than that from coal or oil. Although the occupational-health effects of oil are less than those of coal, the comparison between oil and uranium is not as clear-cut; however, occupational-health risks appear to be higher for uranium because of radiation exposure to employees and miner silicosis. The framework for the comparison is set out systematically, but, since not all the relevant factors could be estimated with confidence, the analysis must be considered preliminary.

The comparison is based on existing plants, but, since technology is advancing rapidly, this comparison is not likely to be valid 10 or even 5 years hence.[7-9] However, the qualitative conclusions are likely to hold in the future and to be better predictors than the forecasts of untried technologies.

OCCUPATIONAL-HEALTH EFFECTS OF EXTRACTION PROCESSES

There are certain inherent dangers, in terms of both accidents and chronic diseases, in extracting fuels from the earth—that is, in mining coal; in mining and milling uranium; and in drilling for, producing, and refining petroleum. The extent of the risk is shown by the following statistics.

Accident Rates

Table 1 presents comparative data from 1965 to 1969 on injuries and rates of injury for coal-, uranium-, and oil-extraction processes.[10,11] Column 5 presents the disabilities per million megawatt-hours of electricity produced in 1969; this calculation involves assumptions explained below.

In 1969, 237 x 10^6 man-hours were spent mining coal.[10] At an average severity rate of 8441 disability days per million man-hours, about 2,005,000 disability days could be expected from accidents. The average accident rates for 1965 to 1969 were used instead of the actual 1969 experience in order to smooth the fluctuations that might occur from year to year. Since about 54.3% of the coal mined in 1969 was used for electricity generation,[10] some 1,089,000 disability days would be estimated to result from the amount of coal mined to generate electricity. This coal generated some 705 x 10^6 MWh;[12] thus approximately 1545 disability days per million megawatt-hours of electricity generated by coal would be estimated to result from coal-mining accidents.

In 1969, 7.80 x 10^6 man-hours went into uranium mining;[10] thus about 67,900 disability days would be expected from accidents. Uranium milling absorbed 3.59 x 10^6 man-hours and would be estimated to generate 3911 disability days. In 1969, 11,870 short tons of U_3O_8 were produced domestically,[10] of which about 4700 tons were sold for electricity production.[13] However, not all of this amount was consumed during the year. New reactors were activated, and there was presumably some buying for inventory. The U_3O_8 requirements per electrical megawatt have been published for a number of LWRs[14] and can be used to estimate the consumption of uranium in electricity production. For these reactors, an average of 0.633 short ton of U_3O_8 is required to provide fuel for the initial core and 0.166 ton for the annual reload per electrical megawatt. Thus the annual fuel requirement would be 0.182 ton/MW(e) when averaged over the life

Table 1 Comparative Data on Accidents Occurring in Various Extraction Processes from 1965 to 1969

Process	Accidents per year		Injuries per 10^6 man-hours	Disability days per 10^6 man-hours	Disability days per 10^6 MWh, 1969
	Fatal	Nonfatal			
Coal mining	246	10,251	43.5	8441	1545
Uranium mining	8	272	39.8	8702	157 (mining and milling)
Uranium milling	1/5	59	17.0	1091	
Oil drilling and production	1104*		10.2	1176	135 (drilling, production and refining)
Oil refining	1060*		5.5	793	

*Includes both fatal and nonfatal accidents.

of a plant (assuming a plant life of 30 years).† During 1969 the total electricity generated by nuclear plants was 14×10^6 MWh.[12] Thus, assuming utilization at 80% of capacity, an estimated 364 tons of U_3O_8 were required to generate electricity in 1969, about 3.06% of the uranium mined in that year. An estimated 2200 disability days would be expected to result from uranium mining and milling for electricity production, approximately 157 disability days per million megawatt-hours of electricity.

In 1969, some 307×10^6 man-hours were spent in drilling, producing, and refining petroleum.[11] At 1969 levels of employment, 285,000 disability days would be expected to result from accidents in these activities. Since 7.71% of petroleum produced domestically and 6.03% of petroleum refined domestically in 1969 were used to generate electricity,[10] approximately 19,000 disability days would be expected from drilling, producing, and refining petroleum to generate electricity. Since this petroleum generated some 144×10^6 MWh of electricity,[12] 135 disability days per million megawatt-hours would result from these operations.

The contrast between coal and the other two fuels is striking. In terms of estimated disability days per million megawatt-hours, coal had 1545; oil, 135; and uranium, 157. In terms of mining and associated accidents, electricity generated by coal carries almost 10 times the health cost of electricity generated by uranium.

However, a note of caution must be entered. The uranium industry is small enough that the current estimates may not approximate the experience if nuclear power generation is expanded substantially Many of the values used in the calculation are estimates rather than actual rates.

Chronic Diseases

A large body of literature is focused on establishing an association between coal mining and respiratory disease.[15-28] Although occasional contrary evidence is reported, there is no doubt that such an association exists. However, the incidence of chronic respiratory disease is difficult to estimate since primary reliance has been placed on pneumoconiosis (black lung) as diagnosed by X-ray evidence.[29] This evidence is not highly correlated with respiratory disability.[16,18,25]

†The amounts of U_3O_8 cited are net amounts and allow for the recovery of uranium from reprocessing spent fuel.

Little of the literature reports an increase in disease prevalence or severity of symptoms by years of mining. The dose–response relation is difficult to estimate for a number of reasons, such as the selection process, which causes the more sensitive individuals and those developing symptoms to stop mining. Thus a simple tabulation by years underground should lead to an underestimate of the adverse effects of coal dust. Lainhart[26] reported a linear increase in the prevalence of pneumoconiosis among working miners with 15 or more years of underground experience. He estimated the following formula for the percentage of workers with definite pneumoconiosis: $y = -12.12 + 0.95$ years. Similarly, the incidences of severe dyspnea (shortness of breath) and persistent cough were found to increase with years underground.

Henschel[24] observed that measures of ventilatory function fall more rapidly with years underground than one would expect from aging alone. He found a close association between reduction in ventilatory function and degree of dyspnea, but only a partial relation between X-ray evidence of pneumoconiosis and ventilatory function.

The simple regression shown above can be used to illustrate the chronic disease and presumably the disability cost of coal mining. According to that regression, the cost of an additional year of underground mining to workers with 13 or more years of experience is a 0.95% increase of these workers with definite pneumoconiosis. Since each worker mines enough coal to generate 9900 MWh of electricity per year, the disability cost of this electricity for all working miners (strictly in terms of pneumoconiosis) is one additional man in 145 with definite pneumoconiosis.

This estimate is not worthy of great confidence, since it neither controls all the relevant variables nor takes account of other disabilities, such as increased bronchitis and emphysema, or other ventilatory symptoms, such as increased dyspnea. However, the estimate at least illustrates how the calculation should be carried out when better estimates of these factors are available.

It is interesting to contrast this chronic disability rate with the previous estimate of accident disability; for example, mining enough coal to produce 10^6 MWh of electricity is estimated to increase chronic disability by 0.7 additional definite case of pneumoconiosis and to increase accident disability by 1545 days. Thus, if pneumoconiosis resulted in total disability, it could be much more important than the accident rate. Accidents cost approximately 6 man-years of disability per million megawatt-hours, whereas 0.7 case of pneumoconiosis may cost up to 20 years of disability, assuming that pneumoconiosis is totally disabling.

Uranium miners should also be expected to have abnormal rates of chronic disability because of occupational exposure to dust and to radon and its daughters. One aspect of the dust is similar to that for any hard-rock mining: the dust produces silicosis in miners' lungs. A second aspect is more peculiar to uranium mining: the mines are radioactive and therefore expose miners to whole-body radiation. In addition, the dust particles are small and radioactive and thus give an especially high dose to the lungs.[30] Many studies have shown an association between uranium mining and ventilatory dysfunction and between uranium mining and lung cancer.[31-37]

Archer and Lundin[33] estimated a dose–response curve for lung cancer from all available data (European and U.S. miners) and concluded that a linear relation fits the data as well as a quadratic form (at least below 5000 WLM*) and that 1000 WLM will increase the lung cancer rate by 26 cases per year per 10,000 miners. Since the median exposure level of U.S. miners is slightly in excess of 1.0 WL,[30] 1 miner-year is approximately 12 WLM, or 1.2% of 1000 WLM. Thus 1 miner-year is estimated to increase the incidence of lung cancer by 3.1×10^{-5} case per year.

A miner-year produces enough uranium to generate 105,000 MWh of electricity; thus the cost of 10^6 MWh of electricity is 3.0×10^{-4} case of lung cancer per year. This health cost is only with respect to lung cancer and does not include other chronic disability, such as silicosis.† This figure for lung cancer can be compared with the health cost of coal mining in terms of pneumoconiosis. One million megawatt-hours of electricity generated by coal was estimated to cost 0.7 definite case of pneumoconiosis; uranium mining leads to only $3.0 + 10^{-4}$ case per year of lung cancer per million megawatt-hours.

*The working level (WL) is 1.3×10^5 MeV of potential alpha energy from radon daughters per liter of air. A WLM is 1 month of mining exposure at this level.

†Investigations during the late 1950s and early 1960s showed that silicosis among uranium miners was only about one-third as prevalent as pneumoconiosis among coal miners.[26,39] However, this was primarily a reflection of differences in length of mining experience between the two groups, the coal miners on the average having much longer mining experience. For workers with more than 20 years of experience, the rate among uranium miners was higher than that among coal miners. The rates for miners with the longest work experience may somewhat reflect higher dust concentrations allowed in the mines during earlier years.

Another way of comparing coal and uranium miners is to examine the total death rates (excluding violent death) for each. Enterline[20] presented data on death rates for coal miners and operatives vs. all male workers, by age, for 1950. Coal miners and operatives had excess mortality ranging from 23% for 20- to 24-year olds to 122% for 60- to 64-year olds. The entire group yielded an excess mortality rate of 67%.

Lundin et al.[34] presented data on uranium miners over the period 1950 to 1967. Expected death rates were calculated for these miners from age–sex–race–cause specific mortality rates for the states in which the mines were located. Excluding violent deaths, uranium miners had 39% excess mortality; among uranium millers, however, total mortality was no greater than expected.[38] Although there was a significant excess in deaths from malignant diseases of the lymphatic and hematopoietic tissues other than leukemia, the numbers were small.

The crude comparison is that coal miners had 67% excess mortality, and uranium miners had 39%. Little confidence can be placed in this comparison since no allowance is made for income levels and other factors affecting mortality. However, it seems likely that the qualitative conclusion is correct; that is, even aside from violent death, coal mining is more injurious to the health than is uranium mining.

A uranium miner produces enough uranium during a year to generate 10.6 times as much electricity as a coal miner produces in a year. This means that, in terms of electricity produced, the excess death rate of coal mining is roughly 18 times that of uranium mining. This factor would be reduced somewhat by the inclusion of other steps in the uranium fuel cycle.

A qualification is needed here since the comparison is essentially between deep mining of coal and deep mining of uranium. Only about half of either fuel is mined undergound.[10,40] Strip mining already supplies almost half of the coal and involves much lower accident rates and chronic disability rates. Insofar as strip mining becomes more important in the future, accident and disability rates will shift in favor of coal. Automation of deep mining would also have a strong effect on these rates. However, the much stricter control measures instituted to reduce radiation exposure of uranium miners should lower the incidence of lung cancer among that group in future years.[30]

OTHER OCCUPATIONAL-HEALTH EFFECTS

Although some data are available on transportation accident rates,[11,41-45] they are not completely differentiated by commodity. Data on the number of fuel shipments can be found in Refs. 40, 44, and 46. Since the number of coal shipments per electrical megawatt is many times the number of uranium shipments,[40,44,46] more accidents and therefore more accident disability must result from coal transportation, even allowing for a shorter average transport distance for coal. The only contradiction would occur if transportation accidents involved breaking the vessel that holds the nuclear fuel (particularly spent fuel) and thus releasing significant radioactivity. No significant radiation exposure has occurred as a result of transportation accidents, and extraordinary care is taken to build transportation vessels that are unlikely to be breached. Brobst[41] has estimated that a truck driver involved in a transportation accident while transporting spent reactor fuel is thousands of times less likely to be injured from radiation exposure than he is from nonradiological crash effects.

Statistics on accidental injury and disability rates for individual segments of the private atomic energy industry, such as reactor operation and maintenance, have been published[47] by the Bureau of Labor Statistics for 1965 to 1970. Data on numbers of employees in these areas are available[48,49] for 1963 to 1970. However, manpower and accident rates for operation and maintenance of fossil-fuel-burning plants are not as well documented. Chronic-disease rates for employees in these activities are also not well documented. The few studies that have examined mortality of public-utility employees or uranium processors have not found rates higher than expected, given the experience of other types of workers.[50,51]

Added cancer mortality risks from some of these activities can be estimated from data on occupational exposure to employees of AEC licensees.[52] The total dose from external radiation reported for a sample of employees involved in activities relating to reactors, fuel processing, waste disposal, and packaging and transporting was about 2800 man-rems in 1969, many times the total exposure to the public from the radioactive stack releases of nuclear power plants.[52,53] An additional 1050 man-rems can be inferred for licensees not included in the sample. (Internal radiation doses were also received by these employees but were not evaluated in Ref. 52 because of the difficulty of determining them.) According to dose–response estimates for radiation-induced cancer which are outlined later in this article, the cost of this radiation exposure would be expected to be about 0.02 to 0.05 death per million megawatt-hours of electricity produced in 1969. However, most of this dose was received by employees involved in fuel processing. Since the amounts of fuel prepared in 1969 exceeded the amounts consumed in generating electricity, and the amount of power-plant fuel reprocessed was less than that consumed, it is difficult to determine the actual mortality risk per million megawatt-hours of electricity. Another problem is that some employees in these activities are not included (such as enrichment-plant employees). Nevertheless, the available data are sufficient to indicate that the occupational-health costs from radiation exposure to employees related to nuclear power production are outweighed by the occupational-health costs to coal miners from accidents and chronic-disease mortality.

PUBLIC-HEALTH EFFECTS OF NORMAL OPERATION OF POWER PLANTS

The normal operation of electric-power plants, both nuclear and fossil fueled, results in the release of heat, radioactivity, and chemicals. Radioactive and chemical effluents have public-health implications, which will be compared. Thermal releases may have various ecological effects, but they have no direct human-health effect and thus are not treated here.

Radioactive and Chemical Effluents

Combustion of fossil fuels produces major quantities of air pollution.[1,2,46,54,55] The generation of electricity from burning coal produces a major proportion of the SO_2, NO_x, and suspended particulates in cities where coal is the principal fuel. In addition, trace amounts of heavy metals and carcinogenic hydrocarbons, such as benzo(a)pyrene, are released.[56-58] Trace amounts of radioactivity in the form of thorium, uranium, and radium have also been found in the ash released from coal combustion, the amount emitted being inversely proportional to the efficiency of the ash-collection mechanism.[59,60]

Most nuclear reactors currently being built are of either the boiling-water type (BWR) or the pressurized-water type (PWR). Most currently operating BWRs release much more gaseous radioactivity, generally in the form of noble gases, whereas PWRs release more liquid radioactive waste, principally tritium. A small amount of radioiodine is also released in gaseous effluent, particularly by current BWRs.[61-65]

The most recently designed BWRs are expected to release much lower quantities of gaseous effluent, because provisions has been made for much longer holdup of these effluents before release to allow most of the radioactivity to decay, as is currently practiced at operating PWRs. In addition, application of the recently proposed stricter discharge limits can be expected to reduce the quantities of radioactive effluents discharged from the LWRs having the highest release levels.[66] Similarly, coal gasification and air-pollution abatement measures will lead to much lower releases of air pollutants from plants burning fossil fuels.

A number of studies have attempted to compare the radioactive and chemical pollutants released per unit of electricity generated from fossil-fueled and nuclear power plants.[46,54,59,60,67-71] However, the comparison is complicated by the different types of reactors, variations in composition of the fuels, the efficiency of the ash-collection equipment for fossil-fueled plants, differing waste-treatment systems, and adjustments for biological activity and the half-lives of the isotopes released.

Martin, Harward, and Oakley[60] presented a careful comparison of radioactive stack releases from power plants, extending earlier work by Eisenbud and Petrow.[59] The amounts of radioactive material released by oil-burning generators are almost undetectable. When coal-burning generators are compared with nuclear generators, problems arise because the radioactive release takes such different forms. Some of the radium and thorium isotopes released from coal combustion are extremely long lived and chemically active. The radionuclides in the ash which are water soluble are assumed to pose a threat to bone, and those which are insoluble are considered to present a threat to the lungs. For nuclear plants the whole-body exposure from noble gases released from the stack is considered most significant. These isotopes are relatively short lived compared with ^{226}Ra in coal ash.

For coal-fired and nuclear power plants, Martin et al.[60] calculated the dose that a new 1000-MW(e) plant would give to individuals in the vicinity of the plants under specified meteorological conditions. To take account of the different forms of radioactive effluent, they calculated the dose as a fraction of the maximum permissible dose recommended by the International Commission on Radiological Protection (ICRP), with a correction for the effect of different stack heights on distribution of radioactivity. Their results, based on 1968 and 1969 data, indicated that a coal-burning plant would apparently pose about 410 times the threat of a PWR, whereas a BWR would pose about 180 times the threat of a coal-burning plant in terms of radioactive releases through the stack.

Terrill, Harward, and Leggett[54] compared power plants in terms of the volume of air that would be required to dilute their stack effluents each year in order to meet conventionally accepted concentration standards. Hull[67] updated these dilution factors, making use of radioactive emissions from a much larger sample of plants and imposing a more stringent standard on the concentration of chemical pollutants.* On the basis of 1969 releases, these factors corroborated the conclusion reached by Martin et al. that the radioactivity released from coal-burning plants was more significant than that from PWRs but less significant than that from BWRs. Since that time, however, Hull has further updated these factors to reflect 1967 to 1971 nuclear power-plant releases and more recent standards for air-pollutant concentrations.[72] Included in his study were SO_2, NO_2, CO, hydrocarbons, particulates, and various radionuclides; however, only SO_2, particulates, and the radionuclides will receive attention in this article. The updated dilution factors for these pollutants are presented in Table 2, except that the discharge quantities for LWRs have been recalculated to reflect only 1971 releases. According to these more recent calculations, SO_2 from coal-fired plants is the residual requiring the most dilution.† The SO_2 from oil-fired plants requires less than half as much dilution; that from gas-fired plants, substantially less. Particulates from coal-fired plants and radionuclides from a BWR lacking extended stack-gas holdup also require a significant amount of dilution. However, the 1971 radioactive releases from both PWRs and BWRs would appear to be more significant biologically than those from coal-fired plants (unlike previous comparisons) but less important than the release of SO_2.

*These studies, based on quantities being emitted from the stack rather than on doses provided, do not allow for differential residence times of pollutants in the atmosphere.

†The value for sulfur dioxide emissions from coal combustion, based on coal with a 3.5% sulfur content, overstates the level of emissions that is currently tolerated in major cities.

Table 2 Volume of Air Required To Meet Concentration Standards for Yearly Emission from a 1000-MW(e) Plant

Type of plant	Pollutant	Standard*	Discharge quantity	Dilution volume, 10^9 m^3
Coal	SO_2 (3.5% S)	80 $\mu g/m^3$	3.06×10^8 lb	1.77×10^6
	Particulates (97.5% removal; 15% ash)	75 $\mu g/m^3$	9.9×10^6 lb	6.0×10^4
	Particulates (^{226}Ra)	2 pCi/m^3	0.0172 Ci	8.6
	Particulates (^{228}Ra)	1 pCi/m^3	0.0108 Ci	10.8
Oil	SO_2 (1.6% S)	80 $\mu g/m^3$	1.16×10^8 lb	6.58×10^5
	Particulates (0.05% ash)	75 $\mu g/m^3$	1.6×10^6 lb	9700
	Particulates (^{226}Ra)	2 pCi/m^3	1.5×10^{-4} Ci	0.075
	Particulates (^{228}Ra)	1 pCi/m^3	3.5×10^{-4} Ci	0.35
Gas	SO_2	80 $\mu g/m^3$	3×10^4 lb	170
	Particulates	75 $\mu g/m^3$	1.0×10^6 lb	6050
Nuclear				
PWR	^{85}Kr and ^{133}Xe	3×10^5 pCi/m^3	1.6×10^4 Ci	55
BWR	Short-lived radioactive noble gases	3×10^4 pCi/m^3	1.33×10^6 Ci	4.4×10^4
PWR	^{131}I (inhalation)	100 pCi/m^3	0.15 Ci	1.5
BWR	^{131}I (inhalation)	100 pCi/m^3	6.6 Ci	66
PWR	^{131}I (ingestion)	0.14 pCi/m^3†	0.15 Ci	1060
BWR	^{131}I (ingestion)	0.14 pCi/m^3†	6.6 Ci	4.7×10^4

*Environmental Protection Agency National Primary Ambient Air Quality Standards,[73] and AEC Standards for Protection Against Radiation.[74]

†A reduction factor of 700 is applied to the inhalation standard for ^{131}I to allow for reconcentration via the ingestion (air–grass–milk) route.

The above comparison is based on concentration standards that are not necessarily equally stringent for chemical air pollutants and radionuclides. Relative to concentrations at which effects on human health have been inferred from epidemiological studies, the concentration standards for radionuclides appear to be more conservative than those for chemical air pollutants.[69] To meet this difficulty, we will attempt to evaluate the relative hazards to individuals of long-term exposure to these pollutants at the specified concentration standards by using mortality risks derived from such epidemiological studies. The relative mortality risks of airborne effluents from fossil-fueled and nuclear power plants will then be estimated. Although morbidity (illness) risks would be expected as well, they are more difficult to quantify and therefore will not be included in the analysis.

Health Effects of Radioactivity

The amounts of radioactive material released from power plants are typically very small relative to background and medical radiation. Although large doses of radiation have been found to increase the risk of death from leukemia and other cancers as well as the risk of genetic damage, little work has been done which gives evidence for effects of such low-level dosage.[75-77]

A number of investigators have attempted to quantify the relation between radiation dose and cancer on the basis of data on Japanese survivors of the atomic bomb, on noncancer patients treated medically with radiation, and on occupationally exposed groups. Assuming a linear dose–response relation, the National Academy of Sciences (NAS) Committee on the Biological Effects of Ionizing Radiation has estimated[78] that an additional 100 mrems of radiation above background per year per person over many years would ultimately produce between 2000 and 9000 extra deaths from cancer per year in the United States, the most likely estimate being 3500. The risk to occupationally exposed groups from a given radiation dose is lower than the risk to the public because of a different age distribution; the mortality estimates for an occupational dose of 5 rems per year range from 380 to 930 excess cancer deaths per million per year. A dose of 1 rem to bone from ^{226}Ra is estimated to produce 0.11 to 0.16 case of bone cancer per million irradiated adults per year. The risk to bone from ^{90}Sr is considered to be lower. The estimate from 1 rem to the stomach is 0.32 to 0.64 death per million per year, and for 1 rem to the remainder of the gastrointestinal tract, 0.22 to 0.44 death per million per year. No estimate was made by the NAS Committee for the risk to skin, because there is insufficient evidence for skin-cancer induction by low dose levels. For the lung, a 1-rem mean dose to bronchial tissues is estimated to produce 1 case of bronchial cancer per million per year. For a dosage to the thyroid, Otway and Erdmann[79] have estimated a mortality risk per rem of one person per million exposed for all ages. Calculations of radiation effects in this article will be based on these estimates, except that no threshold will be assumed.

The 10 CFR 20 concentration standards used in the Martin et al. and Hull studies have been set by the AEC at levels that would limit dosage to exposed individuals from any one radionuclide to 500 mrems/year in the case of exposure to the whole body; for many radionuclides the standards reflect limits on doses to particular organs, with doses higher than 500 mrems/year permitted in some cases.[74,80] Thus continuous exposure over many years to whole-body radiation from noble gases at the concentration limit would ultimately entail an average mortality risk to individuals of 90×10^{-6} per year (according to the NAS mortality estimate). The concentration standard for ^{131}I limits the dose to the thyroid from inhalation of the radionuclide. However, a stricter limit by a factor of 700 is applied to ^{131}I when allowing for reconcentration via the air–grass–milk route. At the latter concentration of ^{131}I in the air, there is a potential dose to the thyroid of 5000 mrems/year to infants from milk and a lower dose to older individuals;[81,82] the average mortality risk to individuals from this concentration would be less than 0.5×10^{-6} per year.

Health Effects of Air Pollution*

A substantial body of literature of laboratory and epidemiological studies of acute exposure to air pollution has established the fact that air pollution causes ill health and increases the mortality rate.[84-86] However, it is difficult to estimate the dose–response curve from this literature. A wide range of dose–response relations are consistent with laboratory evidence and epidemiological evidence from special groups. More precise estimates are needed to determine the public-health effects of pollutant emissions from electricity generation.

Lave and Seskin[85,87-91] have explored this relation statistically, beginning with an examination of the association between the total mortality rate and air pollution in 117 U. S. cities in 1960. The basic regression, taken from Ref. 83, is shown in the following equation:

$$MR_i = 19.607 + \underset{(2.53)}{0.041}\text{ mean }P_i + \underset{(3.18)}{0.071}\text{ min }S_i + \underset{(1.67)}{0.001}\,P/M_i^2 + \underset{(5.81)}{0.041}\%NW_i + \underset{(18.94)}{0.687}\%\geq 65_i + e_i$$

where MR_i = total mortality rate (per 10,000 people) in city i

mean P_i = arithmetic mean of suspended particulate readings in city i

min S_i = smallest biweekly sulfate reading in city i (x 10)

P/M_i^2 = population density in city i

$\%NW_i$ = proportion of the population which is nonwhite in city i (x 10)

$\%\geq 65_i$ = proportion of the population 65 and older in city i (x 10)

e_i = error term for variation in the mortality rate not explained by the equation

In this ad hoc regression, 82.7% of the total variation in the mortality rate across the 117 cities is explained. The relation is a linear equation that predicts the

*Only health effects will be discussed here. Air pollutants have many other deleterious effects, as discussed in Ref. 83.

mortality rate in a city on the bases of (1) air pollution in the city (particulate levels, and SO_2 levels as reflected in sulfate data), (2) the population density, (3) the proportion of nonwhites in the population, and (4) the proportion of the population 65 years of age or older.[92-94] Values are given for the estimated coefficients of the variables; the numbers in parentheses are the *t* statistics for a test that the explanatory variable has no effect (the estimated coefficient is not significantly different from zero). With the exception of population density, all coefficients are extremely significant. Another way of viewing the estimates is to ask how much the mortality rate varies with a 10% increase in one of the variables used in the analysis; these values, shown as "sensitivity coefficients," are given in the following table.

Independent variable	Estimated increase in total mortality rate, %
Mean *P*	0.53
Min *S*	0.37
P/M^2	0.07
% *NW*	0.57
% ≥ 65	6.32

These results show that the mortality rate is significantly related to air pollution and that a 10% increase in air pollution (particulates plus sulfates) is associated with an increase in the mortality rate of 0.90% (0.53 + 0.37). A possible interaction between sulfates and particulates was investigated but was not found to be significant for these data.

Correlation does not prove causation, nor is a multiple regression of this sort more than an indication of an empirical association between air pollution and total mortality (with statistical control for the other relevant factors of population density, nonwhite composition of the population, and the proportion of the population 65 and older). Empirical associations occur frequently and are more often indicative of a particular sample or of a spurious association than of true causation. Although the results of such a statistical investigation should be viewed with suspicion, a variety of tests can be performed to evaluate particular hypotheses about the reason for an observed association. For example, a replication with different data would rule out the association's being due to the peculiarities of a particular sample; explorations with mortality rates for particular diseases or demographic groups would help to clarify the nature of the association and suggest whether it is plausible, given our knowledge of physiology and pathology. Finally, laboratory evidence from animal or human experiments can be used to judge the plausibility of the estimated relation.

To this end, Lave and Seskin have elaborated the basic relation shown in the above equation in a number of ways. The equation was replicated with 1961 and 1969 data; specific mortality rates for 14 diseases were estimated for 1960 (e.g., lung-cancer mortality), and the resulting equations were replicated for 1961. Twenty-eight age–sex–race specific mortality rates were also investigated for 1960 and 1961 (e.g., the mortality rate for nonwhite females during the first month of life). Day-to-day variations in the number of people dying in 5 cities were investigated, as well as year-to-year variations in 26 cities over a period of 7 years. The form of the function was checked by estimating multiplicative, quadratic, and piecewise linear forms in addition to the simple linear form. Finally, a series of tests was performed which should indicate whether the relation was spurious or a true causal one. The sample was split in various ways to see if the regression fit the largest cities as well as the smallest ones; the error term was investigated to see if it had any systematic pattern; other social phenomena known to be related to urbanization but not caused by air pollution (such as crime, venereal disease, and suicide) were investigated and found not to be correlated with air pollution after controlling for other factors; a number of additional explanatory variables hypothesized to affect the mortality rate were added to the regressions.

Neither the equation nor the subsequent work proves that air pollution causes ill health. However, it sheds a great deal of light on the nature of the association and contains estimates of the magnitude of the association in each case. The statistical analysis is aimed not so much at proving causality as at estimating the nature of the relation if it is causal. Since causality can be inferred from the laboratory and epidemiological studies of acute exposures and since the regression coefficients for particulates and sulfates have been reasonably consistent, it is not imprudent to interpret them as estimates of the dose–response relation, even though they cannot be taken as proof in themselves of causality.

The estimates of the effect of air pollution which will be used are those from the 1969 replication, using data for 89 cities, with SO_2 data substituted for sulfates. The regression coefficients will be used to estimate the mortality risk of exposure to air pollutants at the primary concentration standards of the Environmental Protection Agency (EPA) used in Hull's study. According to these coefficients, an additional microgram per cubic meter of mean particulate concentration is associated with an increased mortality of 0.085 per 10,000 per year, and an additional microgram per cubic meter of mean SO_2 concentration is associated with an increased mortality of 0.039 per 10,000 per year.* Thus the exposure for many years to mean concentrations of these pollutants at the EPA primary standards implies an increased average mortality risk to individuals of 638×10^{-6} per year for particulates and 312×10^{-6} per year for SO_2. The primary standards for SO_2 and particulates thus appear to carry many times the mortality risk of the AEC standards for radionuclides.

Relative Mortality Risks from Airborne Power-Plant Effluents

An abstract comparison will be made between the airborne emissions of a 1000-MW(e) coal-burning power plant and a 1000-MW(e) LWR based on the mortality risks estimated above. The method used by Terrill et al. and Hull will be followed in that an arbitrary dilution volume will be assumed for the emission of both plants, 1.77×10^{15} m^3 of air per year, the dilution at which the SO_2 from a 1000-MW(e) plant burning 3.5% sulfur coal is assumed to meet the primary standard. The dilution volume chosen is not important to the conclusions, since both chemical air pollution and radiation dose–response relations are assumed to be linear over the range under consideration, only relative risks are being estimated, and both plants are assumed to be occupying the same site.

The average mortality risk per year for individuals continuously exposed to gaseous effluent at the specified dilution from a plant burning 3.5% sulfur coal with 15% ash would ultimately be expected to be 334×10^{-6} (312×10^{-6} from SO_2 and 22×10^{-6} from particulates). The inclusion of other pollutants in this estimate, such as benzo(a)pyrene, would be expected to add an increment to this risk, and synergistic effects would also play a role. For gaseous effluent from a BWR with a 30-min holdup, the estimated risk per year at the same dilution would ultimately be about 2.25×10^{-6} (2.24×10^{-6} from noble gases and less than 0.013×10^{-6} from ^{131}I, via the air–grass–milk route) and from a PWR, less than 0.0031×10^{-6} (0.0028×10^{-6} from noble gases and less than 0.0003×10^{-6} from ^{131}I). Thus, within the limits of the assumptions made, the emissions from the coal-burning power plant are estimated to present a mortality risk approximately 150 times the risk from airborne effluents of a BWR and approximately 110,000 times the risk from the airborne effluents of a PWR. For emissions of a plant burning 1.5% sulfur coal, the corresponding figures are estimated to be 69 and 50,000 times, respectively (assuming the same ash content), and, for emissions of the same plant removing 75% of the SO_2 via stack-gas scrubbing methods, the estimates are 24 and 18,000 times, respectively.

At the same dilution the emissions from a plant burning 1.6% sulfur oil with 0.05% ash would ultimately present an estimated mortality risk to exposed individuals averaging about 119×10^{-6} per year (116×10^{-6} from SO_2 and 3.5×10^{-6} from particulates), about 53 times the risk from BWR stack effluents and about 39,000 times the risk from PWR stack effluents. For 0.2% sulfur oil the corresponding figures would be 8.0 and 5800 times, respectively, and for 0.2% sulfur oil with 75% of the SO_2 removed, the estimates would be 3.2 and 2300 times, respectively.

The dilution-factor method of comparing power-plant emissions can provide only a first approximation of their relative health effects since other factors affecting pollutant concentration or dispersion, such as different residence times in the atmosphere or different stack heights, are completely ignored. Another problem of the comparison is the crudeness of the dose–response estimates for both radiation and air pollution. For the above reasons, not much confidence can be placed in the difference between the calculated mortality effects of emissions from fossil-fueled plants and most current BWRs. However, the difference between the estimates for fossil-fueled plants and PWRs is strong enough to justify a conclusion that the airborne emissions of PWRs (and BWRs, if they are provided with longer holdup facilities) are substantially less dangerous to human health.

Ideally, a comparison of health effects of generating power from different fuels would consider not only the quantities of pollutants emitted per year but also their dispersion patterns, half-lives, and ambient concentrations in the environment. Meteorology and

*The measure of ambient SO_2, which was most significantly associated with mortality in 1969, was the minimum biweekly reading. However, since the mean concentration was more of interest in the above calculation, the relation was reestimated using the mean SO_2 reading. The regression coefficient for mean SO_2 was not statistically significant, but its magnitude was reasonable relative to the coefficient for minimum SO_2 concentration.

terrain would be important factors to take into account. Population distribution at various distances from a site would have to be known to estimate average doses received by the public.

Such a procedure requires extensive data collection regarding actual sites. Numerous studies have measured concentrations of air pollutants at various distances from fossil-fuel-burning plants.[95] With respect to nuclear power plants, Gamertsfelder has estimated a maximum value for the average annual radiation doses received from 1969 noble-gas effluents by members of the public within various distances of 13 plants.[53] These calculations were based on the percent of noble gases released relative to the amount permitted that year for each plant, the latter being the quantity that, under adverse meteorological conditions, would have been expected to deliver a dose of no more than 500 mrems/year to individuals located at the plant boundary. Population distributions and wind speed were taken into account. Although comparison of the results of these separate studies for fossil-fueled and nuclear power plants would be desirable, it would be difficult to carry out because of differences in meteorology and other factors at the individual sites and will not be attempted here.

However, these comparisons are precisely what should be done in an environmental impact statement for a new power-generating facility. That is, the effluents of power plants of alternative designs and fuels should be more carefully evaluated to estimate the doses of noxious materials which would be experienced by the public. These doses must be evaluated for their public-health effects using dose–response relations such as those discussed above.

An attempt in this direction has been made by Bergström,[96] who compared anticipated emissions from power plants of alternative designs being considered for sites in Sweden. Expected population exposures to radiation from a nuclear power plant and to SO_2 from a plant burning 1% sulfur oil were compared for a range of sites by means of dose–response curves he estimated for both types of exposure. According to his calculations, the health effects of the nuclear power plant would be smaller than those from the oil-fired station by a factor of 10^4 or more. Since the dose–response curves he estimated were derived from acute rather than long-term effects and since population exposure to SO_2 was calculated indirectly, on the basis of dispersion characteristics of tritium, these estimates need to be further refined. However, they serve to indicate the type of comparison that needs to be made.

A maximum value for mortality from noble-gas effluents of nuclear power plants can be obtained by using Gamertsfelder's calculations, referred to above. Adjusted according to 1971 release rates, the average dose per year received by the population within 50 miles of a 1000-MW(e) plant at a typical site would not be expected to exceed 0.36 mrem per person for a BWR or 0.020 for a PWR, with an estimated risk of 0.065 or 0.0036 extra death from cancer per million exposed persons per year for a BWR and PWR, respectively. For an average population of 2,500,000 within 50 miles of the LWRs, 0.16 extra death or less from cancer would be expected per year from noble gases from a typical 1000-MW(e) BWR and 0.009 extra death or less in the case of a PWR.*

The maximum dose to individuals from ^{131}I, via the air–grass–milk route, can be estimated in the same way.† In 1971 the estimated maximum dose (to the thyroid) from ^{131}I discharged by a nuclear power plant averaged about 0.6 and 2 times the maximum dose (to the whole body) from noble gases from a BWR and PWR, respectively.‡ If the average doses from ^{131}I and noble gases are assumed to be in the same ratio as their maximum doses, the ^{131}I doses would be expected to add less than 1% to the mortality from LWRs.

Liquid Effluents from Nuclear Power Plants

Liquid releases from nuclear plants were omitted from the above analysis because of the difficulty of evaluating average exposure via this route. The radionuclide released in greatest quantities in liquid discharges, particularly from PWRs, is tritium, which is considered to be one of the least hazardous isotopes because of the low energy of its beta rays.[99-101] Environmental surveillance studies in the vicinity of Dresden 1,

*These calculations are based on very conservative meteorological assumptions. More realistic assumptions would reduce the mortality estimates.† The proposed restriction of maximum dosage from LWR effluents to 5 mrems/year would also serve to reduce the mortality estimates.[66]

†Maximum doses actually expected to be received by individuals have been estimated for a number of radionuclides from Dresden 1 by Blanchard et al.[97] using more realistic assumptions regarding radioactive dispersal. Pathways considered were external radiation exposure, inhalation, and consumption of milk, leafy vegetables, beef, fish, and drinking water.

‡Although radiation from noble gases has been detected in the air in the vicinity of Dresden 1 nuclear power station corresponding to a dose rate of 5 to 15 mrems/year, the concentrations in milk of ^{131}I from either Dresden 1 or Yankee nuclear power stations have been too low to be detectable.[64,65,98]

Yankee, and Indian Point 1 nuclear power stations[64,65,102] have not been able to detect any significant radiation exposure to the public from aquatic samples which can be attributed to these power plants.§ However, experience at these plants is not necessarily representative of the situation at other plants.

The radioactive releases from nuclear power plants constitute only a minute fraction of the total radioactive material produced within the plants. Most of this radioactivity is produced within the fuel elements, and nearly all the radioactivity is retained there until the fuel is reprocessed; most of the remainder is concentrated and processed as waste for disposal elsewhere. However, both tritium and the noble gases are very difficult to control by conventional waste-treatment methods. Although the quantities currently being released are not considered dangerous over the short run, tritium and ^{85}Kr can be expected to accumulate over time and present more of a problem in the future.¶

PUBLIC-HEALTH EFFECTS OF OTHER RADIOACTIVE AND CHEMICAL RELEASES ASSOCIATED WITH THE URANIUM CYCLE

The above comparisons concerned effluents from normal operation of power plants only. In addition, further analysis must be concerned with the potential hazard to the public from reactor accidents and the possibility of environmental contamination from stored waste. The radioactive and chemical releases from uranium mining and milling, fuel-preparation processes, and spent-fuel reprocessing must also be considered in estimating the total health effects of atomic power.

Accidental Releases from Power Plants

A potentially serious, but statistically unlikely, source of radiation exposure to the public is a major reactor accident.[104,105] Care is taken in designing nuclear power plants to build in redundancies and other features to lower the probability and potential effects of such accidents. The safety record for nuclear power plants has been excellent thus far; however, it is still too early to assume that the safety of all of these systems has been proven and that a serious accident is precluded. One safety area in which reliability has not yet been conclusively demonstrated is the emergency core-cooling system in the event of a loss-of-coolant accident.*[106-108] However, the possibility of serious accidents is not unique to nuclear plants, there being the potential for boiler- or storage-tank explosions at fossil-fuel-burning plants, with consequent release of air pollutants to the environment.

Morgan and Struxness[80] have estimated the probability of a reactor accident that would release 1% or more of the total fission inventory to the environment to be between 10^{-4} and 10^{-5} or less per year per reactor; at this level of probability, less than one such accident on the average might be expected to occur among 200 reactors per 50 years. Starr, Greenfield, and Hausknecht[69] have estimated the total mortality risk from reactor accidents at 6×10^{-5} cancer death per 10×10^{6} population per year per 1000-MW(e) reactor. This risk compares favorably with their corresponding estimate for accidents at oil-fired plants of 2×10^{-4} respiratory death per 1000-MW(e) plant per year for the same population. Since only mortality from leukemia or thyroid carcinoma was considered in the case of reactor accidents, their estimate may be low. Nevertheless, the order of magnitude of this estimate is very small compared with the mortality risk from routine effluents.

Major radioactive releases might also occur in the event of certain externally caused disasters, such as earthquakes or aircraft accidents. Although nuclear power plants are designed to withstand most of these events, it is conceivable that such an accident might exceed the intensity anticipated in the design and cause the reactor containment structure to be breached.[79,110] More work needs to be done on estimating population risk from such accidents.

Accidental releases may also occur in connection with other stages of the uranium cycle, such as fuel transport and reprocessing. Risks to the public should be estimated for these accidents as well.

§Estimates of maximum doses from the liquid effluents of these plants range from 0.03 mrem/year to the whole body from Indian Point 1 (from fish),[102] to less than 0.3 mrem/year to the whole body from Yankee (from fish),[65] to 0.4 mrem/year to the thyroid, 0.02 mrem/year to bone, 0.003 mrem/year to the gastrointestinal tract, and 0.01 mrem/year to the whole body, from Dresden 1 (from fish and drinking water).

¶A number of systems are under development which may virtually eliminate either liquid or gaseous radioactive release to the environment from nuclear power plants.[103]

*Various opinions on the adequacy of the emergency core-cooling system and of interim criteria set for reactors by the AEC to compensate for possible deficiencies in this system were expressed at the rule-making hearings[109] of the Atomic Safety and Licensing Board (RM-50-1) during 1972.

Storage of Radioactive Wastes

In addition to population risks discussed above, there are also risks from the storage of radioactive wastes. Gamma radiation from stored wastes has been measured[65] in the vicinity of Yankee nuclear power station, with an estimated exposure rate of about 3 mR/year at the nearest town and essentially zero at 2 km. Storage of a proportionally higher amount of wastes by a 1000-MW(e) plant in a similar geographic location might be expected to entail about 0.001 additional death per year to local residents (on the basis of the NAS estimate for mortality risk and assuming a local population of a few hundred). This risk would, of course, be higher for a more populated location and a flatter terrain.

Low- and intermediate-level radioactive wastes are periodically transported to commercial burial grounds. These facilities are located in sparsely inhabited areas and are carefully monitored to prevent release of radioactivity to surrounding areas. No migration of radioactivity from the burial sites has thus far been detected; consequently no significant radiation exposure to the public is expected.[40]

The storage of high-level liquid wastes produced at reprocessing plants presents a potentially greater problem. Large volumes of these wastes are generated, containing most of the fission products from the spent-fuel elements. Since these wastes are very high in activity and have long half-lives, their accidental dispersal would create serious public-health problems. To date, such wastes have been stored temporarily in tanks on the sites where they were generated. However, this method of storage is unsatisfactory in the long run because the tanks must be given continual surveillance and replaced when they fail.[111]

The extent of this storage problem has been diminished by the development of solidification techniques, which reduce the volume, mobility, and solubility of these wastes considerably.[111,112] Among the proposals for the ultimate disposal of solidified waste, burial in bedded salt formations is being given the most consideration. However, since this method has not yet been proved satisfactory, construction of an interim near-surface storage facility is planned by the federal government.[40] It is safe to say that the waste-disposal problem has not yet been completely solved.

Effluents from Fuel Reprocessing

Considerable quantities of low-level radioactive effluents are released from the single presently operating commercial reprocessing plant. The radionuclides released in greatest quantity have been ^{85}Kr and tritium. However, in terms of population dose, the ^{90}Sr, ^{134}Cs, ^{137}Cs, and ^{129}I released are also worth attention.[113-119]

In general, these releases have been more serious than those from nuclear power plants. Although the activity of ^{85}Kr released per year has been comparable to or lower than the activity of noble gases released by a typical BWR, the ^{85}Kr is much longer lived. In addition, the quantity of tritium released has been about twice the average amount released by individual PWRs. The ^{90}Sr and ^{139}Cs have been released at rates hundreds or thousands of times the rates at an individual BWR or PWR.* The amounts of radionuclides found in environmental samples near the reprocessing plant have been more significant than those found near Dresden 1 or Yankee nuclear power stations; in particular, such radionuclides as ^{90}Sr, ^{137}Cs, and ^{106}Ru have been detected in streams and in the flesh of local deer and fish, and ^{129}I has been detected in milk from local cows.[64,65,98,119,121]

Martin[119] has calculated population doses from the most significant radionuclides for 1971, updating an earlier study by Shleien.[122] For the population within 50 miles of the plant, a submersion dose of 46 man-rems was delivered from ^{85}Kr in the air. From a submersion dose of this magnitude, a dose of 0.64 man-rem can be inferred to the whole body, 28.5 man-rems to the skin at a depth of 0.07 mm, and 1.1 man-rems to the lungs.[52] For other radionuclides, Martin estimated population doses of 20.8 man-rems to the whole body (16 from ^{3}H in drinking water and 4.8 from ^{134}Cs and ^{137}Cs in fish and deer), 0.8 man-rem to bone (from ^{90}Sr in fish and deer), 0.1 man-rem to the gastrointestinal tract (from ^{60}Co in deer), and 30 man-rems to the thyroid (from ^{129}I in milk)[119] Population doses of this magnitude would entail an estimated mortality risk of 0.004 death (between 0.0001 and 0.0002 death from ^{85}Kr and 0.0038 death from other radionuclides).

Because of the relatively long half-life of ^{85}Kr, a radiation dose would also be delivered to the population beyond the 50-mile radius. Martin estimated a submersion dose of 300 man-rems to the world wide population for the first year following the 1971 release

*Recently installed equipment has reduced the amount of these two radionuclides released.[114,117] In addition, other reprocessing plants under construction have been designed in such a way that there will be no routine discharge of liquid effluents to the environment. (Tritium will continue to be released through the stack.)[120]

and 16.1 times that amount as the long-term population dose,[119] from which a whole-body dose of 68 man-rems, a skin dose of 3000 man-rems, and a lung dose of 116 man-rems can be inferred.[52]

In 1971, 68.8 metric tons of fuel were reprocessed,[117] about twice the amount of fuel discharged per year from a 1000-MW(e) LWR.[40] If all the fuel reprocessed had come from power plants, the long-term population doses from reprocessing per annual operation of a 100-MW(e) power plant would be 34 man-rems to the whole body, 1520 to the skin, and 59 to the lungs. However, much of the fuel reprocessed comes from AEC reactors and has a lower burnup per metric ton than does spent fuel from power plants. Correcting for the higher burnup of fuel from power plants, 30,000 MWd per metric ton of uranium (vs. a burnup of 11,500 MWd/metric ton for fuel reprocessed in 1971),[119] these doses would be 90,† 4000, and 150 man-rems, respectively.‡ Such doses would entail an estimated mortality risk of about 0.02 death. From radionuclides other than ^{85}Kr, the corresponding risk (calculated in the same way) would be about 0.005 death. Thus the total mortality risk from reprocessing effluents per annual operation of a 1000-MW(e) power plant would be estimated at close to 0.03 death, which, although low, would be about three times the mortality estimated for a 1000-MW(e) PWR from stack effluents and would add a significant increment to the risk from nuclear power plants.§

Since substantial amounts of reusable uranium are recovered from the reprocessing of spent fuel, this process in effect serves as a substitute for the mining and milling of uranium ore. According to the AEC,[40] the recovery of fissile material from an annual fuel requirement of a 1000-MW(e) LWR is equivalent to the conservation of about 30,000 metric tons of uranium ore, or about 60 metric tons of U_3O_8. The mining and milling of that amount of U_3O_8 would have been expected to cost about 0.05 death from accidents and about 7.6×10^{-4} case per year of lung cancer. Thus the additional cancer mortality risk incurred from reprocessing effluents is probably outweighed by reduced mortality from uranium mining and milling.

†This estimate of long-term whole-body dose to the worldwide population (3×10^9) is not far from the AEC estimate of 120 man-rems for the eventual annual whole-body exposure to the entire population of the northern hemisphere (4×10^9) from ^{85}Kr per 1000-MW(e) LWR.[123]

‡Proportionality between burnup and fission-product inventory of the fuel has been assumed in these calculations. Differences in composition between fuels from AEC reactors and commercial reactors have been ignored.

§This estimate does not include radiation doses which will be received in later years from tritium or from the exceedingly long-lived ^{129}I. In addition, most spent fuel from power plants has been cooled for much longer than the required 150 days before reprocessing.[119] Higher releases of radionuclides, such as ^{131}I, can be expected if a shorter cooling period is used in the future unless compensating waste-treatment measures are taken.[120] Fortunately more stringent precautions are being taken to reduce releases of the radioiodines.[119]

Effluents from Other Processes

Radiation exposure to the public from the current effluents of uranium mines and mills and plants involved in feed-materials production, isotopic enrichment, and fuel fabrication is not considered significant compared with doses from power-plant or reprocessing-plant effluents.[40,52] For example, it has been estimated that the total population dose from current uranium-mill effluents per annual fuel requirement produced for a 1000-MW(e) power plant is no more than 0.06 man-rem, primarily[40] from airborne ^{230}Th. Other effluents having potential health significance are NO_x from combustion of natural gas in uranium mills; fluoride from feed-materials production, isotopic enrichment, and fuel fabrication; nitrates and ammonia from fuel fabrication; and hexavalent chromium from isotopic enrichment.[40]

SUMMARY AND CONCLUSIONS

A comparison of the health effects of generating electricity from alternative fuels requires that the systems effects of the fuel cycles be considered. For example, the cycle for coal consists in exploration, mining, transportation, power generation, and ash removal; for nuclear fuel the processes for exploration, mining, milling, fuel preparation, transportation, power generation, and disposal of radioactive wastes are included (as well as a subcycle in which reprocessing of spent fuel substitutes for the mining and milling of fresh ore). The entire cycles must be compared for their health effects rather than simply the power-generation phase.

Some tentative conclusions emerge from a comparison of the main components of the cycles for coal and uranium. Occupational-health effects from accidents and chronic diseases are substantially greater for coal mining than for uranium mining and milling per megawatt of power generated. Although complete data are not available on accident and disability rates for other phases of the fuel cycles, the differences between coal and uranium are unlikely to be important when compared with the estimated differences from mining and milling.

Comparing the effluents from power generation is more difficult. Both nuclear and coal-burning power plants discharge radioactivity into the environment in amounts that have little effect on background-radiation levels; the small proportion of radium and thorium in coal which is released into the air seems to be less significant than the noble gases and ^{131}I from a BWR or PWR. When liquid effluents and effluents from reprocessing plants and other phases in the uranium cycle are added to the comparison, it becomes still clearer that the total radioactive release from the uranium cycle is more significant than that from the coal cycle. However, coal-fired generators are a major source of chemical air pollutants, which have been shown to be harmful to health.

Thus a comparison of the total health effects of generating electricity from the two fuels depends on weighing the adverse effects of air pollution from coal combustion and excess accident and chronic-disease disability from coal mining against the excess radioactivity released from the atomic power industry. To accomplish this, one would need dose–response curves for both the radioactive and chemical effluents. Estimates of both dose–response curves have been published, although there is still considerable debate on the effect of low-level long-term exposure to either air pollution or radiation.

In the work reported here, airborne releases were compared in terms of the dilution volume of air that would be required to meet recommended concentration standards and in terms of relative mortality risks to individuals exposed to these effluents at a specified dilution, as estimated from the dose–response curves. In the most conservative comparison considered, a PWR appears to offer 18,000 times less health risk than a coal-burning power plant, and a BWR with a 30-min holdup of stack gases appears to offer 24 times less health risk. Including effluents from other processes in the uranium cycle does not change the nature of the comparison, even when atmospheric buildup of ^{85}Kr from spent-fuel reprocessing is considered. In view of uncertainties in the dose–response curves and differences in atmospheric residence times, which were omitted from the comparison, the factor of 24 between coal-burning plants and existing BWRs must be viewed as suggestive rather than conclusive.

Liquid releases from LWRs were not fully evaluated because there are uncertainties regarding the size of the populations exposed by the various pathways and the average doses received. However, since the population dose from these effluents is considered to be much smaller than the dose from airborne releases, it is unlikely that they would have much effect on the comparison.

The conclusion can thus be drawn that uranium offers lower risks than coal as a fuel, in both the extraction phase and the generation phase.

When coal and oil are compared as fuels, it is clear that the latter offers lower risks in both the extraction phase and the generation phase. However, a comparison of low-sulfur oil and uranium is less clear-cut. The differences in the public-health risks from power-plant emissions favor the PWR; however, the lack of complete data for many phases in the fuel cycles makes it difficult to compare the occupational-health risks from these fuels. Nevertheless, the occupational-health risk per megawatt-hour appears to be higher for uranium because of miner silicosis and radiation exposure to employees in the nuclear power industry. We have not attempted to determine which of the two fuels has the more serious overall health effects, because of the limitations imposed by the available data and the many assumptions, some of them arbitrary, made in comparing power-plant emissions.

The relative health risks of airborne power-plant effluents need to be compared for actual sites, controlling for such factors as stack height, meteorology, terrain, population distribution, and atmospheric half-lives of the pollutants emitted. Improved measures need to be obtained for the population doses received by various pathways from liquid effluents. More complete data are needed on radiation exposure to employees in the nuclear power industry. Also necessary are better dose–response curves for both radioactivity and chemical pollutants. Much more work needs to be done to explore the toxic, mutagenic, and teratogenic properties of radionuclides in low concentrations. This work is not likely to be susceptible to laboratory experimentation. Rather, careful epidemiological work is needed to measure the age–sex–race and disease specific death rates for various groups as well as their exposure to various radionuclides and other environmental insults.

The above comparisons have been based on current data and operating practice. Changes in such areas as mining techniques, mine safety regulations, reactor design, and effluent control methods can be expected to alter both occupational- and public-health risks from electricity generation in the future.

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