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METEOROLOGY IN RELATION TO REACTOR HAZARDS AND SITE EVALUATION

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ABSTRACT

Meteorology is one of several environmental factors that enter into the problem of nuclear reactor site selection and hazards evaluation. More specifically, average wind and turbulence conditions control the degree to which the atmosphere can disperse radioactive material, and these factors must be carefully evaluated in reactor siting and hazards. In addition, other meteorological factors, such as prevailing winds and precipitation, have a bearing on this problem.

The probable ranges of the significant meteorological quantities, at any one location and for different locations, are estimated in order to determine their effect on the reactor problem. Methods used to obtain and interpret meteorological data for this purpose are described. Interrelation between meteorological factors and the distribution of population is of primary concern, and methods of dealing with this problem are discussed.

The role of the national meteorological services in connection with reactor siting and hazards problems is briefly discussed.

INTRODUCTION

The state of the atmosphere near the ground level controls, through the mechanism of turbulent diffusion, the rate of spreading of clouds of gases, or of small particles, that may be produced there. For this reason, meteorology is one of several special scientific disciplines that is studied in evaluating hazards to the public that might arise through release of radioactivity to the natural environment at a reactor site.

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There are two main points at which meteorological factors enter into the analysis of reactor hazards. That branch of meteorology known as climatology, first of all, provides information on the relative desirability of various possible sites for a particular reactor. Secondly, once a reactor design and site have been chosen, study of atmospheric turbulent diffusion at that site enables computations to be made of radioactivity levels and patterns in the site area, so that the effects of routine and possible accidental radioactivity releases to the atmosphere can be studied in detail. Associated with the operation of nuclear reactors, there is also a third area in which meteorological considerations are certain to play an increasingly important part; namely the release of radioactive material to the atmosphere in connection with chemical reprocessing of spent reactor fuels.

REACTOR TYPE AND POPULATION FACTORS

C. K. Beck[1] has pointed out that the evaluation of a reactor site depends to a large degree upon the properties of the reactor, particularly on the fission product inventory, the probability of accidents, and the special protective features that may be provided. This point is illustrated by Figure 1, which shows, for a number of United States' power (P), testing (T), experimental (E), and research (R), reactors, the "exclusion distances" plotted as a function of rated reactor power, in thermal megawatts. The exclusion distance around a reactor is defined as the distance to the nearest point at the boundary of the controlled area, that is the area under direct administrative authority of the organization operating the reactor. These data are based on unclassified reactor hazard summary reports listed by Smith[2,3]. Not all the listed reports were readily available to the writer, and so the entries in the figure are not complete; but they are a representative selection.

It is clear from Figure 1, first of all, that reactors have been located with regard to power level. In general, greater exclusion distances have been provided for reactors that are designed to operate at higher power levels. A similar plot, of reactor power vs. distance to the nearest population center displays much the same characteristics as Figure 1, but of course the distances are considerably greater. There is also a clear cut grouping according to reactor type, as suggested by the dashed lines. For a given exclusion distance, power

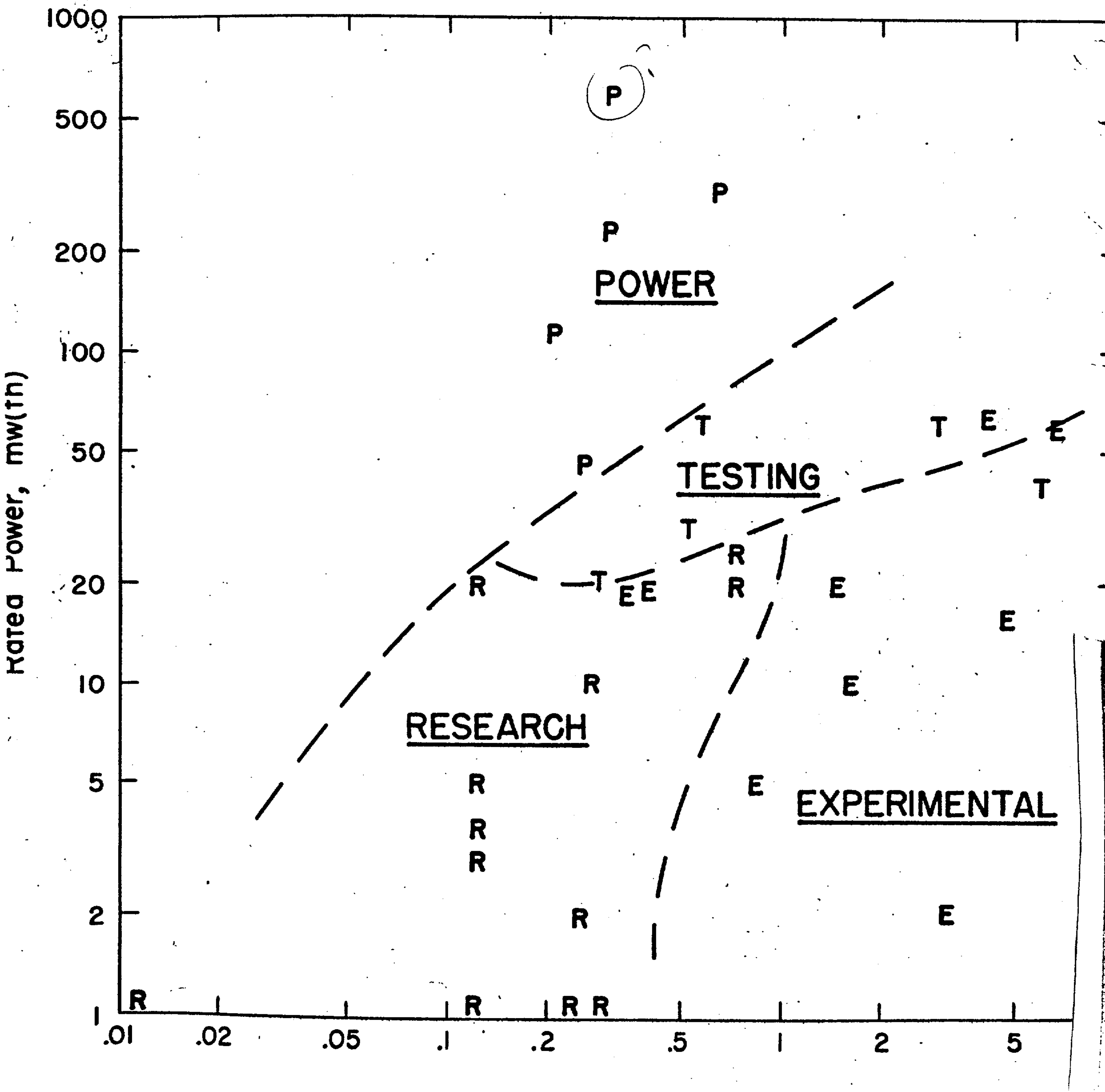

Figure 1. Reactor type plotted as a function of [illegible]usion distance, miles, and rated reactor power, mw (th), for a [illegible] of U. S. reactor projects.

reactors, which are characterized by well proved design and the provision of a high degree of containment, are seen to have been authorized for operation at higher power levels; and experimental and research reactors at the lower. Figure 1 also illustrates the fact that, for a given power level, the experimental reactors, which by their nature may have unproved design features, have been provided with greater exclusion distances than research reactors. These facts reflect a consistent philosophy of reactor siting, based on consideration of proximity to populations, and on reactor design and characteristic operational features. What part, then, does meteorology play in determining, or modifying this point of view?

It is only ordinary prudence to locate a reactor in such a way as to minimize any possible risk to people due to accidental radioacitivity release to the environment. Permissible levels of radioactivity in air and water are generally low, much lower for example than levels for the toxic waste products of ordinary industrial processes. Consequently, other factors being equal one wishes to locate a reactor remote from people, so that the atmosphere provides a natural protective barrier in the event of possible accidental radioactivity releases. The U. S. National Reactor Testing Site, at a location in the state of Idaho, provides an excellent example of isolation, for the purpose of reactor experiments. But economic and utilitarian consideration prevent remote location in the case of most interest, namely large power reactors. It has been mentioned that such reactors will as a rule be a well proved type. Moreover, multiple containment barriers can be provided between the fission products and the environment so as to "contain" the effects of a nuclear accident. And yet since structures and systems, not to mention humans, are never absolutely perfect, the possibility of accidental radioactivity release to the atmosphere must always be considered.

THE NATURE OF ATMOSPHERIC TURBULENT DISPERSION

Since in most respects the dispersion of radioactive material in the air differs little from the dispersion of ordinary industrial and chemical smokes, some methods of dealing with atmospheric dispersion were already available to the atomic industry at the time of its birth. Early studies of the dispersion radioactivity leaned heavily upon results borrowed directly from industrial air pollution research. But problems unique to the atomic energy field also arose, and so this growing industry has found itself to some degree in the meteorology business.

The atmosphere, through the phenomenon of turbulent diffusion, or dispersion, acts to dilute concentrations, by a mixing process. This dilution effect is greatest during periods of high wind speed and intense turbulence. The intensity of atmospheric turbulence is primarily controlled by the degree of vertical thermal stability that is present, as measured by the change of temperature with height. During the day, when the surface layers of air are heated from below by contact with the ground, creating conditions of intense convective mixing, low-lying material or gaseous clouds are rapidly spread about and diluted. On the other hand, at night the ground surface loses heat by radiation, quickly cooling the lower air layers, and virtually eliminating turbulent mixing there. It is a matter of common experience that as a result this diurnal variability of the atmospheric mixing process is very great. Smoke from a chimney may be diluted to the point of invisibility within a distance of a few hundred feet, during the day, whereas at night the same smoke plume may remain visible for many miles. The atmospheric dilution factor may in fact differ by many orders of magnitude between typical daytime and nightime conditions. This effect can be noticed at any location and certainly exceeds by a large amount any differences among various locations in average atmospheric dilution capacity.

VARIABILITY IN SPACE AND TIME OF METEOROLOGICAL FACTORS AFFECTING REACTOR HAZARDS AND SITING

Variability of atmospheric stability conditions

It can be expected that both "good" and "poor" atmospheric dilution conditions will occur in approximately equal proportions almost anywhere, because dilution is under such strong diurnal control. It follows that in general the atmosphere's dilution capicity is not a criterion which sharply discriminates as to desirability among various reactor sites. Table I has been prepared by way of illustration of this statement. It is a tabulation of the frequency of occurrence of "good" atmospheric dilution conditions at certain reactor sites. Data were obtained from the meteorological portions of unclassified reactor hazard summary reports listed in references[2,3]. Good dilution (i.e. unstable vertical lapse rate of temperature) conditions occur about half the time (for those reactor hazard studies that provided low level stability data in a form suitable for this tabulation). There is little reason to doubt that this conclusion applicable generally.

TABLE I

FREQUENCY (PERCENT) OF "GOOD" ATMOSPHERIC DILUTION CONDITIONS, AS CHARACTERIZED BY THE PRESENCE OF UNSTABLE VERTICAL TEMPERATURE GRADIENTS (LAPSE CONDITIONS) FOR A SELECTION OF EXISTING REACTOR SITES

Percentage of time lapse conditions present	Number of reactors indicating this percentage
0-29	0
30-39	0
40-49	3
50-59	9
60-69	3
70-100	0

Variability of atmospheric wind speeds

Wind speed is another meteorological factor directly related to atmospheric dilution. This can be seen by the simple consideration illustrated in Figure 2. If one studies variations in average wind speed for various locations, it is evident that wind speed variability in time, at a given, single location, is approximately equal to the variation in average wind speed that is encountered in space, i.e. at different locations. Data given in Table II illustrate this point.

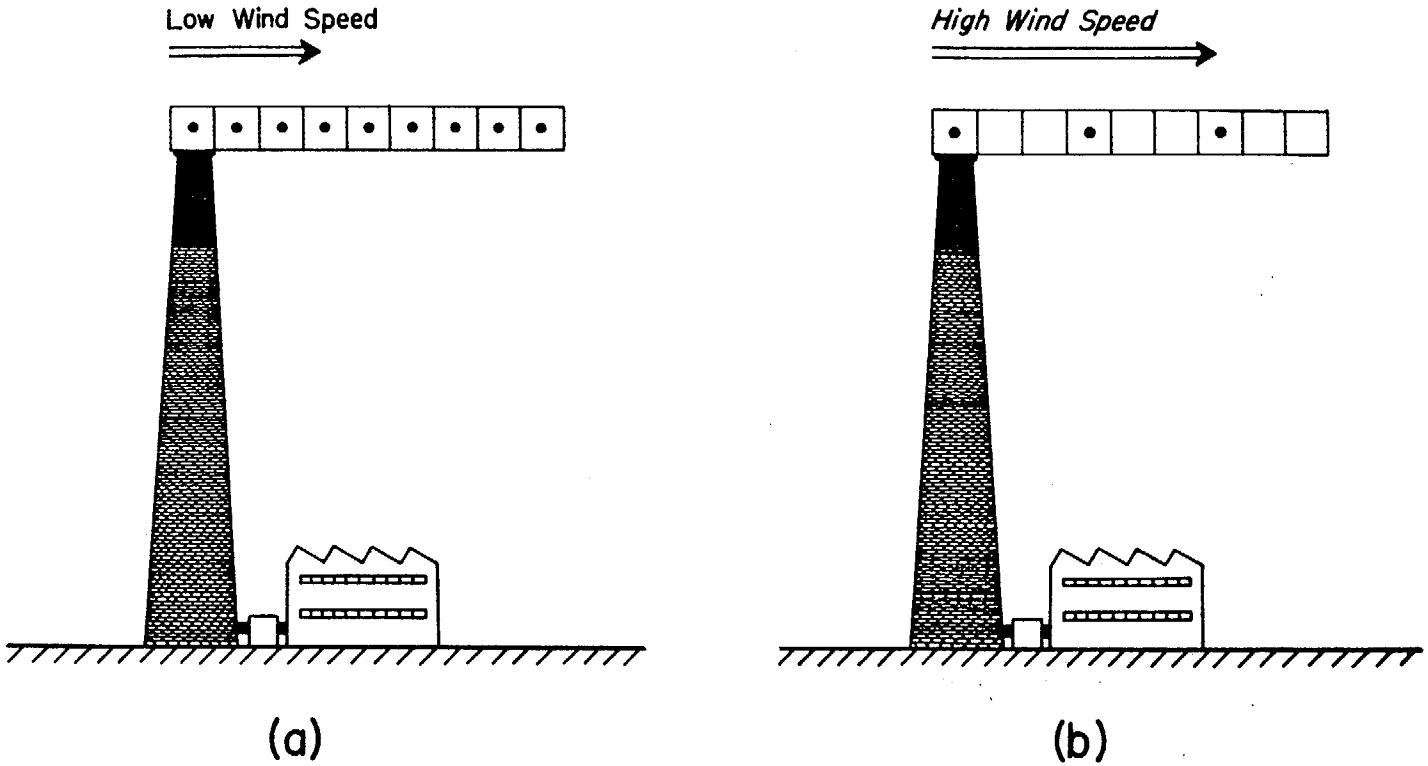

Figure ?. Schematic illustration of the effect of wind speed on atmospheric dilution; at low wind speed, (a), dilution is smaller than at high wind speed, (b).

TABLE II

EXAMPLES OF WIND SPEED VARIATION IN SPACE AND IN TIME

Wind Observation	Low Value	High Value
Annual average considering the United States (Visher[4])	6 mph	14 mph
Average considering 11 observing points in the Oak Ridge, Tennessee, area; autumn season (USWB[5])	2 mph	4 mph
Diurnal variation at height of 2 m above ground (Geiger[6])	4 mph	8 mph

Variations in atmospheric dilution at a particular site due to the variability of the wind speed should be of approximately equal magnitude with variations due to differences in wind speed from site to site. One might expect to be able to find real differences among sites, based on the averaged effect of wind speed on dilution; but it appears that such differences will tend to be rather small and possibly difficult to detect.

Variation of other meteorological factors

Other meteorological elements bearing on reactor hazards do vary significantly with location. For example, rainfall frequency and intensity at a place is quite an important factor, because rain removes radioactive material from the air and deposits it on the ground, greatly increasing exposure levels there. It is of course well known that rainfall frequency can vary greatly from place to place. But inevitable economic and technical factors will ordinarily limit the possible choice of sites for a particular reactor project to some area over which the variability of average rainfall, for example, is not likely to be excessively large.

METEOROLOGY AS A FACTOR IN REACTOR HAZARDS ANALYSIS

Taking all factors into account, it seems fair to conclude that, at any one site, the time variability (diurnal and annual) of the atmosphere with respect to dilution and other items affecting reactor hazards will equal or exceed variations in space, i.e. differences that may exist among different sites. Should it be concluded, then, that meteorological and climatological factors are irrelevant to the problem of reactor site selection? This would be a point of view equally as absurd as the one (heard occasionally) which regards meteorology and climatology as absolutely controlling factors in reactor site selection. The answer is that meteorology (and other environmental factors) must always be considered as one of the several interdependent factors that control reactor hazards and site selection.

At the site selection stage, reactor design features specify what the routine release of radioactivity to the environment will be, as well as the probability and extent of any accidental activity releases. Where paths exist such that radioactive material can find its way out of the reator structure and into the atmosphere, meteorological conditions at proposed site locations become important, and must be studied carefully to determine what distribution patterns will result from both routine and accidental releases. Quantitative methods for handling this problem are described in considerable detail in a monograph, Meteorology and Atomic Energy, prepared by the U. S. Weather Bureau[7] in cooperation with the Atomic Energy Commission. A detailed example of the application of these techniques also has been presented[8].

Given patterns of distribution of radioactive material in the atmosphere, as well as patterns of deposition of this material on the ground, combination of these with information on population distribution yields estimates of the hazard to the public of a proposed reactor installation. For those sites which are operationally and economically suitable for a particular reactor project, this hazards computation permits a ranking in order of desirability. Where, as in the case of large power reactors, economic factors dictate that a location reasonably close to centers of power consumption be chosen, the meteorological dilution calculation, combined with the estimated fission product release and the population distribution, will determine the degree of containment or other special protective measures that need to be provided in order to insure adequate protection of the public.

The basic meteorological data that are need to make a site evaluation can sometimes be obtained directly from records of the government meteorological services. Where there is no meteorological station near a proposed site, it may be possible to infer site conditions from those at more distant meteorological stations. More frequently, limited meteorological observational programs have been carried out at reactor sites, in order to obtain data for a hazard analysis. The extent of the effort devoted to meteorological analysis will of course vary, depending on the nature of the reactor, the meteorological complexity of the problem, and the extent of the existing observational data. Whatever may be the nature of the meteorological program that is determined to be necessary to support a hazards study, to be of value the results must be considered jointly with, and not separately from, the other significant factors bearing on reactor hazards analysis.

METEOROLOGICAL RESEARCH AND THE REACTOR HAZARDS PROBLEM

A meteorologist would be less than candid, and a reactor engineer more than naive, if the first gave and the second accepted the proposition that the meteorology of reactor hazards analysis consists simply in a straightforward application of cut-and-dried techniques. It is not merely an occupational tendency toward caution that causes the meteorologist to couch estimates of atmospheric dilution in terms indicating considerable variability. The diffusive capacity of the atmosphere is in fact quite variable, being a turbulence phenomenon. Moreover, reliable and detailed measurements of dispersion of contaminants in the atmosphere over distances of significance in the reactor hazards problem have proved difficult to achieve. It is only quite recently that any work at all along this line has been undertaken.

As a consequence, considerable reliance has been placed on existing mathematical models of atmospheric dispersion. Lacking suitable confirming observations, and confronted with the necessity for extrapolating dispersion formulae into unexplored ranges, meteorologists have shown considerable ingenuity in adapting known results to the new problems posed by reactors. The improvised solution of a problem in one hazards analysis has often developed into the accepted methodology for later ones.

It is not surprising to find, therefore, that a considerable amount of research, much of it of a rather basic nature, is directed toward improving and firming up existing knowledge of the meteorological aspects of the reactor hazards problem. As new results and methods are evolved, they are almost immediately applied to current reactor hazards analyses. The meteorological portions of the hazards analysis literature clearly reflect this steady improvement in knowledge and techniques.

It is to be hoped that such efforts will continue. This is not to say that a meteorological research unit should be regarded as an indispensable adjunct to every reactor project, of course. But continued improvement of the state of our knowledge of atmospheric dispersion seems clearly to be one of the requirements of the health and safety problems imposed by nuclear reactor operation.

CONCLUSION

Late in the thirteenth century the English Parliament passed an act forbidding the use of coal in London, because of a growing atmospheric pollution problem there. We learn that, thirty-three years later, a violator of this act was actually tried, condemned, and executed[9]. Notwithstanding, the economic advantages to be gained from use of coal, and the dwindling of wood reserves, in the long run proved to be irresistable pressures. Samuel Pepys records his concern with the growing coal smoke pollution problem in seventeenth century London[10], and in modern times this problem occassionally reaches catastrophic proportions. In fact, in some areas the air pollution problem has become so severe that legal action has once again been required to limit the emission of pollutants.

The atomic industry, recognizing the possibility of environmental contamination, has from the outset taken a commendably conservative view toward the atmospheric pollution problem. Reactor design and operation have been conducted so as to keep environmental contamination to a strict minimum. Naturally this imposes an economic penalty. Meteorological research (and that in the other environmental disciplines), safety studies in general and, finally, the resulting reactor design features (containment vessels, waste gas control systems, filters, scrubbers, and so on), certainly cost money and contribute to the cost of nuclear power. But considering the history of the pollution problem that has arisen with the fossil full industry, the policy of the atomic energy industry, which has been to employ meteorology and environmental sciences in order to maintain a strict surveillance and control over potential sources of atmospheric contamination, seems both far-sighted and wise.

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