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UNCERTAINTIES IN ENERGY TECHNOLOGY ASSESSMENTS

by

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ABSTRACT

In order to make important contributions, energy technology assessments must be large, interdisciplinary projects, generally becoming very time consuming and expensive. This small project does not involve a large assessment, but instead combines several different types of investigations aimed at exploring the potential for, and significance of, uncertainty in the energy technology assessment process. First, a survey and discussion is presented of technology assessments, primarily from a methodological viewpoint. A general ideal methodology is developed and the potentials for incorporating uncertainties are described. Second, there is a detailed development of meteorology, demographic and health impact components, the key components in energy technology assessments. There is particular emphasis on the impacts of assumptions and potential methods for incorporating concepts of uncertainty. Finally there are included three small examples of energy technology assessments. These have been tailor-made to demonstrate the possibilities and importances of the concept of uncertainty in these assessments.

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1. INTRODUCTION

We are at a pivotal point in the history of our civilization. The prevailing theory of historians is that the fall of every civilization (Chinese dynasties, Egyptian, Greek, Roman, etc.) has come as a result of energy supplies falling below the minimum energy demands necessary to sustain the infrastructure of those civilizations. For example, the collapse of some is believed to have been caused by the unavailability of wood and slave transportation energy, and the resultant lack of heat, food, and other supplies.

Our industrialized civilization has grown quickly as a result of technologies that have been developed to extract and utilize the hydro and fossil fuels as energy sources. Up to this point in time, not much attention has been paid to energy issues because hydro and fossil fuel costs were so low and supplies were abundant. As these energy resources have depleted, leaving us closer to minimum required energy demands, and as environmental issues have become increasingly more important to the public, assessments of future directions for energy sources and energy technologies will be under more public scrutiny and will have substantially greater importance.

In this study, "technology forecasting" will be included in the term "technology assessment."

Definition:

Technology assessment is the process of taking a purposeful look at the consequences of technological change. It includes the primary cost/benefit balance of short-term, localized marketplace economies, but particularly goes beyond

these to identify affected parties and unanticipated impacts in as broad and long-range fashion as possible. It is neutral and objective, seeking to enrich the information for management decisions. Both "good" and "bad" side effects are investigated since a missed opportunity for benefit may be detrimental to society just as in an unexpected hazard (Carpenter, 1973, p. 41).

Energy technology assessments are generally conducted using assumptions, methodologies, and data that can considerably bias the results. "Moreover, unless and until Technology Assessment is seen in a broader social and philosophic framework, it is bound to be a one-sided apologia for the prowess of existing technology. Genuine Technology Assessment must be essentially critical, not apologetic, with regard to technology" (Skolimowski, 1976, p. 421). Skolimowski says that technology assessments are done by technicians while paying lip service to "social aspects." He adds that "methodology takes precedence over values and we gently ride on the high horse of quantitative techniques toward the instrumental paradise" (ibid., p. 424). This point, that the assessing of a system should be done by those outside of the system to remain unbiased, is difficult to achieve in practice because those with expertise about technologies will naturally have invested considerable personal resources in those technologies and thus will tend to have optimistic biases.

It is clear that either faulty assumptions, methodologies, or data can propound error. "Methodology expresses (and traces the implications of) core assumption reflecting the forecaster's fundamental outlook. Sophisticated methodology cannot save a forecast based on faulty core assumption" (Ascher, 1979, p. 149). William Ascher stresses the

importance of the assumptions compared with methodology: "The development of greater methodological sophistication has not significantly improved forecast accuracy. The (often [greater than] linear) deterioration of accuracy with lengthening of forecast time horizons proceeds regardless of method" (ibid., p. 149). However, the complexity and large data requirements for a methodology are not inherent in the methodology. "It is the real-world situation and not the methodological analysis which presents the complex interrelationship and the necessity of a large data pool. No model nor methodology can greatly simplify a complex situation without losing some validity" (Bareano, 1972, p. 189).

It is instructive to compare technology assessments conducted by institutions with the differing special interests of those institutions. A university study done from a national point of view would likely have a different goal orientation than a corporation or private interest (Humes, 1974, p. 145). Also, assessments may be undertaken to gain support for a favorite project or decision already reached. "Thus it is important to know not just how a forecast was made, but why it was done as well, in evaluating its worth" (Kiefer, 1973, p. 140). These considerations are the motivation for this study, which includes a systematic investigation to determine the areas and extent of biases in energy technology assessments. Both methodological and data biases are evaluated, primarily through the use of equally defensible or superior alternative methodologies or data.

1.1 Historical Perspective

It is interesting to look at past technology assessments in order to see what not to do. History provides us with many examples of technological innovations that were total failures simply because of incomplete technology assessments. Many of these past technology assessments "...have been undertaken in response to a specific problem created by the introduction of new technology into society, rather than in anticipation of innovation... Assessment in the past has often been on a trial-and-error, hit-or-miss basis, with little perspective beyond short-term hazards, opportunities, and alternatives. It has viewed the future narrowly--if at all--as no more than an extension of the immediate past" (Kiefer, 1973, p. 137). Looking back 75 years, experts might have predicted that a gasoline-powered machine would replace the horse-drawn vehicle. But it is unlikely if they could have anticipated that the automobile would be directly responsible for one out of every seven jobs, that it would kill 60,000 U.S. citizens each year, and that it would cause significant impacts on public health via the emission of harmful air pollutants (Jones, 1973, p. 143).

Clearly, we are idealistic and naive if we suppose every nuance of a future technology can be predicted. "To use a historical example, it is doubtful that, given the time and manpower..., we could have predicted the contribution the elevator would make to traffic congestion in cities (assuming continued reliance on individual transit). It is these highly indirect impacts which are, of course, the hardest to foresee and which sometimes have the most far-reaching effects upon the society. They

usually become evident only after prolonged experience with the technology..." (Humes, 1974, p. 156).

No technique of assessment can really envision the flashes of innovation or the unpredictable discoveries which lead to great technological change. The occurrence of technological breakthrough really cannot be predicted. For example, an aircraft industry researcher of the 1940s would have predicted the maximum air speed of a prop plane based on the theoretical limit being the speed of sound. He could not take into account the advent of the jet engine.

Another great deterrent to technology assessment is technological dependence upon sociopolitical influences. "The fundamental difficulty in foretelling social and political change—or of even devising meaningful social indicators for measuring such changes statistically—remains a serious obstacle not only for technological forecasting but for technology assessment as well" (Kiefer, 1973, pp. 139-140). Value systems of society and political authorities are hard to define, and even harder to describe how they will change with time.

1.2 Alternative Methodologies

There are numerous methodologies for technology assessment. Some may work better than others but still depend heavily on the core assumptions. The Delphi technique "...is designed to apply the collective expertise and intuition of a panel of anonymous experts by developing a consensus through several steps of systematic questioning and polling about future events. The polling process is carefully organized so as to minimize the biases that might otherwise arise from interacting personalities or other psychological influences within the expert panel" (ibid., p. 138). Delphi techniques work best when historic data are unavailable, sociopolitical considerations are needed, or qualitative or subjective information is necessary.

Other methodologies including parameter-fitting, curve-fitting, and structural-fitting are used when the appropriate data are available. A refinement of curve-fitting is the envelope curve technique (Kiefer, 1973, p. 138). A general curve is superimposed to a number of specific curves. For example, the maximum speed of transportation could be forecasted by superimposing a curve onto specific historical data of various modes of transportation. Curve-fitting is based on the assumption that there are predictable trends in the manner in which "...the technology that will be put in use tomorrow is foreshadowed by the science of today or is a direct outgrowth of current technological knowledge" (ibid., p. 138).

Other techniques include the jury system, market system, cost-benefit analysis, and adversarial processes. The adversarial

process facilitates the articulation of all relevant facts both pro and con. Unfortunately, this and other assessment methodologies, are particularly susceptible to the biases in the situation where the proponents of a technology have an advantage over the opponents because of organizational and financial resources. This is when technology assessment becomes "...slanted in a subtle and often an explicit way in favor of the assumptions underlying the technological civilization, of which it is supposed to be an assessment" (Skolimowski, 1976, p. 422).

Figure 1-1 shows a generic seven-step methodology laid out by MITRE (Jones, 1973, p. 148). This scheme illustrates how assumptions are built into a methodology. Usually, the assumptions are not quite as evident.

Weighting schemes are frequently used in technology assessments, probably because of their easy implementation and easy interpretation. For example, one methodology computes a score for a technology and allows comparisons of technologies by comparing scores (Humes, 1974, p. 152). The weights are assigned by a panel of "experts" and thus the scheme is essentially subjective. "Even with detailed printed instructions, examples and close supervision, it is impossible to enforce consistency of interpretation and scale on a group of diverse individuals on the first round of assessments" (ibid., p. 154). There is nothing wrong with this type of subjective assessment, except that the highly quantitative methodology sometimes presents the appearance of greater objectivity than is warranted.

An intuitive, hence subjective, method is scenario writing: "A scenario attempts to describe, in systematic but hypothetical and largely qualitative terms, the future sequence of events that would

- STEP 1 DEFINE THE ASSESSMENT TASK
- Discuss relevant issues and any major problems
Establish scope (breadth and depth) of inquiry
Develop project ground rules
- STEP 2 DESCRIBE RELEVANT TECHNOLOGIES
- Describe major technology being assessed
Describe other technologies supporting the major technology
Describe technologies competitive to the major and supporting technologies
- STEP 3 DEVELOP STATE-OF-SOCIETY ASSUMPTIONS
- Identify and describe major nontechnological factors influencing the application of the relevant technologies
- STEP 4 IDENTIFY IMPACT AREAS
- Ascertain those societal characteristics that will be most influenced by the application of the assessed technology
- STEP 5 MAKE PRELIMINARY IMPACT ANALYSIS
- Trace and integrate the process by which the assessed technology makes its societal influence felt
- STEP 6 IDENTIFY POSSIBLE ACTION OPTIONS
- Develop and analyze various programs for obtaining maximum public advantage from the assessed technologies
- STEP 7 COMPLETE IMPACT ANALYSIS
- Analyze the degree to which each action option would alter the specific societal impacts of the assessed technology discussed in Step 5

Figure 1-1 Various Stages in the Process of Technology Assessment

appear logically to evolve, step by step through cause-and-effect relationships, from any given set of conditions or recognized trends. Emphasis is placed on those critical decision points from which alternative chains or events might arise and on the simultaneous interactions between events and their environment. A single set of assumed initial circumstances can generate an entire family of related scenarios (or alternatively futures), any one of which may be plausible" (Kiefer, 1973, p. 138).

"Normative" forecasting starts with some future need "...and attempts to work backwards in time toward present capabilities so as to define the technological pathways and means by which a goal might be reached and to identify the technological barriers which must be overcome in the process. The aim is less to prophesy than to "invent" the future, with the focus not on that which might happen but on that which should happen" (Kiefer, 1973, p. 139). It is clear that such an analysis can be highly subjective and rests on such assumptions as unchanging social values.

The role of methodology in technology assessment should be as a thinking and decision making tool. Assumptions and qualitative aspects inherent in the methodologies should be viewed as flaws and pointed out clearly. If the public is going to take technology assessment seriously, especially in the controversial area of energy, current methodologies and reporting techniques will have to change.

"Forecasters frequently seem more enthralled with the entertaining tasks of model building, manipulating and massaging series of data, and

imposing some sort of formal stylized structure on the seemingly random process of scientific discovery and technological innovation than they are with the more mundane chore of explaining to the world outside what their studies and speculations are all about or how they might find practical application. Increasingly sophisticated and complex methodology may appear designed, as a result, less to make forecasting more reliable and rational than to conceal its shortcomings and veil its relevance to the world at large" (Kiefer, 1973, p. 140).

1.3 The Role of Uncertainty

Uncertainties in technology assessments become very important when comparing different energy technologies. Many uncertainties are beyond the scope of a technical assessment, for example, those uncertainties that result from national priorities shifting substantially over short intervals. Such a shift within our recent experience is the fast-rising concern over energy issues, at the expense of a rapid deemphasis of the space program.

There are, fortunately, many uncertainties that are amenable to treatment within current technology frameworks. Where the accuracy of forecasts often deteriorates linearly with time, one can set rough confidence intervals. Also, much can be done to use data that is as current as possible. Using outdated data propounds error unnecessarily. But there is "...uncertainty as to whether recent data actually represent a new pattern that negates the old assumption" (Ascher, 1979, p. 152).

Probably the greatest uncertainty in technology assessment, and the hardest one to reduce, is due to sociopolitical factors. The nuclear power industry is a good example of this. "The greater uncertainty in forecasting technological developments requiring political decisions and large-scale programs indicates the importance of improving sociopolitical analysis. The social indicators and scenario approaches are two means for achieving this improvement" (Ascher, 1979, p. 149)

William Ascher lists three types of uncertainties in technology assessment in order of increasing uncertainty (Ascher, 1979, p. 153):

- I. Smallest dispersion: Technological areas in which advancement depends on engineering refinements and the disaggregated market diffusion of such innovations.
- II. Less certainty: For predictions of advancement in large-scale programs, the political aspect adds an additional degree of uncertainty to that already surrounding the technical feasibility of the programs.
- III. Most uncertainty: innovations requiring basic scientific breakthroughs.

2. ASSESSMENT METHODOLOGIES AND GENERAL ASSUMPTIONS

In technology assessment the methodologies and the assumptions are usually so intertwined that it is not possible to discuss them separately. Since the methodology can be viewed as the framework of the assessment, as well as the vehicle of the principal assumptions, the alternative methodologies will be treated first.

2.1 Alternative Methodologies

It is an extremely difficult task to try and characterize the range of all possible energy technology assessments. Part of this difficulty is due to the scattering of the methodologies into apparently every possible analytic direction. The rest of the difficulty stems from the lack of any real formalism to the modeling science. As an attempt is made here to develop some of this formalism. Figure 2-1 illustrates a schematic diagram of a proposed methodology that includes all the desirable qualities in an energy technology assessment. One possible starting point for the discussion of methodologies comes from the natural origin for all modeling activities: a definition of objectives. "It is difficult to to make a simple statement of the purpose of integrated assessment; there is a hierarchy of objectives, and the order will change with time and will contain hitherto unknown dimensions. Broadly speaking, there is a need for the timely development of relevant knowledge and its diffusion to a broad audience -- but especially to the general public, regulators, scientists, and engineers" (Gruhl, 1979). The research and academic communities for generally responded to these needs by identifying complex energy technology assessment methodologies, with few actual applications.

Modeling undertaken in an application-oriented, integrative context (i.e., the synthesis and integration of current knowledge) has a better chance of facilitating decision making than modeling undertaken as basic research. This is not to belittle the role of basic scientific research, but to suggest that modeling must be undertaken with different and perhaps more pragmatic objectives (SCOPE, 1976).

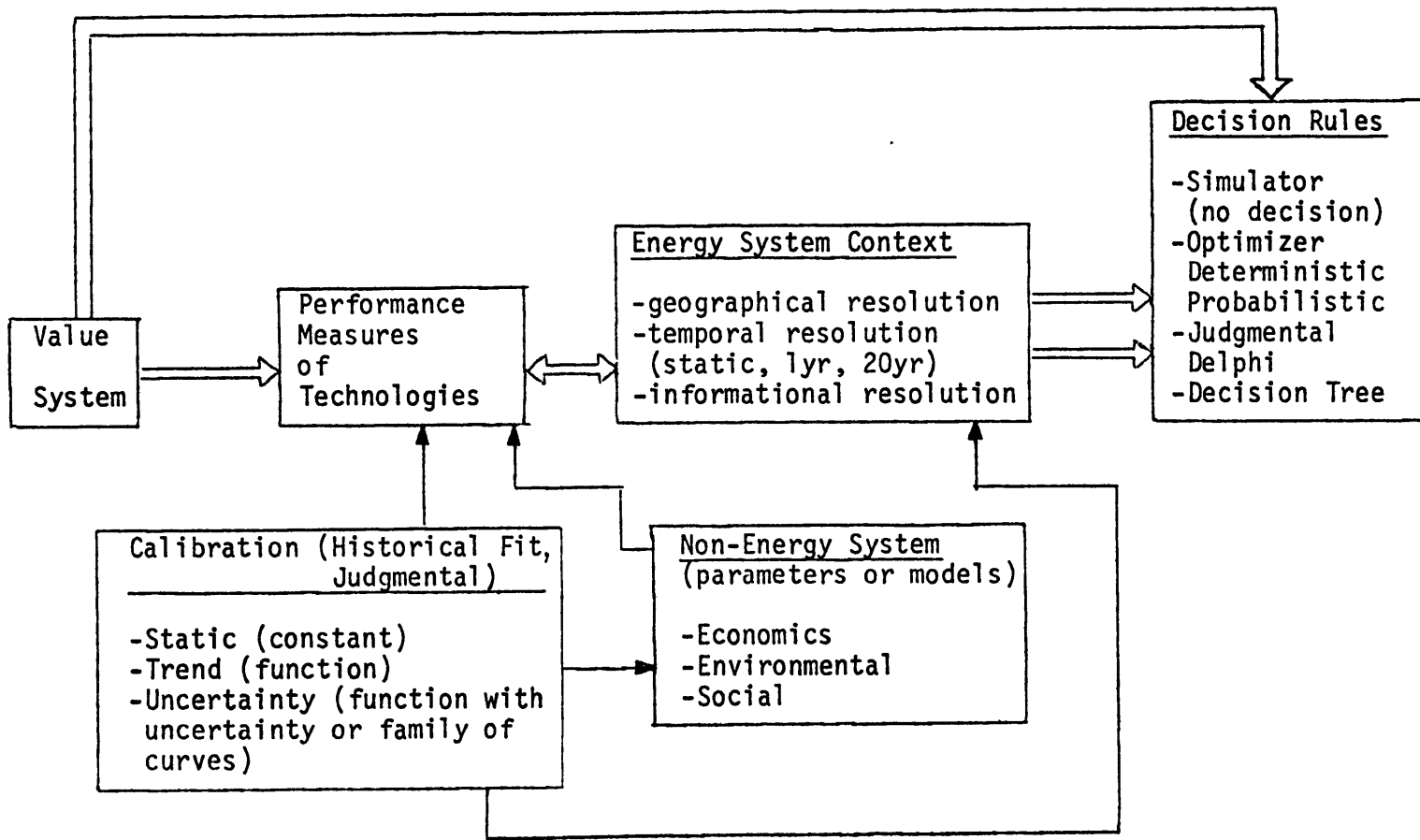


Figure 2-1 General Methodological Framework for Energy Technology Assessments

From an examination of the literature it appears that another natural starting point in the investigation of a technology assessment comes from the data used to characterize the Performance Measures of the Technologies, as shown near the center of Figure 2-1. There are two types of assumptions that pervade the choice of these performance measures. First is the Value System used by the assessor/modeler. Few authors of the assessment literature have reorganized the inherent bias in the types of performance informations that are collected about the technologies. The principal focus of the capabilities of a model is fixed at the point when data is collected about the technologies. The academic and professional backgrounds of modelers also bias the modeling procedure at this stage, due primarily to familiarities with sources and techniques for handling certain types of data. It would be instructive for modelers to begin their modeling activities by stepping back and taking a global perspective to their assessment problem, and documenting the motives for including or excluding data of certain types such as data types listed in Table 2-1.

The second assumption of great importance to the performance characterization is the extent to which the performance measures are coupled to energy system requirements. The most simplistic technology assessments just provide evaluations of performance that are not in the context of the specific needs of the energy system. Whether the technology is to be added to some local area, or to be added massively nationwide, it can be the most dominant part of the assessment to evaluate the manner with which that technology can both respond to the

Table 2-1

SOME OF THE VARIOUS DISCIPLINES
THAT HAVE BEEN ASSOCIATED WITH ENERGY RESEARCH (Gruhl, 1979)

Economics

Policy Analysis

Decision Analysis

Operations Research

Management

Law

Institutional Analysis

Energy Planning

Energy Engineering

Analytic Chemistry

Seismology

Mining

Transportation

Atmospheric Dispersion

Hydrology

Waste Management

Land Management

Ecology

Environmental Management

Health Studies

Psychology

Sociology

Demography

Urban Studies

peculiarities of the other energy supply sources. Recognizing this need, several modelers have provided coupling of the performance measures and the energy system, again as shown in Figure 2-1. Of lesser importance, from the standpoint of energy technologies, is the extent of coupling of the non-energy system to both the energy system and the performance measures (e.g., might there be rate-constraints on the availabilities of certain materials or manpower). The method, format, and data used for the construction and calibration (also shown in Figure 2-1) of the performance measures, energy system model, and non-energy system model, provides another key difference between various energy technology assessments. The concept of uncertainty could generally introduce itself at this calibration stage, being represented by probabilistic characterization of inputs and parameters in the assessment models.

For some reason the Decision Rules portion of Figure 2-1 has presented the principal preoccupation of technology assessors. Perhaps it is because it is usually the non-engineers that conduct assessments and the Decision Rules segment represents the primary part of the assessment that does not deal with engineering problems. Table 2-2 (Gruhl, 1979) shows many of the modeling technologies currently available and it can be seen that any of these can probably be used to capture the essence of the decision rules.

Again as shown in Figure 2-1, the Value System, or the manner of measuring desirability, of the modeler will impose itself strongly on the selection of the Decision Rules. Even for models that do not

Table 2-2

Methodologies Available for Representing the
Decision Rules for a Technology Assessment

Static Optimization

- o Linear Programming
- o Nonlinear Programming
- o Integer and Mixed-Integer Programming
- o Gradient Searches

Dynamic Optimization

- o Dynamic Programming
- o Dynamic Parametrics
- o Optimal Control
- o Stochastic Optimization
- o Algorithmics

Simulation

- o Descriptive, Prescriptive
- o Holistic, Causal, Normative
- o Continuous, Discrete
- o Stochastic Representation
- o Parametric Analysis
- o Allocation and Equilibrium
- o Input/Output
- o Econometric, Trend Analysis
- o Regression
- o Organizational Modeling
- o Interpretive Structural

Nonmodeling

- o Judgment Eristics
- o Expert Opinions
- o Hedonic
- o Decision Analysis
- o Individual Behavior
- o Bidding and Simulation Games
- o Cross-Impact and DELPHI

include decision logic, there are value systems implicit in the types and displays of outputs. Some value systems that have been used in energy/environmental models include:

- o Bureaucratic (exhaustive) display,
- o Noninferior sets,
- o Multiattribute decisions,
- o Infinite value or uncompromised protection,
- o Cost-benefit or economic optimum, and
- o Surrogate indexes or weighting schemes

In addition, each of these systems can be operated with or without explicit quantifications of the risks involved in the decision-making process. The obvious problem with value systems is that impacts not predicted by the model will carry no weight in the model's decisions. Extremely important issues such as stability of the establishment, survival of the private electric power sector, or intergenerational equity therefore generally are not considered in models because vulnerability to foreign disruptions, infrastructure problems, intervenor effects, and public perceptions of problems are not included in model outputs.

Despite the obvious importance and uncertainty inherent in the Value System, we found no models that offered alternative system nor discussed the biases of the system presented. In an assessment it would seem to be very important to be able to separate the "value judgments" from the methodology. An assessment technique will not be useful if the user cannot use his own value system or clearly see the author's.

L. Thiriet urges the use of caution when dealing with quantified subjective judgments: "We feel that one's first concern should be to make the method used acceptable both to the authorities and to the public. (We think the influence of the public should probably only increase in the future). One should therefore avoid resorting to too hermetic a language, using a too complicated system of notations, aggregation, evaluation of probabilities. This would save one from the temptation of believing in the rationality of choices in the field of environment, when these contain an irreducible and very important part of non-rationalizable elements. Moreover, the results of such a sophisticated study would not convince the public" (Thiriet, 1974, p. 230). L. Thiriet prefers a study that "...avoids all quantitative value indicators which would risk letting the reader in a hurry believe in a rational and scientific estimation. It should, on the other hand, suggest options judged preferable to others by arguing -- one might also say by pleading -- in a sufficiently detailed manner to allow the authorities to make their decision by the light of a clearly expounded document" (Thiriet, 1974, p. 233).

2.2 Imbedded Assumptions

Ascher points out the importance of assumptions: "It must be recognized that behind any forecast, regardless of the sophistication of methodology, are irreducible core assumptions representing the forecaster's basic outlook on the context within which the specific trend develops. These core assumptions are not derivable from methodology; on the contrary, methods are basically the vehicles, or accounting devices, for determining the consequences or implications of core assumptions that were originally chosen more-or-less independently of (and prior to the method)" (Ascher, 1979, p. 150).

Ascher states that forecast accuracy is dependent on the core assumptions and the methodology is obvious or secondary when the assumptions are valid. A methodology cannot redeem a forecast based on faulty core assumptions. One source of faulty assumptions is due to the specialization of most forecasters. Obsolete assumptions are sometimes used unknowingly due to the forecaster's specialization and the broad context of the assessment. This is why a panel of experts can be so effective for interdisciplinary technology assessments.

"Since the choice of methodology, which largely determines the cost of the study, is not as crucial to forecast accuracy as is the appropriate choice of core assumptions, recent inexpensive studies are likely to be more accurate than older, elaborate expensive studies. ...multiple-expert-opinion forecasts, which require very little time or money, do quite well in terms of accuracy because they reflect the most up-to-date consensus on core assumptions. When the choice is between

fewer expensive studies and more numerous, up-to-date expensive studies, these considerations call for the latter (Ascher, 1979, p. 152). More emphasis should be placed on establishing core assumptions and testing their validity.

In most energy technology modeling a deterministic approach is used. This study contends that there are often unacceptable and unnecessary assumptions involved in such an approach. A probabilistic approach would be inherently less biased and the appropriateness and difficulties of its use will be discussed. In addition, in the use of nonlinear models, deterministic approaches may have significant errors even with respect to expected values. When the inherent risk aversion in the energy decision process is also factored in, it should be clear that deterministic approaches must be very crude or inappropriate.

Another caution in using probabilities in technology assessments is "Maintaining uniformity and consistency of interpretation...; it is the great weakness of methods based on quantified subjective judgments" (Humes, 1974, p. 152).

A major advantage of a probabilistic scheme would be in dealing with a complex model with many inputs. For example, it seems clear that decisions based on multiplying probabilities (assuming independence of parameters) would be inherently less biased than decisions based on a complex document stating all the relevant issues. It would have to be made clear how the probabilities were arrived at and any uncertainty in independence of parameters would need to be discussed. Another advantage of a probabilistic scheme is the ability to quantify

uncertainty. Thus uncertainties could be traced through the model, and proper attention could be focused on parameters needing most reduction in uncertainty for decision making and R&D planning.

Energy decisions are inherently risk averse due to the inelastic demand for energy and the long time lags associated with increasing supply. However, most technology assessments use deterministic approaches which lead to the use of an expected value in fuel pricing, supply, etc. But the use of an expected value is at best only appropriate in a risk neutral analysis. Thus, for energy analysis, a probabilistic approach would be much more appropriate due to the availability within such an approach of the capabilities for incorporating inherent risk aversion.

Another imbedded assumption in most technology assessments is the level of detail or resolution at the decision points of the model. This resolution is of three types:

- (1) geographic
- (2) temporal, and
- (3) informational.

The first two types of resolution are quite obvious. It may be less obvious that models may work at two or more levels of resolution, performing computations at one level of resolution, then aggregating those results to yield outputs or information for decisions at broader levels of aggregation. Informational resolution is the final type of detail that will be mentioned. Aside from the disciplines that are included in a model's methodology, the model builder is faced with

myriad decisions and implications concerning the types of information that are carried in model components and linkages. Unfortunately, three of the principal criteria used for the selection of information to be incorporated are: 1) availability of data, 2) computational burden, and 3) the degree of amenability of this information to the chosen modeling methodology. Ideally the criterion for selection should be the information's relative importance to the policy applications of interest.

2.3 An Illustrative Example

A decision-making model developed by Irwin D.J. Bross separates the value system and uses a probabilistic scheme: "Bross evaluates the data relative to the values of the assessor and the probability of real world events occurring. The 'prediction system' is the process by which forecasts are made based upon the data; application of probability theory 'leads to predicting systems which associate a probability with each possible outcome, and this probability can be used to make decisions'" (Bareano, 1972, p. 180). Figure 2-2 shows a schematic diagram of this model.

These probabilities can be determined by a variety of methods: they could be determined by a Delphi technique, "...they could be predetermined, they could be selected by a jurying and discussion process, or assigned by experts based on their experience and expertise" (Bareano, 1972, p. 183).

Some further examples, such as the comparison of fluidized bed combustion to MHD, illustrating some of the concepts related to resolutions, are presented in the final chapters of this thesis.

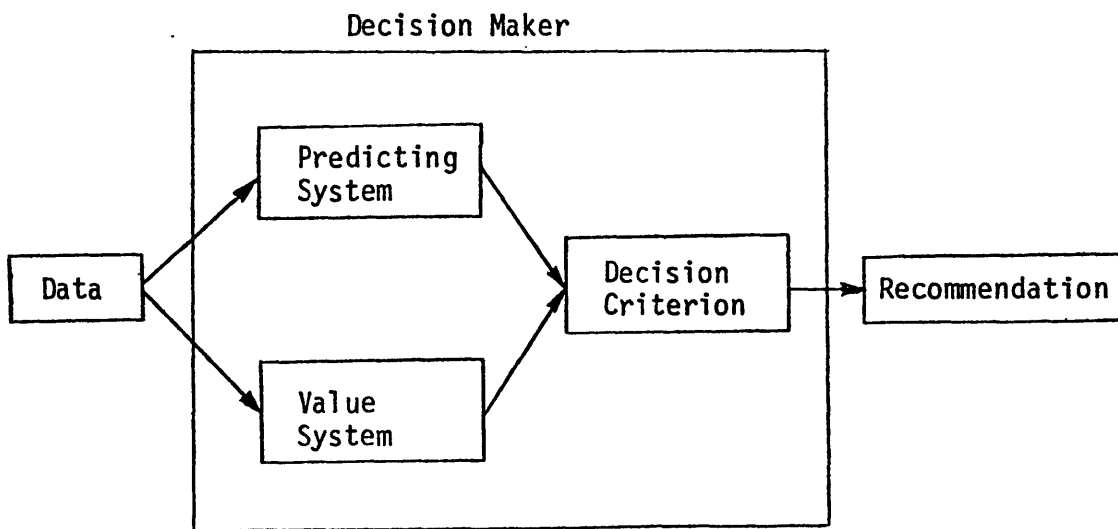


Figure 2-2 Bross Decision-Maker for Incorporating Concepts of Probability Into Technology Assessments

3. INVESTIGATION OF SOME ASSESSMENT COMPONENTS

It would literally be impossible to investigate in depth all of the various components of an energy technology assessment. For this research a single area of connected assessment components has been chosen for evaluation, these being the components that evaluate the dispersion and health impacts of air pollutants from energy facilities. Not only are these particular components becoming increasingly important in assessment activities, but they appear to be poorly modeled in the several assessments investigated. The discussions presented here relate to the effects of the various assumptions and the possibilities for modeling uncertainties.

3.1 Characterizing the Meteorology at a Site

Energy policy has in the past not been defined well enough to address generic versus specific power plant siting problems in relation to pollutant emissions and meteorological factors. Plants that would not be appropriate at one site might be desirable at another site simply due to wind patterns. The fact that siting is a variable over which there is considerable control implies that the use of national average meteorological characteristics will put a technology in a much poorer perspective than would be appropriate.

The state of the art with respect to the characterization of the meteorology in technology assessments has generally been, at best, a one or two parameter representation solely of the background concentrations. These one or two parameters are usually the 24-hour maximum and the annual average concentrations of one or two of the regulated pollutants (usually SO₂ and total suspended particulates). More detailed characterizations of sites generally must await the site selection process, when hour-by-hour chronologic representations of background pollutants are sometimes collected.

In many ways it is obvious that the diversity of available sites cannot possibly be a factor in assessments as they are currently conducted, with the one or two parameter representations. However, it doesn't seem as though the chronologic representation is the only other resort. In fact there is some literature (Gruhl, et al, 1979) on "exposure profiles" that would seem to be suitable in some modified form for assessment purposes. An exposure profile, as shown in Figure 3-1, is a time-collapsed representation of the hour-by-hour pollutant

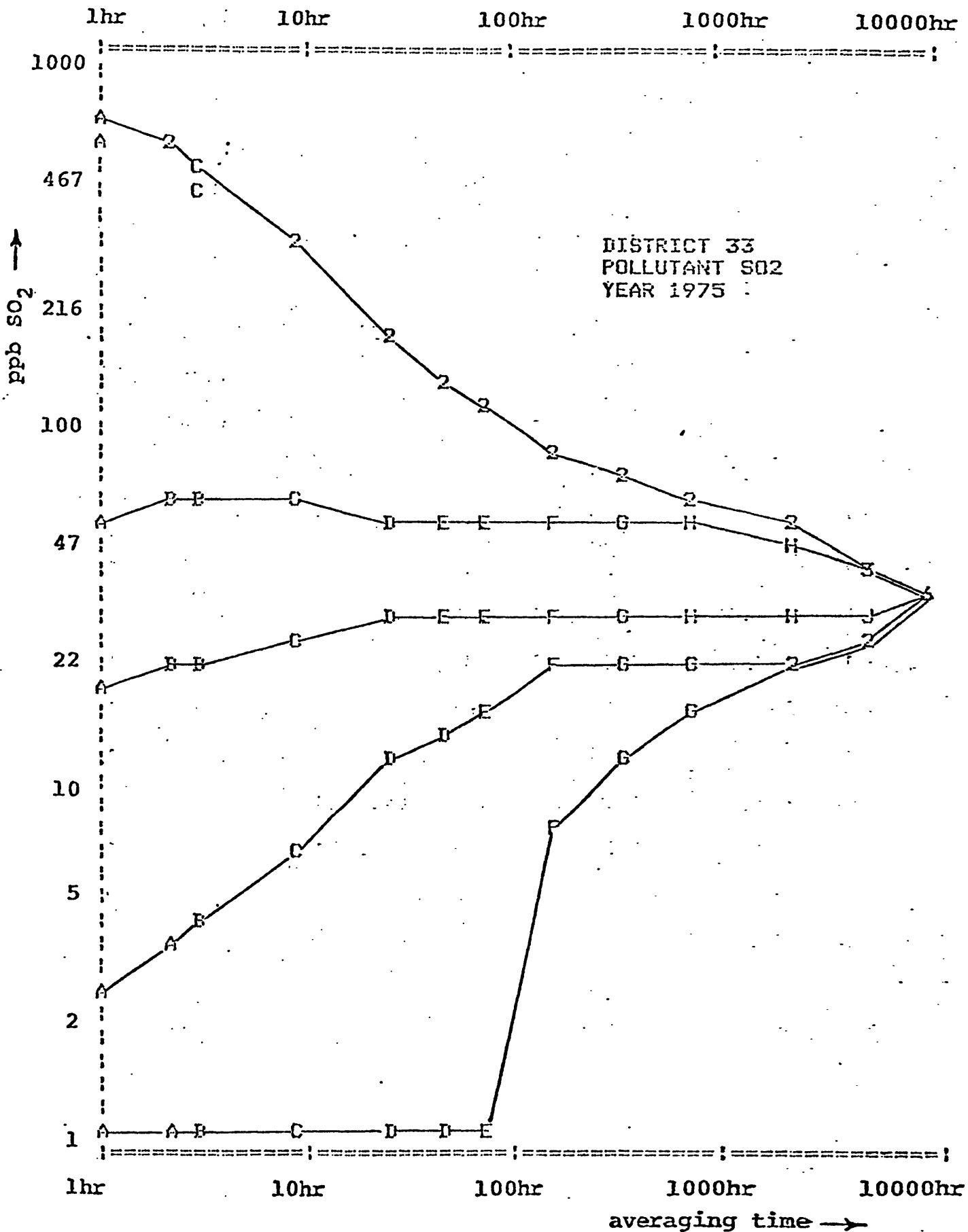


Figure 3-1 Exposure Profile, including 100%, 84%, 50%, 16% and Minimum values of pollutant concentrations for various averaging times

information that is important for pollutant regulations and health impact modeling. The time-collapsed format effectively collects and displays the probability distributions for the various pollutants at the different averaging times. Figures 3-2 and 3-3 show the tremendous contrast that can exist between the exposure profiles for different neighboring sites. This data, available from the Chestnut Ridge area of Pennsylvania (Gruhl, et al, 1979), shows the magnitude of the problems that can be encountered in the usual two-parameter characterizations of air pollution at a site.

Figure 3-4 shows the relatively similar shapes of the exposure profiles for other air pollutants. The representation of air pollution, however, cannot be made using a single index such as SO_2 . Table 3-1 from (Gruhl, et al, 1979, p. 28) shows that the rankings of various population areas, according to cleanest and dirtiest pollutant conditions, is very different for the different pollutants.

The conclusion of this brief excursion into background pollutant characterization is that

- (1) the important pollutants must be individually represented,
- (2) the various averaging times should be separately treated, and
- (3) probability distributions of each pollutant at each important averaging time seems ideal.

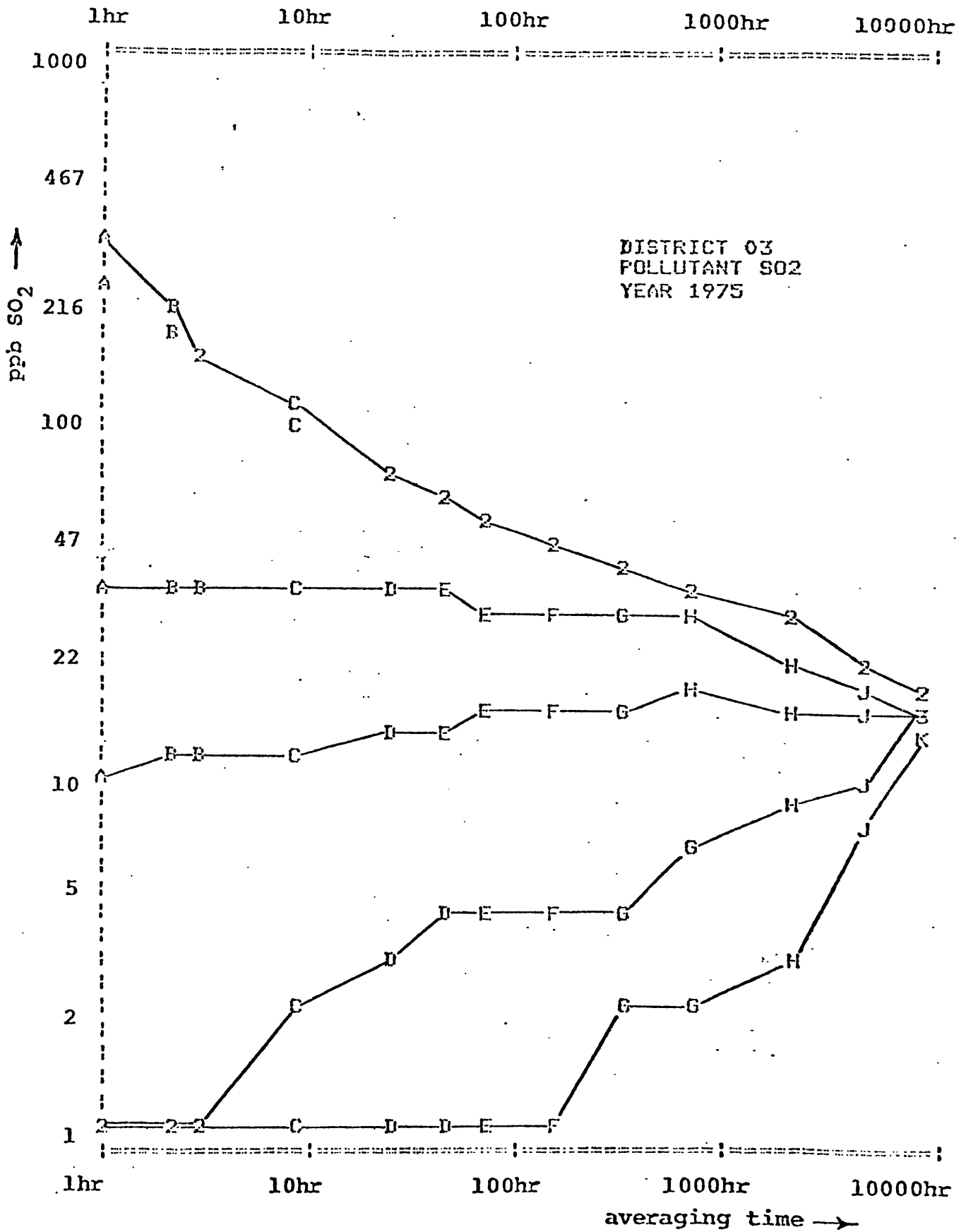


Figure 3-2 SO₂ Exposure Profile, with much blunter arrowhead with significant long-term cleansing periods.

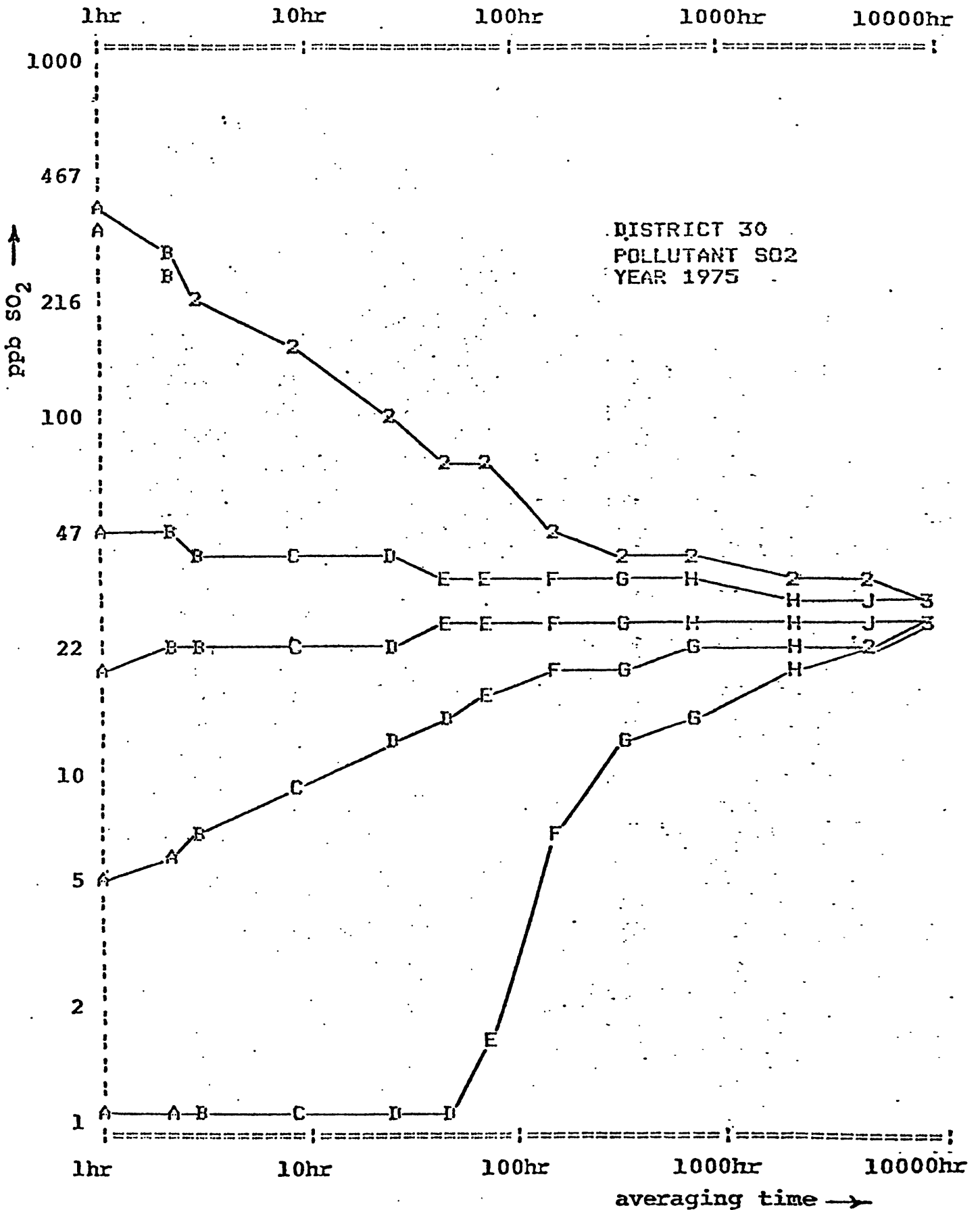


Figure 3-3 SO₂ Exposure Profile, with slightly sharper profile with a higher point at the annual average.

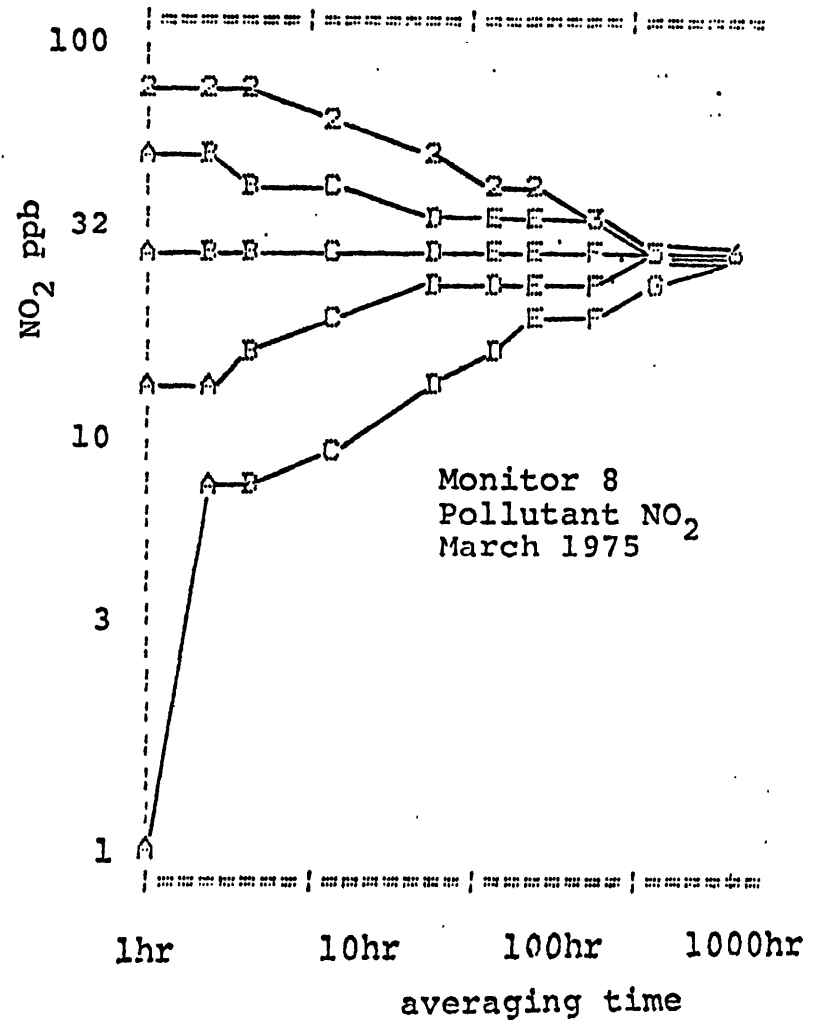
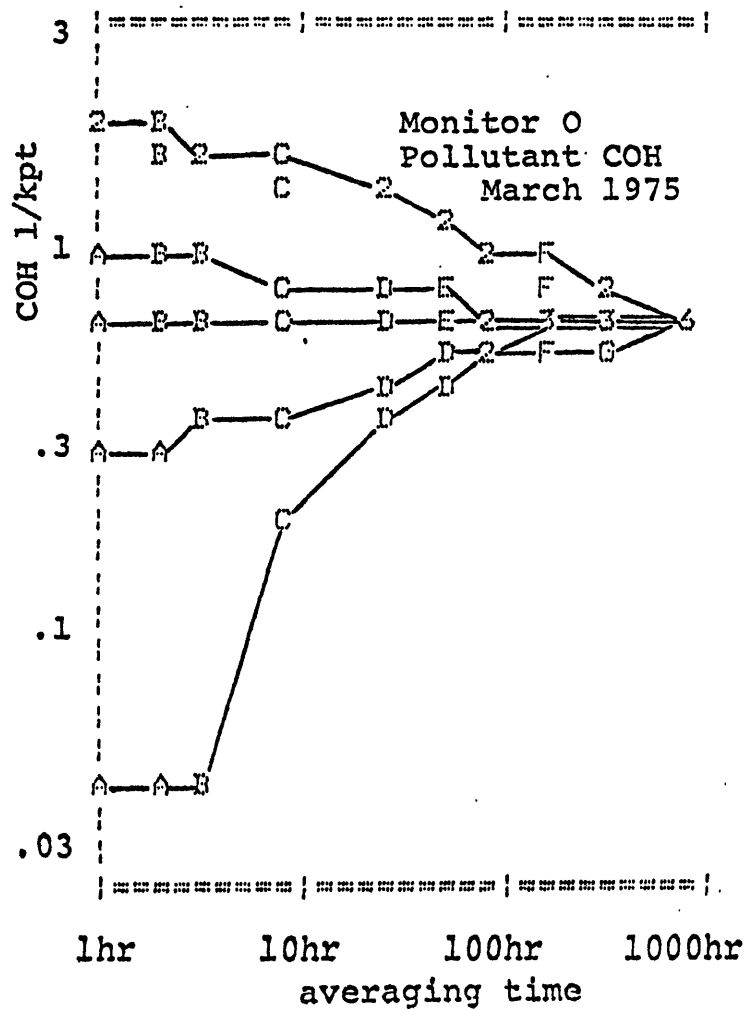


Figure 3-4 Exposure Profiles for Some of the Other Pollutants

Table 3-1

Ranks of Study Areas
by Individual Pollutants, 1975

<u>Study Area</u>	<u>Sample Size</u>	<u>SO₂ Rank</u>	<u>NO₂ Rank</u>	<u>COH Rank</u>
1	5	9	10	5
2	31	12	11	6
3	77	11	22	32
4	24	13	12	7
5	9	14	20	9
6	37	27	21	27
7	79	36	23	1
8	66	28	26	2
9	68	26	19	4
10	46	16	18	10
11	41	15	13	13
12	114	19	14	12
13	110	25	25	31
14	103	35	24	3
15	220	29	34	30
16	524	31	33	23
17	284	33	29	33
18	53	23	32	22
19	385	3	35	29
20	77	18	28	15
21	129	21	27	11
22	370	17	17	28
23	161	22	16	34
24	52	24	30	36
25	66	8	31	16
26	60	20	36	8
27	63	6	15	21
28	191	10	7	35
29	322	2	2	25
30	126	7	8	26
31	233	1	1	14
32	192	4	3	17
33	233	5	4	19
34	421	30	5	20
35	279	32	6	17
36	197	34	9	24
Total	<u>5448</u>			

1 = dirtiest
36 = cleanest

3.2 Air Pollutant Dispersion Modeling

Dispersion models tend to be very inaccurate but are important in an overall assessment. Some of the uncertainties in dispersion models are discussed here. Specifically, proposed here is that exposure patterns to surrounding populations be simulated using emission patterns and various different air pollutant dispersion models. It seems clear, for example, that the use of Gaussian models will make unwarranted exaggerations in peak concentrations compared with sector-averaging models or real situations.

The equations for the molecular diffusion of gases were developed by the physiologist Fick in analogy with Fourier's laws of heat conduction. Fick's law states that the diffusion of a gas is in the direction of decreasing concentration and is proportional to the concentration gradient. The following differential equation has been derived from this principle:

$$\frac{d\chi}{dt} = \frac{\partial}{\partial x} \left(K_x \frac{\partial \chi}{\partial x} \right) + \frac{\partial}{\partial y} \left(K_y \frac{\partial \chi}{\partial y} \right) + \frac{\partial}{\partial z} \left(K_z \frac{\partial \chi}{\partial z} \right)$$

Where χ is the concentration, $K_{n=x,y,z}$ are the coefficients of diffusion, and $x, y,$ and z are distances in three-dimensional space. The values of the K 's can vary widely, and in practice one cannot readily determine the magnitude of the K 's as a function of time. As an approximation, most models assume that the distribution of pollutants in a plane is Gaussian, which represents the simplest set of solutions to the diffusion equation.

The following equation is often used in determining ground level concentrations downwind from a continuous-point source (Slade, 1968):

$$\chi_{(x,y)} = \frac{Q}{\pi \sigma_y \sigma_z \bar{U}} \exp - \left[\frac{h^2}{2\sigma_z^2} + \frac{y^2}{2\sigma_y^2} \right]$$

where

X = concentration (Ci/m^3)

Q = source strength (Ci/sec)

\bar{U} = mean wind speed (m/sec)

σ_y, σ_x = crosswind and vertical plume standard deviations (m)
 $\sigma_y = \sigma_y(x), \sigma_z = \sigma_z(x)$

h = effective stack height (m)

x, y = downwind and crosswind distances (m).

Numerical values for σ_z and σ_y depend on the roughness of the terrain and weather stability conditions. If any accuracy is required; σ_z and σ_y must be determined experimentally at site locations. Figures 3-5 and 3-6 show order of magnitude values for σ_z and σ_y for different classifications of weather stability. Such a calculation involves many uncertainties and should only be used as an order of magnitude calculation.

Monitoring specific power plants for pollutant concentrations can be plagued by uncertain data. For example, comparing measured and calculated concentrations of SO_2 from coal plants depends on the reliability of the coal sulfur content data. The calculated values of hourly SO_2 emissions for the Clifty Creek power plant were uncertain because "...only monthly average coal sulfur content could be obtained from FPC Form 67 for the plant as a whole" (Mills, Lee, 1980).

Fay and Rosenzweig's model is used to provide estimates of long term average pollutant levels at large distances from a large collection of sources (Fay and Rosenzweig, 1978). This model is applicable for time periods of months to a year and for pollutants travelling distances

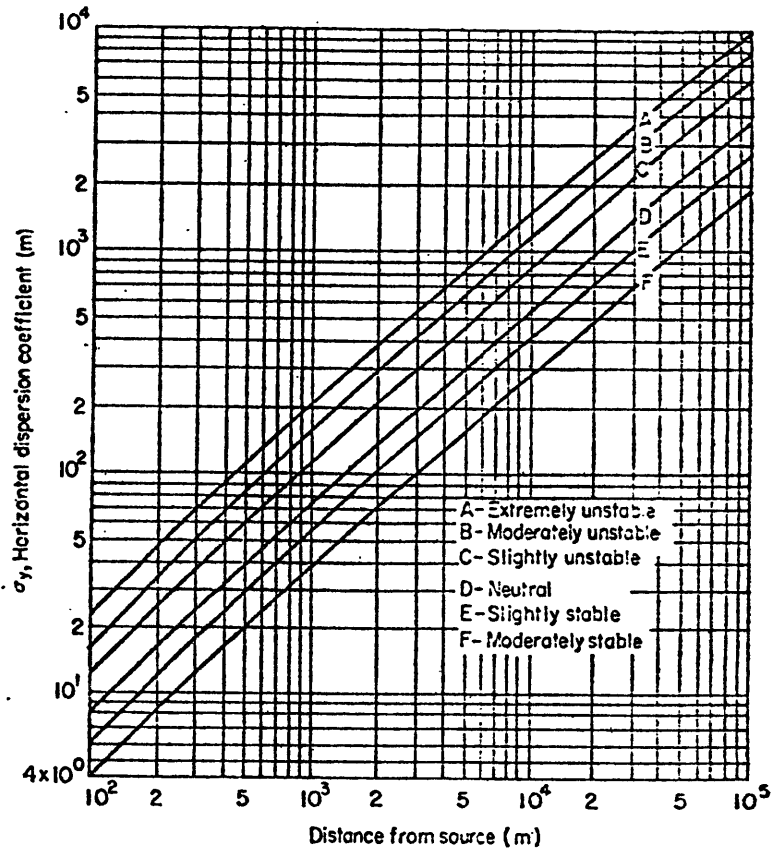


Figure 3-5 Lateral Diffusion (σ_y) Versus Downwind Distance from Source for Pasquill's Turbulence Types (Slade, 1968).

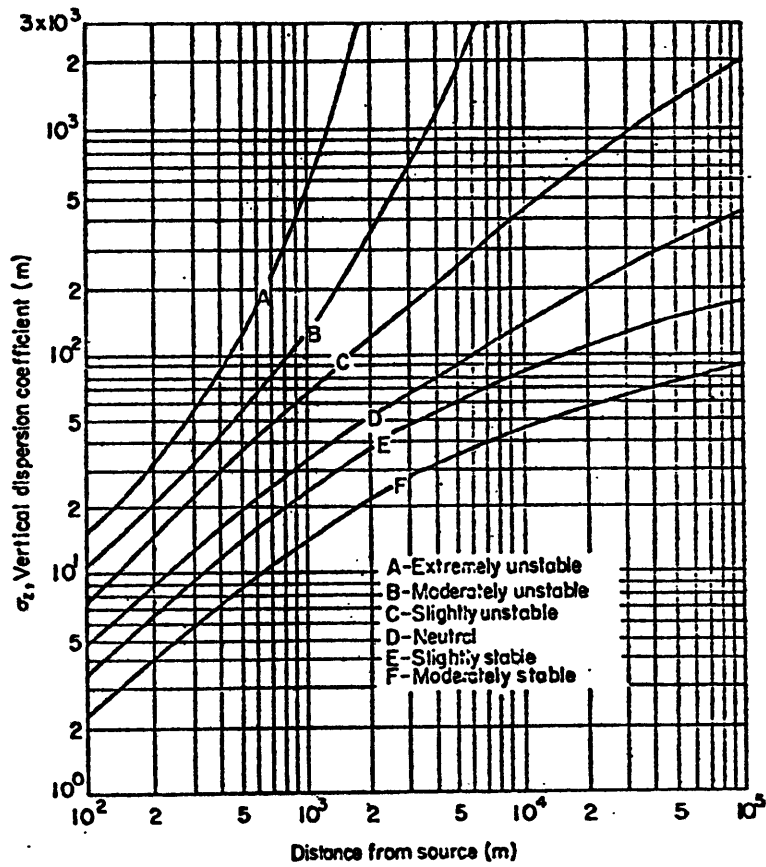


Figure 3-6 Vertical Diffusion (σ_z) Versus Downwind Distance From Source for Pasquill's Turbulence Types (Slade, 1968).

greater than about 100km.

This diffusion model has several advantages. Compared with any of the trajectory models, it is not necessary to time-average over a large spatial domain for which very detailed wind speed and precipitation input data are required in order to calculate trajectories for each of a large number of sources. This greatly reduces the cost of a practical computation. In contrast with the short-term averaged models...whose characteristics may be expressible in analytical form, our model will be valid at the very large travel distances and for the long averaging times which are of interest in long-distance pollutant transport phenomena. (Fay, Rosenzweig, 1980).

Although this model uses a simplifying assumption in deriving the analytical form which probably limits the accuracy, it compares well with other more complicated (and expensive) trajectory models.

The difficulty of achieving accuracy in atmospheric transport models is demonstrated even in this state-of-the-art model. Using values of sulfate concentrations predicted by the model and comparing them with U.S. atmospheric sulphate measurements yields "a disappointingly low correlation coefficient of 0.46....Our model could not account for the significant variations in concentrations within short distances which were observed." (Fay, Rosenzweig, 1978). Figure 3-7 shows the model predictions compared with the observed data. Other models have similarly poor correlations. "Wendall et al (1977) compared trajectory-puff model calculations with these same measurements averaged for the month of April 1974, finding a correlation coefficient of 0.40. Similarly, they found that the spatial variability of observed data could not be duplicated by their model". (Fay, Rosenzweig, 1980). Uncertainties in the observed data could be partially responsible for the poor correlation. A polynomial surface was fitted to the observed

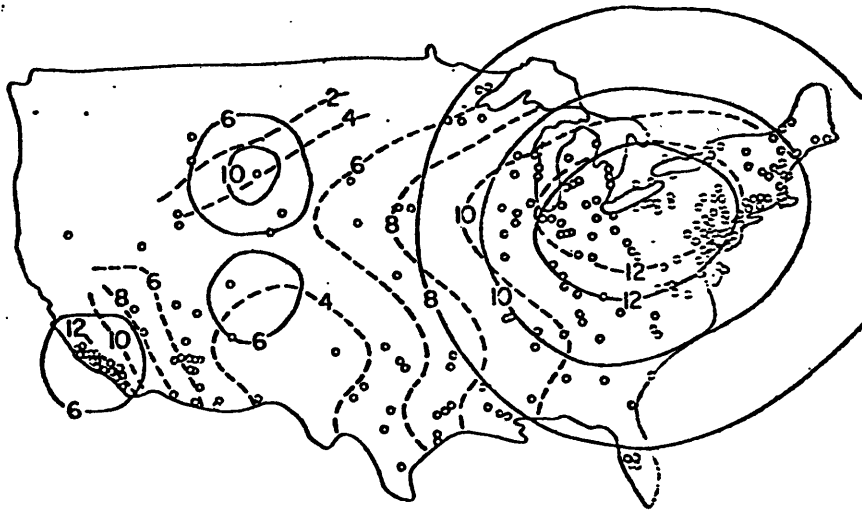


Figure 3-7 A comparison of calculated (solid line) and measured (dashed line) annual average sulfate concentrations ($\mu\text{g m}^{-3}$).

data points by least squares to smooth out local effects. The best correlation coefficient of 0.75 was obtained by using a fifth-order polynomial. The rest of the uncertainty is primarily in the emissions data, and to a lesser extent in the structure of the model.

Since both long and short distance transport models are fairly inaccurate, it would be best to include a standard deviation with predicted concentrations. This standard deviation could be carried through health and environmental impact models to obtain a range in uncertainty. Certainly using a point-source concentration would not be warranted in most cases but does provide an upper bound for pollutant doses.

Given (1) the format for characterization of air pollution, (2) the "exposure profile", and (3) the dispersion models, the question now arises how can these be brought together to make some statement about the groundlevel air pollution impact of an energy facility. In some cases, such as in the Chestnut Ridge case, where air pollution data is abundant, and the power plant is operating, and there are persistent winds, the impact of the facility can then be inferred from the available data. Figure 3-8 shows this situation, and here a subtraction (assuming perfect correlation of concentration peaks and valleys where in fact about 0.5 correlation would be more appropriate) can yield the ground-level impact of the facility. This, however, is only applicable for the one downwind distance, and does not represent a generalizable exposure profile. In addition, the conditions required for such a development are almost nonexistent.

There are two other possible ways of developing the groundlevel

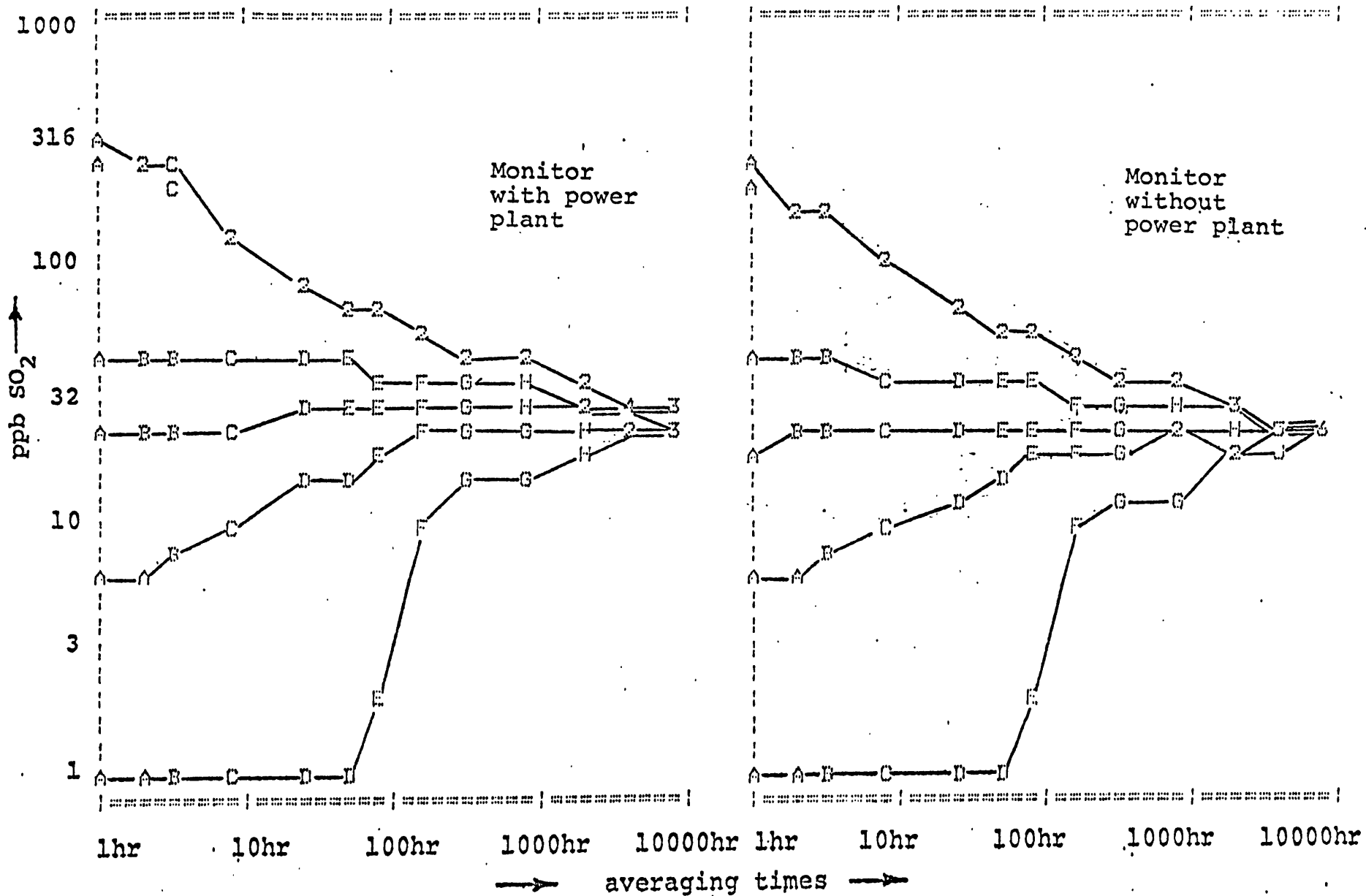


Figure 3-8 Example of a monitor with and without the effects of a coal-fired power plant in its exposure profile.

impact information for a facility. One, and the only one we found in the literature, involves a postulation of a time series of emission information, and the use of these emissions, along with nearby hourly meteorological data and the dispersion models, to simulate the hourly groundlevel concentrations. Again these types of studies are found only in the expensive and detailed phases of the facility siting process.

It appears that a somewhat more aggregate, but still useful, technique might be developed. Such a technique would perhaps use time-collapsed (exposure profile type) representations of emissions, wind speeds, wind directions, stability, and mixing depths, and the correlations between these variables, as inputs to some time-collapsed dispersion model. It would seem that such a research effort on "time-collapsed dispersion models" would be both very intriguing and highly useful.

In a simple example of some of the effects of site-variability of meteorologic data, an existing simulator, AEGIS (Gruhl, 1978), was somewhat modified. This simulator can handle site-specific and technology-specific cases in which the uncertainties in all data are carried forward to the uncertainties in the output. Figure 3-9 is a block diagram of the various modules used for this example. Additional information about this probabilistic simulator can be found in (Gruhl, 1978). The cases generated include:

- Size = 1900 MWe,
- Year = 1998,
- Coal = Southern West Virginia bituminous,
- Plant = Conventional coal-fired boiler
- Capacity Factor = 70%,

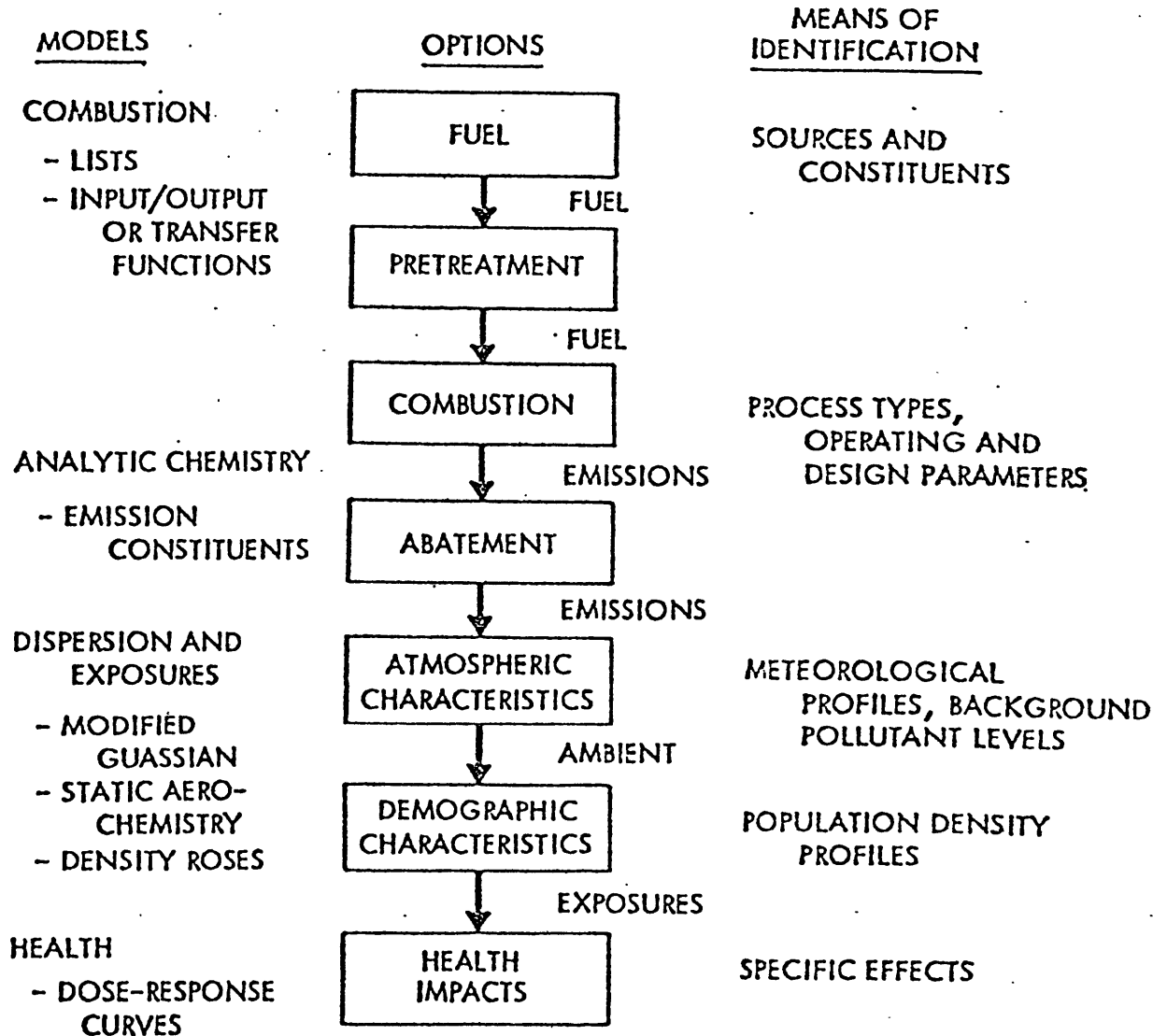


Figure 3-9 Combined probabilistic simulator of a technology-specific and site-specific situation.

- Stack = 235 m,
- Demographics = 0.8 times Indian Point in 1980 (estimated), and
- Health impact mode = LAMM, a deterministic linear addition mortality model based upon consensus and recommended standards, thus representing a consensus "worst case" model.

Given these assumptions, Table 3-2 shows the significant variation in "worst case" health impact predictions based upon the different meteorologic assumptions.

Table 3-2 Probability Distribution of Worst Case Health Impacts from 1900MW Coal-Fired Facility on Sites with Different Meteorological Conditions

	Annual Public Health Mortalities				
	0%	16%	50%	84%	100%
High Dilution Site	.03	.07	.15	.28	.43
National Average Site	.04	.09	.19	.36	.55
Low Dilution Site	.05	.11	.24	.44	.67

3.3 Modeling the Population Surrounding Energy Facilities

Site-specific population densities and distributions must be considered to address generic versus specific power plant siting problems properly. Technology assessments usually do not include such a consideration, and again as in the case of generic meteorology there may be siting opportunities that are two or three orders of magnitude less dense than national average populations.

It is instructive to survey some of the population density data bases that can be used for power plant siting and models existing that take population densities into account. "Spatial Analysis and Suitability Modeling" (see Appendix) developed by Oak Ridge National Laboratory, involves routes for suitability, siting, and impact analyses of power plant siting. Population densities are taken into account by two methods: a polygonal area method (on the order of counties) and a grid cell system at the sub-county level. Another package, "Population Analysis System" (see Appendix) can be applied to power plant siting as well as a tool for measuring aesthetic impacts of strip mining, for establishing nuclear power plant restriction zones, and for use in determining siting factors in waste disposal. The data source is the MESX census tape containing populating enumeration districts with the centroid locations given in latitude-longitude. The program computes population densities from an irregular pattern of enumeration district centroids at which the population count is known. The program uses a distance-weighted interpolating technique and a normalization technique to preserve known county population totals. The populating densities are computed for a specified latitude-longitude for any area in the United States. The population

densities are given in people per square mile, and multicolor contour maps may be generated showing regions of varying people per square mile. Another source of populating data is "1950, 1960, 1970 U.S. Human Populating Counts by County" (see Appendix) which covers all U.S. counties and states by five year age groups.

In any energy technology assessment, power plant siting is an important consideration. For example, if the plant is considered as a health hazard to the public, it must be sited in a low population density area but not so far from the populating center that significant transmission losses will result. Usually only generic power plant siting problems are addressed in technology assessments. However, adding specificity to siting problems can significantly change the assessments. For example, a coastal site with a high population density inland and zero populating density (of course) off the coast might (with the proper meteorological considerations) be more appropriate than a generic assessment would predict. The generic assessment would usually only consider the population density and the distance from the plant to the population center.

As an example one might consider a site where prevailing winds are in the direction away from the population center. An approach including meteorological factors at a specific site might be to overlay the prevailing wind rose pattern onto a map showing populating densities and population centers. Preliminary research seems to indicate that such a site specific analysis should be done by hand rather than by using a computer code because the cost outweighs the benefit. For these hand calculations knowing just the county populations may be appropriate,

depending upon the size of the geographic area to be covered in the assessment, and the sizes of the counties in the area to be considered, see Figure 3-10. Supplementary population information can be obtained from topographic maps, such as for Homer City, PA in Figure 3-11, from which sizes of towns can be estimated. Aside from some of the material discussed in the Appendix, the only more detailed information, aside from expensive on-site surveys, can be obtained from maps for Homer City, PA in Figure 3-12, which sometimes show every house.

Using the modified AEGIS simulator described previously, and the average meteorologic characteristics, the effects of the Homer City populating pattern are compared with two other sites to demonstrate the potential variations, see Table 3-3.



Figure 3-10 Portion of U.S. Map Showing the Areas of the Country Where County-Aggregated Population Data is of Greater or Lesser Resolution

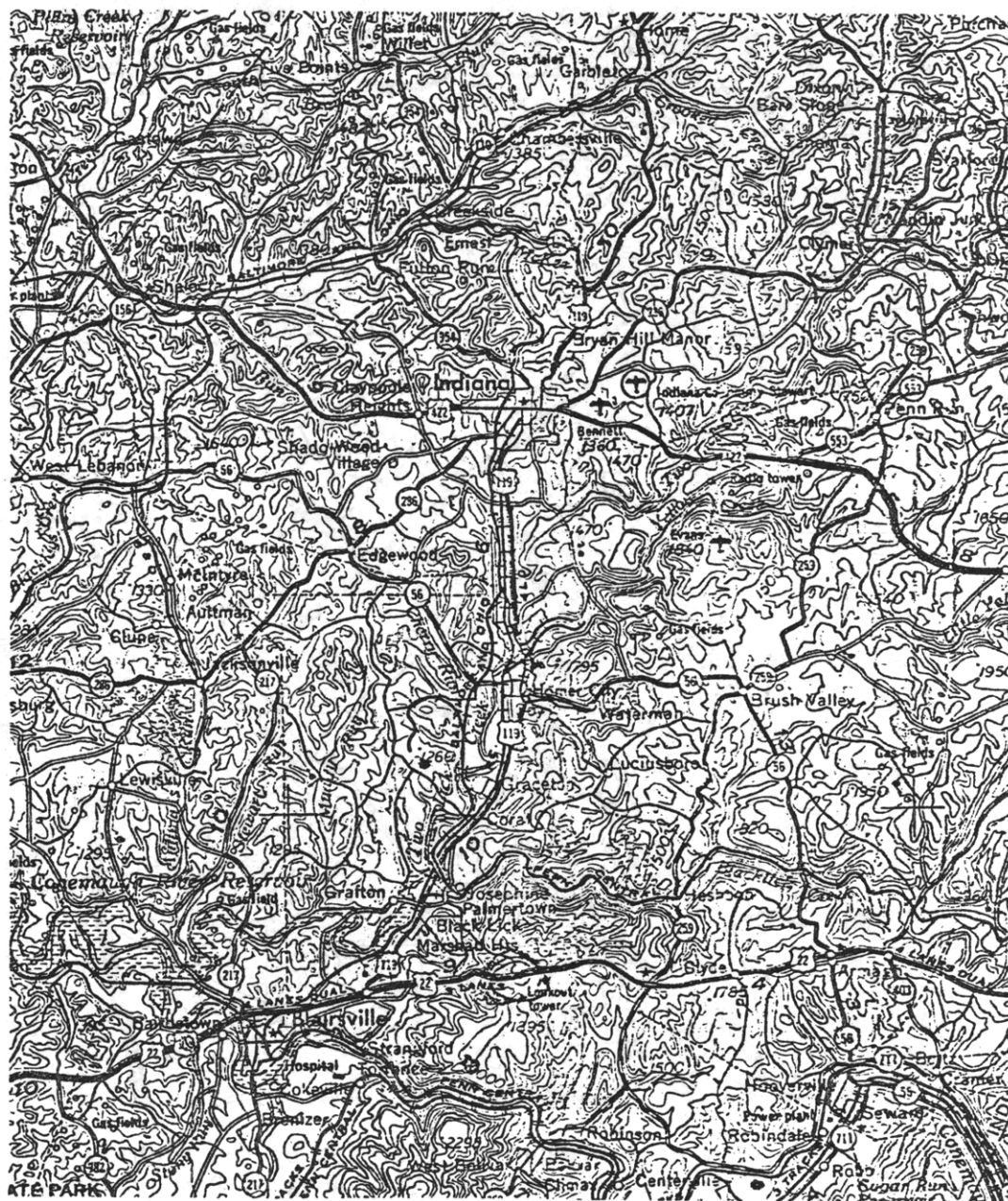


Figure 3-11 U.S. Government Topographic Map of the Homer City Area of Pennsylvania, For Use in Establishing Demographic Profiles of Sizes and Distributions of Towns

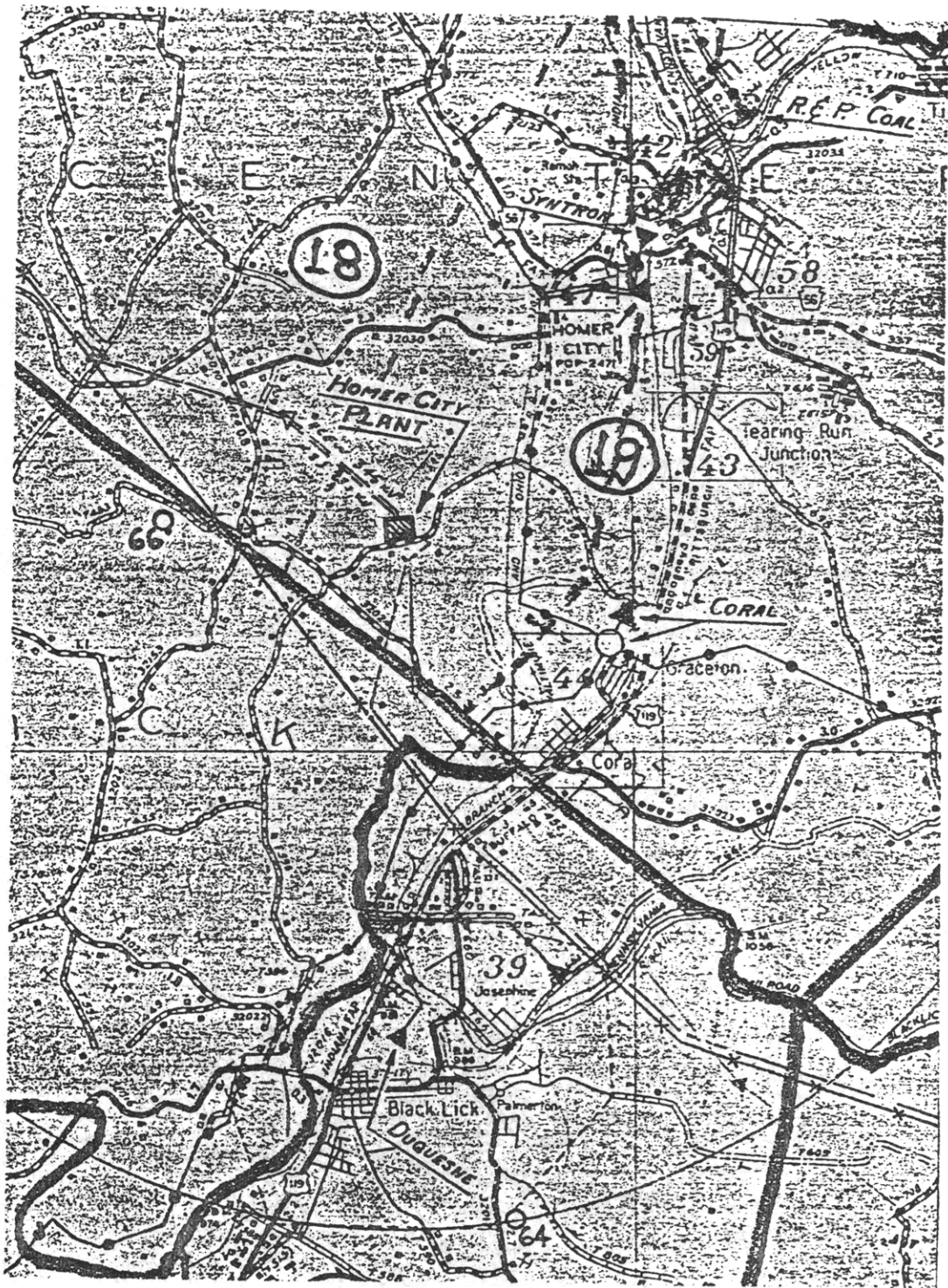


Figure 3-12 Copy of a Blueprint Developed by the Highway Department Showing All Houses in the Homer City Area of Pennsylvania

Table 3-3 Probability Distribution of Worst Case Health Impacts from 1900MW Coal-Fired Facility on Sites with Different Demographic Conditions

	Annual Public Health Mortalities				
	0%	16%	50%	84%	100%
Farley 1972	.02	.05	.11	.20	.31
Homer City 1980	.04	.09	.19	.36	.55
Indian Point 1980	1.38	3.09	6.39	11.94	18.15

3.4 Modeling the Health Impacts of Air Pollution

Health modeling is an essential part of an energy technology assessment since it relates various characteristics of a technology to the direct health impacts on man. Underlying assumptions of health models (such models often being the crudest pieces of information in an assessment) should be clarified in order to signal the limitations of the model. Uncertainties and biases in the health model output are here discussed in light of their importance to the overall assessment. Also in the following materials various health models are discussed with respect to standard coal-fired plants to see if their predictions are expected to cluster or not. This is a test of the validity, transferability and uncertainties associated with the use of such models as part of technology assessments.

Epidemiology, in environmental health issues, is a markedly different sort of analysis as compared to, say, an engineering assessment. It is primarily concerned with humans and is observational rather than experimental. The reason for this is that any experimenting done on humans must, on ethical grounds, not be harmful. Epidemiology,

... depends on observations of association between ill-health and exposures that were accidental or inadvertent and that are distributed capriciously and in biased and often unknown ways through the population. It is rare that the observation of association between a particular disease and a particular exposure in any one study can be said with confidence to indicate a causal connection between the two. (MacMahon, 1979)

Since epidemiology rarely involves the treatment of sick people, only a small number of physicians enter the field. The fact that there is a small force of manpower in epidemiology today does limit its impact on society. As additional harmful air and water pollutants are identified

in the future, many more epidemiologists will be needed for the study of environmental health issues.

Another limitation of epidemiologic studies concerns the time scales of the observations. Since the object of study and investigator have approximately the same lifetime, serious problems may result when the disease of concern develops on a time scale of a substantial fraction of a lifetime. Long term studies are also needed even for short-term diseases because in the process of looking for one-in-a-million levels of impact, both large numbers of individuals and long years of study are required. Finally, there are a number of other reasons why it is extremely difficult to establish a correlation between air pollution and health impacts:

- (1) There are a huge number of confounding variables that are much more important than community air pollution in causing health impacts, including smoking, previous health histories, diet, exercise, genetic predispositions, other ethnic variables, stress, income levels, quality of health maintenance, educational attainment, and other social variables,
- (2) indoor pollution at home, due to cooking, air and water heating, can exceed the air pollution standards (e.g. for natural gas cooking and NO_x standards),
- (3) occupational exposures to air pollution and other materials that are synergistic or antagonistic to the community level pollution exposures,
- (4) there are about 60,000 different contaminants of air, and although not all may be important there are several hundred that might be of concern, necessitating individual, and combinatorial, investigations.
- (5) people are highly mobile, and, for example, generally work or go to school in very different air pollution environments than the locale around their homes presents, (Gruhl, Speizer, Maher, Samet, Schenker, 1979) shows that 3 to 6 miles can present a substantially different type of air pollution exposure.

Thus we see some of the inherent problems in health modeling. Much

can be done in improving our observation and analyses to build our knowledge of the relationship between environment and health. For instance, epidemiological information could be stored and processed by computers on a much larger scale than now exists.

The National Commission on Air Quality conducted a study to review epidemiological studies of air pollution with a statistical emphasis (Ricci, Wyzga, 1979). This study discussed the two major types of epidemiological studies which are cross-sectional and time-series. "Cross-sectional mortality studies, examine spatial differences in mortality and attempt to relate them to specific air pollutants. In these studies, it is necessary to ensure that those factors which influence geographic differentials in mortality and are correlated with air pollution are included in the analysis." (Ricci, 1979). Time-series mortality studies attempt to correlate changes in the ambient levels of pollution with differences in mortality over time in a single specified geographic region.

Almost all epidemiological studies use multiple regression analyses. Uncertainties in these analyses can come from unavailability of data, infrequency of measurement and the lack of spatial extent of the air pollution monitoring networks. It has been mentioned that cigarette smoking exacerbates health impacts from air pollution. However, census data does not include such information as cigarette consumption. Air pollution monitoring usually comes from a single monitoring station, typically located in the center of an urban area. Thus in many cases, the recorded pollution level may be much higher than the true mean, leading to biased results. Another consideration cited as important in (Ricci, Wyzga, 1979) is that most people spend the large part of their time indoors

(about 85%) and the ambient concentrations that are monitored reflect outdoor exposures. It may be that humans are exposed to more dangerous levels of pollutants indoors from cigarette smoking (smokers and non-smokers) than from airborne pollutants outdoors.

In all of the studies reviewed, there is little discussion of violations of the assumption underlying the techniques utilized, pretest bias, and other considerations. The model results do not seem to cluster. For example, "The Lave and Seskin sulfate results demonstrate considerable variability. For example, for both the 1960 and 1969 data, the quadratic and linear spline model specifications perform better, according to the R^2 s, than the linear model. These two models, for 1960 data, suggest that at elevated levels of minimum sulfates health benefits can increase with increasing sulfate levels." (Ricci, 1979) The Lave and Seskin results for all analyses but the Chicago analysis show no positive association between daily mortality and air quality. The Chicago results show a statistically significant association between SO_2 and daily mortality but no particular measurements are included in the analysis. "... Hence it is not clear whether the association attributed to SO_2 ... is real or reflects the association between SO_2 and particulates which may be associated with mortality." (Ricci, 1979)

Another assumption in time series analyses is that the population is homogeneous over the length of the study. This assumption may hold over a short time period but for longer periods it is certain to introduce inaccuracies. In most studies this is not taken into account. Factors that might lead to inhomogeneities in population over time include permanent mobility, seasonal mobility, weather conditions, day of the

week, and holidays.

It was found that the studies reviewed did not carefully apply the multiple regression analysis. "A careful scrutiny of existing mortality studies indicates that they are of little if any value in deriving a quantitative dose-response model of the health effects of air pollution.

Existing studies contradict each other. They utilize different data and data sources, covariates, and levels of aggregation. " (Ricci, 1979). The time series studies show no consistent relationship between SO_2 and mortality. Both the cross-sectional and time series studies suggest a positive association between mortality and particulate matter. "Although a majority of those studies which examine SO_2 have identified some positive association between SO_2 and mortality, these results are rarely statistically significant. Furthermore, there are many cases where negative associations between mortality and SO_2 occur, and many of the studies which report positive associations between SO_2 and mortality do not include measures of particulate. Hence SO_2 could be serving as an index for other pollutants in these studies." (Ricci, 1979). In addition, we have found that the majority of epidemiological research has resulted in no associations, and these studies are generally left unreported or have little or no impact on the existing understanding of the problem. Of more than 100 studies investigated there was 'dismissed' research because of:

- (1) no correlations with SO_2 , SO_4 , NO_2 , ozone and/or particulates, and
- (2) negative correlations with SO_2 , NO_2 , ozone, and/or oxidants.

If these studies were in fact well conducted then it is obvious the sort of tremendous bias this selective reporting will exert.

D.E. Cooper, et al, also point out that the Lave and Seskin study has some severe data limitations. "The pollution measurements are, at best, remote approximations to an individual's exposure to a specific pollutant." (D.E. Cooper, 1979). Although present toxicological evidence indicates that the acid sulfates are the harmful sulfur species, no data on acid sulfates were available to Lave and Seskin. In addition to the lack of data on cigarette smoking, no data were available on the size distribution of the suspended particulates, despite the fact that this is a crucial factor.

The D. E. Cooper, et al. study shows that the work of Lave and Seskin has considerable bias: "Dr. Emanuel Landau, reviewing their book, notes their regrettable habit of ignoring their own caveats, and the selectivity of the authors in choosing those bits and pieces of data which support their conclusions! ...He summarizes his review by saying that 'Lave and Seskin have demonstrated once again that even sophisticated and innovative analysis cannot compensate for intrinsically poor data' " (D.E. Cooper, 1979)

Lave and Seskin also fail to use the multiple regression analysis properly.

Their method involves the addition or deletion of variables to their regression equation, with a subsequent examination of whether or not the variable(s) in question make a contribution to the explanatory power of the regression. Although the number of regression equations they cite in their book is impressive, they have barely scratched the surface in investigating the goodness of fit of alternative models. For example, their equation 3.1-2 contains 7 explanatory variables; their data base contains 60 explanatory variables, from which there would be 386,206,920 possible regression equations with seven variables. For an equation containing 10 explanatory variables, there would be about 75 billion possible equations.
(D. E. Cooper, 1979)

Lave and Seskin could calculate the statistical significance of the several coefficients and get a measure of the explanatory power of the variables. The problem lay in the enormity of the number of possible regressions they would need to examine. Even though they used high speed computers, their "deletion - substitution" method limited the number of regressions they could investigate. D. E. Cooper, et al used a "Leaps and Bounds Regression Algorithm" which "...permits one to find the best fitting equation of a given size from a large number of explanatory variables, without going through the laborious 'substitution' process used by Lave and Seskin". (D. E. Cooper, 1979). Cooper et al. found sulfate and particulates not to be statistically significant contributing factors to mortality. The Lave and Seskin study inferred a causal relationship between sulfates, particulates and mortality from their figures of statistical significance. Neither study "proves" that pollution is or is not related to mortality rates. The only firm conclusion we can make is that the data base used by both studies was weak and therefore the conclusions from both studies are tenuous.

Cooper, et al. illustrate the problems associated with publicizing uncertain results concerning health issues. A Brookhaven National Laboratory study was publicised saying that 21,000 people east of the Mississippi River are dying prematurely each year from sulphur dioxide gas and microscopic sulfate particles. A subsequent report,

said that uncertainties involved with the model calculation meant that the actual number of premature deaths east of the Mississippi River could have ranged from zero to about 50,000. Furthermore, the Brookhaven letter said that implementation of President Carter's proposal to burn more coal could actually reduce by about 2,000 (by the year 1985) the number of

premature deaths each year, rather than increase it (by the year 2010) by the previously cited 14,000. Moreover, they added that 'the uncertainties are so large that one must question the significance of any specific numbers.' (Cooper, 1979).

The "Community Health and Environmental Surveillance System", called "CHESS", was a program developed by the EPA to relate air pollution levels to health effects in a number of American communities. The results of this study were rather dubious. For example, the paper demonstrated that people living in unpolluted areas show more symptoms of air pollution impacts while black people living in highly polluted areas do not show any symptoms. Other strange results include the indication that children in Riverhead are healthier because of air pollution and that cleaner air in the Bronx and Queens causes shortness of breath. Cooper et al conclude that it is, "...obvious that they [EPA] failed, utterly and completely, to show a statistical connection between mortality (or morbidity) and ambient levels of 'suspended sulfate'." (Cooper, 1979).

One might conclude that the uncertainties in aforementioned studies are not particularly important since such studies are merely "academic" endeavors. But such studies are actually used in energy policy decisions. On September 11, 1978, the EPA administrator Douglas M. Costle proposed new source emission regulations for steam electric generating facilities. In substance, the regulations meant that coal plants burning either low-sulfur or high sulfur coal would have to install SO₂ scrubbing equipment. Senator Lloyd Bentsen posed the question; "'Are we prepared, and can we afford, to spend somewhere between \$26 and \$48 billion between now and 1990 to reduce sulfur dioxide emissions by an additional 11%?'" (Cooper, 1979). The Electric Power Research Institute estimated that the

new regulations will require utilities to pay \$200 billion between now and the turn of the century. Neither the federal government, nor the electric utility would actually pick up this tab. It is ultimately the consumer who will pay this, directly on his electric bill. Thus we see that environmental impact and health models should be a concern to the public and uncertainties in the models need to be narrowed. It may be well worth it to spend some money on some well thought out research programs to reduce the uncertainty before spending huge sums of money on possibly unnecessary scrubbing facilities.

Finally, two reports that provide additional insight into the problems in health modeling are (Viren, 1978) and (McDonald, Schwing, 1973). The Viren study imbeds the Lave and Seskin and some other investigations into a larger framework, allowing for the use of additional explanatory variables that had not previously been examined. Some of the significant findings of the Viren study were that there were variables, namely educational attainment and income levels, that were strongly correlated with mortality, but rarely used as contributing variables in the construction of health models. In addition, age, sex and smoking have geographic variations that are correlated with pollution levels, and thus entangle the modeling problem. Finally, there were significant correlations between sulfate levels and cigarette sales, age of housing, divorce rate, use of public transportation, and temperature. In recalibrating the prominent health models, the Viren study showed that as they added additional explanatory variables such as those just discussed, they observed considerable flip-flopping from positive correlations between air pollution and mortality, to negative correlations, back to positive

then negative, and so on. The approach used in (McDonald, Schwing, 1973) was ridge regression analysis, in which they bound certain of the coefficients in the air pollution/health models and recalibrated those models. They found that the models investigated were virtually indifferent to large variations in their coefficients. Part of the problem was caused by high correlation (0.96) between various pollutants.

There are two additional avenues that have been pursued in this investigation. The air pollution data used was that which was available from the Chestnut Ridge area of Mid-Western Pennsylvania (Gruhl, Speizer, Samet, Schenker, 1979). First some correlations were made between the maximum 24-hour exposures for SO_2 , NO_x , and COH (coefficient of haze, as measure of particulates and smog). The correlation between SO_2 and NO_x was about 0.65, but the correlation between SO_2 and COH was -0.23, and nearly zero correlation between NO_x and COH. The prevailing thesis that SO_2 can be used as an index of general air pollution will have obvious problems.

The second effort to verify standard epidemiological assumptions concerns the universal contention that general exposure to air pollution can be characterized by the 24 hour maximum and/or the annual average concentration. Using exposure profiles for the same Chestnut Ridge area, several different types of exposure indexes were postulated, see Table 3-4. These indexes were calculated for each of the 36 districts in the area, and the results were ranked, see Table 3-5. As can clearly be seen in this table, indexes 5 and 6, 24 hour and annual averages, are not good indicators of the various types of exposure to air pollution. For example, in district 32 indexes 5 and 6 show it to be one of the cleanest

Table 3-4 Pollution Indexes for SO_x

Index	Names	Description
1	General	-Sum of 99, 84, 50, 16, and 0 percentiles for 1hr, 3hr, 8hr, 1 day, 3 day, 1 week, 1 mo, 3 mo, and 1 year
2	Short-Term Acute	-Sum of 99 and 84 percentiles for 1hr, 3hr, 8hr, 24hr
3	Short-Term High	-Sum of 99, 84, and 50 percentile for 1hr, 3hr, 8hr, and 24hr
4	3Hr Standard	-Ratio of 99 percentile to 3hr threshold standard
5	24Hr Standard	-Ratio of 99 percentile to 24hr threshold standard
6	Annual Standard	-Ratio of 99 percentile to 1yr threshold standard
7	Short-Term Cleansing	-Sum of 16 and 0 percentiles for 1hr, 3hr, 8hr, and 24hr average times
8	Long-Term Cleansing	-Sum of 16 and 0 percentiles for 3 day, 1 week, 1 mo, 3 mo averaging times
9	Short-Term Moderated Acute	-Sum of 90 and 84 percentiles for 1hr, 3hr, 8hr, 24hr
10	Short-Term Moderated High	-Sum of 90, 84, and 50 percentiles for 1hr, 3hr, 8hr, 24hr.

*Note in all cases 99 percentile means second highest value, as written into the threshold standards.

Table 3-5 Ranking of Neighboring Air Pollution Districts for Various Air Pollution Indexes

Districts	Index 1	Index 2	Index 3	Index 4	Index 5	Index 6	Index 7	Index 8	Index 9	Index 10
1	12	12	12	12	12	22	22	22	22	22
2	11	11	11	11	10	11	23	12	12	12
3	10	10	10	9	18	12	15	17	11	11
4	9	9	9	10	11	1	3	18	10	10
5	3	5	5	5	22	5	16	11	9	9
6	18	18	18	1	34	9	12	36	20	20
7	8	8	8	18	17	4	24	3	8	18
8	1	1	1	4	33	2	17	35	18	5
9	4	4	4	17	20	10	18	9	5	8
10	7	7	7	8	16	20	13	10	23	23
11	17	17	17	7	8	18	11	2	4	4
12	2	2	2	2	9	3	2	16	16	1
13	22	26	26	3	15	8	36	5	15	16
14	16	16	16	26	26	17	10	20	1	15
15	23	3	3	34	19	27	7	8	7	7
16	26	34	34	16	23	21	8	15	21	21
17	3	25	25	25	7	30	9	4	30	17
18	20	23	23	24	14	15	20	7	17	30
19	34	30	30	30	35	7	14	1	27	2
20	15	24	24	19	29	16	25	34	2	36
21	30	27	27	35	31	23	26	14	36	27
22	25	20	20	27	32	19	5	23	14	3
23	24	19	19	23	5	26	19	19	3	35
24	27	15	15	20	36	36	4	26	35	14
25	19	31	31	31	24	25	35	21	26	26
26	35	35	35	15	21	14	21	13	19	19
27	31	33	22	33	25	13	1	30	31	24
28	36	22	33	36	4	28	6	29	34	25
29	14	14	14	32	13	35	27	25	24	28
30	33	32	36	29	28	24	28	27	28	34
31	29	29	29	22	1	32	30	24	13	13
32	32	36	32	14	6	6	34	6	25	31

Table 3-5 (continued)

33	21	21	21	21	2	31	32	28	29	29
34	13	13	13	28	3	29	29	31	33	6
35	28	28	28	13	30	34	31	33	6	33
36	6	6	6	6	27	33	33	32	32	32

areas, a ranking of 6, whereas many of the other indexes show it to be nearly the dirtiest, rankings of 31 to 36. Either the 24 hour maximum and annual average values are, by good fortune, the physiologically important averaging times, or there is considerable change that must be implemented in the way epidemiologic research is conducted.

It seems apparent that the health impacts that have been used in past technology assessments can at best be construed as slight hints of what might possibly be the worst case health impacts. At worst these estimates are misleading and their use is counterproductive in the assessment process. It seems clear that adequate measures of the uncertainties in these models would be extremely important for conveying the levels of speculation associated with any numbers that are turned over to the policy decision process.

4.0 TECHNOLOGY ASSESSMENT EXAMPLES

In order to make important contributions, energy technology assessments must be large, interdisciplinary projects, generally becoming very time consuming and expensive. This small project does not involve a large assessment, but instead combines several different types of investigations aimed at exploring the potential for, and significance of, uncertainty in the energy technology assessment process. This chapter includes three small examples of energy technology assessments that have been tailor-made to demonstrate the possibilities and importances of the concept of uncertainty in these assessments.

4.1 Example of a Single Technology Assessment -- Fusion

This illustrative discussion of an energy technology assessment example is of the type where a single technology is assessed. In this type of assessment the basis for the decision at the end of the analysis simply involves a comparison of the benefits and the costs of the particular technology. This type of analysis is most useful for far-future technologies, for which there are generally no comparable technologies, nor well-defined consequences that can be investigated in depth. The example described here is fusion power.

The prospect of controlled fusion for producing electric power is very desirable because it would virtually be a limitless source of energy. The fuel, heavy hydrogen, would be obtained from seawater at virtually no cost. However, the obvious advantages must be weighed against the disadvantages and uncertainties associated with fusion in order to make a judgment of its net potential benefits. There are considerable uncertainties associated with the scientific, engineering, safety, and commercial aspects of fusion power.

The physics of controlled fusion is not fully understood at this time. Many plasma instabilities have been understood and rectified, but microturbulence still remains a problem in plasma confinement. Alcator scaling confinement time,

$$\tau \propto na^2 \quad (n = \text{plasma density, } a = \text{plasma radius})$$

is an empirical relation and the physics behind this is not yet understood. However it seems probable that the uncertainty of the scientific aspects of fusion will be reduced in the near future because of the large amount of research being done on the problem.

The largest uncertainty of fusion power is associated with the engineering and materials problems. The engineering feats required for the feasibility of fusion reactors make the engineering for fission reactors seem trivial. Every technology used in a fusion reactor is a "high" technology. For example, the neutral beam, first wall, superconducting magnet, and lithium blanket technologies are not yet fully developed.

There is uncertainty associated with the environment to which the first wall will be exposed. There is a tradeoff between materials lifetime and machine size: for a given power output a large machine will have a lower neutron flux on the first wall, hence a longer lifetime. A smaller machine with the same power output will have a higher flux, hence a shorter lifetime, but will have a greater efficiency than the larger machine.

Much uncertainty exists in our neutron damage data base. It is simply not known what the effects of high energy neutron damage on materials will be. Most of the neutron damage data comes from fission reactor research involving only low energy neutrons. There is a fair amount known about neutron damage to stainless steel and nickel-based superalloys but very little is known about damage to vanadium, titanium, or molybdenum (exotic materials proposed for use in fusion reactors).

There is also not much data on how accessible these exotic materials are. In particular, very little is known about available vanadium resources. Also, there is no existing mining infrastructure associated with these materials as well as little welding or fabricating experience.

In addition to many extremely difficult (if not impossible) engineering problems, fusion power involves some radioactivity. The easiest fusion reaction to achieve is the D-T reaction (Chen, 1974, p. 279):



Tritium (T) could be produced in a lithium blanket from neutrons from the fusion reaction:

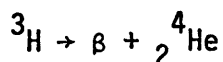


Even a reactor fueled by deuterium alone would involve tritium:



Only in the much higher ignition temperature reactions could tritium be avoided.

Tritium decays with beta radiation with a half-life of 12.3 years.



Tritium affects the entire body, that is, it is not organ selective (Piet, 1979, p. 12). Beta decay from tritium may also alter the DNA structure. Tritium follows hydrogen in the environment - HTO and HT are the tritiated forms of water and hydrogen gas respectively. Thus, tritium is hazardous because there is no biological shield for it and detection is difficult. Experiments show that 99% of HTO inhaled is absorbed by the lungs while only .1% of HT is absorbed. Thus HTO is much more dangerous to humans than HT (Ibid, p. 12). There is room for improvement in the existing data base for tritium as much of the present data (chemical and physical) comes from experiments using deuterium or hydrogen.

We can see from the current controversies involving fission that ultimately the public determines the United States' energy policy.

Before the public will allow fusion power as a major energy source, apparently they must be comfortable about whether tritium releases will be under control and not dangerous. To get some feel for what "under control" means one can set some threshold values for tritium releases. The natural inventory of tritium consists of approximately $30(10)^6$ Ci, where Ci \equiv Curie (Darvas, p. 10). The birth rate is about $1.6(10)^6$ Ci/year. Many threshold value models use 1% of the natural inventory as a limit of tritium releases. Another approach is to set tritium release rates to that of fission fuel reprocessing plants. An accepted value for this is 10-20 Ci/day. However, a tritium factory at Marcoule, France, using double jackets for all components, reports a tritium loss of 4% (Darvas, p. 22). This much release would be too great for a fusion reactor as the tritium inventory in the reactor is very large. For example, a 5GW plant circulates 675 g/day of tritium from the lithium blanket (Darvas, p. 16). This implies that much stricter tritium control must be used in a fusion power plant. Fusion reactor design should be determined by using state-of-the-art tritium control, setting a limit on tritium releases, and from this determining all other parameters.

With the hundreds of meters of piping in a fusion power plant, there are many ways for tritium to escape. The main tritium loss mechanisms are permeation, leakage (pipes, pumps, valves, etc.), losses through maintenance, and through tritium contaminated wastes. Permeation is by far the greatest mechanism of loss of tritium. Experiments show that the tritium permeation rate is proportional to the square root of the tritium partial pressure. But new evidence suggests that at

pressures less than 1 Torr the permeation rate is directly proportional to the partial pressure. "This would substantially reduce our calculated tritium permeation rates, rendering tritium losses via the permeation mechanism insignificant" (Kabele, p. 40).

Leakage from valves, pumps, and flanges could be trapped by a containment building, oxidized to HTO, and stored. However, present technology has 90% efficiency which implies that 10% of the leakage escapes to the environment.

Maintenance of a fusion power plant may introduce radioactivity to the environment as well as exposure to plant workers. The first wall of a fusion reactor must be removed every few years because of damage due to the high energy neutrons. This allows a path for neutron induced radioactive material as well as tritium to escape. The large amount of tritium required for the fusion reactor implies maintenance problems. Disposing of tritium saturated piping and hardware is still another mechanism for tritium release to the environment (Kabele, p. 40). Major maintenance may add 100 - 1000 Ci/year to present tritium release estimates (Piet, 1979, p. 33).

Many uncertainties are involved with tritium release mechanisms. For example, oxide films may be used to prevent tritium permeation. There is the uncertainty that permeation is significant depending on which permeation rate law is valid. Also, it is expected tritium control technology will improve by the time fusion power is technically feasible. Thus while we cannot predict that public unacceptance of tritium releases will prevent fusion power from becoming a major energy source, we can see the potential problems that might arise.

Figure 4-1 shows a schematic view of a fusion reactor, including the tritium flow design (Darvas, p.3.). This also shows the energy conversion system having the most probable tritium leak. Most fusion reactor designs (e.g. UMAK I) use a steam/turbine energy conversion design. The blanket material, lithium, captures the thermal energy of the neutrons thus serving as a coolant and tritium breeder. Lithium is an excellent coolant and has the benefit of low partial pressure of tritium due to the stable Li-T bond (Kabele, p. 41). Again, this implies less release of tritium.

Carnot efficiency,

$$\eta = \left(1 - \frac{T_{\text{cold}}}{T_{\text{hot}}}\right)$$

where T_{hot} is the temperature of the coolant, dictates that if one increases this temperature, better plant efficiency will result. But increasing the temperature of the coolant increases the partial pressure of tritium thus increasing the tritium release rate. Thus there is a trade-off between plant efficiency and tritium release.

Modeling has been done to estimate the amounts of tritium exposed to man by fusion reactors. The "maximum individual" dose estimate is ~ 5 mrem/year (Piet, 1979, p. 16). "Maximum individual" refers to an individual located on the plant site boundary. A typical fission plant is required to allow no more than 5 mrem/year exposure to the maximum individual. It must be remembered that the tritium release for a fusion plant will increase roughly with the power output of the plant. Thus, the local exposure limit may set limits on the power outputs of fusion plants. Cost estimates of fusion plants tend to be independent of the

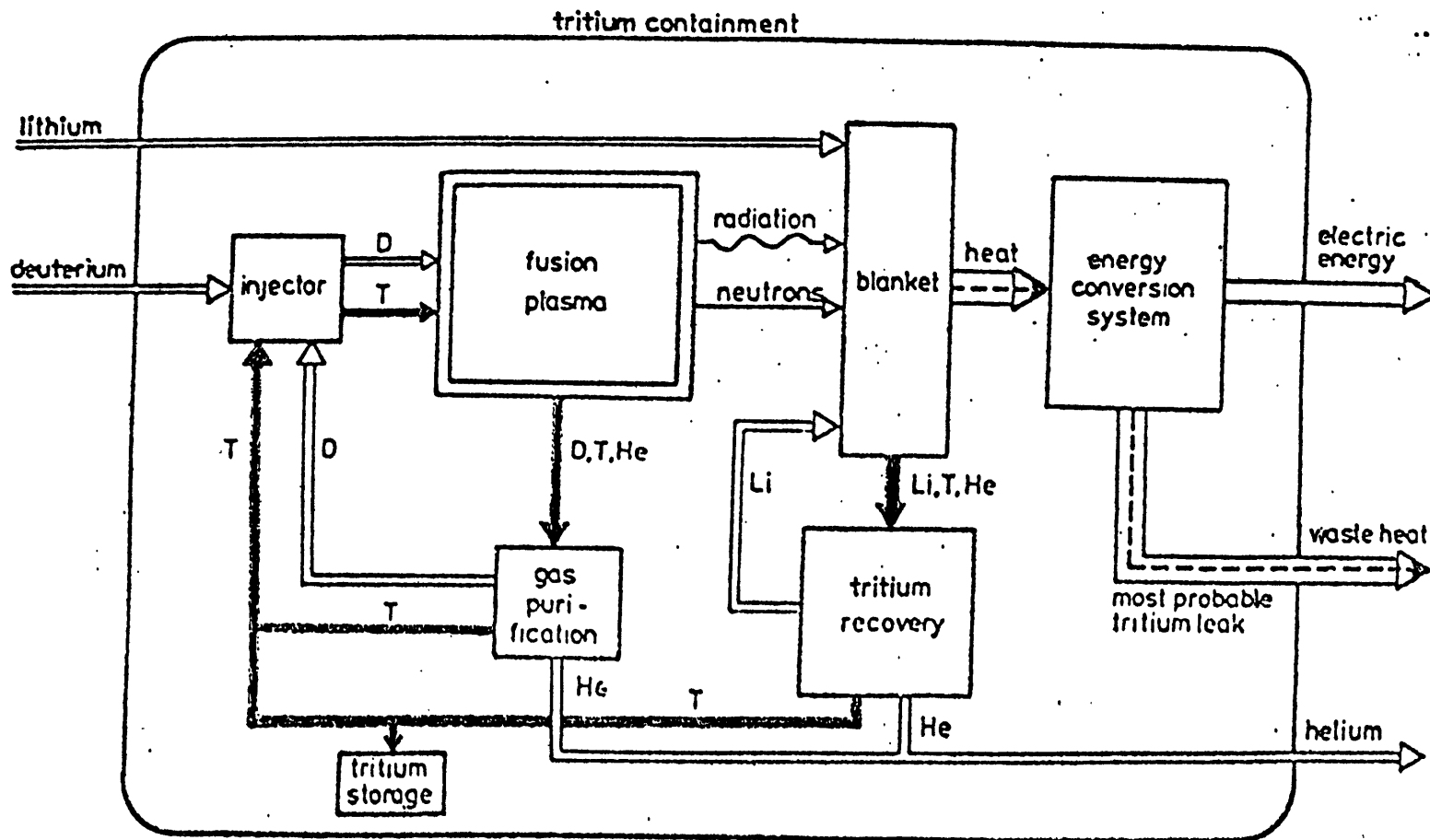


Figure 4-1 Schematic View of a Fusion Reactor and of the Flow of Tritium Fuel

design. One reason for this is because designers simply would not get funding for research if the cost of a fusion reactor were outrageous. Since so many variables and uncertainties are involved in tritium dispersion modeling, one might suspect that it is not a coincidence that the numbers for tritium exposure are similar for fusion and fission plants.

It is instructive to note that the 5 mrem/year threshold value is a value judgment as to what risk is acceptable to society. By the time fusion power is technically feasible, this value judgment might change, effecting the design of the facilities and possibly even their implementation feasibility.

Fusion power proponents are likely to receive public scrutiny on the tritium issue. When controlled fusion becomes a reality, engineers will have to design to meet the contemporary tritium release standards. Government funding of fusion research may decrease due to anticipation of the tritium issue as well as the immense engineering problems of fusion. On the other hand, it may turn out that tritium releases can be kept negligible by some new tritium control technology. Also, fusion research could head toward using the higher ignition temperature reactions with no radioactive fuel or products.

Another uncertainty associated with fusion is its commercial feasibility. Fusion reactors will be very expensive due to the high technology required. It has yet to be demonstrated whether or not fusion power will be competitive, in economic terms, with alternative energy sources.

In summary, uncertainties associated with safety (i.e. tritium control), scientific, engineering, and economic feasibility of fusion

power will have to be reduced significantly before sound technology assessments can be conducted. At some point in time fusion power may be abandoned as a possible commercial energy source if these uncertainties are reduced to the point of recognizing the unfeasibility of controlled fusion power. On the other hand, the uncertainties may be reduced in favor of fusion power. A technology assessment methodology that explicitly incorporates uncertainties, such as those proposed in Chapter 2, will thus be particularly useful for these far-future technologies. Decision makers could then keep track of the range and magnitudes of the uncertainties in the performance of the technologies. Such uncertainties, levels of risk aversion, and expected costs of R & D projects to reduce uncertainties, can be used together to make the appropriate decisions at the development, demonstration and commercialization stages of the evolution of an energy technology.

4.2 Example of a Comparative Technology Assessment--Fluidized Bed Versus MHD

Over the next 30 years, two technologies that will be competing as the primary method for converting coal to electricity are fluidized bed combustion (FBC) and magnetohydrodynamics (MHD). Although both technologies are currently receiving substantial R&D funding, the emphasis in the past has varied from one to the other. At some point in time it is quite conceivable that a choice will be made to continue with just one of these technologies. This choice, it would seem, will depend upon the uncertainties about the two processes. As long as both technologies are some distance from commercialization, they are both likely to receive continued funding, not only because a clear "winner" cannot be predicted, but because at this point it is not certain that both will even "finish the race." In this type of technology assessment it seems that the decisions must be made by watching where the technologies stand with respect to each other as their performances come into sharper focus. With uncertainty being such a key issue, the only tool we could find available that explicitly included uncertainty was the AEGIS simulator that we modified for the examples in Chapter 3. Thus it is used again here.

First a very brief description of the technologies is in order. Fluidized bed combustion processes use coal ground to about pea size. This coal is fed uniformly into the combustion chamber, or bed, where air rushing in from the bottom of the combustor at about 8 feet/sec actually suspends the small pieces of coal. These suspended coal particles have the appearance of a fluid, generally seeking a particular

level and sometimes even displaying waves. In such a fluidized bed the coal combusts much more completely than it usually would. When the coal is burned down to the ash this ash is carried away by the fluidizing stream of air or is moved out of the bed area. A major advantage of fluidized bed is that small pieces of limestone can be introduced into the bed to absorb the sulfur oxide pollutants. Some of the uncertainties that still exist about this technology are enumerated in an EPA-sponsored report (Gruhl, Teare, 1978), and principally involve particulate control and uniform coal feeding problems.

MHD processes involve the combustion of pulverized coal at extremely high (5000°F) temperatures. At these temperatures the combustion gases ionize. When moved across a strong magnetic field electric current is drawn (onto electrodes) directly from the combustion gases. After passing through the magnetic field the gases are still hot enough to drive a conventional turbine cycle power plant. The advantage of this combined process is an extremely high efficiency, but there are still considerable problems, as listed in another EPA-sponsored report (Gruhl, 1977), including principally the slag coating of the electrodes and erosion of the turbine blades by the highly corrosive high temperature combustion gases.

For comparative purposes the conditions used to drive the AEGIS simulations of fluidized bed and MHD facilities are much the same as those used in Chapter 3, namely:

- o 1900 MW size
- o 1998 startup date
- o West Virginia bituminous coal
- o 70% design capacity factor
- o 155 meter stack
- o national average meteorologic conditions Indian Point 1980 population distribution, and
- o LAMM - linear additive mortality model of consensus worst case health consequences of facility generated air pollution.

The MHD facility chosen was an open cycle coal fired design. The fluidized bed combustor (FBC) was of a standard, moderately pollutant-controlled design, using raw limestone #1359 as the sorbent.

Table 4-1 shows a selected set of performance measures that resulted from these simulations. For comparative purposes the middle column of Table 4-1 can be used as the value from a deterministic assessment. In every one of the deterministic comparisons there is a clear winner. However, examining the probabilistic information, with these technologies still on somewhat uncertain grounds, only in energy efficiency and respirable particulates are there clear winners. That is to say, there appears to be no chance of making a mistaken choice, i.e. where all values for one technology are superior to all values for another technology.

There are two caveats to this result. First, for two of the performance measures, investment cost and cost of electricity, there are common factors of uncertainty, such as cost of capital. Thus the FBC

Table 4-1 Comparison of Some Performance Measures for Fluidized Bed and MHD Facilities

		0%	16%	50%	84%	100%
Investment Cost (\$Mill)	MHD	1219.8	1364.2	1529.5	2095.7	2736.0
	FBC	814.0	821.2	829.5	1088.3	1412.5
Cost of Electricity (Mills/kwh)	MHD	25.3	28.1	33.2	43.1	54.7
	FBC	20.9	22.2	24.6	30.0	36.4
Energy Efficiency (percent)	MHD	45.9	47.3	48.6	49.1	49.7
	FBC	33.5	34.4	35.6	36.8	39.9
Commercialization Year	MHD	1995	1996	1999	2003	2021
	FBC	1988	1988	1991	1995	2005
Sulfates (gm/min)	MHD	10.1	33.6	611.0	1338.	3225.
	FBC	157.8	576.3	1602.2	3504.	5662.
NOx (1000gm/min)	MHD	5.7	14.3	17.1	29.5	64.6
	FBC	15.4	20.1	25.1	32.3	37.1
Particulates Respirable (1000 gm/min)	MHD	6.0	53.2	55.1	68.4	81.7
	FBC	672.6	1311.0	1869.6	2720.8	3226.2
Polycyclic Organic Material (gm/min)	MHD	.3	.9	2.7	8.9	27.4
	FBC	3.23	66.5	164.	720.	2360.
Annual Public Health (Mortalities)	MHD	.15	1.4	4.4	9.3	14.4
	FBC	8.5	34.7	109.4	235.	404.

may in fact be certainly superior to MHD in costs once the common factors of uncertainty are investigated. Second, the respirable particulate and polycyclic organic material (POM) outputs of the FBC might be intolerable, and thus in a more detailed investigation additional particulate controls could be added at a cost. In more detailed work, the flexibility within each technology must be part of the assessment process.

In tracing back the health impacts of the technologies it turns out that the FBC particulate control will also take care of most of its health impact difference from MHD. Thus, in general, FBC is favorable from the cost and commercialization year perspectives, while MHD is far ahead in efficiency and particulate emission areas. This leaves the sulfate and NOx problems. As clear cut as the sulfate issue seems, at the level of uncertainty currently displayed by these technologies there is about a 30% chance of error from a choice of MHD as the minimum sulfate producer (a 70% chance of error choosing FBC). In investigating these emissions in terms of the regulations or the suspected health impacts it turns out there is no substantial issue here at all. Although there is great uncertainty, in neither case do the levels reach the recognition levels.

This leaves the NOx issue, which is not only becoming a health (cardiac, pulmonary, and carcinogenic) problem, and an acid rain issue (causing nearly 40% of acid rain), but unlike particulates and sulfur compounds there are no good control opportunities. Examining the emissions information, MHD is the more favorable from the

deterministic (50%) point of view. However, if the decision maker is risk averse he may well decide that FBC is more favorable, particularly where the health impacts are substantially (nonlinearly) greater at higher levels.

Instead of this being a peculiar situation, it may in fact be the norm. Farther-future technologies are generally pursued because they do have an expected advantage. These technologies will, however, have much greater uncertainty, thus under risk averse decision situations they will look less favorable. This is a clear demonstration of the importance, and perhaps the necessity, of technology assessment methodologies that include measures of uncertainty.

4.3 Technology Assessment from an Issue Perspective -- The Global CO₂ Problem

The final illustrative discussion is an example of technology assessment used in a reverse mode. Once a new problem is identified, such as the global CO₂ problem, then technologies can be reassessed in the light of this "new" performance measure. In the example presented here, the long-range CO₂ problems of the fossil-fueled technologies are contrasted with the nuclear power technologies and its potential health impacts.

The current public debate over nuclear power is a very complex and sensitive issue. But many people are unaware or selectively ignore the global CO₂ problem which perhaps deserves as much attention. The reasons for this disparity in national concern have some of their roots in the inadequacies of current technology assessments -- both funding and methodological inadequacies.

Atmospheric CO₂ is transparent to visible light but will absorb infrared radiation given off by the land, oceans, and clouds at temperatures much less than that for solar radiation. The CO₂ then reradiates a portion of this absorbed energy back to the earth. Without the atmospheric CO₂, this portion would be lost to space. The effect of trapping this heat in the atmosphere is called the "Greenhouse effect" (Keeny, et al, 1977, p. 201). Many uncertainties and feedback loops are involved; for example, as the temperature rises from the greenhouse effect, dissolved carbon dioxide in the ocean tends to escape into the atmosphere thus resulting in an enhanced greenhouse effect (Keeny, et al., 1977, p. 202).

Volcanic and geothermal contributions to atmospheric CO₂ amount to approximately .04 billion tons C/year. This is small compared with the fossil fuel contribution, ~5 billion tons C/year. This value in turn is small compared with the natural carbon fluxes in the atmosphere and oceans (Baes et al., 1976, p. 3). Figure 4-2 shows the observed increase in atmospheric CO₂ from 1958 to 1974 (Baes, et al., 1976, p. 11). The CO₂ concentration before and after the industrial revolution are 295ppm and 330ppm respectively. Figure 4-3 shows the cumulative CO₂ production and observed CO₂ increase (Baes, et al. 1976, p. 20). Thus we see that the burning of fossil fuel is probably responsible for the observed increase in atmospheric carbon dioxide.

From the known amounts of fossil fuel-produced CO₂ and atmospheric CO₂ it has been calculated that ~50% of the produced CO₂ has been removed from the atmosphere. This is a crucial point because most of the modeling done has assumed a 50% atmospheric storage. Figure 4-4 illustrates the possible CO₂ release from forest clearing proposed by R. M. Rotty (Rotty, 1979, p. 8). This implies that much more CO₂ is put into the atmosphere than was taken account for and thus the fraction of CO₂ airborne is reduced. This will drastically change the modeling results previously obtained assuming 50% storage. However, W. S. Broecker et al. conclude, contrary to Rotty, that "...current estimates of ocean uptake are sufficiently firm to exclude the possibility that appreciably more excess CO₂ is dissolved in the sea than has been estimated through the use of existing models" (Broecker, et al., 1979, p. 409). They conclude that the regrowth of previously cut forests and the enhancement of regrowth resulting from the excess CO₂ in the

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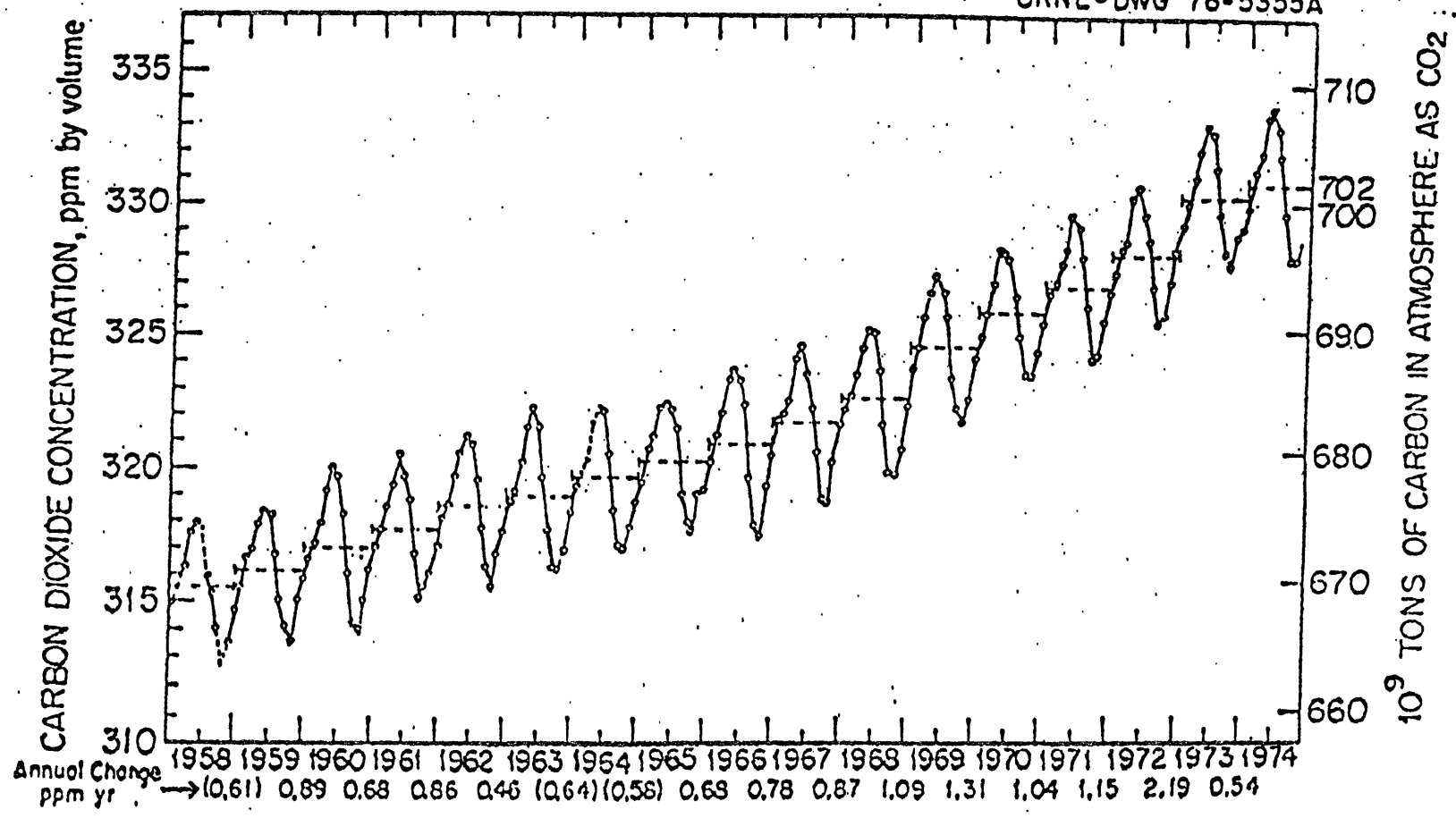


Figure 4-2 Atmospheric Carbon Dioxide Concentration at Mauna Loa Observatory

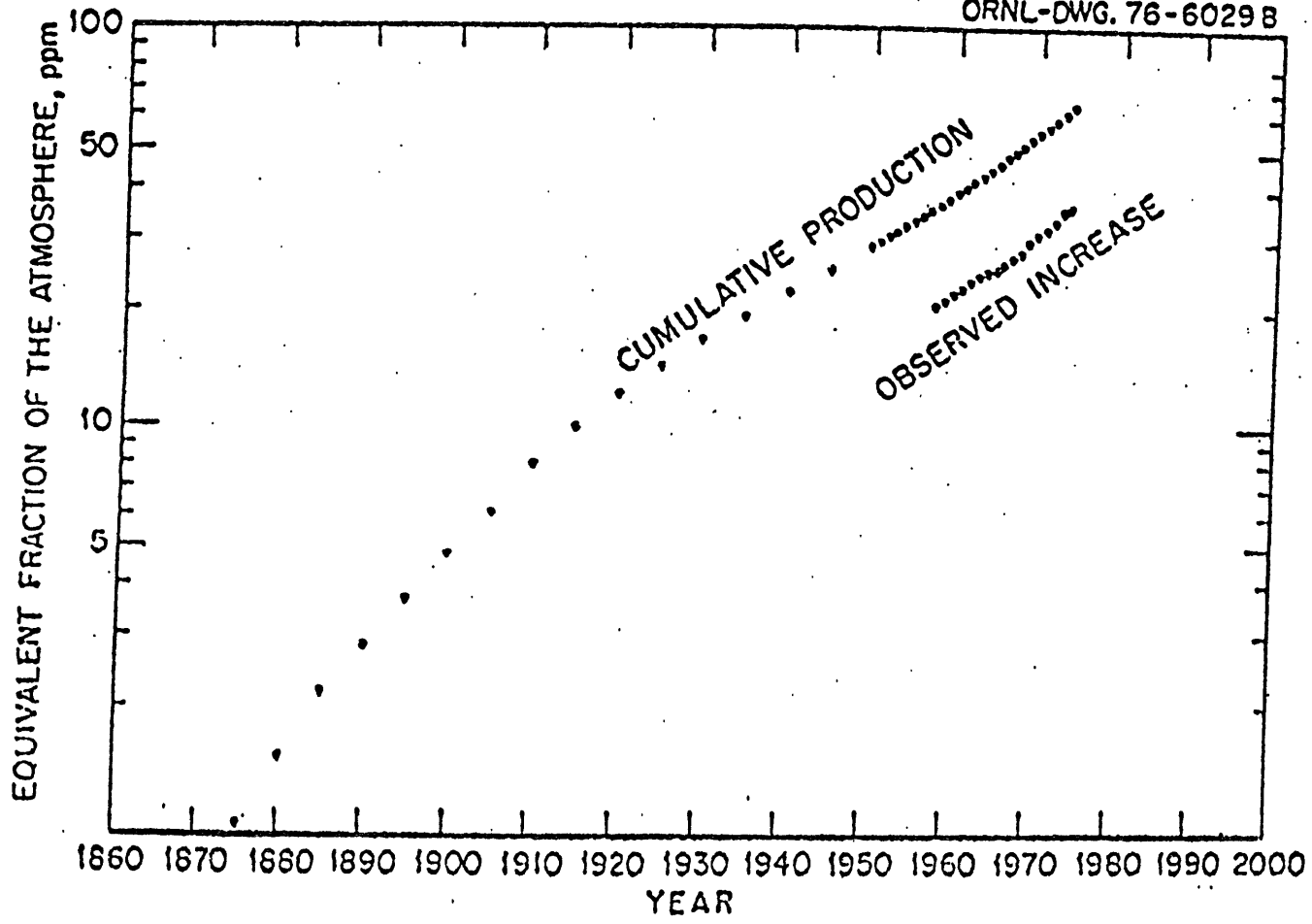


Figure 4-3 Cumulative CO₂ Production and Observed Increase in the Atmosphere

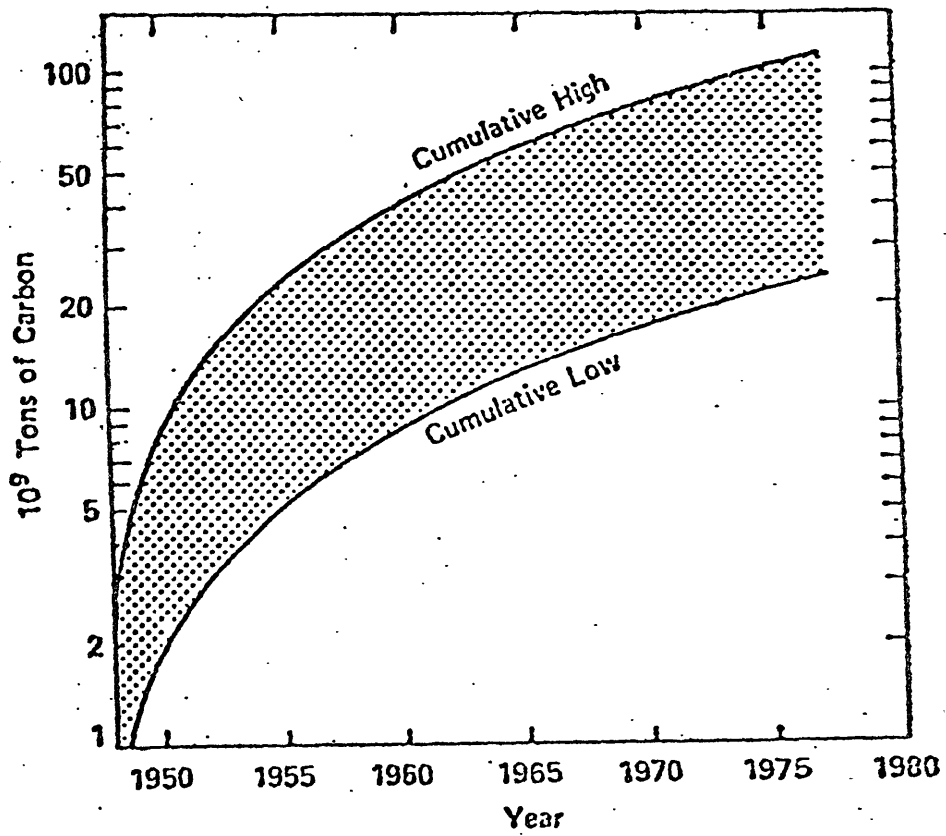


Figure 4-4 Possible CO₂ Release from Forest Clearing

atmosphere have probably balanced the rate of forest clearing during the past few decades.

W. S. Broecker et al confirm the 50% storage assumption by cross-checking several times: the first method is based on the requirement that the net influx of naturally produced $^{14}\text{CO}_2$ into the ocean be equal to the rate of decay of ^{14}C residing in the sea. The result is 19 ± 6 moles of CO_2 per square meter per year (Broecker, et al, 1979, p. 411). the second approach is based on the deficiency of radon gas observed in the surface ocean mixed layer. The best estimate for the CO_2 exchange rate based on radon is 16 moles per square meter per year. These two independent methods give fairly consistent results. They also cross-check the vertical mixing in the sea by using bomb produced tritium data (Broecker, et al. 1971, p. 412) yielding the result of atmospheric storage, 52%. The basic CO_2 modeling results have also been confirmed by a group of experts convened by the National Academy of Sciences: "We have tried but have been unable to find any overlooked or underestimated physical effects that could reduce the currently estimated global warmings due to a doubling of atmospheric CO_2 to negligible proportions or reverse them altogether" (Wade, 1979, p. 912-913). Thus we see that a consensus on the problem is being developed and model results are clustering. This means that the CO_2 problem warrants more attention than has been previously paid.

The most energy-frugal global strategies coupled with the results of the aforementioned models, "...would force the world to get its energy 50% from new non-fossil sources by about the year 2010, if a CO_2 level of 500 ppmv is not to be exceeded, and about 2020 if a CO_2 level

of 600ppmv is not to be exceeded. The technology shifts implied ... will be very difficult, and would require a high degree of global cooperation, much more than now seems apparent" (Rose, 1980, p.2.).

Based on the market penetration time of past U.S. technologies, the most optimistic market penetration time for the non-fossil sources is 50 years (Rose, 1980, p. 9). This coupled with the uncertainty in the CO₂ level and uncertainty in the energy growth yields an action initiation time range of 1970 - 1990 (Rose, 1980, p. 10). Thus we may have run out of time to rectify the CO₂ problem. However, it seems clear that a firm bound does exist and therefore ignoring the problem because of disputed models and uncertainty can no longer be justified.

The climatological changes predicted are mainly deleterious since species and crops are optimized to existing conditions. Regional dryness, oceans flooding coastal regions from melting ice caps, and decreasing the world productivity are some of the potential problems. Although predicting climate change is a somewhat uncertain venture climatologists are agreeing that drastic climate changes (hence food production) are inevitable at a CO₂ level of 600 ppm. The consequences of restricting global food production from its currently meager rate would be devastating, having a much more direct impact on civilization than the energy crisis (Rose, 1980, p. 11).

The effect of temperature increase on the level of the oceans is not as catastrophic as imagined previously. Since the ice areas and oceans are so massive, they serve as very long term heat sinks. Figure 4-5 illustrates the increase on the level of the oceans for alternative

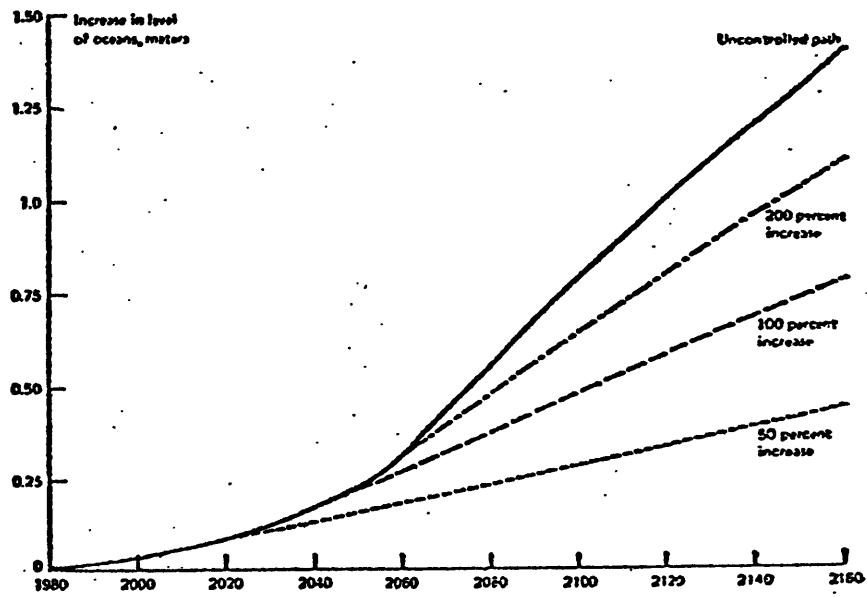


Figure 4- 5 Estimates of the Effect of Temperature Increase on the Level of Oceans for Alternative Paths of Carbon Dioxide Concentrations.

paths of carbon dioxide concentrations (Nordhaus, 1979, p. 150). Note that the level increases only 1.5 meters by the year 2160 for the worst case. Another note of interest is "... that even though the climate as a whole is warmed, a cooling of continental climates may occur because of weakened westerlies; Newson's study predicts the continental United States will cool by 8⁰C (Nordhaus, 1979, p. 134).

William Nordhaus offers some economic and technical strategies for the control of carbon dioxide: "The problem is a classical example of economic externality. An externality arises when economic agents do not pay for the entire social cost of their activities" (Nordhaus, 1979, p. 135). He suggests that the most efficient way to reduce emissions is not to reduce consumption but to change the composition of production away from carbon-based fuels.

Once some notion about an efficient path has been obtained, there must be a way of assuring that the millions of economic actors have incentives to reduce emissions. In the real world, the policy can take the form either of taxing carbon emissions or of physical controls (such as rationing). In an efficient solution, the two are interchangeable in principle; in practice, the use of taxes is much simpler because the taxes tend to be much more uniform than the quantities. I therefore will concentrate on 'carbon taxes' as a way of implementing the global policy on a decentralized, individual, level (Nordhaus, 1979, p. 137).

Nordhaus suggests that CO₂ can be compressed and pumped into the oceans at a depth of at least 2000 meters and will stay there since it would be at a specific gravity heavier than water. His analysis shows that the cost of this scheme is only about one-thirtieth of the cost of putting the CO₂ into the atmosphere. "The reason for this anomaly is that by the time carbon is put into the deep ocean it is locked up there for about 1000 years: (Nordhaus, 1979, p. 153).

The nuclear power industry has been widely attacked as a threat to human health. "Critics are primarily concerned about the possibility of catastrophic reactor accidents and the health and environmental problems associated with nuclear wastes and plutonium. These risks are real and must be considered in any assessment of nuclear power." (Keeny, 1977, p. 16). Clearly, there is uncertainty associated with regarding the effects on health and the environment of radiation and regarding the probability of nuclear accidents. But in normal operations, a 1000 MWe nuclear plant has been estimated to cause one fatality per year from radiation and occupational accidents to workers and the public (Keeny, 1977, p. 17). A comparable coal plant, meeting new standards causes from two to twenty-five fatalities per year. Thus in normal operation, nuclear power has smaller adverse health impacts than coal. Or in other terms, the uncertainty in health impacts for nuclear power (for normal operation) is bounded by the health impacts for coal. The most pessimistic case for a nuclear accident still is bounded by the coal plant estimates. Thus "... even when the possibility of reactor accidents is included, the adverse health effects of nuclear power are less than or within the range of health effects from coal" (Keeny, 1979, p. 19).

The other main public concern about environmental impacts of nuclear power is waste disposal.

We are convinced that nuclear wastes and plutonium can be disposed of permanently in a safe manner. If properly buried deep underground in geologically stable formations, there is little chance that these materials will reenter the environment in dangerous quantities. Even if material were somehow to escape eventually in larger quantities than seems possible, it would not constitute a major catastrophe

or even a major health risk, for future civilizations.
(Keeny, 1979, p. 19)

However, the current worldwide temporary management of nuclear waste appears to constitute a greater threat than permanent underground storage. On balance, nuclear power has significantly less adverse environmental impact than coal. Or, the uncertainty is bounded by the environmental impact of coal.

We see that the uncertainties associated with nuclear power and the CO₂ problem are fairly well bounded. It also seems clear that the maximum possible damage to the biosphere by nuclear power is dwarfed by the maximum possible damage due to the global CO₂ problem. Then why is there such an obvious disparity in national concern between these two issues? The answer to this question is complex and warrants much discussion and research. One reason is that the CO₂ problem is a global concern and international efforts tend to be weak compared with national efforts (Rose, 1980, p. 3). Also, "the CO₂ problem has all the features that lead to present inaction: not easily definable, no closely affected group (now), no strong institutional mechanism, disputed models, long time before bad consequences, many uncertainties". (Rose, 1980, p. 12). However, the long time perspective of the CO₂ problem is comparable with the long time perspective of nuclear waste disposal. Both of these issues concern the morality of leaving serious long term problems with future generations.

The reasons for the apparent disparity in public concern include poorly developed and poorly presented information about both the CO₂

problem and the actual environmental impacts of nuclear power. Also, the nuclear debate is much more glamorous: radiation is unseen, unknown and highly dangerous. CO₂ is natural and fossil fuels have been around for a long time. Further, the prospect of world starvation is much less glamorous than the idea of a catastrophic nuclear accident.

Much can be done to rectify the current disparity in concern. Research can further reduce the uncertainty associated with the CO₂ problem. Also, the sooner a consensus on the problem is more fully developed, the sooner the public will pay more attention. Finally, the government and other concerned institutions can disseminate accurate and unbiased information concerning such issues as nuclear power and the global CO₂ problem. The initial steps toward the resolution of this problem lies squarely in the lap of good solid technology assessment. There are some initial hurdles to overcome, and perhaps the largest is the credibility of assessments. There are several reasons why past assessments have fostered a lack of credibility:

- (1) technologies have generally been assessed by experts in those technologies, who obviously have a promotional bias,
- (2) issue-oriented assessments have generally been conducted by experts or interest groups with strong negative biases, and
- (3) sufficient data have always been lacking, nevertheless the presentations of assessments tend to have an appearance of exactness.

For all of these reasons technology assessments have not stood the test of time. Through the appropriate makeup of assessment teams and the use of probabilistic methodologies these credibility problems should, for the most part, be resolved.

5. SUMMARY AND CONCLUSIONS

In this study, a systematic investigation was made of energy technology assessments to evaluate their effectiveness. Most of the assessments studied contained significant flaws in assumptions, methodologies, and/or data bases. In addition to assumptions usually being hidden in the methodology, most technology assessments were biased in some way because of special interests. Such a biased approach is not "wrong", it is just inappropriate not to have the assumptions and interests of the assessor pointed out clearly so that the biases can be separated from the assessment. Even though probabilistic assessments have potential problems in implementation and interpretation, their use in a complex analysis seems more appropriate than the use of a deterministic approach.

Meteorological factors must be considered to address specific power plant siting problems. A technology assessment that applies national average meteorological characteristics to a specific site will most likely be biased against the fossil-fueled technologies. A much more accurate analysis would result by capturing the characteristics of the specific meteorological conditions at specific sites.

Atmospheric transport and dispersion modeling used in technology assessments are generally very inaccurate. It seems clear, from the studies reviewed, that the simplifying assumptions used make the pollutant concentration estimates too crudely. What is needed is an uncertainty bound rather than a specific value. In that way, models using dispersion results (e.g. health models), would be much more useable in the policy environment. It is difficult to have confidence in health model results, for example, when the dispersion model used is known to

be inaccurate but does not give uncertainty bounds.

Populating densities and locations must also be carefully characterized to properly address specific power plant siting problems. An ideal specific siting analysis would include specific meteorological, and specific population data as well as including an uncertainty bound on the dispersion modeling results. In large scale technology assessments where it would be inappropriate to model all available sites, it would seem to be important to have several categories of generic sites for use in the analyses.

Current health modeling contains many more uncertainties than any other portion of the technology assessment process. However, health model results are used for policy decisions, many times with little knowledge of the uncertainty. Of the 255 health impact articles surveyed the majority showed that there was no impact on health from community air pollution levels. Furthermore, some of the articles showed beneficial effects of air pollution. Most of the 30 models available in that literature showed severe data and statistical problems. It seems apparent that the health impacts that have been used in past technology assessments can at best be construed as slight hints of what might possibly be the worst case health impacts. At worst these estimates are misleading and their use is counterproductive in the assessment process. It seems clear that adequate measures of the uncertainties in these models would be extremely important for conveying the levels of speculation associated with any numbers that are turned over to the policy decision process.

Fusion power is a far-future technology that requires an individual

cost/benefit assessment since there are really no comparable technologies. The uncertainties associated with safety (i.e. tritium control), scientific, engineering, and economic feasibility of fusion power will have to be reduced significantly before decisive technology assessments can be conducted. At some point in time fusion power may be abandoned as a possible commercial energy source if these uncertainties are reduced to the point of recognizing the unfeasibility of controlled fusion power. On the other hand, the uncertainties may be reduced in favor of fusion power. A technology assessment methodology that explicitly incorporates uncertainties (such as those proposed in Chapter 2) will thus be particularly useful for these far-future technologies. Decision makers could then keep track of the range and magnitudes of the uncertainties in the performance of the technologies. Such uncertainties, levels of risk aversion, and expected costs of R&D projects to reduce uncertainties, can be used together to make the appropriate decisions at the development, demonstration, and commercialization stages of the evolution of an energy technology

The comparison of coal-fired fluidized bed combustion and MHD is more typical of the setting in which technology assessments have generally been employed. The results of this example show some of the biases inherent in deterministic assessments, particularly with regard to situations where the uncertainties may well be more important than the expected values of the performance measures of comparable technologies.

An issue-oriented assessment such as an assessment of the global CO₂ problem works backwards, from an identified problem to the possible solutions. In this study, a comparison was made between the CO₂

problem and the environmental impacts of nuclear power. The CO₂ problem seems to have a much greater damage potential to the biosphere than nuclear power. The obvious national disparity in concern over these two issues raises a question about the credibility of issue-oriented assessments. The initial steps toward the resolution of the CO₂ problem will be realized when such issue-oriented assessments are made more credible by using sufficient data, explicitly characterizing uncertainties, minimizing biases with systematic and comprehensive interdisciplinary investigations, and making assessments publicly available for peer and independent evaluations.

R&D priorities should be set up in such a way so as to reduce the uncertainty in energy technology assessments. Obviously, where the greatest uncertainty lies and where this uncertainty crosses over into critical decision areas, is where the most urgent research is needed. Probabilistic methodologies can be implemented to provide precisely the necessary probabilistic information that is necessary for developing priorities on R&D funding strategies. Here again it would appear that the information about uncertainty is more important than the expected values.

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APPENDIX -- POPULATION DATA BASE REFERENCES

(19)

Title - 1950, 1960, 1970 U. S. Human Population Counts by County

Date - 780703

Contact Person - Puja, Phyllis M.
Argonne National Laboratory, Energy and Environmental
Systems Division
9700 S. Cass Ave.
Argonne, IL 60439
FTS 972-3980

Source - Andrew Loeb1 (615) 483-8611, Ext. 3-6781
Oak Ridge National Laboratory
Regional and Urban Studies Department
P.O. Box X
Oak Ridge, TN 37830

Documentation - Derived from published U.S. Bureau of the Census data
from 1950, 1960, 1970 census volumes on tapes

Subject Coverage - U. S. Census Population counts by 5 year age groups

Geographic Coverage - all U. S. counties; states

Data Time Span - 1950, 1960, 1970

Status - in use

Access - Unlimited

Media - Magnetic tape; 1950 file is 3160 records each 773 bytes long;
1960 file is 3160 records each 869 bytes long; 1970 file is
3135 records each 1013 bytes long

Computer data - IBM 370/195 OS/MVT with a 9-track tape drive; EBCDIC

Abstract - This tape contains the U. S. Census Bureau, 1950, 1960, 1970
Decennial censuses of the population counts by age, sex,
race for all U. S. counties. For 1950 and 1960 totals for
states are also included. The age and race groups covered
are as follows: (1) 1950: (0-4, 5-9,...,75+), (Total,
white, nonwhite); (2) 1960: (0-4, 5-9,...,85+), (Total,
white, nonwhite); (3) 1970: (0-4, 5-9,..., 100+), (Total,
white, negro).

Keywords - human populations; population dynamics; population density;
age groups

(Shriner, 1978, p.7)

(521)

Title - Population Analysis System

Date - 780615

Contact Person - Durfee, R. C.
Oak Ridge National Laboratory
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Oak Ridge, TN 37830
615-483-8611 Ext. 3-0106; FTS 850-0106

Source - Developed at ORNL

(521) - continued

Documentation - None directly. Related documents are: "Geographic Data Systems Part II: Application to the Environmental Analysis of Strip Mining in Appalachia," R. C. Durfee and R. G. Edwards, ORNL/RUS-27 in preparation; "Assignment of Erts and Topographical data to Geodetic Grids for Environmental Analysis of Contour Strip Mining," R. C. Durfee et al, presented at the American Society of Photogrammetry, American Congress of Surveying and Mapping in Washington, D.C. on February 22-28, 1976 and symposium on remote sensing application to North American land use, in Phoenix, Arizona on October 26-30, 1975.

Subject Coverage - Computation of population densities

Status - under development; in use

Access - limited

Media - disc

Computer Data - IBM; IBM 360; LT. 540K Bytes, Calcomp, Versatec, and PR-80 Plotters; Fortran

Applications - This package has been applied to problems of determining population distribution for measuring aesthetic impacts of strip mining for suitability analysis in power plant siting, for establishing nuclear power plant restriction zones, for use as siting factors in waste disposal, for civil defense calculations, for nuclear radiation studies associated with environmental impact studies, etc.

Data Source - The MESX census tapes containing population numerations for enumeration districts with the centroid locations given in latitude-longitude.

Abstract - The computer sciences division has developed a program to compute population densities from an irregular pattern of enumeration district centroids at which the population count is known. The technique uses a distance weighted interpolation technique for all centroids within the window of interest. The procedure also includes a normalization technique to preserve known county population totals. The population densities are computed for a user specified latitude-longitude grid system. Any area in the United States may be selected for study. A multi-colored shaded contour map may be produced showing regions of varying people per square mile. These polygonal regions may be saved in a separate polygonal data base. The county outlines may be plotted on the display as well. The population densities are given as people per square mile. The interpolation procedure also includes empirically derived adjustments to reduce the "over-influence" of densely spaced centroids in highly urbanized areas on distant rural areas. The contour maps are cartographic in nature using various map projections and scales to overlay base maps. The contour regions may be stored as polygonal data bases for later analysis and display on other maps,

(521) - continued

Abstract (continued) - showing, for example, major cities.

Comments - This package consists of a series of modules which are combined by personnel experienced in the system. The individual modules are not transportable to any other facility at present. Work is planned for FY 78-79 to implement another interpolation procedure and provide appropriate documentation. The system is still under development and is presently being used in conjunction with ORNL research applications.

Keywords - population density; computer graphics; maps (Shriner, 1978, p. 118)

(791)

Contact Person - Durfee, R. C.

Title - Spatial Analysis and Suitability Modeling

Address - Oak Ridge National Laboratory
P.O. X

City - Oak Ridge

State - TN

Zipcode - 37830

Phone - 615-483-8611 Ext. 3-0106; FTS 850-0106

Source - Developed at ORNL

Documentation - None directly. Related documents are: Regional Studies Program Annual Report January 1 through December 31, 1976, R. M. Davis et al. Oak Ridge National Laboratory, ORNL/TM-5838, August, 1977; Toward a regional power plant siting method; AEC-Maryland Regional Siting Factors Study, FY1974 Progress Report, S. I. Yaffee, C. A. Miller, Oak Ridge National Laboratory, ORNL-TM-4944, November, 1974; the Maryland Power Plant Siting Project: An Application of the ORNL Landuse Screening Procedure, J. E. Dobson, Oak Ridge National Laboratory, ORNL/NUROG/TM-79, April, 1977.

Subject - Routines for suitability, siting, and impact analyses of power plant siting.

Abstract - The computer sciences division has developed a group of spatial analysis routines for suitability, siting, and impact analyses of power plant siting. These packages combine and analyze regional and national data bases to build indices that are combined together to calculate suitabilities. One group of packages works with polygonal areas (counties, BEA's, etc.) at the county level while the other operates on a grid cell system at the sub-county level. The data bases represent many variables such as water availability, population density, seismicity, coal reserves, barge channels, railroads, energy demand, air quality maintenance areas, etc. A subset of the polygonal analyses operates on the PDP-10 interactively. Existing and planned power plants are included

(791) - continued

Abstract (continued) - in the analysis along with new capacity that must be sited. Water quality impact analyses are calculated and mapped also for specific regions, as a result of siting future facilities. The calculations performed in the software include proximity calculations for accessibility to coal and energy demand. Exclusion factors are also included to meet minimal power plant requirements. The user places importance weightings on the siting factors before the composite analysis is performed. The results of the two packages may be plotted with the polygonal mapping system or the cell mapping system, respectively.

Geographic Coverage - Maryland; Southern U.S.; Ohio River Basin; U.S.

Status - Under development; in use

Access - limited

Media - disc

Computer - IBM

Configuration - IBM 360, .LT. 540K Bytes; PDP-10, .LT. 50K Words

Language - Fortran

Application - These packages have been used in energy facility siting problems in Maryland, the South, the Ohio River Basin, and at the national level. A variety of technologies have been analyzed including coal combustion, nuclear, and coal conversion.

Comment - These packages contain a series of modules which must be combined by personnel experienced in the system for any particular application. The individual modules are not transportable to any other facility at present. Work is planned for FY 78-79 to develop a generalized transportable system with appropriate documentation. The system is still under development and is presently only being used in conjunction with ORNL research applications.

Update - 780615

(Shriner, 1978, p. 304)