

Scientific Background on Probabilistic  
Air Pollution Dosage Modeling

J. Gruhl

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## 1.0 Dosage Modeling for Operating Strategies

There is an increasingly urgent need for methods and mechanisms that could be used to compare various energy options from an impact, rather than just an emissions or ambient standards, viewpoint. Some type of overview capability for determining the pollutant dosages of different SCS and other abatement control technologies would be a relatively inexpensive way of providing additional, extremely valuable, decision-aiding information.

Ideally, some kind of quality-of-life measure would be an excellent prospective from which to consider environmental consequences of different SCS and abatement equipment strategies. Unfortunately, assessments of quality-of-life measures are too subjective and too complex for use in this context. There are, however, some reasonable extensions that can be made to increase the accuracy and usefulness of current methods. The research and developments suggested in this section is aimed at accomplishing these extensions primarily through the use of dispersion modeling, using the available site- and technology-specific information to result in concentration vs. duration vs. population profiles for the different pollutants for future R&D.

There are several goals of the proposed research. First, it would be advantageous to have a consistent, appropriate methodology that could result in the display of population doses not only for single-plant SCS situations, but that could also be used in regional expansion studies and in national energy scenario evaluations. None of these energy options can currently be compared environmentally in a systematic way beyond the stage of declaring whether or not standards are likely to be violated. A second goal is to extend to the dosage stage all of the sophisticated probabilistic models that are proposed for operation and dispersion formulations in previous chapters. A final objective is to complete the dispersion and systems analysis work necessary for an ultimate, actual health effects assessment mechanism. This area has been recommended to ERDA as an important task

by the Congress through the Office of Technology Assessment report, "An Analysis of the ERDA Plan and Program," pp. 223-226. Once accomplished this proposed dosage assessor could operate as a vehicle for much current health effects data and would thus provide direction, format, and incentive for future health research. The responsibility for further, more meaningful environmental assessments for SCS's, regional energy facility siting, or whatever, would then be beyond dispersion and systems modeling and into the health effects field.

### 1.1 Scientific Background Relative to Operating Strategies

The scientific background relating to a general purpose dosage assessment mechanism is given in the following chapter. Background material for dosage modeling more directly related to SCS's is given here, see Figure 1.1

While there has been no published research directly in the field of dosage modeling for SCS situations there are related studies that are analogous and applicable from several different disciplines. The reason there has been no SCS dosage research involves the timing of the motivating factors. First, there has been little motivation to have any other measures than the ambient standards. Recently, however, there have arisen several factors which have provided this motivation:

- (1) recent health effects research has resulted in evidences and speculations to show that current standards are likely to be changed both in magnitude and form (that is, pollutant combination standards);
- (2) more and more there is a real possibility of having to choose between two options that both violate the standards; and
- (3) meeting ambient standards is not necessarily a good measure for avoiding environmentally sensitive situations.

Another recent motivation for going to dose modeling is the increasing availability of dose-response health effects data.

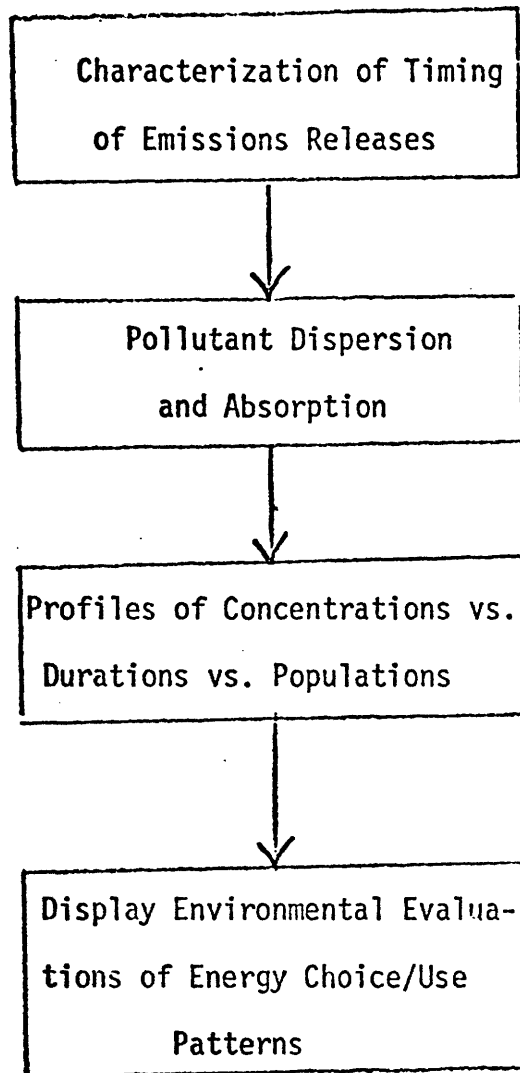


Figure 1.1 Block Diagram representation of the relation of the various parts of the problem.

Literature analogous to the problem of characterizing the timing of emissions releases comes from the area of power production simulation. The Booth-Balerieux simulation techniques and the existing production costing programs might be used analogously in what could be called "pollution production simulations." Work in this field has progressed quite far and can generally be divided into chronological simulators and time-collapsed simulators. Chronological studies preserve time as a variable and operate as if in real time. Time-collapsed simulators substitute other parameters for time, such as percentage of some time period, and thus can substantially speed computations. The MIT Energy Laboratory has conducted literature surveys and research using both techniques, see references (Schweppe, et al., 1 and 2), (Gruhl, et al.), (Ruane, et al., 1) (Gruhl, 1 and 2), among others.

The crucial and quite different step in this dosage modeling area is the development of profiles of concentrations vs. durations vs. populations, and little literature is available here. The task to be performed, nonetheless, is easily described. The Gaussian-type diffusion model can easily take the emission timings and plume buoyancy variations and assuming population densities (given in polar coordinates) and climatological data, one can quickly compute the concentration-duration-population surface of interest (Szepesi ). In the case of radiation dose computations, methodologies and computer programs are relatively sophisticated, quite adequate, and readily available. One reason for the advanced stage of this research area is the prevalent, conservative, linear dose-response assumption (rather than a sigmoid curve). This linearity assumption results in the single measure of radiation impact, the "man-rem", that is, the product of concentrations, durations, and populations. Although there exist models of the various separate environmental pathways of radiation travel, see (Slade) and (Plato, et al.), there are also excellent composite models that

are appropriate for use as analogies to the chemical pollutant problem or are appropriate for direct study of radiation dosage profiles [see refs. (Frigerio, et al.), (Rohwer and Struxness), (Hub, et al.), and (EPA)]. If for some reason the consensus opinion is that the linear dose-effect model is no longer valid then the same concentration-duration-population method would have to be used for radiation as is necessary for chemical pollutants and again there would be no literature available on the subject.

Perhaps the most difficult portion of this suggested program is the display of the environmental evaluations of energy choice/use patterns. Ideally, if the health effects dose-response functions were available and incorporated in a type of overall assessment mechanism then the results could be displayed without any problem, pollutant by pollutant, collected by area, or collected across the board. Problems do arise, however, when the conversion to actual health effects is not (yet or ever) included in the overall mechanism. Several studies have directly (Reiquam) (Finklea, et al.) or indirectly (many using linear regressions) tackled this issue by weighting pollutants according to their undesirability, providing for easy comparisons of alternatives, including several dollar-equivalent studies [such as refs. (Babcock and Nagda), (Lave), (Kneese), (Ridker), and (Wolozin)].

Although the non-human "doses" of pollutants are not included in the scope of this current paper, there are instances when the display of non-human effects can have analogous applications for the display of human effects. The modeling of doses and effects on animals, vegetation, and materials is further along than human dosage and effects modeling because direct experimentation is possible and a more objective viewpoint can generally be taken. There are numerous studies of aggregated effects and individual impacts (such as deterioration of structures, tires, textiles, and so on.) Some of the best displays of effects can be found in the water quality literature.

Reviews of much of the material for converting water pollution residuals into dosages and impacts can be found in parts of (NAE) and (Gruhl,3). The simplest method for developing a measure of aquatic impact is to sum the measures of the different residual's concentrations,  $C_i$ , divided by the respective toxic limits,  $T_i$ , in the manner:

$$\sum_{i=1}^n \frac{C_i}{T_i}$$

Although this measure ignores synergisms, it can be quite effective, and has been used extensively in water quality criteria.

Another type of impact assessment uses the collaboration of expert opinions to develop water quality indices for the different pollutants as a function of their variation from natural levels. Some of these indices even include upper and lower limits of confidence [see ref. (Brown et al., p. 180), also see refs. (Wilhm and Dorris) and (Patrick) and for dose-response curves including durations of exposure see ref. (Battelle-Northwest)].

Another method of water quality assessment utilizes a measure of species diversity in an aquasystem. The well-evidenced contention is that the amount of variety of species in an aquatic community can be a good sign of the health of the aquasystem as a whole [for examples of such studies see refs. (Mihursky, et al.), and (Moore, et al.)]. There exist quite a number of other water quality models [see e.g., refs. (Dailey and Harleman) and (Russell and Spofford)] and some even go so far as to identify all the possible benefits (Meredith and Ewing, p. 845) and then associate dollar costs with these benefits (Nemerow and Farg, p. 671).

The impacts of land-use are quite vague. The visual and psychological intrusions are clearly not amenable to quantification. One of the few well developed methodologies that exists in the area of impact of land-use is in the calculation of farming, residential, or recreational values of land, see refs. (Eckbo) and (Spore and Nephew, pp. 209-223). These studies



involve the evaluation of the resource lost (or available) due to land development, erosion, or pollution; and they rely heavily upon estimates of usage and subjective measures of values.

Health effects research is not an explicit part of this current report. However one objective of this report is to postulate a mechanism that leaves open the eventual possibility of incorporating health effects information. Thus, the choice of the appropriate overall methodology will depend greatly upon the types of health effects data that are now or could be available and upon the pollutants that would have to be grouped and accounted together because they act synergistically or by similar physiological mechanisms. There are decades of literature in this particular area, some is briefly discussed in the following chapter. In summary, there are several situations where the dosage modeling components must be properly fitted to health effects situations:

- (1) handling new pollutants as they are recognized to be potential hazards;
- (2) coupling pollutants that are found to act together synergistically; and
- (3) divide groupings of pollutants as differing toxicities within the group are found, such as splitting hydrocarbons according to different levels of carcinogenic toxicity.

## 1.2 Suggestion for Research on Dosage Modeling of Operating Strategies

The scope of the research suggested in this section covers the dispersion and systems analysis tasks necessary to take pollution effects to a dosage-impact level. No health effects research is involved, just the systems machinery necessary to display dosage implications of different SCS's and other energy choice/use patterns. This dosage information by itself can clearly be quite important in making well-informed decisions, and elsewhere

or at a later time with the application of some of the large amount of increasingly adequate dose-health effects data, this dosage modeling mechanism could provide even more meaningful decision-aiding information.

In terms of the scale of a project that would be appropriate for the type of research that has been here suggested, it is probably advisable to deal with the problem in an aggregate type of formulation at what might be called a mesoscale level. It should probably not be a macroscale approach, that is to say not correlating and scaling dosages regionally according to changes in tons of emissions. It should probably also not be a microscale project, simulating the pathways and impacts of puffs of pollutants individually. It would be an interesting project, in fact, to determine exactly at what scale this whole problem could best be attacked.

#### 1.2.1 Ideas for a Probabilistic Dosage Methodology

Roughly, some of the considerations involved in developing dosage profiles would be:

- (1) probabilistic models of magnitudes and durations of emission releases from the sources, perhaps in a load-duration or a load-frequency duration formulation;
- (2) probabilistic dispersion modeling methods (from the other portions of this study);
- (3) probabilistic background modeling of concentrations and durations (from the other portions of this study); and
- (4) probabilistic or deterministic models of "population density roses" in the different wind directions around the emission sources.

Some of the methodology here has been developed in varying degrees for nuclear facility siting 'accident' case studies. The probabilistic nature is, however, much different, as are the "one shot of radiation studies" vs. "erratic bursts of pollutants", possible correlations of operations and

- Task 1      Develop a probabilistic method for characterizing and relating profiles of emission timings and durations, background models, and dispersion models so as to come up with profiles of populations vs. concentrations vs. durations
- Task 2      Make the methodology capable of eventually yielding dosage information appropriate to possible potentiating, antagonistic, and nonlinear health effects of pollutant combinations
- Task 3      Develop a format for clearly displaying complex dosage information and present the impacts and implications of probabilistic dosage modeling in terms interpretative of ambient standards
- Task 4      Perform an individual plant case study and a regional expansion case study

Table 1.1

Suggested Tasks for Future Research on Probabilistic Dosage Modeling

meteorologic conditions, and multi-pollutant background models.

The output from this type of research would probably be in the form of a profile of pollutant concentration versus duration-of-exposure curve for the affected populations. Without any simplifying assumptions (such as, in radiation studies, the "concentration times duration times population" equals man-dose) this type of profile could be in the form of a surface such as that shown in Figure 1.2. Such a three-dimensional formulation is further complicated by the uncertainties involved in all of the data and modeling. Thus, with the necessity for some measure of confidence associated with each point on the surface (probably a geometric standard deviation), it is obvious that some sort of simplification must be sought. Two obvious potential simplifications involve:

- (1) a man-dose number that would result from a linear dose-effect assumption, or
- (2) some other single parameter or single-valued functional description of the surface displayed in Figure 1.2.

Making the second option quite plausible are the well-evidenced theories of lognormal distributions of concentrations at a sensor (and thus for a population), and the straight line characteristic of the log of concentration versus the log of duration. Incorporating probabilities in these models could then simply involve computation of deviations.

Because this methodology retains the physically significant mechanisms of the processes, unlike regressions, future refinements in models could easily be incorporated. Also avoided are the difficulties that regression studies have in regional planning studies where their results can be misleading because:

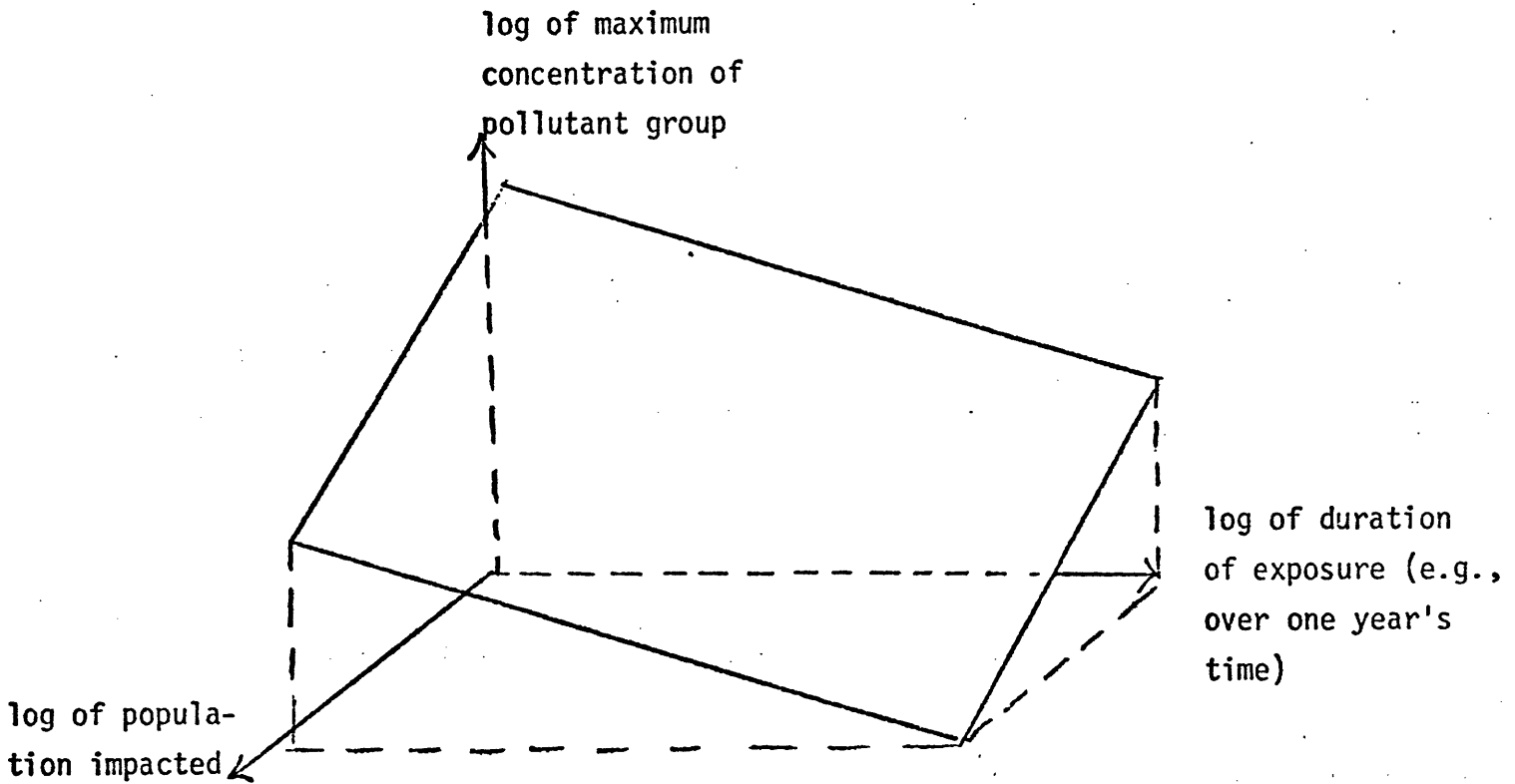


Figure 1.2

Hypothetical example of a concentration-versus-duration-versus-population surface.

- (1) old sites for facilities will not be the new sites,
- (2) the best sites have generally been taken, and
- (3) there are widely different siting alternatives for the same technologies, for example, river siting versus offshore siting of nuclear facilities.

In addition, because the proposed methodology preserves physically significant models there is an opportunity to take troublesome, large uncertainties in the dosage results and assign them back to the responsible data or models and to thus have a chance of correcting the problem.

#### 1.2.2 Finding a Methodology Appropriate to Health Effects

There is a definite need to have a dispersion mechanism that could ultimately be coupled to health effects results. This task would assure that the dispersion and system analytic gap is filled so that it would not delay the arrival of health impact modeling.

Some of the implications of health effects results upon the choice of an appropriate dosage model are given at the end of Section 1.1. The obvious implication is that the model must be capable of collecting pollutants in groups and in weighted combinations (a difficult task if the weightings are nonlinear and the pollutants are poorly correlated over time.) There is also feedback possible in the other direction, that is, once an overall methodology is developed it would be immediately useful in pointing toward appropriate formats for data from health effects research.

It is instructive to consider what would be ideal in terms of health effects data. For each effect, e.g., annoyance, nonspecific morbidity, mortality, genetic mutations, and so on, and for each pollutant group, the ideal health effects information would probably look like Figure 1.3. With such information, the population-duration-concentration surfaces could quickly

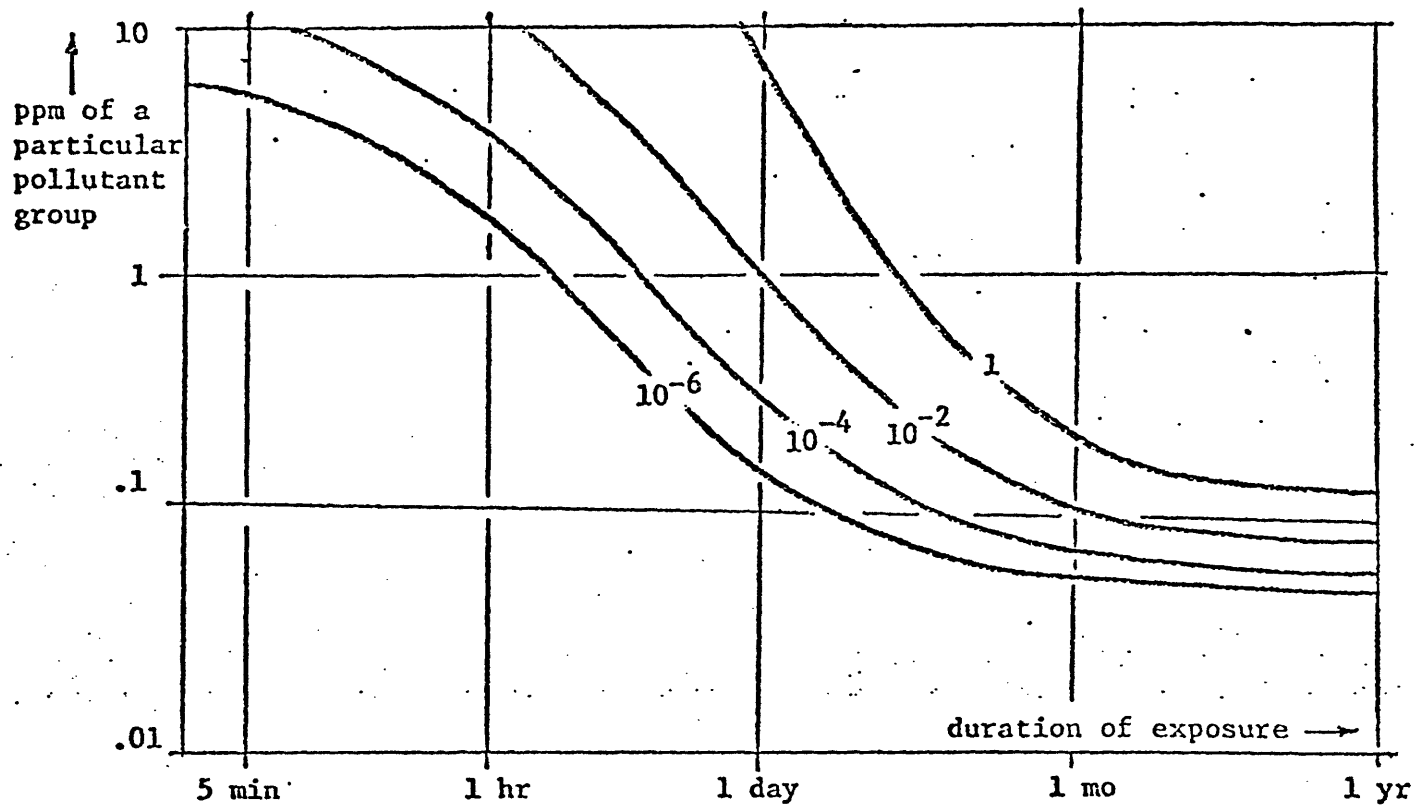


Figure 1.3

Hypothetical, ideal health effects curve showing probabilities of a particular effect at all different concentrations and durations.

be translated into ultimate effects (or differential effects between two strategies). How close the health effects data are to this ideal format varies widely with pollutants, but some are very close to the ideal. Although it is not suggested initially to do any health effects data collection or application, a sense of urgency can be gathered from health effects results such as those displayed in Figure 1.4 that for some time now have been awaiting appropriate formatting guidelines and driving mechanisms from the dispersion and systems analytic fields.

### 1.2.3 Suggestions for Display of Dosage Information

An effective display of these complex dosage results will be essential if those results are to be widely used and understood. An important task, that is suggested here as a useful problem for information display, involves the quantitative estimates of the obvious limitations involved in the use of ambient threshold standards. The inadequacy of the current standards can quickly be seen with some simple probabilistic dosage modeling that can show that there is always a finite probability of violating the ambient standards twice in one year. A number of techniques in power systems have been developed to handle "forced outages" and some seem to be directly applicable in this area of assessing the implication of different interpretations of the standards. Of course, some of the terms are quite different "one day in ten years" vs. "only once a year," "loss of load probability" vs. "expected probability of violating standards", "expected energy unserved" vs. "expected populations or areas subjected to violations", and a number of other measures and deviations. The use of existing techniques and programs could be very worthwhile.



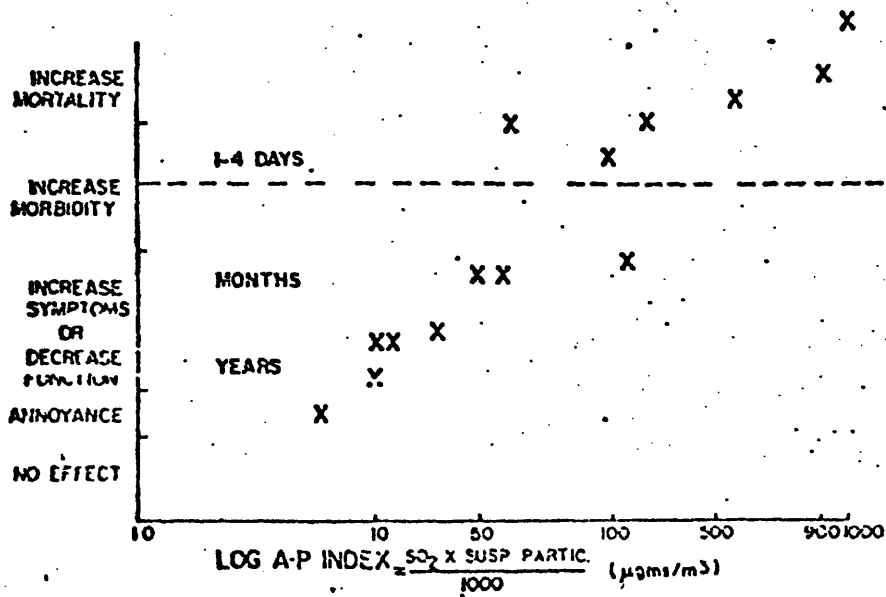
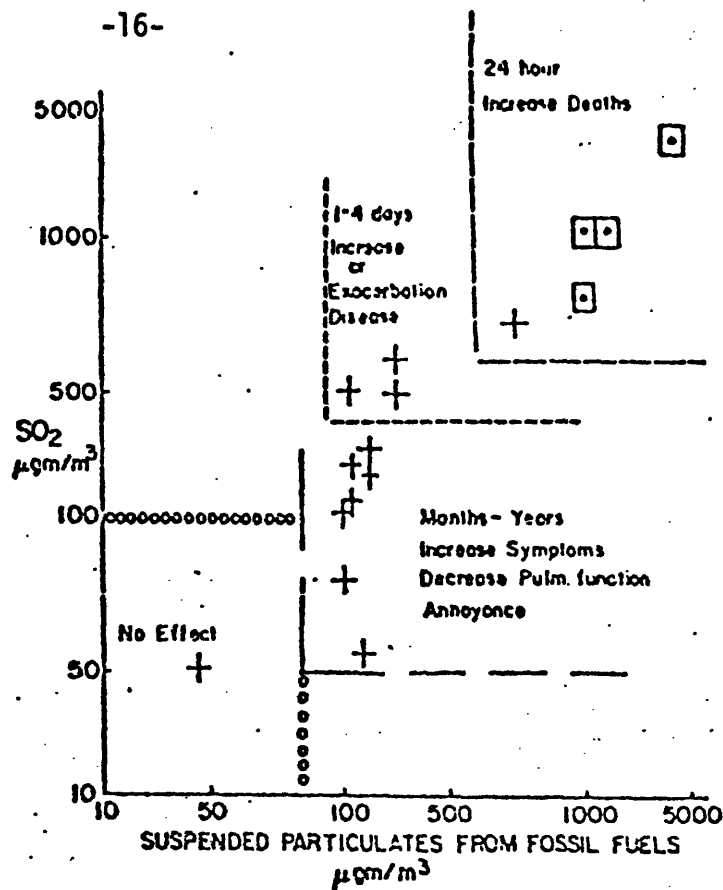


Figure 1.4

Dose Response Curve for Sulfur Dioxide and Total Suspended Particulates (private communication, Dr. Benjamin Ferris, Harvard School of Public Health, 1973).

#### 1.2.4 Suggestions for Case Studies

Two types of case studies would be appropriate as initial tests of the explicit dosage modeling tasks suggested previously. The first would be a study of a specific individual energy facility, possibly an electric power plant using various abatement equipments or pollution control strategies. Such a case study should be run on a typical, but actual, facility so that problems of data availability and collection can be investigated. The second type of case study that would be highly appropriate and useful would be a regional energy planning problem. Again it would be desirable to have this test case reflect a real situation such as a regional electric power system expansion plan, attaching different types of pollution abatement equipments and different operating strategies to the dosage simulation mechanisms.

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## 2.0 Dosage Modeling for Planning Situations

The need for systematic environmental assessments grows as there become more instances where decisions must be made the alternatives of which have different environmental consequences. Some of these decisions that currently are of great significance are:

- (1) national and regional questions that will affect future energy scenarios;
- (2) research, development, and demonstration priorities for new energy sources;
- (3) choice and siting of new energy facilities; and
- (4) assessments of costs and benefits of pollution abatement techniques.

Environmental assessments are routinely made in all of these categories but rarely are there environmental evaluations taken beyond the level of tons of emissions.

In category (1), the motivation for looking at whole energy scenarios from an environmental viewpoint has come from a number of sources. The NEPA requirement for assessments of environmental alternatives was one of the early motivating forces. When it became difficult on individual projects to make assessments of the myriad of potential new energy sources, overall, general assessments were prepared by, among others, the Department of the Interior.

The next use of wide scale environmental assessments came when national energy modeling, such as in (Hoffman) and (Baughman), showed amenability to a type of input/output (Just) treatment of "environmental residuals" or emissions. Emissions data bases were developed (notably at Hittman Associates, and Teknekron, Inc.) and they were eventually coupled to the energy modeling (at CEQ [CEQ,1] and at Brookhaven National Laboratory [Hamilton] re-

sulting in the MERES system [CEQ,2] and [University of Oklahoma]).

At different stages of development and sometimes with some crude emissions-to-ambient scalings, environmental consequences of several policy questions have been studied, as in Project Independence (FEA), but despite these attempts at extending it, the MERES system is the current state-of-the-art.

Although the MERES system is a tremendous step forward, there is still a great deal to be gained by extending it so it can differentiate, for example, between offshore and city sites, or inert and carcinogenic hydrocarbons, or widespread low doses and concentrated high doses of pollutants.

In category (2), there is clearly a motivation for taking the environmental comparisons of new energy sources beyond the emissions viewpoint. Total life cycle and indirect emissions can now be computed (University of Oklahoma), (Hamilton) but there is no systematic mechanism for taking these emissions through dispersions and determining the sizes of affected populations. Some of the new technologies that can now, or should soon, be compared environmentally include:

New Energy Supplies

- Geothermal Power
- Fusion Power
- Breeder Reactors
- Photovoltaic Solar Power
- Wind Energy
- Ocean Thermal Gradients
- Tidal Power
- Biomass Energy
- Power from Solid Wastes

New Conversion Techniques

Synthetic Fuels from Coal

Shale Oil

Fuel Cells

Magnetohydrodynamics

Thermoelectric Generation

Thermionic Generation

New Energy Utilization Devices

Heat Pumps

Solar Space Conditioning

Electric Automobiles

New Environmental Control Technologies

Emission Controls

Dispersion Controls

The motivation for research in category (3), choice and siting of specific energy facilities, currently comes primarily from electric power system and oil refinery interests. Here, the significant environmental questions include quantities and qualities of sites, timing of developments, and sensitivity to future environmental issues. Both industry and government groups have conducted site surveys but in very few cases do the surveys include dispersion modeling or dosage studies (the notable exception is the exhaustive nuclear reactor siting procedure).

The final category concerns environmental assessments of pollution abatement techniques. Here, obviously, lies the important question of cost-benefit of particular pieces of abatement equipment or emissions standards. In addition, through design changes, control procedures, and intermittent use of abatement equipments, it is possible for many types of energy processes to change the mixes and timings of the pollutants re-



leased. Ambient concentration and dosage models could provide significant information for these environmental planning and operation decisions.

Within all of these separate types of environmental assessment problems lie some additional motivations for ambient condition and population-dosage modeling. First is the eventual goal of the development of a mechanism that could provide actual health effects assessments. Second, in all of these areas there is an immediate need for quantification of the uncertainties in the final results. The "hardness" of the input data is largely known (it is listed with each coefficient in the Hittman data base) so what is needed is a method and demonstration for carrying forward these uncertainties. Finally, since the MERES system is now just for emissions there is a need for a general mechanism that can deliver results in terms of ambient concentrations and population-doses, with fast turnaround time on new problems that are certain to come up in the future.

There are decades of literature relevant to this topic. Some has already been mentioned, most of the rest is fragmented and very specific to the particular discipline involved. All the necessary pieces are, however, available. The only task remaining is the formulation and application of the appropriate systematic methodology.

In quickly relating some of the relevant literature it would be helpful to view them in terms of the position they would hold in the overall structure of the problem. A block diagram representation of that structure is given in Figure 2:1.

The survey and characterization of energy sources has been done in very uneven quality for the various energy sources. Little is known about the characteristics of some of the more speculative, future sources (e.g., geothermal and ocean thermal gradient power) and especially those whose final methods have not been formalized (e.g., fusion). The Hittman and Teknekron data bases mentioned previously have the best across-the-board source

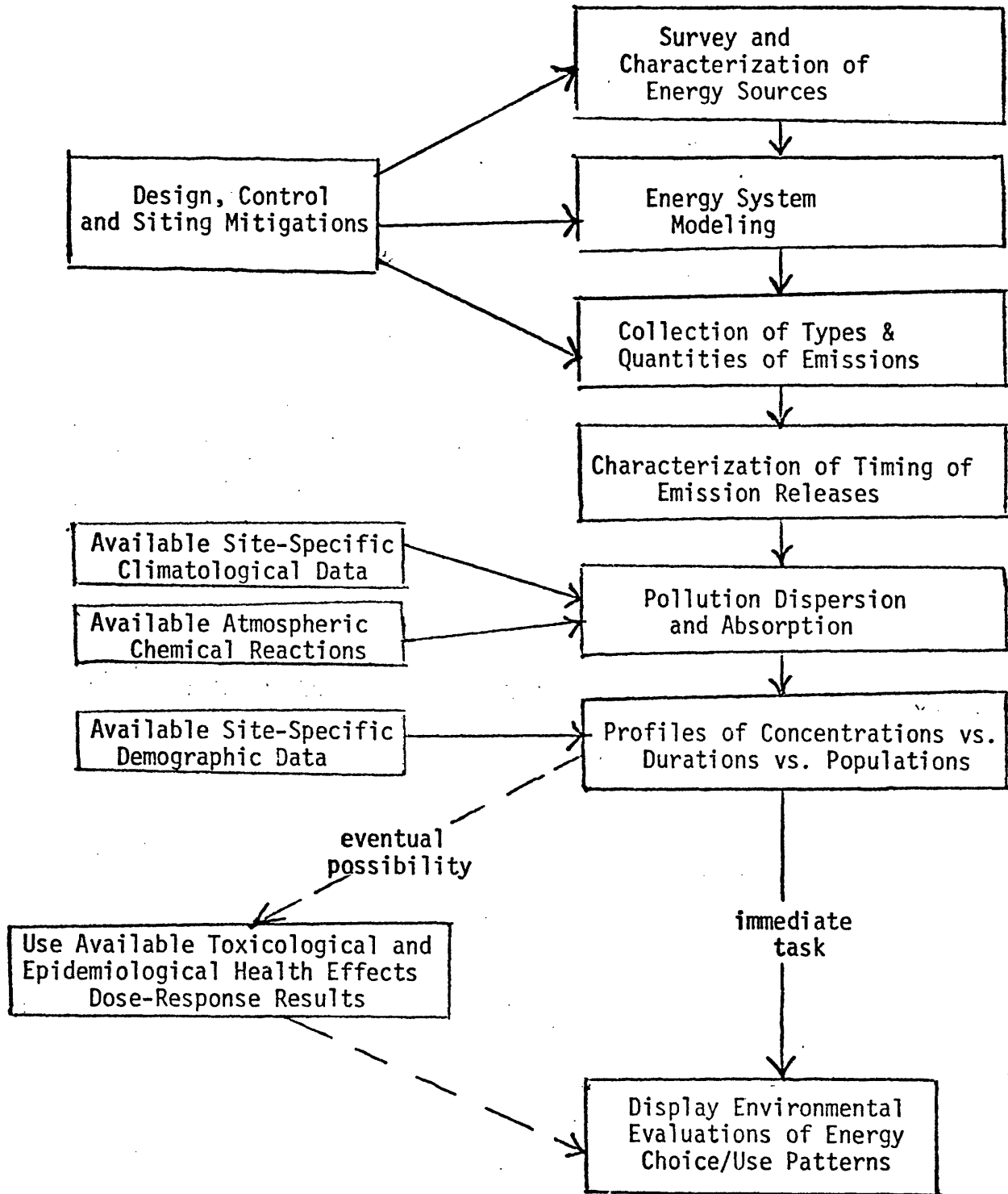


Figure 2.1 Block diagram representation of the relation of the various disciplines.

surveys. The MERES data (University of Oklahoma) was derived from those previous sources but has less information because some categories have been dropped as have the measures of "hardness" on the data. There are many other source surveys including some by the MIT Energy Laboratory (White), (White, et al.).

Methods of mitigating pollution problems during the design, control and siting processes are key concerns in an overall assessment. A great deal of work on combustion process and combustion equipment design for future and current energy technologies have and are taking place at MIT, in industry, and in other institutions. Pollution control during operation and during siting have been studied and applied and survey papers have been performed at the MIT Energy Laboratory (Schweppe, et al., 1) (Gruhl, et al.) and (Ruane, et al.).

Energy system modeling in the MERES system derives from the static Reference Energy System (Hoffman) at the Brookhaven Energy Systems Analysis Group. This model takes each time period (usually a year) and logistically matches supplies to demands for specific energy types. Some modeling of interfuel substitutability is also included. It is probable that before too long (as recommended in [Office of Technology Assessment], pp. 223-226) different types of energy models may be used to drive the emissions matrices in the MERES system. A dynamic model such as the MIT Energy Laboratory Baughman model (Baughman) might be used, or any of a large number of other national energy models that have been developed, (Macrakis) and (Searl) describe many. Despite the driving energy model, at this stage it is likely that the basic MERES system alone would be used to gather emissions figures for the next two or three years.

The next block of Figure 2.1 the collection of types and quantities of emissions, is the last function performed in the existing MERES system.

Including additional categories that have been left out of the current MERES system but for which system-wide information is available, the current emissions categories are:

Water Pollutants (tons/10<sup>12</sup> BTU)

Dissolved Solids

Acids

Bases

PO<sub>4</sub>

NO<sub>3</sub>

Other

Total

Suspended Solids

Nondegradable Organics

Total Solids

BOD

COD

Thermal (BTU/L)<sup>12</sup>BTU)

Radioactive (curies/10<sup>12</sup>BTU)

Air Pollutants (tons/10<sup>12</sup>BTU)

Particulates

NO<sub>x</sub>

SO<sub>x</sub>

Hydrocarbons

CO

Aldehydes and other

Total Radioactive (curies/10<sup>12</sup>BTU)

Solids (tons/ $10^{12}$  BTU)

Land (acre-year/ $10^{12}$  BTU)

Occupational Health

Deaths (per  $10^{12}$  BTU)

Injuries (per  $10^{12}$  BTU)

Man-Days lost (per  $10^{12}$  BTU)

Potential Large Scale Disaster (yes or no)

In addition to these categories the Hittman data base includes measures of "hardness" for each piece of data.

With the scope of this current overview aimed solely at air pollution dosage modeling, with capabilities to extend it to cover health, the categories of primary interest here are the Air Pollution, Occupational Health, and Potential Large Scale Disaster. The rest of Figure 2.1 will be looked at in this context.

The next block in Figure 2.1 characterization of timing of emissions releases, was skipped in the FEA work on Project Independence (FEA). Instead, scalings of regional ambient conditions were developed (ERCO) from scaleups in regional emissions for some pollutants. This procedure is an excellent method of short-circuiting some of the data requirements, but it cannot be extended beyond regional estimates, and is of little use in dose modeling. Since this then is the end of current practices, the remainder of the literature comes from smaller piecemeal studies or tangential fields.

Analogous to the problem of characterizing emission release timings is the area of power production simulation. In fact, existing programs

can be used in an area that might analogously be called pollution production simulation. A great amount of theoretical work in this area has been done in the electric power industry, some at the MIT Energy Laboratory, (Schweppe, et al., 2) (Gruhl, 1), and (Gruhl, 2), among others.

After the characterization of frequencies and durations of emissions comes the tracking of the environmental pathways through which these emissions will disperse, (Department of Interior), (Russell and Spofford), (Butler), (Whitman, et al.), (U.S. Geological Survey), (Frigerio, et al.), and (Gruhl, 3). Both here in the pathways, and later in the "dose modeling" most of the relevant, objective research and literature has been performed in the radiation and water quality fields.

There are generally eleven pathways listed for the dispersion of radionuclides from energy facility atmospheric (six pathways) and liquid (five pathways) discharges, (NAE), p. 180. The two pathways most applicable in the dispersion of nonradioactive materials are (1) atmospheric discharge-whole body external exposure and (2) atmospheric discharge-inhalation exposure. The total exposure of man to radionuclides from nuclear reactors is a well-documented area, and under the prevailing assumption of linear dose response, adequate modeling has taken place. The probability of large scale disaster is, however, a widely varying number and in an overall environmental assessment would have to be handled either with large uncertainty or in scenarios under different assumptions. Although there are numerous calculations that show that the radiation from fossil facilities is effectively more than that from comparably sized nuclear plants, see (NAE), p.38 and (Eisenbud and Petrow), the fossil-discharged radioactive material is not in a form readily transferable to man (Martin, et al.) and (Goldstein, et al.) and thus has not required the trace through of all the possible pathways.

The air pollution literature is abundant in atmospheric transport and diffusion models -- all levels of sophistication can be found. However, consistent with what would generally be a nonspecific nature of the terrain and climatological data, and for simplicity of application and accuracy over longer averaging times, the clear edge must be given to a modified generalized Gaussian diffusion model (Pasquill), (Turner), and (Schweppe, et al., 3). This diffusion model is for point sources and results in the simulation of the averaged groundlevel concentrations under assumed wind speeds, turbulence, pollutant emissions, effective stack heights, downwind distances, and mixing depths. Some type of sector-averaged model may be fastest and best (Schweppe, et al., 3) for large scale assessments. Urban and area pollution sources (that is, non-point sources) can either be handled with sector averaged models that push close "downwind distances" up to some minimum level (although they do not then conserve pollutant mass) or they can be modeled with macro-modeling or ventilation techniques, for which there are numerous models (Miller and Holzworth), (Pooler), (Martin), (Moses) (Stern). In addition to the abundance of literature there are also a considerable number of projects currently under development in the area of pollutant dispersion and absorption. (Mahoney at ERT, Lexington, Mass.; Van Otta in Norway; Meyers at Brookhaven; and many others). These and other forthcoming advances would increase the accuracy and applicability of any overall environmental assessment mechanism that is based upon physically significant (although possibly quite aggregated) models.

The next blocks in Figure 2.1 concern site-specific informations. Detailed site-specific data is systematically collected primarily by pollutant-producing industries engaged in regional expansion planning. Most of this information, however, is necessarily quite confidential. Some systematic surveys are being conducted on the west coast, but for the most

part little information exists and especially little on quantities of good sites (Meier). Regionally, and even by airsheds, there are fortunately, great amounts of climatological and population density data. Ambient levels for some pollutants are, of course, kept, as are wind rose data (and some pollution roses, see [Marsh and Foster], [Miller and Niemeyer], and [NCC]) for regions all across the country. An ever increasing number of regional studies are being conducted (at Lawrence Livermore Laboratories, Brookhaven National Laboratories, National Cancer Institute, and many other places) to find area by area correlations of industries, pollutants, and health effects. Although these studies use correlation techniques and not physical dispersion models, they still make available systematic data bases both for input and for validation of physical models.

From Figure 2.1 the block labeled "applicable atmospheric chemical reactions" including removal processes (Haagen-Smit and Wayne) could be one of the thorniest areas of an overall environmental assessment mechanism. Not only is there very little information available in this field (according to a National Academy of Science study) but the inclusion, in an overall model, of what is known in the way of atmospheric chemical reactions could introduce computational and data requirement difficulties. For example photochemical smog modeling can depend nonlinearly upon the concentrations of  $\text{NO}_x$ , oxidants and certain reactive hydrocarbons, with a rate of reaction dependent upon incident light at a particular frequency. Oxidation of  $\text{SO}_2$  to  $\text{SO}_3$  and sulfates depends upon ammonia, metallic salts, humidity, and other factors. If atmospheric reactions were placed in an overall assessment mechanism some compromises between ultimate accuracy and model requirements would have to be considered.

In Fig. 2.1 the block "profiles of concentrations vs duration vs populations" represents a crucial and quite different step in the overall



assessment mechanism and so, again, literature is not available here. The type of activity represented here, nevertheless, is easily described and this description and the applicable analogous research efforts are described in Chapter 1. Also included in Chapter 1 is a description of the literature relevant to the box in Fig. 2.1 labeled "display of the environmental evaluation of energy choices/use patterns."

Health effects research efforts can be broadly classified as either in-the-laboratory, toxicological research or in-the-field, epidemiological correlation studies. The best documented area here is the translation of the "man-rad" radiation doses into health risks (see, for example, [Frigerio, et al.], [Hickey, et al.], [NAS], [Wilson], [Starr, et al.], [ICRP], [Stannard], [Goldman] and [Eisenbud]). The available sources of information cover the total range from completely aggregated effects such as single measures of mortality risks, to varying degrees of disaggregated effects -- some including three levels:

- (1) disease mortality
- (2) gene mutations and genetic death; and
- (3) accidental injury and death;

and some sources develop dose-risks for different diseases in each part of the body. Thus, statements of the effects from radiation of different energy choice/use patterns would be quite easy to make (using of course the linear dose-response assumption).

The environmental residuals named "deaths, injuries, and man-days lost" are already available (from the Hittman data base) in the form of impact upon humans. Some care, however, must be taken to closely correlate these units of measure for occupational impacts with those used for displaying radioactive and chemical pollutant impacts to the general public.

Although a great deal of information is available about the relative and absolute impacts of the various non-radioactive air pollutants, (Babcock

and Nagda), (Lave), (Kneese), (Ridker), (Wolozin), (Schwartz), (Shults and Beauchamp), (Anderson), (Walther), and (Rummo), it is of very uneven quality, uses different assumptions of "significant" effects, and is not in a readily usable format.

Carbon monoxide is a pollutant whose effects are relatively well known (see, for example, [NAPCA], [Ferris] and [Rummo]). Vegetation and structural damages are unknown near ambient levels (NAPCA) and the uptake in humans and animals is readily translated into percent carboxyhemoglobin levels in the blood. Scales of doses versus effects are defined with relatively wide agreement (especially at the higher doses).

Much is also known about the separate effects of sulfur oxides and particulates (Rummo). In light of recent information, however, there is substantial (see [HEW]) and [Ross], pp. 28-32) evidence to support the theory that there is (synergistic) potentiation of the effects of these pollutants when they are in combination. Ref. (Rall) shows the good correlation between "health effects", "duration of exposure", and "SO<sub>2</sub> times suspended particulates" in a large number of research efforts. A significant amount of work has been done toward the development of the dose-response curves for this combination, and it is certainly no more difficult to collect the product of these concentrations than it is to collect their concentrations separately.

A number of other interactions of pollutants with SO<sub>2</sub> have been studied, including SO<sub>2</sub> with NO<sub>x</sub>, and SO<sub>2</sub> with hydrocarbons. Of particular impact, and significant enough to perhaps warrant special consideration, (Goldsmith), p. 352, are the "SO<sub>2</sub> and water vapor" formation for sulfuric acid aerosol, and the "SO<sub>2</sub> and oxidants" formation of sulfates. Evidence is presently available that is applicable to the definitions of acceptable levels of some dose-response relationships (Goldsmith), (Bartigelli), (ACS), and (Plunkett).

Several combined forms of  $\text{NO}_x$  and other pollutants have shown combinations with synergistic effects.  $\text{NO}_2$  and oxidants form nitrates that are currently "stealing" some of the effects previously attributed to sulfates. Models are also available for the reaction of  $\text{NO}_x$ , HC, and sunlight to produce photochemical smog (Babcock), p. 656; (Patterson and Heneim) p. 28; and (Goldsmith), p. 369. If collected and accounted in combination the separate health effects can be totaled, in addition, the potentiations can be assessed.

There are of course numerous other air pollutants that have known or suspected health effects, and some of the trace metals are certainly in this class (Federal Register), (Hickey).

It is, in summary, apparent that many of the pieces are available that are needed to develop a general purpose, systematic, environmental assessment mechanism.

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