REVIEW OF METHODS FOR ASSESSING THE CARCINOGENIC HAZARDS FROM COAL-USING ENERGY TECHNOLOGIES

by

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Abstract

This report contains material relevant to the development of methodologies for evaluating the cancer risks associated with atmospheric pollutants from coal combustion and conversion processes. Information is presented on methods and sources (1) of regression analyses in this field, and (2) of physically significant simulation mechanisms, including potential functional modules of such mechanisms, particularly those modules dealing with energy facility emission characterizations, atmospheric dispersion, aerochemistry, population exposure patterns, and carcinogenic dose-response studies. In addition to listings of several key references and bibliographies in these areas, there is a discussion of some of the research in progress, the urgency of the situation, and some of the barriers to the development and dissemination of timely results.

Acknowledgements

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1. Introduction

The United States is heading toward an energy-tight situation that has the potential to become of enormous importance to our economy and lifestyles. Little has been done to mobilize the domestic energy supply system, and currently imports of energy are increasing, with dependence on foreign, cartel-vulnerable sources well ahead of pre-Arab-oil-embargo levels. The present national energy policy, as of the latest reports, recommends pressing forward with utmost speed on the research on the uses of coal, our only domestic source that can introduce significant energy by the year 1990. If one Project Independence (Federal Energy Administration, 1974) scenario is correct the commercialization of new coal conversion and combustion technologies in the next ten years would rival wartime production efforts. The known, suspected, and unknown carcinogenic potentials of the pollutants from those coal-use technologies and the possible enormous mass of emissions is cause for concern.

Regardless of the scenario that is projected there is certain to be significant change in the energy choice/use patterns of the future. The amount of health effects information that will be known and useable to those who make our future energy choices is another cause for concern. The current statistics give evidence of the potential magnitude of this problem: cancer is killing one of five Americans now, more than five times the combined U.S. military deaths in the Viet Nam and Korean wars. The per capita increase is now about 2.3% per year; the losses at a minimum estimated to be $15 billion annually and the source: about 90% of cancer is from environmental sources (Epstein, 1976).

The outline of the major barriers to the implementation of an appropriate program to cover these concerns is contained in the "Ray Report" (Ray, 1973, 19:50, p. 32):

> "Supporting Evidence:
>
> It is clear that a sound base of scientific capability exists for this work. No major difficulties with scientific feasibility are foreseen in achieving the goals. Few engineering problems are anticipated, but close cooperation between biologists, environmental scientists and technology development engineers will be required to minimize environmental impacts of present and new technologies. The major potential barriers are: (1) inadequate commmunication between the environmental scientists and the energy technology developers and (2) lack of established policy for the timely incorporation of environmental impact data into the development and implementation of energy systems and associated technology."

The ideal manner in which to deal with barrier (1) is by providing: consistent assumptions and formats and a methodology and mechanism for quick interpretation of the implications (gaps, priorities, new directions) of any of the developed data as it becomes available in any of the related fields. Barrier (2) of the "Ray Report," outside of the possible political solutions, could best be attacked by distributing widely the data that becomes available, making widely useable some type of simulation mechanism for easy interpretation of results, and, most importantly, making the results of carcinogenic health effects assessments in a format readily useable for the intercomparison of the diverse, competing energy technologies. Making this information available would help to ensure that intelligent decisions would be made about our future energy choice/use patterns, and it would facilitate the task of raising the level of public understanding of the alternatives.

There is, fortunately, decades of literature in this area; one bibliography has over 500 sources (Gruhl, 1976a). Some of the literature most significant to the various functional components of a systematic energy/health mechanism is described in the following chapter.

2. Review of Previous Most Significant Work

Most of the previous work on health effects of alternative energy sources has been done on electric power generation. The associated health impacts, excluding mining-related occupational cancers and cancer related to radioactive emissions, have not included carcinogenic hazard assessments. The literature related to the current discussion is thus fragmented with different sources only applicable to portions of the overallmethodology.

The general schematic for simulation of the health effects of a single energy facility is roughly the same for all of the mechnisms that have now or are soon to be developed. The following figure is the functional representation of a tentative Argonne/ERDA mecahnism that is being developed by the author and several others at the MIT Energy Laboratory (Gruhl, et al., 1976).

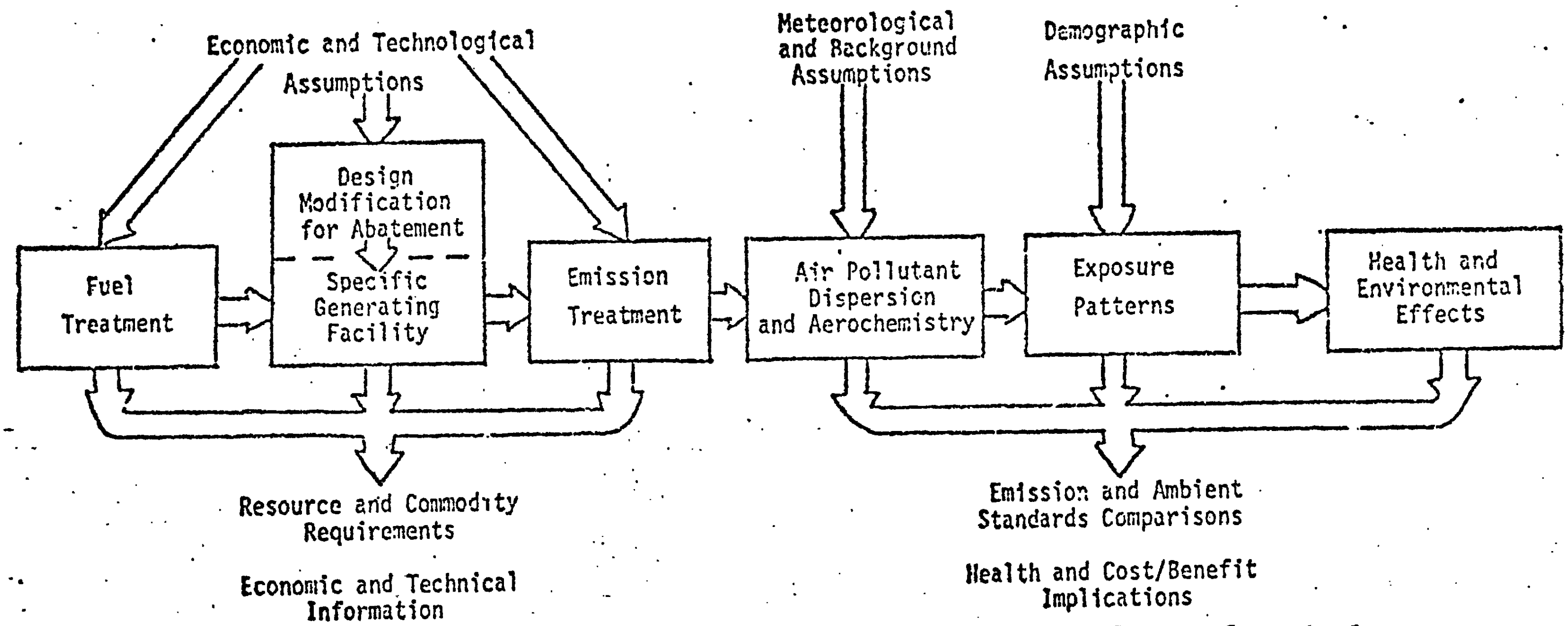

Figure 2.-1 Schematic of simulation mechanism for health effects of a single energy facility (Gruhl, et al., 1976).

Various studies have concentrated on one or more of the functions in the block diagram representation in Figure 2.-1. In the description of the literature that follows, the terminology in that diagram will be used to define the scopes and the functional modules that are aggregated in the several regression analyses.

2.1 Energy-Related Health Assessments

The previous and on-going work that is perhaps most applicable to this particular field is the simulation mechanism that has been developed for Argonne/ERDA by the MIT Energy Laboratory. This mechanism has been computerized, (Gruhl, 1976b), and is constantly being improved with better models and data. The goal of this research is to develop a mechanism that can be used to compare the health effects of alternative coal-fired electric power facilities and their environmental control options. Technologies to be included in the scope of that effort are low sulfur coal, various coal cleaning processes, solvent refined coal, low BTU gasification for power, fluidized bed combustion, other advanced coal-electric systems, stack gas cleaning, and supplementary control for fuel switching and load shifting according to weather patterns.

The modeling of the combustion and control processes is being performed by various subcontractors. The simulation mechanism that models the environmental impacts, given the technical factors from the subcontractors, is the MIT Energy Laboratory task (Gruhl, et al., 1976). This simulation mechanism can be operated in sensitivity studies by parameterizing any number of options, such as: the alternative combinations of generation and control technologies, regional assumptions on fuels and energy demand characteristics, accounting procedures, fixed capitalization charges, and various other economic and performance criteria.

The output of this mechanism for each energy plant/control option chosen is in the form of a list of resultant factors:

1. Economic Resultant Factors
    1. Total Investment ($)
    2. Capital Investment Normalized ($/1000MWe)
    3. Operating Cost
        A. Fixed Operating Cost ($/MWe/yr)
        B. Variable Operating Cost ($/MWhr)
    4. Annualized Cost ($/Yr)
    5. Total Cost per Unit Output (mills/kWhr)

2. Performance Resultant Factors
    1. Capacity (MWe)
    2. Production (MWhr/yr)
    3. Design Capacity Factor (%)
    4. Operating Capacity Factor (%)
    5. Availability (%)
    6. Energy Efficiency (overall losses and ancillary, %)
    7. Expected Lifetime of Unit (yrs)

3. Applicability Resultant Factors
    1. Commercialization Date (2000MWe production capacity, yr)
    2. Operating Experience (MWe-yr)
    3. Licensing and Construction Time (yrs)
    4. Maximum Rate of Installation (MWe/yr)
    5. Potential for Advancement of Technology (e.g., mills/kWhr reduction in output price per year after commercialization)

4. Resource Requirements
    1. Renewable Energy (as % of primary energy)
    2. Land Use (acres/MWe)
        A. On-Site Requirements
        B. Waste Disposal and Other
        C. Pondage Requirements

3. Manpower Requirement (non-operating, man-yrs)
4. Water Consumption (gallons/MWhr)
5. Materials Requirements (tons/MWyr/material)
6. By-Products (disposal costs or sales, $/MWyr)

5. <u>Environmental Consequences</u>
   1. Emission Standards (% of each standard)
   2. Emissions (normal and upset)
      A. Air Pollutants (tons, BTU/MWyr for specific pollutants)
      B. Water Pollutants (tons, BTU/MWyr for specific pollutants)
      C. Waste Solids (tons/MWyr for specific wastes)
      D. Radioactive Pollutants
      E. Noise (decibels/full load)
   3. Upset Conditions (hrs/MWyr)
   4. Ambient Standards (% of each standard)
   5. Occupational Health
      A. Mortalities (deaths/yr/MW)
      B. Morbidities (illnesses/yr/MW)
      C. Man-Days Lost (man-days/yr/MW)
      D. Occupational Health Costs ($/yr/MW)
   6. Public Health
      A. Mortalities (deaths/yr/MW)
      B. Morbidities (illnesses/yr/MW)
         i. Chronic Respiratory (cases)
         ii. Aggravated Heart-Lung Symptoms (person-days/yr/MW)
         iii. Asthma Attaches (cases)
         iv. Children's Respiratory (cases)
      C. Public Health Costs ($/yr/MW)
   7. Pollution-Related Damage Costs (total health and other, $/yr/MW)
      A. Biota Costs ($/yr/MW)
      B. Material Damage Costs ($/yr/MW)
      C. Aesthetic Costs ($/yr/MW)

There is an ordering mechanism being developed that will be useable in sorting out (by preferences, thresholds, weightings, and so on) the critical differences between the several alternative technologies being examined.

The starting point in the development of that simulation mechanism for Argonne/ERDA was the National Academy of Sciences simulator (National Academy of Sciences, 1975), see Figure 2.1-1.

The options available for study using the NAS assessment mechanism include:

Fuels:
Coal (3 types: high sulfur, low sulfur western, low sulfur eastern)
Uranium

Generators:
Existing coal-fired 620MW
New coal-fired 612MW
Old coal-fired plant recoverted from oil to coal 620MW
Nuclear 1000MW

Fuel Treatment:
Coal Cleaning (Preparation only)

Emission Treatment:
Scrubber
Intermittent Control and Tall Stacks

Site Locate:
Urban
Remote

The resultant health effects categories are the same as those listed in the outputs of the Argonne/ERDA mechanism.

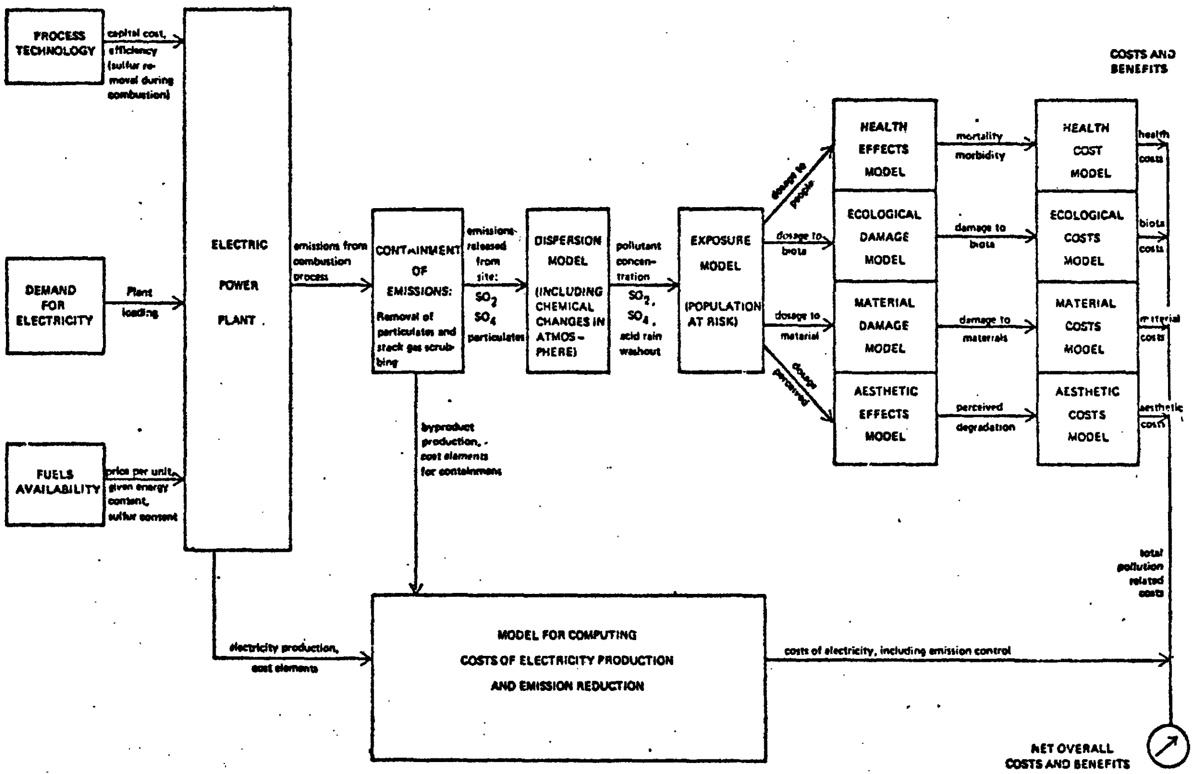

Figure 2.1-1 Block diagram representation of NAS methodology (NAS, 1975)

This NAS study was admittedly quite crude, but it did offer an excellent example of the extent to which an energy/environment assessment could be carried. The analyses performed with this mechanism included a number of excellent sensitivity studies with respect to uncertain parameters such as sulfation rates. Some of the obvious places where advances on the NAS model were in order included, in particular, the crude one meterological condition dispersion model and the extension beyond the SO_2-particulate method for determining health effects.

Critical reviews of some of the other health effects assessments of alternative electric power technologies can be found in (Comar and Sagan, 1976) and (Institutt for Atomenergie, 1975). The most important comparative studies of the health effects of different energy technologies include: (Argonne National Lab, 1973); (Energy Research and Development Ad, 1975); (Carnow, 1974); (Gruhl, 1976c); (Hamilton, 1974); (Lave and Freeburg, 1973); (Rose, 1975); (Sagan, 1974); (Starr, Greenfield and Hausknecht, 1972); and (U.S. Atomic Energy Commission, 1974). Many other articles are listed in (Gruhl, 1976a).

The only source that really attacks the carcinogenic aspects of coal-fired electric generation is (Watson, 1970). This is, however, more a listing of carcinogenic suspects that are believed or known to be in electric power plant emissions. The methodologies described in this report are in fact intended to be ways of extending the current state-of-the-art beyond that type of listing effort by putting real impact quantifications and measures of uncertainty on the results.

All of the references just listed skip one or several of the functional modules shown in Figure 2.-1. For example, two blocks in almost all health/energy assessments that are not dealt with by physically-significant models are the "Air Pollutant Dispersion and Aerochemistry" and the "Exposure Patterns." Generally this short-cut is taken by using correlations of regional tons of emissions to regional health/damage estimates. Another assumption used by all of these studies was the utilization of SO_x (sometimes with particulates) as a gross general indicator of approximate total air pollution.

A number of other health/energy studies are underway and these programs are described in section 2.2 Research in Progress. One effort that is not completed but which does have substantial interim progress is the SEAS-Strategic Environmental Assessment System (Environmental Protection Agency, 1975). SEAS currently exists in module form only, the package to be put together by 1979-1980. Briefly it is a model of the interaction of energy and environmental problems with the entire national economy (modeled using a large input/output scheme). Thus, SEAS takes into consideration materials and resource availability, capabilities of supporting industries, and so on. The list of atmospheric pollutants collected is impressive, still its application to carcinogenic hazard assessments is not possible. Hydrocarbons, for example, are all in one category with no regard to carcinogenic potency.

Ambient concentrations in SEAS are estimated from emission-to-ambient scaling procedures much like those used in Project Independence (Federal Energy Administration, 1974). Health effects are included only insofar as they are reflected in the dollar consequences of the emission-to-damage scaling estimates (the emissions from the 1973 National Emission Data System collection by industry and pollutant, the damages from 1971 estimates by region).

There are about 40 key sources listed in (Gruhl, 1976a) of emissions or ambient concentration (but not public health) comparisons of alternative energy technologies. Perhaps the most important data base of this type is the one annually updated by the government: "Energy Alternatives: A Comparative Analysis" (University of Oklahoma, 1975). This data base, among other places, can be accessed at Brookhaven National Laboratories and can be manipulated using the MERES system (Council on Environmental Quality, 1975). As comprehensive as this information is on the current and advanced energy technologies, except for the occupational health data there is not much of interest to this current discussion. Emissions are collected in the categories: particulates, NO_x, SO_x, hydrocarbons, CO and aldehydes. Even these values are displayed without the measures of uncertainty which can be retrieved from some of the original data bases at Hittman, Battelle, and Teknekron (Battelle Memorial Institute, 1973), (Hittman Associates Inc., 1974, and 1975).

2.2 Environmental Assessment Methodologies

The field of systematic assessments of environmental impacts has, particularly in the past five years, been an area of intense and valuable research. From its beginnings decades ago in resource planning, mostly of water or land use, the assessment methodologies have been developed and applied to virtually all of the areas where choices are to be made that have different environmental impacts. A significant review of this general field was sponsored by EPA (Warner and Preston, 1974).

Systematic carcinogenic assessments have been developed largely in two areas of the government. The National Cancer Institute has made a number of contributions to this field, a summary of these efforts from the energy technology viewpoint can be found in (Schneiderman, 1975). The EPA in its Cancer Assessment Group has developed an assessment methodology for determining chemical carcinogen risks (Environmental Protection Agency, 1976). For the chemical carcinogens the EPA has altered the stance of "lowest practicable level" regulations used for carcinogenic ionizing radiation releases to a stance of "balancing risks and benefits as a basis for final regulatory action." Thus, there was a need for an assessment methodology.

While this EPA carcinogenic assessment methodology can make a number of important contributions to this particular field it is not wholly applicable by any means. Assessment mechanisms for regulatory use, in general, have levels of risk aversion built in at any number of places. One example is the prudent assumption of the direct linear non-threshold relationship between biological effects and amount of dose. Another built-in risk aversion is the use of the dose to the highest exposed individual as the design criterion. In the context of this current discussion, in which a curve of carcinogenic risk versus probability might be a result, different levels of risk aversion would be different points on a curve all of whose points are important in a comparative assessment context.

Some of the other outstanding examples of environmental methodologies that are relevant to this report's topic are in the area of cost/benefit/risk assessments of nuclear power. Some of the best results from this field are in (Gillette, 1974), (Hammond, 1974), (Jordan, 1970), (Rudman, 1974), (Sagan, 1972), (U.S. Nuclear Regulatory Commission, 1975), (Wilson, 1972) and an excellent critical review of this field in (Starr, Rudman and Whipple, 1976).

2.3 Operations and Emissions Characterization

The first step in modeling the emissions from the combustion or conversion processes is the careful characterization of the constituents in the fuel. This report is concentrating on coal as the fuel because of the immediate and increasing role for coal in the national energy plan. The near term, now to 1985, emphasis as set forth by ERDA, will be on the direct combustion of coal. The mid- and long-term priority is on coal conversion to gaseous and liquid fuels.

Perhaps the most important single factor in characterizing coal is the occupational health consequences per unit heat value. These health hazards, due to the carcinogenic dusts, suspended and soluble organic and inorganic chemicals, can be found in many data bases, (University of Oklahoma, 1975) or (Council on Environmental Quality, 1973), for example. As far as characterization of chemical constituents, coal has a virtual periodic table of elements (Abernathy and Gibson, 1963) and (Bowen, 1966). There are important regional variations that must be taken into account such as factors of 1000 differences in uranium, arsenic, and beryllium concentrations between regions. Compilations of coal constituency breakdowns by region are available (National Aeronautics and Space Administration, 1976), (National Coal Association, 1973), and others.

The physical processing of coal involves health problems in the suspended or soluble inorganic and organic chemicals in treated or untreated waste water. Modeling of the pathways and data on the effects of these pollutants is available (Hamilton, 1974) and that and other projects like it are continuing to refine their results.

The major emphasis in this report is on the airborne dispersion of carcinogens. As such the important emissions characterizations for use in this type of mechanism would be the modeling of the atmospheric effluents of advanced combustion processes. The MIT Energy Laboratory and the MIT Schools of Engineering have emissions modeling efforts for all of the major coal-using energy technologies, with just a few of the others involved being: MHD-NASA, Exxon, Argonne; Fuel cells - NASA, Exxon, Argonne; Advanced gas turbines - NASA; Fluidized bed combustors - Battelle, Argonne, EPA, Exxon, TVA; Stack gas scrubbers - Argonne, EPRI, EPA, TVA: NO_x control - Argonne, EPA; Gasification - Exxon, ERDA, EPRI, Battelle; Liquefaction - ERDA, Battelle.

Some of these advanced processes involve a great many known or suspect carcinogenic agents: trace and heavy metals, radionuclides, polycyclic hydrocarbons, precursors to nitrosamines, and organic sulfur compounds. Liquefaction plants are particularly rich in aromatics with 13 of the 14 most potent known carcinogens occurring in their process streams (private communication, J. Liverman, ERDA, August 1975).

The completed and ongoing emission research programs include emission categories of widely varying specificity. Some are collecting only SO_x, NO_x, and particulates while others contain great detail on radionuclides (Martin, Howard and Oakley, 1971) (Eisenbud and Petrow, 1964), and trace and heavy metals (Argonne National Lab, 1973), (Ragaini and Ondov, 1975), (Berry and Wallace, 1974), (Kaakinen, Jordan, Lawasoni, and West, 1975) and (Klein and Russell). Quantitative surveys are generally not available for specific organic compounds that are emitted from the conversion and combustion processes.

The timing of the release of the pollutants is an important aspect of an overall simulation mechanism. This particular area is a field in which a great deal of expertise exists, most of it was originally developed for use on power plants and power systems, for characterization of energy facility operating conditions to determine the frequency and duration of pollutant emissions, (Gruhl, 1974), (Gruhl, 1973a), and (Gruhl, 1973b), including literature surveys cosponsored by ERDA and EPRI (Schweppe, Ruane, and Gruhl, 1975) and (Gruhl, Schweppe, and Ruane, 1975). The most useful available techniques for dealing with the simulation of emission timing come from the analogous area of power production simulation. 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 simulate operation 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.

2.4 Pollutant Dispersion and Population Exposure Patterns

It can generally be very difficult, due to site-specific conditions, to track water pollutants through the ecosystem to determine their ultimate impact upon humans. Tracing and quantification of pollutant effects through these aquatic pathways are available (Hamilton, 1974), (Gruhl, 1973c), and others. The most likely human exposures to most of the potential carcinogens from expanded use of coal will, however, be through atmospheric pathways and until there are other indications, and because of the great complexity of modeling aquatic pathways, it would probably be desirable to concentrate on the atmosphere initially.

For the purpose of simulating atmospheric pollutant dispersion there are a large number of excellent computerized models. The state-of-the-art knowledge on the 1-100km multiple point source modeling that can be superimposed on area background sources covers a great range of sophistication. The gross, regional regression models are probably too coarse for use in the context proposed in this report; the puff and microscale models are too detailed. It is likely that a technique that is consistent with the accuracies and time consumptions of the other portions of the described methodology would be some type of Gaussian plume model, probably sector-averaged as is used in (Ruane, et al., 1976).

Although most atmospheric dispersion modeling has been aimed at the more commonly studied pollutants, extensive literature is available on special considerations for trace metals and other pollutants in the so-called "hazardous" category (Junge, 1969), (Klein, et al., 1975) and (Mills and Reeves, 1973).

Long-range dispersion modeling (Junge, 1969), (Nord, 1973), (Reiquam, 1970), (Rodhe, Person and Akeson, 1972), (Szepesi, 1964), and (Zeedrick and Velds, 1973) is another area of modeling necessary in this type of approach.

Information required for the characterization of the likely background concentrations of the future is very difficult to find. Current background levels of the common pollutants are, however, readily available, as are fairly adequate data on trace metals [(Argonne National Lab, 1973), otherwise generally collected in separate reports by elements, refer to the lists in (Gruhl, 1976a)], heavy metals (Schroeder, 1970), (Fowler, 1975), and organic compounds (Environmental Protection Agency, 1973), (Ketserides, Hahn, Joenicke, Junge, 1976), (Sawicki, 1967), and (Watson, 1970).

Aerochemistry is another very difficult module of a physically significant simulator of pollutant effects. It is, however, an equally difficult and important area in regional regression analyses of pollutant effects. One of the few computerized aerochemical simulators available is that developed by NAS, see Figure 2.1-2.

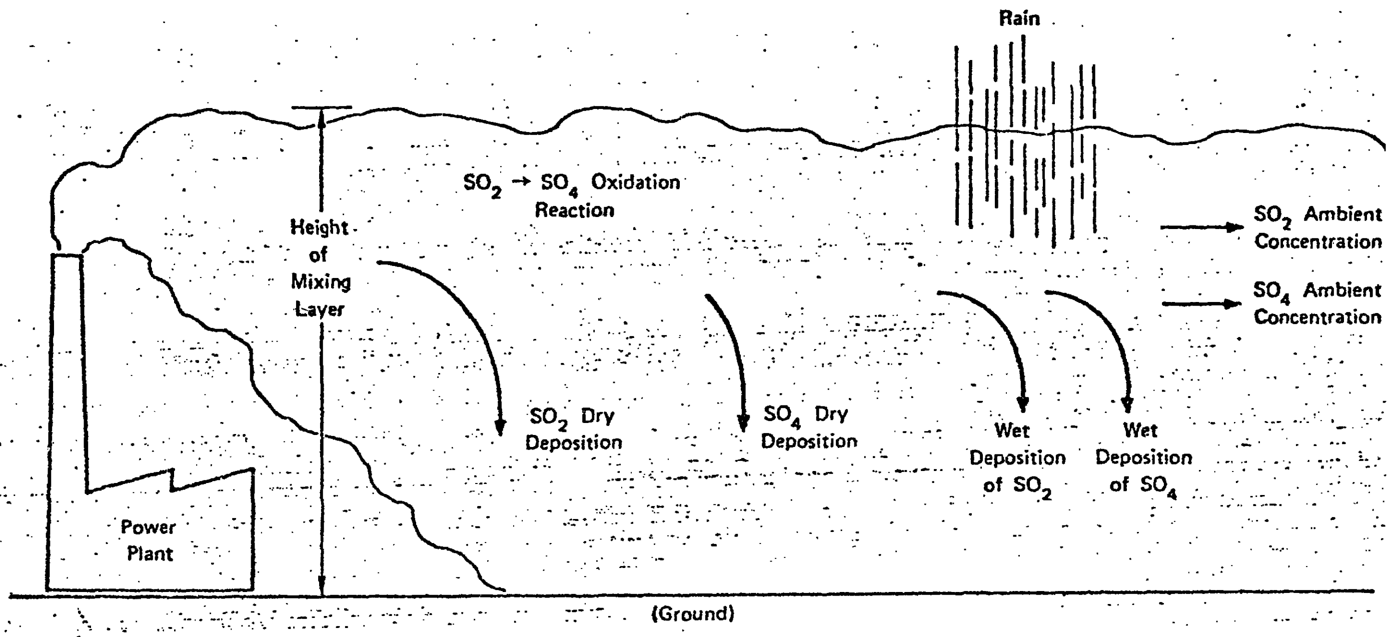

Figure 2.1-2 NAS model for emission to ambient relationship for sulfur emissions from a representative plant (NAS, 1975)

Sulfation is a far from well-known phenomenon, but at least this starting model is available that can be improved as further information is developed. Other atmospheric reaction rates and reactions are less well known: inorganic and organic nitrogen compounds (Butcher and Charlson, 1972), (Davis, Smith and Kluaber, 1974), (Preussman, 1974), and (Systems Applications Inc., 1974); organic sulfur and other organic compounds (National Research Council, 1972), and (Young and Phillips, 1975).

Demographic assumptions are necessary in order to develop population exposure patterns. Currently available on the MIT model is the same option as used by NAS (National Academy of Sciences, 1975) for a typical urban or a typical remote siting location, see Figure 2.1-3.

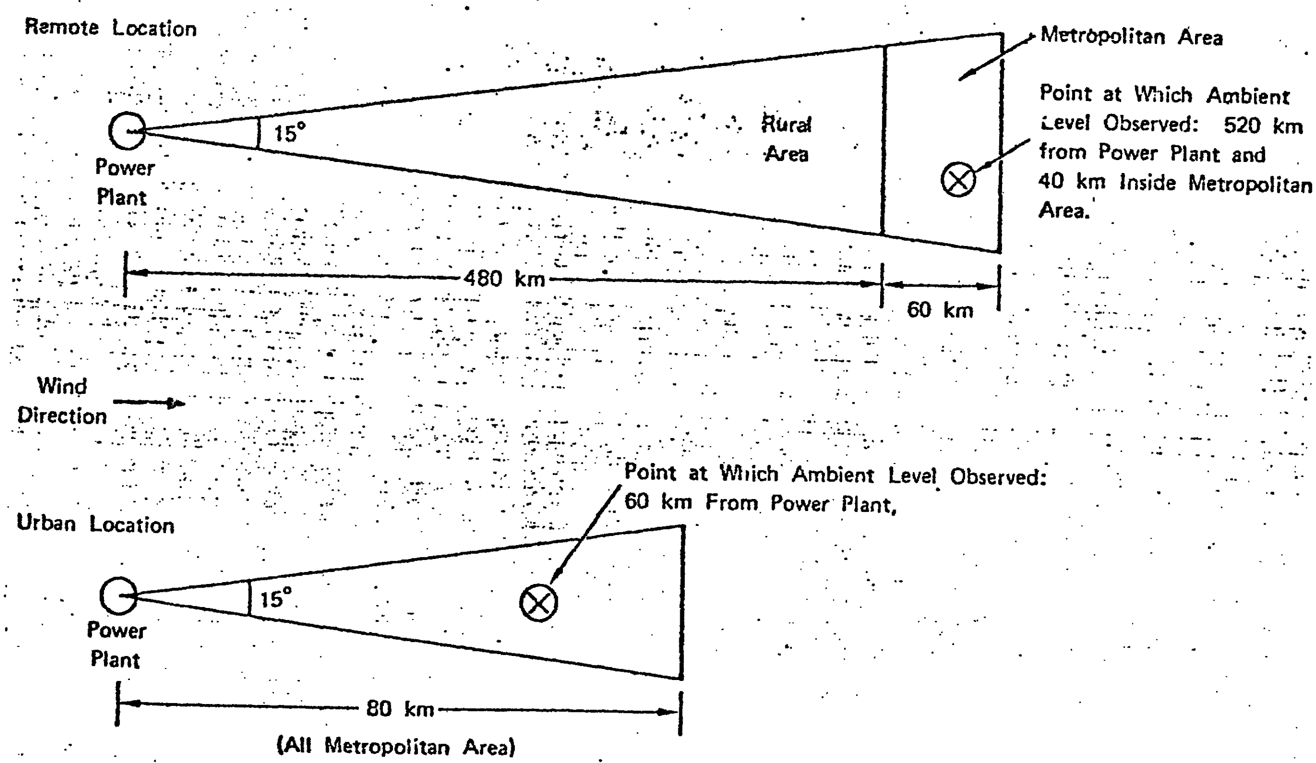

Figure 2.1-3 Geometry of NAS assumptions of remote and urban (NAS, 1975)

Most of the early research on population exposure patterns was concentrated on the assessment of one-shot accidents. For example, one study was performed on the effects of a nuclear reactor accident compared with the impact of a conflagration of the fuel supply for an oil-fired power plant, see Figure 2.1-4. Nuclear reactor accident assessments remain as the most elaborate pollutant/demographic studies due to the licensing requirement for a very tedious complete characterization of the distribution of population around a proposed site. A number of excellent studies of population exposure patterns have been developed for this purpose: (Frigerio, et al., 1973), (Hart, 1974), (Honstead, 1970), (International Committee on Radiological Protection, 1969), (Kolde and Kahn, 1970) and (Sagan, 1971).

There are some additional considerations that must be incorporated when extending the methodologies of radioactive exposure patterns to the chemical pollutants; the one-shot studies become series of erratic bursts; and the indoor-outdoor patterns are more important (Environmental Protection Agency, 1972). Work in progress that has interim results in this field of chemi-

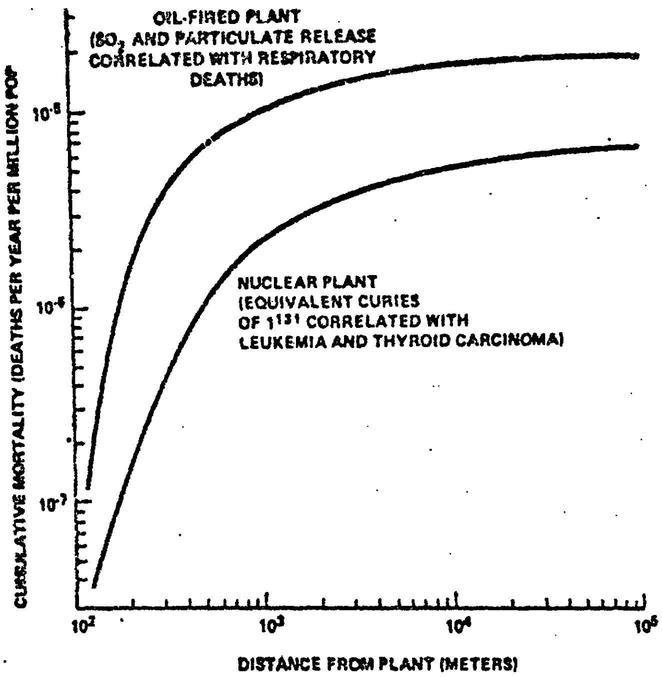

Figure 2.1-4 Cumulative mortality as a function of distance from oil conflagration and nuclear releases from power plants. (Starr, Greenfield and Hausknecht, 1972)

cal pollutant exposure patterns includes: a TVA computer-graphic display of specific environmental distribution patterns; the EPA methodology guidelines (Environmental Protection Agency, 1976) for developing cancer risk exposure patterns; and the ERDA-sponsored program on chemical pollutant population exposure patterns (Gruhl, 1976d) being performed at the MIT Energy Laboratory with continuation fundspending December 1976 from the air quality and epidemiological groups in the Division of Biomedical and Environmental Research. The efforts in the continuation of this research would be directed at the development of probabilistic dispersion and demographic models to result in a method for creating concentration-versus-duration-versus-population surfaces. These surfaces would then characterize the impact of energy facility operation on exposed populations, see Figure 2.1-5.

There are several indications that the surface in Figure 2.1-5 could be characterized by a single curve (due to the straight-line characteristic of 'log of concentration' versus 'log of duration' for a stationary sensor). With such a characterization the uncertaintly associated with the exposure pattern could easily be characterized (using a similar curve for geometric deviation, for example). This type of exposure pattern information would splice together perfectly with dose-response information in the appropriate format (assuming the concentration in Figure 2.1-5 is actually a potency index as described in the following section).

2.5 Carcinogenic Hazards of Air Pollutants

The principal carcinogenic air pollutants that result directly from the conversion and combustion of coal include a list of polycyclic and other aromatic hydrocarbons, trace elements and radionuclides. Given an opportunity to react in the atmosphere, a whole series of organic nitrogen and sulfur compounds join the list as indirect carcinogenic emissions. Finally, if the sus-

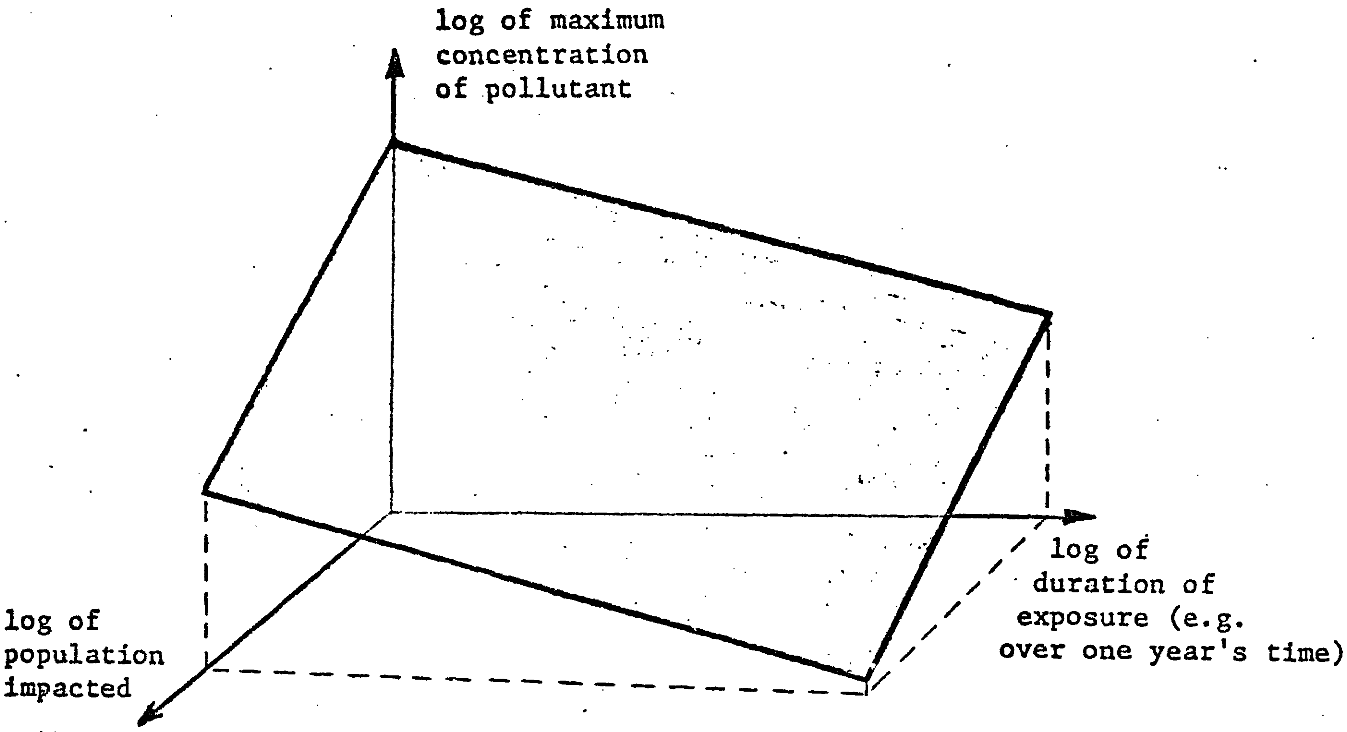

Figure 2.1-5 Hypothetical example of a concentration-versus-duration-versus-population surface (Gruhl, 1976d)

pected promoters are also included then the list of agents to be considered expands to include almost all of the common pollutants. For example, SO_2 is a suspected potentiator of the carcinogenic effect of polycyclic organics such as benz(a)pyrene; some metal oxides, such as Fe_2O_3 act similarly as accelerators; NO_2 and ozone are suspected of interfering with complex clearing mechanisms and thus contributing to carcinogenesis; NO and NO_2, in the presence of ammonia and acids in coal combustion plumes could contribute to the formations of nitrosamines of pronounced carcinogenicity (Preussman, 1976). It is thus obvious that the systematic assessment of carcinogenic hazards cannot concentrate on a small set of pollutants but must take an across the board approach.

It is important initially (and in future extrapolations) to have the information on the carcinogenic potency of individual pollutants and synergistic effects of whatever combinations of pollutants are available from existing data bases (National Cancer Institute, 1974). It is obvious, however, that for this field to progress new and even uncharacterized mixtures of pollutants likely to impact future populations would have to be postulated and synthesized and these new mixtures would have to be tested for carcinogenicity to more accurately account for synergisms.

In addition to the NCI data base (National Cancer Institute, 1974) some of the many sources of information on atmospheric carcinogens include (Buck and Brown, 1964), (Carnow and Meier, 1972), (Fenter and Margetter, 1973), (Hettche, 1971), (Hueper, 1966), (Stocks, 1966), (Winklestein and Kantor, 1969), (U.S. Dept. of HEW, 1962), and (Wynder and Hamond, 1967). These data vary considerably in applicability to the systematic framework concept. Much of this data is in terms of thresholds at which effects are noticed, and even when this format is used very systematically, it is not in the most useable form, see Figure 2.1-6.

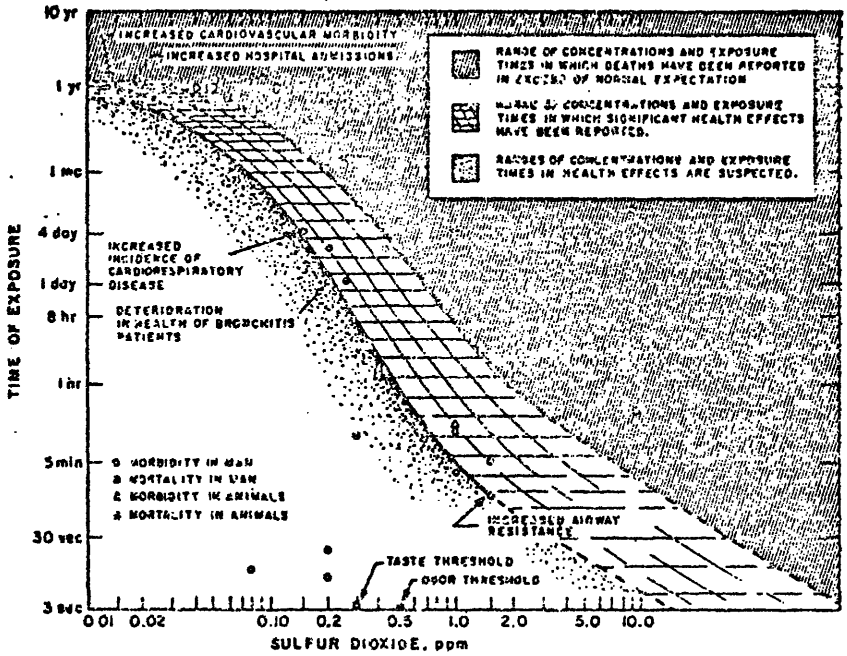

Figure 2.1-6 Dose-response thresholds for sulfur dioxide (U.S. Dept. of HEW, Publication No. 1619, 1967)

A more useful format, from the assessment viewpoint, is a dose-response relationship for predicting magnitudes of effects: linear non-threshold (Bruces, 1958), linear with threshold (National Academy of Sciences, 1975), log-profit, and half-power (Starr, Greenfield, Hausknecht, 1972) models have all been used. Some studies have bounded above and below with different types of models (Starr, Greenfield, Hausknecht, 1972).

The ideal format for operating on population exposure patterns has a different dose-response pattern for each health effect to be modeled (such as mortality, mutation, stomach cancer, total cancer, or whatever). Associated with each effect there is a functional combination of the potentiating, antagonizing, or additive pollutants and this functional combination acts as an index of the potency of the particular combination. Ideally, then, curves of probabilities of an effect at the different potency-duration pairings would be plotted, see Figure 2.1-7. A display similar to Figure 2.1-7 showing instead the isopleths of geometric standard deviation associated with each pairing would add the very useable probabilistic information.

There are, of course, problems with this postulated 'ideal' format, for example in the treatment of abnormally susceptible populations. Hopefully, socio-economic indexes or density implications might be worked directly into the potency functions to the extent that they affected health responses. In any event, Figure 2.1-7 can offer a useful initial format for assessment purposes; the available health effects data can generally be easily fitted into its appropriate position on this format. The regression analyses are the primary exception.

The problem with regression analyses is that they never claim to establish causal dose-response relations, just statistical association. The variables of a regression analysis are certain only to be indexes of the true (perhaps unknown) causative agents. The results of regressions can be useful in the absence of knowledge of causative agents or, possibly, in independent evaluation of results.

The most widely publicized regression analyses of health effects of air pollution have been reported in (Lave and Seskin, 1974) and (Hickey, 1971).

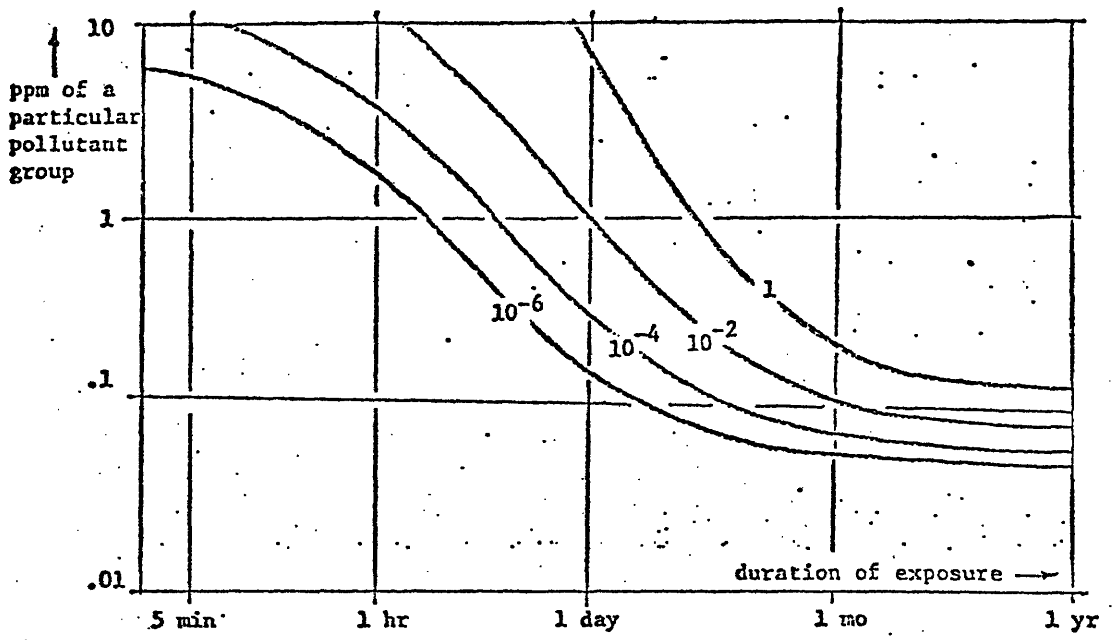

Figure 2.1-7 Dose-response information in a format ideal for assessment use. (Gruhl, 1976d)

Common pollutants, trace metals, and organics have been employed as indexes to carcinogenic hazards (Hickey, et al., 1970), (National Research Council, 1972), (Schneiderman, 1975).

3. Research in Progress

Many of the programs described in sections 2.1-5 are continuing. There are, in addition, several new projects that can be expected in the future to provide significantly valuable inputs to this physically significant simulation field.

Government sponsoring of much of the current health/energy research was initially outlined in Dr. Dixy Lee Ray's report to the President (Ray, 1973). Delineation and coordination of governmental health/energy responsibilities have largely evolved from the King-Muir interagency working group report on research needs in health and environmental effects of energy.

At ERDA the programs of principal importance to this type of research include: (1) "Assessing the integrated health, environmental, and socioeconomic impacts of alternative coal extraction, processing, and combustion technologies," a program charged with data organization and coordination necessary for intelligent decision making, and the analysis of all the information in a cost-benefit framework;" and (2) "Determine the biomedical effects of pollution resulting from coal extraction, processing, and combustion" including a continuing evaluation, interpretation, exhaustive review, and summary of available information.

EPA is increasingly being charged with short-term problems, however, there is a considerable amount of information being developed that can be of initial use in an overall assessment. The EPA has begun the funding (2/76) of an Integrated Technology Assessment program at Teknekron, Inc. (Teknekron Inc., 1976). This involves the development, by about 1980, of a simulation mechanism that will model the social, environmental, and economic problems of electric utility systems. Included in their current plans are modules to simulate dispersion and exposure patterns. A similar ERDA program, National Coal Assessment, is being carried out by Argonne National Laboratories as part of its Regional Studies Program.

Current ERDA programs in population exposure pattern studies include research on the methodology for describing the populations surrounding energy facilities in terms of demographic, socioeconomic, and health indexes. The HNL work is concerned with areas of Tennessee; Argonne has chosen eleven different locations. Los Alamos Scientific Laboratories are presently conducting tissue analyses of the general population in specific locations to determine trace metal accumulations attributable to nearby fossil-fueled facilities. These studies will attempt to create exposure patterns without dispersion modeling.

Mutagenic and carcinogenic activity of fossil-fuel combustion components are currently being studied at six ERDA laboratories (HNL, Argonne, UCLA, Pacific Northwest, Lawrence Livermore, and Franklin McLean). Accidental exposures around pilot facilities are to receive top priority in the collection of data on health effects. As far as the planned research is concerned, the array of chemical agents is so complex and the expertise so rare that only the potentially hazardous materials of highest "priority" are being investigated. As far as breakdowns in methods of approach for determining the effects of fossil-fuel pollutants they are roughly: pollutant-nucleic acid interaction (Brookhaven, Lawrence, Los Alamos); differentiation between inducing and promoting activities (Argonne, Holifield, Lawrence); rapid screening of coal conversion process streams and products (Holifield); determination of likely doses to man (Argonne, Pacific Northwest, Brookhaven, Inhalation Toxicology Research Institute, University of Tennessee, and University of California-Davis); and pollutant interactions and dose-response determinations (Pacific Northwest, ITRI, Holifield, and University of Rochester).

4. <u>Suggestions</u>

To the extent possible, pollutants should be accounted in separate categories. The sheer number of different compounds in, for example, the aromatic hydrocarbon group would, however, necessitate some aggregate categories. Such aggregations should be made with due regard to potencies, synergistic and aerochemical interactive tendencies, similar specific targets (among possibilities such as lung, pancreas, colon, breast, prostate, uterus, esophagus, or stomach), similar systemic targets (such as respiratory, gastrointestinal, genital, and so on), or similar physiological mechanisms (such as having similar actions when combined with important enzymes, or according to classes of DNA damage patterns and thus affected by the same types of chemical, dietary, radiation, or natural repair mechanisms).

Care in choice of categories would facilitate the handling of newly recognized pollutants, or newly recognized synergisms, but there would certainly still arise some problems. The complexity of the entire dose-response situation, particularly in the very low dose range, might originally be handled in a <u>man-chem</u>, linear, non-threshold, dose-response relationship, using a unit of measure equivalent to the known man-rem effects. Simple additive assumptions could initially be used in the absence of information on synergisms. Also as an initial simplifying tactic, 5%, 50%, and 95% points could be used in place of the entire probability distribution curve.

An approach that results in the quantification of the magnitudes of carcinogenic effects is recommended rather than just an agent identification and listing procedure. It is becoming increasingly clear that the choice among future energy technologies will be a choice among different <u>degrees</u> and balances of economic and health insults. In that type of comparative analysis, magnitudes are of paramount importance. Early estimates on these magnitudes can also be used to prioritize the future research efforts among the infinite number of alternative tasks.

A physically significant simulation approach is suggested rather than use of regression studies. Regression of previous effects to previous emissions carries a number of assumptions that are difficult to reconcile with the decreasing quality of sites, increasing densities of populations, and widely varying siting alternatives (river versus offshore, for example). Also, extrapolations to situations far different from existing conditions is difficult, especially for very different energy and emissions mixes, new background pollutant levels, and 'new' pollutants. A physically significant approach can be initially attacked and continually improved on all fronts; fuel characterization, combustion modeling, dispersion, aerochemistry, exposure patterns, and dose-response relations.

Finally, a probabilistic framework is suggested rather than a deterministic formulation. The key assumptions, models, and data all contain different degrees of uncertainty. It is important to follow these uncertainties forward through the simulation to determine the quality of the analytic results, so that intelligent comparative decisions on risks can be made. It is also important to be able to follow the critical, but poor quality, results backward through the simulation to identify and prioritize research to reduce the responsible uncertainties.

5. Summary

Cancer has a particularly severe physical, economic, and mental impact on affected individuals and their families. It is becoming increasingly apparent, however, that large amounts of carcinogens may be emitted from those current and future coal-using energy technologies upon which our nation is heavily relying. The question is whether or not our energy system will be contrary to the general expectation of individuals and society with regard to human health and life.

The current ratio of rehabilitation funds to research funds in this cancer/energy field is not known, but it is likely to be very large. Certainly that ratio will increase, not primarily due to lack of funding, but due to lack of qualified research manpower. This is a limitation that ought to receive at least as much attention as the two "Ray Report" barriers discussed earlier.

Cancer risks cannot be eliminated completely, but there are strong indications that we could be making better choices and that we could be directing searches toward more desirable energy/cancer balances. This current discussion has revolved around the possibility for developing a methodology that might aid in deciding those choices and directions with more assurance than is otherwise possible.

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