FINAL REPORT

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ANALYSIS PROGRAM FOR SYNFUELS

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BY

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INTEGRATED HEALTH AND ENVIRONMENTAL RISK

ANALYSIS PROGRAM FOR SYNFUELS

LIST OF FIGURES

ABSTRACT

The Integrated Health and Environmental Risk Assessment Program for Synfuels was established by the Office of Research and Development, U.S. Environmental Protection Agency, for the purposes of developing and evaluating the health and environmental effects of synfuels technologies, evaluating the uses of synfuels, and providing a data base for use in a system of regulatory control and establishment of applicable standards.

The program sponsored and supported research and field investigations which produced valuable scientific input data and developed assessment methodology to evaluate the health and environmental effects of synfuels and the technologies used to produce them.

The research program included work performed by a number of EPA laboratories, academic institutes, several national laboratories, and private research organizations throughout the United States. One major field investigation was done in Yugoslavia as a cooperative effort with two U.S. Federal agencies, two U.S. National Laboratories and several industrial, governmental, and academic organizations in Yugoslavia.

Research results have been made available through technical presentations and reports, user's meetings, the peer review process, workshops, and user's manuals. In addition, a number of reports, supported by this project, are scheduled for publication in the near future.

A useful compilation of information and data on synfuels and synfuels technologies has been gathered; needed environmental and health data have been produced; and the assessment frameworks for environmental effects and for health effects have been developed for synfuels using concepts and procedures of risk analysis. This data base and these methodologies are documented and available for application if and when the United States decides to embark on the full-scale development and application of one or more synfuels technologies.

I. INTRODUCTION

Synthetic fuels usually are considered to include gaseous and liquid fuels as well as solid fuels which have been produced from the conversion of coal, oil shale, tar sands, and various forms of biomass. The conversion processes may be defined as synfuels technologies, and there are a number of these.

Among the reasons for using synfuels technologies are: the removal or conversion of nitrogen, sulfur, and other components which give rise to undesirable pollutants; the utilization of domestic energy resources and the achievement of independence from foreign sources; the replacement of unavailable, depleted, or more costly supplies of natural fuels; and the production of higher calorific fuels by the removal of unwanted constituents, such as ash, for more economical fuel handling and transport.

Some of the impetus for synfuels research in the United States was generated by the oil embargo of a few years ago and by a continuing increase in the costs of finding and producing new fossil fuel and other energy sources. It is also widely recognized that the world's supply of readily producible oil and natural gas is limited and will be exhausted in a matter of a few decades.

With increased demands for energy, it is prudent to secure alternative sources of energy along with the technologies necessary for their production and utilization. Energy conservation methods, while helpful, are not sufficient to achieve national goals of meeting energy requirements. In addition, a number of newer energy production technologies, such as solar and fusion, are long-range efforts with uncertain results.

Thus, for the decades immediately ahead, it appears that in addition to its sources of natural gas and oil the United States will be dependent primarily on coal, uranium, and perhaps oil shale.

During the recent decade of concern with energy sources there also has been a fundamental interest in and need to achieve and maintain basic environmental quality. The intense national mood and interest were codified in the passage of the National Environmental Policy Act of 1969 (NEPA63). In 1970 the U.S. Environmental Protection Agency and the Council on Environmental Quality were established.

Consequently, there has been a merging of two national concerns; namely the need to develop and produce alternate long-term energy sources and the need to make the technologies and fuel utilization processes as benign and innocuous to the public and the environment as possible. The constituencies and advocates for these two major national objectives are neither mutually exclusive nor completely compatible in all respects.

To some extent, the Energy Security Act of June 30, 1980 (ESA80) embodied each of these concerns (Di84). The Act created the U.S. Synthetic Fuels Corporation (SFC), defined its purpose, organization, financing, and responsibilities, outlined the environmental and health protection and monitoring requirements of each recipient of financial assistance from the SFC, and set production goals for industrial output of synthetic fuels.

Of particular interest here, in addition to the industrial stimulus it provided, are the definition of "synthetic fuels" and the requirements for environmental and health protection. According to the Energy Security Act, synthetic fuels are any solid, liquid, or gas produced from coal (including lignite and peat), shale, tar sands, certain categories of heavy oil, water for its hydrogen content, coal-oil mixtures, and magneto hydrodynamic topping cycles. The major environmental and health protection and monitoring provisions ensure that the supported projects will be consistent with protection of the environment and environmentally acceptable, have a high potential to meet regulatory requirements, and present a plan for monitoring environmental-and health-related emissions.

Several Congressional Committees, such as the House Committee on Science and Technology and its Subcommittee on Energy Research and Production, have expressed the view that environmental, health, and safety research is the key to the prospects for developing and building environmentally acceptable synthetic fuel plants (Du84). These committees, of course, are supply oriented with emphases on national security, energy, and technology rather than on environment, health, safety and protection.

Individuals with industry, such as G.K. Vick of Exxon Research and Engineering Company (Vi84), have also stated their views regarding the need for safety and protection as an inherent part of industrial synfuels technology development. The developed technologies need to be safe to workers, customers, the environment, and the general public as well as acceptable to the customers and the public.

Because the U.S. Environmental Protection Agency put into place a comprehensive program of research and development to produce needed information and data for the development of regulatory standards for synfuels technologies and the use of their products, the environmental and health protection programs are being developed on a concurrent basis with synfuels technologies.

A major component in the Environmental Protection Agency effort was the establishment of the Integrated Health and Environmental Risk Analysis Program for Synfuels, set up under the aegis of the Office of Research and Development. This program supported basic research to obtain data needed for the uptake of synfuels chemicals by various environmental media and for biological data regarding the effects of synfuels chemicals on human populations. These experimental research programs provided some of the needed input into environmental effects models as well as health effects models.

Another major attribute was the close and effective coordination established between the Integrated Health and Environmental Risk Analysis Program for Synfuels in the EPA with its counterpart organization in the U.S. Department of Energy, the Health and Environmental Risk Analysis Program. There were close personal relationships between the respective project officers and their staffs and among the several research groups involved with the various research efforts. Such activities were most useful and added greatly to the efficient production of research results while avoiding duplication.

This positive climate for synfuels work and research, including health and environmental effects studies, has, of course, changed over the years. In fact, the trend has been to reduce support and thus curtail technology and research efforts.

II. ENERGY TECHNOLOGIES TO PRODUCE SYNFUELS

Synthetic fuels are produced in a number of countries to help them meet energy requirements. However, in the United States there has been little emphasis placed on the need to develop synfuel technologies. In this section we shall briefly review synfuels technologies and the possible production of synfuels for use. The establishment of the SFC added emphasis to these efforts within the United States.

The basis for synfuels technologies is the conversion of carbonaceous materials to synthetic fuels through the process of hydrogenation. Thus, our common fuels such as natural gas and gasoline have a higher hydrogen content than the raw materials considered as resources for conversion. These include coal, oil shale, tar sands, and several forms of biomass.

In the hydrogenation processes water is the source of hydrogen. Therefore, the synfuel technologies are intended to decrease the carbon to hydrogen ratio in the conversion process. For example, on a mass basis the ratio of carbon to hydrogen varies from about 15 for bituminous coal, approximately 9 for crude oil, to 6 and 3, respectively, for gasoline and methane. Oil shale and tar sands are close to crude oil in carbon to hydrogen ratio and are thus more amenable to synfuel technology than coal.

An environmental concern is the amount of mineral material contained in the energy resource. If the content is high, large quantities of material must be mined and handled and the resulting large volumes of solid waste must be disposed of in an acceptable manner.

The hydrogenation process may be direct, indirect, or by pyrolysis, either alone or in combination. In the direct process, hydrogen at high pressure is used, whereas steam is used in the indirect process. The pyrolysis process involves heating the raw hydrocarbon source until it thermally decomposes into its several products.

In the book, "Synthetic Fuels" (Pr82), the various conversion processes are defined and described in detail. The process selected is usually based on a variety of chemical and physical properties of the raw fuel and these properties and the conversion process characterize the products which are generated.

There is a variety of types of coal in the United States whereas there are two principal types of oil shale, namely that from the Green River Formation and black shale. The oil shales contain "kerogen" which is not a member of the petroleum family but contains a high-molar-mass organic material. The major part of the oil derived from "kerogen" is obtained from pyrolysis.

Tar sands contain a high-viscosity crude hydrocarbon in the form of bitumen which is a member of the petroleum family. The United States is not a major source of tar sands, but extensive deposits have been identified in Canada.

Various forms of biomass can be converted to synthetic fuels and the production of alcohol from the fermentation of grain is a good example. However, in the United States, grain is looked upon more favorably as a food stuff than as an energy source. Wood is a biomass energy resource, but it is not known whether or not it can be used on an economic basis.

Approximately 80 percent of the world's supply of non-renewable energy resources is in the form of coal. Thus, the United States, with about 25 percent of the world's coal reserves, is in a most favorable position.

In applying various synfuels technologies to the conversion of coal to synfuels, the thermal efficiencies are about 40-50, 60-65, 65-70, and 70-75 percent for indirect liquefaction, gasification, direct liquefaction, and solvent refining, respectively.

Oil shale is found nonuniformly in the world with approximately two-thirds identified in the United States. Of the remainder, Brazil has about one-quarter with smaller quantities found in several other countries. It is not certain how effectively and efficiently synfuels can be produced from these identified resources of oil shale.

Tar sands are found in various countries in the world with major resources found in Canada, Venezuela, and the U.S.S.R. The United States has relatively minor quantities located almost exclusively in Utah. Unless newer and more efficient conversion processes are found, the U.S. resources will not support other than relatively small production efforts.

Thus far, there are no full-scale synfuels plants in operation in the United States. However, there are plants operating in various other countries, and some have been in operation for a number of years.

The United States does have several pilot plants in operation or in advanced preparation for operation. This is important experimentally in that actual samples of effluent and other source terms can be obtained for use.

If health and environmental protection research can continue on a concurrent basis with engineering development of synfuels technologies, these efforts will come to fruition in time to guide decisions regarding full-scale production methods and priorities. Results of such efforts can help provide guidance in control technology, avoidance of accidents, remedial actions to spills and other contaminating events, and appropriate modification of the process and the product.

As summarized by Gray and Drucker (Gr81), various epidemiological studies and toxicological research on several synfuels conversion processes have suggested that the products may have carcinogenic properties as well as greater acute and chronic toxicity when released to the environment as compared to crude petroleums.

As with any new technology, it behooves us to fully evaluate synfuels technologies before they are extensively used in the United States. We must understand their nature and characteristics and develop the appropriate data base to document their health and environmental effects and thus undergird the development of regulatory standards and strategies.

Risk analysis is a useful tool in this effort and can be used to predict the frequency, characteristics, and severity of health and environmental consequences.

An initial step in the process of assessment (risk analysis) is the identification and quantification of the possible source terms from the various synfuel technologies as well as from the handling and use of the synfuels. Information and data in this regard are contained in a series of four reports produced by TRW Energy Technology Division (TRW83a, TRW83b, TRW83c, TRW83d).

Three of the reports provide estimates of source terms for liquid synthetic fuel technologies; whereas the fourth contains an analysis of the various aspects associated with utilization of synfuel products. Results are given in terms of Risk Assessment Units (RAU) (Mo82)[1]. In the three conversion process reports (TRW83b, TRW83c, TRW83d), the technologies are described and eight processes are discussed. For example, in the direct coal liquefaction process, H-coal, SRC-I, SRC-II, and the Exxon Donor Solvent methods are covered; in the indirect coal liquefication process, Fischer-Tropsch synthesis via Lurgi and Koppers-Totzek gasification methods are presented; and the TOSCO II and Paraho processes are contained in the report on oil shale extraction.

The fourth report, "Source Term Estimates for Synthetic Fuels Technologies Analysis of Product Utilization"(TRW83a), characterizes the products produced by the eight synthetic fuels processes described in the companion reports, discusses the likely mode of transportation, and describes the end uses of each product.

1 This Unit will be defined and discussed in Section III of this Report.

III. ASSESSMENT OF SYNFUELS TECHNOLOGIES

The assessment of synfuels technologies is complex due to the multitude of potential effluents and their chemical and physical forms, the various media these are in, the effects of process parameters, and the uncertainty as to which technology may reach commercial scale and begin production. Thus, the approach has been to examine all feasible technologies as their development progresses.

Our interest is assessment of the health and environmental effects of the synfuels technologies as they relate to the workers in the conversion process and to the public and the environment due to potential impacts resulting from the synfuels technology or the use of synfuels. This is a broad scope, but it is critical in establishing pertinent regulatory standards and controls.

In order to deal with the multitude of chemicals involved in the effluents and products of synfuels technologies, the approach was taken to group these in categories which were designated as Risk Assessment Units (Mo82). The procedure would then be to select one or more representative chemical components from an RAU for studies of effects. This process would then make the system manageable and allow progress to be made in the research and development in a reasonable time frame.

The RAU's were designated based primarily on their chemical characteristics. Other factors could be used, such as technology production parameters or health and environmental effects. The list of RAU's is shown in Figure 1 and had 38 categories.

FIGURE 1
RISK ASSESSMENT UNITS/CATEGORIES

NUMBER	CATEGORY	DESCRIPTION
1	Carbon Monoxide	CO
2	Sulfur oxides	SOx
3	Nitrogen oxides	NOx
4	Acid gases	H_2S, HCN
5	Alkaline gases	NH_3
6	Hydrocarbon gases	Methane through butanes, acetylene, ethene through butenes; C_1-C_4 alkanes, alkenes, alkynes and cyclo compounds; bp<~20° C
7	Formaldehyde	CHO
8	Volatile organochlorines	To bp~120° C; CH_2Cl_2, $CHCl_3$, CCl_4
9	Volatile carboxylic acids	To bp~120° C; Formic and acetic acids only
10	Volatile O&S heterocyclics	To bp~120° C; Furan, THF, thiophene
11	Volatile N heterocyclics	To bp~120° C; pyridine, piperidine, pyrrolidine, alkyl pridines
12	Benzene	Benzene
13	Aliphatic/alicyclic hydrocarbons	C_5 (bp ~ 40° C) and greater; paraffins, olefins, cyclocompounds, terpenoids, waxes, hydroaromatics
14	Mono/Diaromatic hydrocarbons (excluding benzene)	Toluene, xylenes, naphtahlenes, biphenyls, alkyl derivates
15	Polycyclic aromatic hydrocarbons	Three rings and greater; anthracene, BaA, BaP, alkyl derivatives
16	Aliphatic amines (excluding N-heterocyclics)	Primary, secondary and tertiary nonheterocyclic nitrogen, $MeNH_2$, DiMeNH, TriMeN
17	Aromatic amines (excluding N-heterocyclics)	Anilines, naphthylamines, amino pyrenes; nonheterocyclic nitrogen

18	Alkaline nitrogen heterocyclics ["aza-arebes"] (excluding "volatiles")	Quinolines, acridines, benzacridines; excluding pyridines
19	Neutral N, O, S heterocyclics (excluding "volatiles")	Indoles, carbazoles, benzofurans, dibenzothiophenes
20	Carboxylic acids (excluding "volatiles")	Butyric, benzoic, phthalic, stearic
21	Phenols	Phenol, cresols, catechol, resorcinol
22	Aldehydes and ketones ["carbonyls"] (excluding formaldehyde)	Acetaldehyde, acrolein, acetone, benzaldehyde
23	Nonheterocyclic organo sulfur	Mercaptans, sulfides, disulfides, thiophenols, CS_2
24	Alcohols	Methanol, ethanol
25	Nitroaromatics	Nitrobenzenes, nitropyrenes
26	Esters	Acetates, phthalates, formates
27	Amides	Acetamide, formamide, benzamides
28	Nitriles	Acrylonitrile, acetonitrile
29	Tars	
30	Respirable particles	
31	Arsenic	As, all forms
32	Mercury	Hg, all forms
33	Nickel	Ni, all forms
34	Cadmium	Cd, all forms
35	Lead	Pb, all forms
36	Other trace elements	
37	Radioactive materials	Ra-226
38	Other remaining materials	

The work on the RAU concept and its development was done by a group of researchers in the field during 1981 with the final list completed early in 1982. During 1982 the decision was made to replace Unit with Category which was a more definitive and meaningful term.

This concept proved very useful. It permitted a rational grouping of the myriad of chemical compounds potentially produced and emitted from a synfuel site. Thus, it provided common analysis categories for the assessment of health and environmental effects.

The RAU/RAC concept was reviewed by a Peer Review Group in early 1983 and one of its comments is paraphrased below:

> The RAU concept adopted for health and environmental assessments seems to be a workable compromise between the overwhelming problem of dealing with a large number of chemicals on a case-by-case basis and the intractable problems associated with risk assessment of complex mixtures. The approach has certain limitations, e.g. the toxicity of an RAU category for one industry may be quite different than that of the same category for another industry, but these difficulties seem surmountable if rigid estimates of RAU toxicity are avoided. The rationale provided for use of RAU's was straightforward and reasonable, chemical categorization must be compatible with analytic methods, and categories should be mutually exclusive and collectively exhaustive.

The work on RAU/RAC was done under the direction of the Integrated Health and Environmental Risk Analysis Program (IHERAP) of the Office of Research and Development (EPA). Its functions were reorganized and work was launched early in 1981. Research was performed both at EPA facilities and under contract with appropriate outside organizations. Major groups involved with this work are:

Industrial Environmental Research Laboratory - Research Triangle Park, North Carolina

Environmental Research Laboratory - Corvallis, Oregon

Environmental Research Laboratory - Duluth, Minnesota

Environmental Research Laboratory - Athens, Georgia

Brookhaven National Laboratory - Upton, New York

Oak Ridge National Laboratory - Oak Ridge, Tennessee

Los Alamos National Laboratory - Los Alamos, New Mexico

Comparative Animal Research Laboratory - Oak Ridge, Tennessee

University of Wyoming - Laramie, Wyoming

Georgia Institute of Technology - Atlanta, Georgia

Tennessee Valley Authority - Chattanooga, Tennessee

There were also other major interests and programs in synfuels technologies and their health and environmental effects. These were undertaken by the:

U.S. Department of Energy

National Institute of Occupational Safety and Health

U.S. Synthetic Fuels Corporation

Mechanisms to provide effective coordination and cooperation in appropriate common areas of work were established early in the program effort. There were frequent contacts and meetings amongst researchers as well as exchanges of correspondence and reports, liaison meetings, and joint research conferences. In most cases, representatives of the Federal agencies participated in each others meetings in synfuels related work.

A chronology of major events in the history of the Integrated Health and Environmental Risk Analysis Program for Synfuels is presented as Figure 2. It includes important events in the management and direction of the program and covers such things as Peer Review Group meetings, User Review Meetings and Workshops. Details of these events are contained in the project files and/or reports published in the scientific literature.

Work was needed to identify potential health and environmental adverse effects, quantify the nature and characteristics of these effects, transform these quantitative estimates of hazards into estimates of risks to man and the environment, and develop effective regulatory standards and control procedures.

Work on synfuels technologies from the engineering viewpoint and in atmospheric effluents was centered at the Industrial Environmental Research Laboratory, Research Triangle Park. The Tennessee Valley Authority also had a roll in the area of synfuels technology due to their work in energy production.

The occupational health and safety aspects of the program were a cooperative effort by Brookhaven National Laboratory and Los Alamos National Laboratory.

FIGURE 2

INTEGRATED HEALTH AND ENVIRONMENTAL RISK ANALYSIS PROGRAM
CHRONOLOGY OF EVENTS

TIME FRAME	EVENT	PLACE
November 17-18, 1980	Scoping Meeting	Oak Ridge, TN
March 3, 1981	Reorientation Memo	Washington, D.C.
April 21-22, 1981	Dixon Committee Meeting	Oak Ridge, TN
July 21-22, 1981	Categorization of Chemical Compounds Associated With Synthetic Fuels Technologies for Risk Assessment	Alexandria, VA
August 17-18, 1981	Combustion Product Evaluation	Alexandria, VA
October 5, 1981	Preliminary Report on RAUs	Oak Ridge, TN
November 4-5, 1981	User Review Group	Washington, D.C.
November 18-19, 1981	Peer Review Group	Knoxville, TN
January 25, 1982	"Final" List of RAUs	Washington, D.C.
May 6, 1982	Peer Review Panel (Health Effects)	Upton, NY
May 18, 1982	Peer Review Panel (Food Chain)	Oak Ridge, TN
September 23-24, 1982	User Review Group	Washington, D.C.
January 18-20, 1983	Workshop on Water Modeling	Atlanta, GA
March 22-24, 1983	Workshop on Food Chain Modeling	Washington, D.C.
March 29-30, 1983	Peer Review Group	Alexandria, VA
October 27-28, 1983	Peer Review Panel (Food Chain)	Corvallis, OR
December 14-16, 1983	User Review Group	Washington, D.C.
May 5, 1984	Program Suspended	Washington, D.C.
November 9, 1984	Peer Review Panel (Kosovo Study)	Upton, NY

Epidemiology and medical effects evaluation of the synfuels technologies were performed at Brookhaven National Laboratory as was the risk analysis for health effects.

The environmental assessments and environmental transport and fate models were a function of Oak Ridge National Laboratory as was the risk analysis for environmental effects.

Food chain models were developed and implemented at ORNL. Research to develop necessary parameters and data for the models was done at three laboratories, considering both the needs of the food chain models and the priorities established by the health effects groups.

Studies on uptake, distribution, and retention of selected RAC chemicals by cows, swine, and poultry were done at the Comparative Animal Research Laboratory in Oak Ridge. The plant uptake, distribution, and retention studies of a terrestrial nature were done at the Environmental Research Laboratory, Corvallis, whereas the work related to aquatic species was performed at the University of Wyoming and at the Environmental Research Laboratory, Duluth.

The Environmental Research Laboratory, Athens, was involved with the water pathway and especially work on the modeling of synfuels chemicals.

Certain management functions including responsibility for Workshops and the Peer Review Process were located at the Georgia Institute of Technology.

IV. OCCUPATIONAL HEALTH ASSESSMENT

Due to the lack of large-scale operational synfuels plants in the United States it was necessary to utilize other types of facilities, with some comparable characteristics, to study the occupational health aspects of synfuels technologies. The other approach was to identify and use a large-scale, commercial synfuels plant located in another country. Both approaches were instituted and are represented by studies on coke-oven workers and workers at the coal gasification plant in Oblic, Yugoslavia, Autonomous Province of Kosovo, which is operated by Elektroprivreda Kosovo.

The purpose of these studies was to relate occupational exposures of workers to synfuels chemicals (or comparable industrial chemicals) to various health parameters which may be identified and measured. Thus, the coke-oven worker population was to serve as a surrogate population for an actual worker population engaged in a synfuels technology.

COKE-OVEN WORKERS

The rationale for selecting the Pittsburgh coke-oven workers for study (surrogate group) was the similarity between the exposures to toxic substances in coal hydrogenation technology and coal conversion to coke. Also, there is a large amount of epidemiologic data available on the coke-oven population, and it demonstrates the risk of respiratory and genitourinary malignant disease is significantly increased.

A fundamental reason for a study of the coke-oven workers was to demonstrate the usefulness of a unique approach to health and environmental risk analysis. Thus, while the synfuel industry is being developed on a small-scale basis, the analysis of its technology, products, and waste streams as to their health and environmental effects should provide a solid basis for environmentally sound practices in technology development.

Concurrent with the study of coke-oven workers, there were plans being made to conduct a large-scale epidemiological study of coal gasification workers in Yugoslavia. The coke-oven worker study would thus serve as a small-scale pilot study in which to use, evaluate, and modify the proposed clinical measure's methodology of the Yugoslav project.

The four objectives of the pilot study are taken from an unpublished report "Coke-Oven Workers Study" (Mi84).

1. To evaluate the epidemiological and clinical methodologies to be used in the Yugoslav project.
2. To identify, if possible, potential occupationally-related morbidity effects.
3. To provide information to be used in the Integrated Health Risk Analysis Program based on human exposure to chemicals that represent risk assessment factors or are surrogates for Risk Assessment Categories (RAU's).
4. To provide data on the upper levels of health impact of synfuels related production and processes for input into an Integrated

Health Risk Analysis. These data relate work site exposures to relevant pollutants and toxicants to the health status of workers and neighboring populations.

The initial plan was to evaluate coke-oven workers with 20 years employment in the same plant and with a minimum of five years "topside" exposure, and control subjects, matched by age, sex, race and cigarette smoking history, employed for 20 years in the same plant, but never as cokers, i.e. non-exposed.

Planning also called for the transport of the members of the study population to the Medical Research Center at Brookhaven National Laboratory for three days of medical evaluation including standard clinical tests plus more recently developed test procedures. These new procedures included cytogenetics (chromosomal aberrations and sister chromatid exchange), *in vitro* cultures of hematopoietic percursor cells (CFU_c, BFU_e, CFU_e), ventilation - perfusion lung scans, and benz-a-pyrene DNA adducts measured in peripheral blood cells. Each person would also have a complete occupational chemical exposure profile determined.

The report (Mi84) presents in detail the rationale and objectives of the Pittsburgh coke-oven worker study, the selection of workers, clinical health assessment procedures, and exposure assessment procedures. The report also compares the actual study outcomes to the expected outcomes and discusses lessons learned from the actual processes. These lessons are then to be applied to the final designs of the Yugoslav study as well as any future planned, similar U.S. studies. Finally, the text concludes with descriptions of the study findings and recommendations.

Several very important lessons were learned from this study. There was a severe selection bias of both workers and controls due to a variety of reasons. These included the effects of a recent strike, financial loss to take the several days needed to participate in the study, and the inconvenience of traveling to New York for the clinical evaluation. These and other causes also minimized the number of workers willing to participate.

It was also difficult to obtain any meaningful exposure data on workers. Causes included many uncertainties in obtaining occupational histories, lack of information on specific exposure histories, and the inability to make arrangements for the collection of pertinent samples in the work place.

Also complicating this situation is the meager amount of information in the literature on exposures of workers to specific chemicals. Exposure data are generally available as a coal tar pitch volatile measurement which is a nonspecific analytical procedure for monitoring benzene or cyclohexane soluble compounds and thus not very useful for addressing exposures in terms of specific chemical species (RAU's). Thus, it was not possible to develop useful exposure profiles for the individuals studied, except for coal tar pitch volatiles.

A large amount of time, over an extended period, was devoted to negotiations with industry management and union representatives. Also, industry management, although willing to comply with the law or union contract clauses in the release of information, would not release information which may be detrimental to future negotiating positions or which may indicate over exposures to future occupational health standards. The lesson is that future U.S. studies must identify other mechanisms to obtain the understanding and cooperation among the workers that the benefits of participation in health effects studies are important to the worker, his family and his co-workers.

These lessons learned were carefully reviewed as to guidance for the Yugoslav study. Many factors involved are different between the two sites. In Kosovo there would be complete and full participation by management and the workers and, thus, no self-selection bias. Work dossiers, containing a record of all lifetime employment, are maintained for each worker. A clinic and a laboratory are fully staffed and available for worker medical examinations as well as specimen collection and analysis. Also, at the Kosovo Plant, exposure data were obtained by actual industrial hygiene sampling measurements.

Conclusions for the Coke Oven Workers Study, in addition to those summarized as lessons learned, are given below (Mi84):

> Complete cooperation by workers and management is necessary for the success of any in-depth health assessment evaluation of workers for morbidity. The health evaluation and occupational history exposure questionnaires were satisfactorily validated. Information was obtained on several new experimental clinical evaluation test procedures as predictors of disease. New information was obtained and understanding improved regarding basic mechanisms and

synergistic effects that coke-oven emissions (complex mixtures) have on human health. Epidemiologic study methodologies, full-scale retrospective and prospective, were substantiated.

KOSOVO COAL GASIFICATION PLANT WORKERS

The Kosovo coal gasification plant was selected for study because it was readily available for study and was a large-scale operating facility which has been in use since 1973. It employs Lurgi East German technology and design and produces medium BTU commercial gas as well as several other products.

The research study was a joint cooperative effort of the U.S. Environmental Protection Agency, the U.S. Department of Energy, and the National Institute of Occupational Safety and Health in the United States and various groups in Yugoslavia. These include the Institute Kosovo, University of Kosovo (formerly University of Pristine), Institute for Application of Nuclear Energy to Forestry, Veterinary Medicine and Agriculture, Institute for Medical Research and Occupational Health, and the cooperation and assistance of Elektroprivreda Kosovo which operates the coal gasification plant in Oblic (outside Pristina) in the Autonomous Province of Kosovo.

United States interest in the study of this Yugoslav synfuels plant center on three areas:

1. An occupational health study of workers in an actual operational facility before one is placed in operation in the United States.

2. Possible generic use of the results in the continuing health and environmental evaluation of synfuels technologies.

3. A long-range interest in continuing the policy of cooperative scientific exchanges with Yugoslavia.

Of course, it is well recognized that the Kosovo plant is of an old design and has limited pollution and occupational health engineering control features. However, results could represent a "worse case" exposure situation which could provide valuable information for use as guidance in the design, construction, and operation of coal gasification plants in the United States.

The coal gasification plant is operated as part of a large industrial complex. The gas produced is used partly for fuel and partly for fractionation; that is, for the recovery of hydrogen which is further used for ammonia synthesis. The fraction of gas after hydrogen recovery is enriched with methane which is mixed with the remainder of pure gas.

Major components of the coal gasification plant are:

1. Six generator units.
2. A condensation plant.
3. A rectisol plant for purification of raw gas.
4. An air separation plant (oxygen and nitrogen are produced).
5. A tar and medium oil separation plant.
6. A phenol separation plant.
7. A plant for biological treatment of waste waters (not operated).

The coal for the conversion process is obtained from two strip mines located nearby. These mines produce lignite coal which is pulverized and dried by the Fleisner drying procedure before use in combination with oxygen and superheated steam at a pressure of 23 bars and a temperature of 350°C.

Previous cooperative work with the Kosovo facility has been done for several years by Radian Corporation and various Yugoslav institutions and supported by the EPA's Industrial Environmental Research Laboratory - Research Triangle Park, NC. Much of this effort was to characterize process streams and fugitive emissions at the gasification plant.

The basic purpose of the study was to conduct an occupational health assessment of workers engaged in a coal gasification facility as one of the synfuel technologies. It would thus provide an opportunity: to assess the impact of a coal gasification facility on the health of its workers and the community adjacent to the facility; to evaluate the feasibility and acceptability of present safety and health standards for the protection of workers and the applicability of work practices and control procedures; and to obtain needed information and data well in advance of large-scale synfuels technology development in the United States.

Initial efforts by the Yugoslavs were initiated in 1980 to evaluate the health consequences that the coal gasification imposed on the workers and the local, general population. In 1983, a second phase joint cooperative effort to be conducted by investigators from the United States and

Yugoslavia was negotiated. It was to be a comprehensive health effect study consisting of industrial hygiene (exposure), epidemiological, and clinical components.

The industrial hygiene program was designed to: characterize the chemical and physical stresses in the workplace; investigate the use and effectiveness of engineering control systems, and employee and administrative work practices; evaluate plant and comparitive population exposures; conduct special studies to assist the clinical and epidemiology programs; develop information and technology transfer between United States and Yugoslav coal gasification plants; initiate technology transfer to Yugoslavs for subsequent routine monitoring; and to accomplish communication, liaison, and logistic activities with the Yugoslavs as needed (Ja84a).

The purpose of the investigations of the health effects from exposure was to evaluate the potential impact of the plants' operation on the workers and the general public (Mor85d). Effects of exposure to various chemicals in the working environment will be studied in detail in the exposed and control workers. Detailed assessments of the effects on people working in the generator plant, phenolsolvan plant, and rectisol plant will be made. Similar procedures will be employed to any population exposed to various contaminants. The industrial hygiene studies, carried out concurrently with the clinical and epidemiological investigations, will allow the establishment of a cause/effect relationship between the presence of chemical substances and health impairments, if such are observed.

Progress and the status of these research efforts are discussed in a report by Morris (Mor85a). He also discusses the background of this cooperative work, including the agencies and groups involved and the specific responsibilities of individual organizations. According to Morris, the responsibility for industrial hygiene and exposure monitoring were split among BNL, LANL, and the NIOSH Morgantown, WV, laboratory whereas the BNL had responsibility for health effects and epidemiology.

The protocol for the July, 1984 characterization campaign (Ja84a) and the strategy for the industrial hygiene personnel sampling campaign scheduled to begin in March, 1985 (Ja84b) were developed by the cooperative work of BNL, LANL, and NIOSH groups.

Detailed plans for the research on health effects and epidemiology were prepared by the BNL (Mor84a). Early efforts in these areas address respiratory illnesses and skin cancer.

Essentially all these efforts were cooperative ventures between Yugoslav and American scientists and support personnel. The expertise of each country was used effectively.

These studies are continuing although certain preliminary results and conclusions have begun to appear. For example, an entire session of "The 1985 American Industrial Hygiene Conference" in Las Vegas, NV in May, 1985 was devoted to the title "Occupational Health Study of the Kosovo, Yugoslavia, Coal Gasification Plant" (AIHC85). Papers ranged from an overview of the study and a discussion of the Lurgi process at Kosovo to the details and results from the industrial hygiene, clinical, and epidemiological studies. The authors of these papers were from Yugoslavia and the United States.

Results of the 1981-82 Yugoslav conducted sampling, the 1984 joint United States/Yugoslav area sampling campaign, and the 1985 joint personnel sampling campaign all show that worker exposures to a wide variety of coal gasification airborne workplace contaminants are usually below occupational exposure limits (such as those of the American Conference of Governmental Industrial Hygienists). On the other hand, acute exposure to such contaminants as CO and H_2S can occur due to process leaks. These observations must be tempered in view of the fact that engineering control of airborne contaminants is not as extensive at Kosovo as would be found in the United States and that maintenance and upset event exposures were not included (Ja86a, Ja86b). The latter report, Ja86b, is a draft report on the Industrial Hygiene Program as a part of the overall report on the Kosovo studies.

V. SUPPORTING ACTIVITIES

To evaluate the exposures and effects of synfuels chemicals on health and the environment, it is necessary to determine the extent to which these materials are taken up and retained in the food chain. For practical purposes the food chain is divided into two major categories, namely terrestrial and aquatic. In addition, the terrestrial category may be conveniently subdivided into plants used for food and food-producing animals.

ANIMAL RESEARCH

The work on food-producing animals was performed by the Comparative Animal Research Laboratory (Oak Ridge Associated Universities) in Oak Ridge, TN. This was an experimental effort to determine and evaluate the significance of food chain contamination from synfuels technologies by studying the ingestion, metabolism and retention of synfuels chemicals in chickens, pigs, and cows.

The goal was to develop data for use in the food chain analysis of synfuels-related chemicals by determining the uptake and biological retention of RAU/RAC compounds in food-producing animals (dairy cattle, swine, and poultry) and obtaining the transfer coefficients required for food chain exposure assessments. These species of animals are widely used by humans for supplies of meat, milk and eggs.

Specific goals of the project were to:(Ei82)

1. Determine the biological retention of representative compounds following acute and chronic oral administration to food-producing

animals; determine the accumulation and loss of these compounds in consumable products following an acute dose; and determine the rate of accumulation in tissues when they are administered chronically.

2. Determine and employ practical methodology for the isolation and quantitation of selected compounds that are representative of the major chemical classes found in synfuels products and waste materials.

This laboratory was also involved in the early research of plant uptake of synfuels chemicals. The goal of this phase of the work was to determine the extent of uptake, transport, and concentration of representative compounds in selected vegetable crop species commonly used by man as foods. Included within the test plant selection was broad physiological and morphological diversity with reference to the plant organ used for human consumption (Sc82).

The report by Schwarz and Eisele (Sc82) represents a good summary of the rationale for the research materials selected for study, procedures used in both acute and chronic studies, sampling, analysis, and radiometric methods, species of animals utilized in the experiments, and certain results obtained for several RAU compounds.

Data for studies of naphthalene (RAU#14), naphthol (RAU#21), and 7-methylbenz (c) acridine (RAU#18) indicate that all three compounds are transferred to and found in various animal products, i.e. milk, eggs, and meat. Thus, for these chemicals there is a potential risk from the food chain. Similar results were obtained for studies of BaP (RAU#15) in chickens and pigs.

Early research work by this group using a hydroponic experimental system demonstrated that pea, onion, and lettuce plants took up naphthalene, naphthol, and 7-methylbenz (c) acridine and that the parent compound or its metabolites reached the edible portion of the plant in a relatively short time.

Other results from this group have been reported in the literature (Ei85a, Ei85b, Ei86). These data cover work on other synfuels chemicals, such as aniline (RAU#17) and indole (RAU#19), as well as additional information on the total program and its results. These other synfuels, when used in feeding experiments, demonstrate an accumulation and retention of them or their metabolites in consumable meats, eggs, and milk. Of course, in all the synfuels feeding experiments performed there is a difference in species and in tissue distribution and concentration. This suggests that exposures would depend upon the quantity of contaminated food consumed as well as the specific product involved.

The capability of biomagnification may allow an animal to accumulate relatively small quantities of chemicals into levels that are considerably in excess of that encountered in the environment. Since almost the entire animal is ulitized either directly (consumable products) or indirectly (animal feed additives, etc.), and with many animal products subsequently being recycled into alternate food products (dried eggs in baking products, etc.) which have a long consumer shelf life, the possibility of prolonged exposures of humans to low levels of chemicals must be recognized.

TERRESTRIAL PLANT RESEARCH

The terrestrial plant research was conducted at the Environmental Research Laboratory, Corvallis, OR. The overall goal of the plant research program was to obtain an understanding of the mechanisms of xenobiotic chemical uptake, translocation, accumulation, and metabolism in plants. This knowledge was then applied to the various chemicals associated with the several synfuels technologies. Models were developed which coupled the plant data with the movement of water, photosynthates, and mineral nutrients to predict vegetational bioaccumulation and food contamination and thus a portion of the environmental fate of toxic chemicals (Bo85).

An EPA report (McF86), "Plant Exposure Laboratory and Chambers" presents details on the design, construction, and operation of the laboratory and the exposure chambers. The objective was to be able to do plant uptake studies in a manner in which toxic and radio-labeled chemicals could be contained and controlled in an environment where plant physiological parameters can be observed and positively managed. This report also contains appendices which address the computer programs devised to manage the equipment and data from the exposure laboratory; the source code and description used for the control program; details of the construction drawings and parts list pertaining to the plant exposure chamber; the diagrams for electronic components of the laboratory; details of the construction and calibration of the thermistor used for temperature regulation; and the construction of the hydroponic plant nursery as well as the recipes for several nutrient solutions. Other computer management and calculational programs were developed to assist in the accomplishment of the experimental work.

Initial screening work was done using excised roots of barley plants to learn the uptake characteristics of toxic organic chemicals. A number of papers describe the experimental procedures (Wi85a, Wi85b) and the results obtained with a number of synfuels chemicals (McF85a, Wi83, Wi84). The paper by McFarlane and Wickliff (McF85a) is a summary of their work in using excised barley roots for uptake studies of several organic chemicals labeled with carbon-14. Chemical uptake rate constants for the chemicals tested were ranked in the following order: captan~phenol>aniline>ethanol~ indole ~ trifluralin ~ propanil>1,2,4-trichlorobenzene(TCB)>nitrobenzene~ atrazine>bromacil>simazine>monuron. Thus, captan was taken up more rapidly than the other chemicals studied. Such studies, of course, do not represent uptake of chemicals from soil into whole, intact plants, but they do represent a valid plant/chemical interaction which forms part of the complete system of chemical-plant kinetics, as noted by the authors.

Whole plant uptake studies have been completed with bromocil, phenol, nitrobenzene, captan, butanol 1,3-Di nitro benzene, 2,6-dechlorabenzonitrile, and para-nitrotoluene; and other uptake studies are scheduled. The results of studies for uptake of nitrobenzene and bromacil by hydroponically grown mature soybean plants are discussed in a presentation by McFarlane et al. (McF85b). Another report detailed the comparison of chemical fate in plants of 2 herbicides (bromacil and dichlorobenzonitrile) with two industrial chemicals (nitrobenzene and dinitrobenzens) (McF86a).

Related to this plant work was the development of a computer searchable data base on the Uptake, Translocation, Accumulation, and Biodegradation of Organic Chemicals in Plants (UTAB). A description of this data base and its use is in a paper presented at the Annual Plant Physiology meeting in June, 1985 (Va85). This data base was developed as an expansion of a data base, PHYTOTOX, developed at the University of Oklahoma.

Another output from personnel working in Corvallis research was the development of a plant uptake model. This model was described in a paper, "A Mathematical Model of the Bioaccumulation of Xenobiotic Organic Chemicals in Plants," by Boersma *et al*. (Bo85). The long-range plan is to parameterize this model for various plants and couple it with a soil model to allow prediction of plant uptake on the basis of chemical parameters.

ACQUATIC RESEARCH

The Environmental Research Laboratory, Duluth, MN and the University of Wyoming have been responsible for the work on aquatic toxicity data for synfuels process waters. The emphasis in this cooperative effort has been on aquatic hazard assessment of untreated process waters likely to be discharged, treated process waters, and process water fractions.

Primary and secondary objectives are taken from a research plan by Biesinger, *et al*. (Bi82):

Primary Objectives:

1. Evaluate the aquatic toxicity of potential untreated discharges from oil shale processing, coal gasification and tar sands extraction, emphasizing mine drainage waters, raw and spent oil shale leachates, and untreated process waters to be discharged to spent oil shale or ash piles.
2. Evaluate the aquatic toxicity of treated process waters from pilot-scale water treatment methods for oil shale processing, coal gasification and tar sands extraction, including retort, condenser, blowdown and air treatment wastewaters.
3. Identify principal toxic fractions and constituents in process waters studied under Objectives 1 and 2 from oil shale processing, coal gasification and tar sands extraction.

Secondary Objectives:

1. Compare chemical and toxicological characteristics of process waters from advanced fossil-fuel processing technologies to determine similarities and differences as a basis for minimizing needs for further toxicology characterization and for simplifying design requirements for treatment technologies.
2. Advance the state-of-the art in aquatic toxicology by comparing results of traditional methods (e.g., 96-hour flow-through acute, embryo-larval, and life cycle tests) with new candidate procedures which may be more sensitive or serve other testing objectives (e.g., pathology, behavior, population - level and community-level tests).

This research plan also presents results obtained, a proposed complex effluent hazard assessment scheme, and a summary of conclusions to date. These conclusions are that:

Oil shale process water toxicities are similar within groups.

Oil shale process water treatment effectiveness varies.

Raw oil shale leachate toxicities vary, depending on shale source.

Oil shale mine waters appear to be non-toxic.

Few data are available on spent oil shale leachates and shale oils.

Underground coal gasification process water toxicities are similar.

Tar sands process waters are less toxic than oil shale and coal conversion process waters.

Hazard assessment protocols are needed for synfuel-related products and waters.

A later report by Bergman and Meyer (Be83) in 1983 summarizes two years of research in aquatic ecosystem effects of process waters produced by synthetic fuel technologies. A major conclusion is that there is a wide variation in the toxicity of various waste waters, and, therefore, each must be evaluated individually. The report also contains some information related to possible treatment methods to reduce toxicity to aquatic animals.

Another aspect of this part of the research has been the development and operation of two information and data storage and retrieval systems. The first is titled AQUIRE for Aquatic Information Retrieval Data Base (Ru84). The objectives of this system were to provide a comprehensive, systematic, computerized compilation of aquatic toxicity data for single compounds, and to analyze toxicity data on sufficient chemicals and organisms to provide comparisons among organisms, chemicals, and test endpoints.

The second data base is named CETIS for Complex Effluents Toxicity Information System (Cr84, Gu84). The objectives of this system parallel those for ACQUIRE except that CETIS deals with complex effluents rather than single compounds.

Both of these data storage and retrieval systems are parts of the much larger data base systems in use by the Environmental Protection Agency. These programs are coded to facilitate ready access to the various data bases which comprise the total system.

VI. ENVIRONMENTAL RISK ASSESSMENT

Environmental risk analysis has been defined as the process of estimating the probability of adverse changes in the environment which are the result of human activities. This is an emerging field and a lot of effort has been directed towards its development during the past decade.

It was looked upon as a potentially important contribution to decision making in a report by Gove et al. in 1983 (Go83). These authors indicated the applications by Federal regulatory agencies of risk data for developing regulatory standards. They also pointed out the usefulness of risk analysis elements being integrated into research when appropriate.

These and other considerations were in mind in establishing the Integrated Environmental and Health Risk Analysis Program for Synfuels. It was envisioned that pertinent information and data could be developed which would be useful to the agency in regulatory decision making.

Hopefully, effluent waste streams from a technology process can be ranked by environmental risk; changes in risk level associated with various control technology options can be estimated; sensitivity of risk estimates to variables which are site dependent can be estimated; and areas where further research could reduce the uncertainty in and further refine estimates of risk can be identified.

Early efforts were directed toward identifying toxicological data, quantifying adverse environmental impacts from synfuels chemicals, developing environmental risk assessment methodology, applying the resulting methodology to specific examples of synfuels technology, and identifying of areas which required additional environmental research.

An early report by Barnthouse et al. (Barn82), which was titled "Methodology for Environmental Risk Assessment of Synfuels Technologies," described the procedures and methodologies planned for the environmental risk assessment for synfuels. Other literature citations regarding the methodology development for environmental risk assessment as well as results from the research are Barn84, Barn85c, Barn86a, Barn1, Barn2, Bart83, Bart84a, ON82, ON83, Su85b, Su1, and Su2.

The efforts were scheduled to cover risk assessment for three synfuels technologies (direct coal liquefaction, indirect coal liquefaction, and shale oil extraction), including five selected environmental endpoints (reductions in fish populations, development of algal populations, reductions in timber yield, reductions in agricultural production, and reductions in wildlife populations), five possible methods for estimating risk (analysis of extrapolation error, quotient method, fault tree analysis, analytic hierarchy process, and ecosystem uncertainty analysis), and comparisons of the results derived from the various methods for risk estimation. These efforts were discussed in detail by Barnthouse et al. (Barn82) and periodically by the ORNL personnel in progress reports, such as (Barn83a) and (Barn84a), which were made to the EPA Project Officer.

The toxicological data base was obtained from the literature and primarily through the various computer data bases which have been developed in recent years by EPA and other organizations. The availability of toxicity data for synfuels chemicals has increased appreciably during the last several years.

Since the United States does not have large-scale synfuels plants in operation, it was necessary to simulate several reference environments in which modeling could be done. The report, "Generic Environments for Synfuels Risk Assessments," by Travis et al. (Tr83) describes in detail the two reference sites selected as well as the alternate site.

Thus, the risk assessments are generic in nature in that they are for the purpose of evaluating risks associated with technologies rather than with those associated with specific plants at particular sites. The report (Tr83) also discusses the near-field and the far-field of each reference site with emphasis on the near-field in which significant concentrations of at least some of the synfuels chemicals might be expected to occur.

The important parameters considered by Travis et al. (Tr 83) in selecting sites for synfuels technologies were an ample source of synfuels stock of satisfactory quality, a reliable and sufficient supply of water of adequate purity, and industrial interest in developing it as a synfuels facility site.

In each case, the physical description (terrain, meteorology, surface and subsurface hydrologies, and vegetation in the region), ecological populations-at-risk (resident aquatic flora and fauna, resident terrestrial flora and fauna, and nonresident members of these groups), and human populations-at-risk (people residing in the region, people who consume water from the region and people using foodstuffs from or derived from the region) are described and discussed for each of the selected reference sites. Various relevant parameters for these sites are contained in several appendices.

The reference site for the oil shale treatment facility is the region of the Green River Formation of northwestern Colorado, southwestern Wyoming, and northeastern Utah. There are large resources of oil shale in this region and the quality of the deposits is quite high. For analogous reasons, the generic environment selected for a coal liquefaction site is the region denoted as the Appalachian Basin. This region is centered in eastern Kentucky and western West Virginia. There is a large and ready supply of coal in the region which is undesirable for many other purposes.

These reference sites, the western one and the eastern one, readily meet the resource and water supply criteria and would seem desirable for large scale industrial development if decisions are made to proceed with an oil shale extraction technology facility or a synfuels plant for coal liquefaction. Perhaps the characteristics of these two reference sites are different as to their physical environments, ecological populations-at-risk, and human populations-at-risk.

An alternate reference site was selected for some synfuels facilities in the Fort Union Basin which is located in northwestern South Dakota, western North Dakota, and eastern Montana. There is an abundance of adequate coal and availability of good water in the region. Again, the characteristics of the physical environment, ecological populations-at-risk, and human populations-at-risk are much different from the two reference sites identified above.

The report by Travis, et al. (Tr83), titled "Exposure Assessment Methodology and Reference Environments for Synfuel Risk Analysis," presents an exposure assessment methodology for evaluating health and environmental risk from synfuels technologies and provides broad characterization for the two reference environments in which synfuels facilities might be sited. Certain modifications in the environmental assessment methodology and its applications are enumerated in this report.

The methodologies include atmospheric, aquatic, and terrestrial food chain pathways, and these are discussed in detail. The atmospheric pathway covers areas up to 50 km and those beyond 250 km from the site. These are well covered by existing models, whereas the main problem area is between 50 and 250 km from the site. The aquatic pathway covers surface and ground waters, whereas the terrestrial system includes drinking water, agricultural produce, beef and milk, and default values regarding site specific parameters.

Reference sites are the same as described in the earlier report by Travis et al. (Tr83). That is, each is described in terms of its physical environment, ecological populations-at-risk, and human populations-at-risk.

The report stresses that the methodologies and parameters are generic and intended only for screening purposes. Assessment methodology is described very well and important details regarding the environmental exposure assessment are given. Obviously, the reference sites are used for assessment as no commercial synfuels facilities are currently operational in the U.S.

A report, ORNL/TM-9070 (Barn85b), provides an analysis for all 38 RAU's (RAC's) when released on a unit basis into the environment. They provide results of a risk analysis study performed for the 38 categories of chemical contaminants that may be released to the environment by synthetic fuels production facilities. They discuss modeling of the environmental transport and fate of contaminants in the atmosphere and in surface water, quantification of risks with respect to the five ecological endpoints in the research protocol, and utilization of the two reference sites.

Using a uniform release rate for comparative purposes, the risk analysis is limited to estimating the relative risks of the various RAU's as functions of their environmental chemistry and toxicology. Tables present the effects on specific endpoints and rank the RAU's accordingly. The rankings were determined by several procedures and differ somewhat in relative values although the rankings are highly correlated.

Barnthouse, et al. (Barn85b) also identified a number of fairly significant uncertainties in their work. The quantification of uncertainties in risk analysis for ecological systems has been addressed by Barnthouse et al. (Barn83b), whereas problems related to ecotoxicity data extrapolation are discussed by Suter et al. (Su84b, Su85a). Toxicological data suitable for use in risk analysis are fairly abundant for fish and relatively sparse for other organisms (Su83). Frequently, the diversity and lack of comparability of the test systems used limit the utility of the existing data. When considering uncertainty in expected environmental concentrations of synfuels chemicals and predicted effects thresholds for fish to synfuels effluents, the uncertainty of the toxicological effects is much greater than that concerning environmental transport (Bart84b, Bart85).

The environmental risks associated with several synfuels technologies are presented in three recent reports, ORNL/TM-9074, "Environmental Risk Analysis for Direct Coal Liquefaction" (Su84a), ORNL/TM-9120, "Environmental Risk Analysis for Indirect Coal Liquefaction" (Barn85a), and ORNL/TM-9808, "Environmental Risk Analysis for Oil from Shale" (Su86). The primary purposes of these reports are to help guide environmental research on synfuels technologies by identifying the most hazardous synfuels chemicals and to determine the most important sources of scientific uncertainty regarding the fate and effects of these synfuels chemicals.

As indicated earlier, the strategy involves grouping the effluent synfuels chemicals into representative groupings, RAU's, utilizing reference sites which have characteristics of sites likely to be selected for commercial synfuels sites, and assessing environmental risks in terms of five specific adverse ecological endpoints; namely reductions in fish populations, timber yield (or undesirable changes in forest composition), agricultural production, and wildlife populations, and development of algal blooms that detract from water use.

A synopsis of each report is taken almost verbatim from the report's summary.

Report ORNL/TM-9074 (Su84a) on direct coal liquefaction contains results of a risk analysis of four direct coal liquefaction technologies: Exxon Donor Solvent (EDS), Solvent Refined Coal-I (SRC-I), Solvent Refined Coal-II (SRC-II), and H-Coal. All four technologies had equal capacities (2.72×10^4 Mg coal/d) and the same waste treatments. All were located in a reference environment resembling eastern Kentucky. Estimates of concentrations of released contaminants in the air, and surface water of the reference environment were obtained, using a simple Gaussian-plume atmospheric dispersion and deposition model and a steady-state surface water fate model. Concentrations in soil and soil solution were obtained from a terrestrial food chain model.

Risk to the five ecological end points were estimated using one or more of three methods: the quotient method, analysis of extrapolation error, and ecosystem uncertainty analysis. In the quotient method, estimated environmental concentrations were compared to toxicological benchmarks such as LC_{50}'s (lethal dose to 50% of the population exposed) available for standard test organisms. In analysis of extrapolation error, statistical relationships between the sensitivities to contaminants of the various taxa of fish and between acute-and chronic-effects concentrations were used to estimate, with appropriate error bounds, chronic-effect thresholds for reference fish species characteristic of the reference environment. Taxonomic extrapolations were used to express the acute effects of RACs in terms of a common unit, the 96-h LC_{50} for largemouth bass. The extrapolated LC_{50}'s and the source-term estimates were then combined and used to assess the acute toxicities of the whole effluents from the four technologies. In ecosystem uncertainty analysis, an aquatic ecosystem model was used to compute risk estimates that explicitly incorporate biological phenomena such as competition and predation that can magnify or offset the direct effects of contaminants on organisms.

With respect to fish, nine RACs were determined to be significant for one or more technologies. RAC 5 (ammonia) was the only RAC found to be significant for all technologies, waste water treatment options and analysis methods. RAC 34 (cadmium) was significant for all technologies and water treatment options according to the quotient method and by all three methods for EDS and H-Coal. The whole effluent from the H-Coal technology with conventional water treatment appeared to be the most acutely toxic. For all technologies, conventional pollutants appear to be more hazardous to fish than the complex organic contaminants usually associated with synfuels.

Algal toxicity data were available for only 10 RACs. Because of the diversity of experimental designs and test end points used in algal bioassays, it was not possible to rank the RACs using the quotient method. However, most of the toxicity quotients calculated for algae were lower than the corresponding quotients for fish. Ecosystem uncertainty analysis suggested greater risks of effects on algae than did the quotient method, primarily because reductions in grazing intensity related to effects of contaminants on zooplankton and fish. Both methods indicate that RAC 21 (phenols) and RAC 34 (cadmium) posed a significant risk to algal communities.

Conventional pollutants, especially SO_2 and NO_2, were found to have the greatest potential effects on terrestrial biota. Ground-level SO_2 concentrations for all technologies were within 1 to 2 orders of magnitude of phytotoxic levels, even excluding background concentrations. Gaseous pollutant levels were well below toxic concentrations for terrestrial mammals; however, it was not possible to assess risks to nonmammalian wildlife (e.g., birds). Of the materials deposited on soil, RACs 31 (arsenic), 33 (nickel), and 34 (cadmium) pose the greatest threat of toxicity. However, observable effects are unlikely unless these trace elements are deposited on soils with high background concentrations and chemical properties favoring the solution phase.

The report on indirect coal liquefaction, ORNL/TM-9120 (Barn85a) contains the risks associated with two indirect coal liquefaction technologies: Lurgi gasification with Fischer-Tropsch synthesis and Koppers-Totzek gasification with Fischer-Tropsch synthesis. The plant configurations evaluated were adapted from design information provided by the developers of the technologies. Both configurations reflect a feed coal capacity of 2.72×10^7 kg (30,000 tons) per day. Source terms for atmospheric and aqueous waste streams were based on published process conceptual designs and test data obtained from bench-scale, pilot, or demonstration units. Control technology efficiencies were extrapolated from similar applications in other industries.

A reference environment resembling eastern Kentucky or West Virginia was employed in the risk analyses. Estimates of concentrations of released contaminants in the air, soil, and surface water of the reference environment, were obtained, using a simple Gaussian-plume atmospheric dispersion and deposition model and a steady-state surface water fate model.

Risk to the five ecological endpoints were estimated using one or more of three techniques: the quotient method, analysis of extrapolation error, and ecosystem uncertainty analysis. In the quotient method, estimated environmental concentrations were simply compared to toxicological benchmarks such as LC_{50}'s available for standard test organisms. In analysis of extrapolation error, statistical relationships between the sensitivities to contaminants of the various taxa of fish and between acute-and chronic-effect concentrations were used to estimate, with appropriate error bounds, chronic-effect thresholds for reference fish species characteristic of the reference environment. Taxonomic extrapolations were used to express the acute effects of all RACs in terms of a common unit, the 96-h LC_{50} for largemouth bass. The extrapolated LC_{50}'s and the source term estimates were then combined and used to assess the acute toxicities of the whole effluents from the two technologies. In ecosystem uncertainty analysis, an aquatic ecosystem model was used to compute risk estimates that explicitly incorporate biological phenomena such as competition and predation, which can magnify or offset the direct effects of contaminants of organisms.

With respect to fish, nine RACs were determined to be significant for one or both technologies. RAC 5 (ammonia) and RAC 34 (cadmium) were the only RACs found to be significant for both technologies and all risk analysis methods. RAC 4 (acid gases) was significant for both technologies, according to the quotient method and analysis of extrapolation error; however, this RAC could not be addressed using ecosystem uncertainty analysis. The whole effluent from the Lurgi-based technology appeared to be somewhat more acutely toxic than the corresponding effluent from the Koppers-Totzek technology. For both technologies, conventional pollutants such as ammonia, cadmium, and hydrogen sulfide appear to be substantially more hazardous to fish than the complex organic contaminants usually associated with synfuels.

Algal toxicity data were available for only ten RACs. Because of the diversity of experimental designs and test endpoints used in algal bioassays, it was not possible to rank the RACs using the quotient method. However, most of the toxicity quotients calculated for algae were lower than the corresponding quotients for fish. Only RACs 33 (nickel) and 34 (cadmium) would be judged significant for any technology using the quotient method. Ecosystem uncertainty analysis suggested greater risks of effects on algae than did the quotient method, primarily because of reductions in grazing intensity related to the effects of contaminants on zooplankton and fish.

Conventional pollutants, especially SO_2 and NO_2, were found to have the greatest potential effects on terrestrial biota. Ground-level SO_2

concentrations for both technologies were within 1 to 2 orders of magnitude of phytotoxic levels, even excluding background concentrations. Gaseous pollutant levels were well below toxic concentrations for terrestrial mammals; however, it was not possible to assess risks to nonmammalian wildlife (e.g., birds). Of the materials deposited on soil, RACs 31 (arsenic), 33 (nickel), and 34 (cadmium) appear of greatest concern for phytotoxicity. However, observable effects are unlikely unless these trace elements are deposited on soils having pre-existing high concentrations of these elements and chemical properties favoring the solution phase.

The third report in this series for oil from shale, ORNL/TM-9808 (Su86) contains results of a risk analysis of the Paraho and TOSCO-II oil shale technologies. The source terms were estimated for commercial-scale operations producing 7.9 and 7.6 x 10^6 L/d of syncrude for Paraho and TOSCO-II, respectively. Because of Colorado State regulations, the plants were assumed to have no direct aqueous discharges. All wastewaters were assumed to be used to wet the spent shale, which is landfilled with other solid wastes. The chemical composition of the leachate from this mixture and its transport to ground and surface water were estimated. Atmospheric emissions were dispersed by a Gaussian-plume model, deposited on the landscape, and accumulated in the soil. The analyses, results, and conclusions of this research are intended to be generic and are not estimates of actual impacts of specific plants at specific sites.

The leachate was less dilute in the creek water than in the nearest well. Creek water contained several RACs in concentrations that exceeded a hundredth of measured toxic concentrations for fish, algae, livestock, wildlife, or irrigated crops. They are benzene, mono/diaromatic hydrocarbons, polycyclic aromatic hydrocarbons, alkaline N heterocyclics, neutral N, O, or S heterocyclics, carboxylic acids, phenolics, nickel, cadmium, and total dissolved solids. All of these categories deserve additional attention in future research and assessments; however, total dissolved solids (TDS) is the category that appears most likely to cause environmental problems because its incremental concentration is quite high (290 mg/L) relative to potentially toxic levels, and because the leachate will enter the Colorado River system where TDS is already a problem for both agriculture and aquatic life.

Of the atmospheric emissions, only SO_2 and NO_2 had predicted concentrations in air that were within a factor of 100 of thresholds for effects on growth or yield of flowering plants. Although these gases are unlikely to reduce crop or range yield at the predicted concentrations, site-specific assessments should consider the effects of rough terrain and background pollution levels on concentrations of these gases. Arsenic was predicted to accumulate in soil to concentrations that were greater than a tenth of those that are reported to reduce plant growth. Future assessments should consider the speciation of the emitted arsenic, transformations in the soil, and background concentrations of toxic trace elements in the soil.

None of the RACs appears to pose a significant threat to wildlife due to inhalation. However, the available data on inhalation toxicology is almost entirely derived from mammals and other taxa, particularly birds that may be considerably more sensitive.

Although they are not considered in this analysis, it appears that construction, mining, and waste disposal are more likely to reduce the productivity of plants and animals than are the emissions from shale processing. Major sources of uncertainty include the composition and transport of leachate from the mixed solid waste and wastewater, effects of accumulation of chemicals in wildlife food chains, effects on nonmammalian wildlife, and effects of terrain on air pollutant concentrations. Useful guidance for evaluating monitoring requirements for a synfuels technology site and for the determination of ranking of supplemental monitoring requirements is given in a recent report by Jones et al. (Jo86).

The final report from the ORNL group, "User's Manual for Ecological Risk Assessment," by Barnthouse et al. (Barn86b), is its most important product. This methodology, developed for use in the synfuels environmental risk assessment, can be applied to many other types of assessments. The User's Manual presents the rationale for the synfuels assessments, describes the derivation and mechanics of the three techniques used in those assessments of synfuels risks, and discusses the limitations and other potential applications of ecological risk assessment methods.

VII. HEALTH ASSESSMENT

It was, of course, recognized that synfuels technologies would produce a multitude of chemical products some of which could have adverse effects on biological systems, including people. Therefore, it was necessary to evaluate these chemical entities to determine those which were harmful, at what levels, and under what conditions.

Test procedures using a variety of biological end points were studied. For convenience, these can be divided into relatively short-term screening studies and those of long-term duration which usually are more definitive, more resource intensive, and require longer to evaluate.

The short-term screening tests included *in vitro* assays using various species and strains of bacteria for the detection of toxicity, mutations, and chromosome damage and recombination. Similar assays have detected toxicity, mutation, cell transformation, and chromosome damage utilizing cultured mammalian cells as the test organism.

Health studies of a long-term nature have used whole animals, especially rodents, to evaluate reproductive effects, skin carcinogenicity, inhalation toxicology, neurobehavioral toxicology, and teratology and developmental toxicology.

We have also used direct observation of humans and human-health-records to determine biological effects of synfuels technologies. These clinical and epidemiological procedures can be used when a population or worker group has been exposed to relatively high levels of contaminants and is available for direct or indirect study. Occupationally exposed groups fit into these categories as do certain populations that live in the areas adjacent to synfuels facilities which impact the surrounding environs from discharges of synfuels chemicals.

A complicating factor in health effects as well as environmental effect studies is that no actual synfuels by products and environmental emissions from commercial synfuels technologies facilities are readily available in the United States for evaluation. Therefore, products from a few pilot plants can be studied, and simulated effluents can be made and used on a surrogate basis. These procedures inherently introduce uncertainties into the bioeffects and environmental effects studies.

The actual effluents from synfuels technologies depend on the nature of the resource material, the technology employed, a variety of process parameters, the number and nature of any control procedures, and various features which are site specific. These are desirable problems when one considers the luxury of evaluating a complex energy technology from an environmental protection standpoint prior to its introduction into our industrial society.

The opportunity is thus available to perform health and environmental risk assessments on synfuels technologies during the very early formative and design stages of the technology development. This should be effective in that guidance and any needed controls can be identified early on and used to moderate plant design and operation. The process should be much more effective than waiting for plant design and construction or regulatory pressures based on immediate need.

Information and data on health effects of synfuels chemicals have been presented at a series of annual symposia hosted by Oak Ridge National Laboratory (Co80, Co84). These symposia have included many other aspects of synfuels technologies such as the engineering, chemical characterization, environmental transport and effects, occupational health, and control technologies.

The first of these symposia, "Synthetic Fossil Fuel Technology, Potential Health and Environmental Effects" was held in 1978, and the proceedings were published in 1980 (Co80). Seven papers at this symposium were devoted to biological effects studies and ranged from short-term mutagenicity studies using bacteria to studies using rabbits and mice to evaluate the toxicological and carcinogenic effects of shale oil products. In many of these studies, as well as others, positive results have been observed on the induction of adverse biological effects in the study species.

The proceedings of the 1982 Fifth Life Sciences Symposium, titled "Synthetic Fossil Fuel Technologies, Results of Health and Environmental Studies," was published in 1984 (Co84). There were eight papers devoted to subjects identified in the proceedings as "Toxicology and Transport, Transformation, and Fate". Many of these papers involved in vivo studies whereas Morris, et al. (Mor84c) addressed the use of comparative approaches in extrapolation to health risk. Four papers were based on research supported and sponsored by the Integrated Health and Environmental Risk Analysis Program for Synfuels (Co 84).

A good summary of the bioeffects of synfuels has been published by Rom and Archer (Ro80) as "Health Implications of New Energy Technologies". They address such areas as coal workers pneumoconiosis and respiratory disease, effects from coal liquefaction, and studies related to the production of liquid fuels from shale oil. There are many adverse health effects which have been noticed and documented.

Health experience from these and other health effects studies needs to be carefully reviewed and evaluated in order that steps can be taken in technology development to:

1. Help assure adequate worker protection.
2. Prioritize and select for further development those processes that present minimal or controllable carcinogenic hazards.
3. Insure the incorporation of adequate engineering control measures in plant design as operational procedures.

Many other literature citations can be found which deal with health effects studies of synfuels chemicals. Representative ones include an early review of potential impacts of oil shale technology by Slawson and Yen (Sl80), an article titled "Health Hazards and Pollution" (No80) which deals with chemicals from a coal liquefaction plant, toxicological assessment of refined shale oil using short-term microbial testing by Roa et al. (Ro81), a paper by Timourian et al. (Ti81) which deals with in vitro and in vivo testing of shale oil products using tests of comparative mammalian genetic toxicology (this test indicates that carcinogenicity decreases after hydrotreating and that since cytogenetic endpoints can be measured *in vitro*, *in vivo*, and in man this test can be used to relate test data to human exposure), and the article by Gray (Gr83) which reviews the research conducted on health and environmental effects of selected synfuels by Pacific Northwest Laboratories.

Health effects research has effectively demonstrated that various effluents from the several proposed synfuels technologies can cause a wide variety of detrimental biological effects. These results can be used for guidance in future technology planning as to priorities, control schemes, and evaluation systems.

The framework to accomplish a comprehensive evaluation of synfuels technologies as well as a comparison of their relative merits is risk assessment. This tool in terms of environmental risk assessment and health risk assessment will be reviewed as to its current status and applicability.

VIII. INTEGRATED HEALTH RISK ASSESSMENT

The health risk assessment aspects of the program were the responsibility of personnel at the Brookhaven National Laboratory (BNL) within the Biomedical and Environmental Assessment Division. The major goal was to assess the health risks associated with synfuels technologies. The research was not in direct support of regulatory development for synfuels, although it was recognized and appreciated that the assessments might at some future time be the basis for regulatory actions.

Program focus from the beginning was on a variety of media; i.e., considerations of concentrations of synfuels chemicals introduced into various environmental media. There were expectations that the synfuels program would be a good place to explore and employ integrated assessment on a pilot basis, and that this, in turn, might chart a similar course for the EPA to move towards consideration of integrated risk in its regulatory policy. At the time, the agency was media oriented and thus separately working with air, water, and solid wastes.

Potential health effects from synfuels chemicals cover a rather broad spectrum. However, perhaps the major concern of most people and many agencies is the induction of cancer. For this reason, the initial focus of the work at the BNL was on cancer induction in humans.

In the report BNL 51783 (Kr83), Kramer et al. describe and discuss the full range of health impacts associated with synfuels chemicals. The report reviews the literature for human health effects for each of the thirty-eight Risk Assessment Categories. Later, this report was completely updated.

The health risk assessment was broken down into hazard identification, dose-response assessment, exposure assessment, and risk characterization (NAS83). Such assessments can then be used by decision-makers in establishing regulatory options and in making decisions regarding allocation of priorities and research funding (Mor85c). Several recent reports review the background methodology, laws, and regulations related to cancer risk assessment (OTA81, OSTP84). Also, Anderson et al. (An83) described and discussed applications of quantitative risk analysis in the systematic process of deciding appropriate public policy.

Good estimates of cancer risks from synfuels chemicals was one aim of the BNL research team were efforts to define the uncertainty of those estimates. Therefore, a number of alternate models were set up to explore the uncertainty by observing the differences among models (Mor84b). Also discussed in this article by Morris et al. were a workable definition of health risk assessment, its applications, a step-by-step analysis of its principal components (hazard identification, dose-response assessment, exposure assessment, and risk characterization), and a concise summary of cancer biology.

An important activity was the extensive and comprehensive effort to review the literature to identify and characterize the input data needed to run the several selected models. In this process, lists of chemicals by

RAC were developed; the biomedical literature was searched for studies performed on those chemicals; results were then screened; and pertinent reports were selected for analysis.

The research programs' first analysis was for "unit effects" of selected synfuels chemicals using the six predictive models. These models, described by Morris, et al. (Mor84b), include three statistical models, probit, logit, and Weibull, and three stochastic models, one-hit, multi-hit, and multi-stage.

Results from this first analysis are contained in a draft report (Mor83) which was prepared for the EPA in May 1983. The report was titled "Cancer Risks from Unit Exposure to Chemical Risk Assessment Categories: A Data Base and Preliminary Application" and authored by Morris, et al. The use of unit effects was necessary because the final emission rates for each RAC to be applied for each of the synfuels technologies had not been determined and thus, there were no exposure estimates for specific synfuels technologies.

Unit effects applications also served to exercise the models and identify some of the weak points in the analysis and were useful in addressing questions of trade-off between air and water emissions of synfuels chemicals. These efforts were closely coordinated with the environmental assessment work at the ORNL and resulted in the production of population exposure estimates by RAC and by the selected pathways; namely air, water, and food chains. Exposure estimates were then coupled with the unit effects estimates to yield cancer risk ranges for each selected synfuels technology.

Moskowitz, et al. (Mos85) address potential tumor risks to public health from synthetic-fuel plants. The two plants selected for study were a direct liquefaction-Exxon Doner Solvent-and an indirect liquefaction-Lurgi-Fischer-Tropsch which were located at a representative site in the eastern United States. For these analyses, gaseous and aqueous waste streams were characterized, and the exposures modeled included those from inhalation, terrestrial and aquatic food chains, and drinking water supplies. The analysis suggested that emissions of polycyclic aromatic hydrocarbons, aromatic amines, neutral N, O, S, heterocyclics, nitriles, and other trace elements pose the largest quantifiable risks to public health. The authors point out several pertinent areas which need additional development to improve the model results.

Throughout this research effort, progress was reported in the literature and through various workshops and meetings which included EPA-organized peer reviews and users' meetings.

Some of the more formal presentations which were made by members of the research team from BNL are:

July 6-7, 1982	Workshop on Risks from Mixtures of Chemicals, Harvard University, "Comparisons of Ratio Determinations of Carcinogenicity," H. Fischer and "When More Than Additive is Less than Synergistic," J. Nagy.

September 7-9, 1982	Workshop on Problem Areas Associated with Developing Carcinogen Guidelines, Brookhaven National Laboratory, "Definitions of (Cancer) Potency," H. Fischer, Proceedings of Workshop were published as BNL 51779 (BNL84).
October 24-27, 1982	Fifth Life ORNL Sciences Symposium, Gatlinburg, TN, "Extrapolation to Health Risk: Use of Comparative Approaches," S. C. Morris. The Proceedings of this Symposium were edited by Ken Cowser and published in 1984 (Co84).
November 6-9, 1983	ORSA/TIMS Meeting, Orlando, FL, "Estimating Potential Environmental Cancer Induction from Proposed Synthetic Fuel Plants," S. C. Morris (Mor85c).
April 20, 1984	Brookhaven National Laboratory, Applied Mathematics Department Seminar, BNL, Upton, NY, "Estimating Cancer Risks from Environmental Emissions of Complex Technologies," S. C. Morris. Published as "Estimating Cancer Risk From Complex Technologies: A Users' Manual," S. C. Morris, et al., BNL 37220, October, 1985.
September 30-October 3, 1984	Society for Risk Analysis Meeting, Knoxville, TN, "Treatment of Uncertainty in Cancer Risk Analysis," S. C. Morris, et al.

October 20 - 24, 1985	Twenty-Fourth Hanford Life Sciences Symposium, Health and Environmental Research on Complex Organic Mixtures, Richland, WA, "Epidemiological Bases for Assessing Health Effects of Exposure to Complex Organic Mixtures: Need for Evaluation," Samuel C. Morris. Published in October 1985 as BNL 37307 (Mor85b).

The Users' Manual, BNL 37220, (Mor85c), produced by the research group at BNL, summarizes their work on this project and provides the necessary information to use these methods in extension of this program or in other suitable applications. Emphasis is on potential effluent discharges from synfuels plants to air, water, and food chains. However, the developed methodology is applicable to any technology.

IX. USER REVIEW MEETINGS

In order to establish and maintain effective communication between the synfuels research program and the potential users of the knowledge to plan, institute, and operate a regulatory program for synfuels, a system was set up to periodically hold Users Review Meetings.

These Users Review Meetings basically brought together the EPA Project Officer, the various members of research groups, and the EPA officials representing the components of the Agency which would be involved in developing and implementing a regulatory control program. Representatives from the EPA Headquarters as well as its Regional Offices participated.

Three Users Review Meetings were held. These occurred November 4-5, 1981, September 23-24, 1982, and December 14-16, 1983, in Washington, D.C. Two-way communications were continued between these special meetings by telephone, personal contacts, the exchange of correspondence, and dissemination of reports and other technical documents.

The process served to provide practical and timely input into the research programs and concurrently inform the users of the status, form, and nature of the research efforts as well as the plans for the future. These efforts were effective and mutually beneficial.

X. WORKSHOPS

In the course of the EPA Integrated Health and Environmental Risk Analysis Program for Synfuels, two workshops were held involving experts in risk analysis and those engaged in particular modeling efforts. The first was held in Atlanta, GA in January, 1983, and was titled "A Workshop on Water Modeling Needs and Available Techniques for Synfuels Risk Assessment" (Do83). A second workshop, "Workshop on Food-Chain Modeling for Risk Analysis," was held in Washington, D.C. in March, 1983 (Br85).

The emphasis of the first workshop was limited to available "water models". These are models for runoff, surface water, and soil/groundwater which are capable of predicting chemical migration and fate. The characterization of the current approach to synfuels risk assessment led to an identification of the current needs of risk analysis for water models. The principal need is for relatively simple models/techniques that provide estimates of environmental exposure concentrations with an acceptable level of uncertainty.

Of course, if a simple model does not provide the type of information and statistical characterization needed, it is necessary to proceed to more complex models if these are available for application. The workshop participants addressed this issue by contributing to the development of a hierarchy of different levels of available models/techniques, ranging from the simplest possible techniques to the most sophisticated models.

Particular models/techniques for each level of the hierarchy were identified, along with a characterization of the modes of transport, transfer, and transformation processes that are considered, and the usually expected uncertainty levels.

The goals of the workshop and the conclusions reached by the participants are taken from Donigan and Brown (Do83). The three stated goals were to:

1. Have those currently performing synfuels-related risk assessments describe their needs for models to predict chemical migration and fate in hydrologic systems.
2. Have those currently involved in the development, testing and application of such models respond to these needs by discussing the capabilities and limitations of current state-of-the art water quality and chemical fate models.
3. Provide an overview of the current potential use of water models for conducting risk analysis of chemical releases associated with synfuel technologies.

Presentations and discussions by participants at the workshop indicated that there is a wide variety of water models available for use which range from simple dilution type calculations, through those which may consider advection, dispersion, sorption, volatilization, hydrolysis, photolysis, and biodegradation, to those detailed, site-specific models/techniques which generally consider all the key transport, transfer, and transformation processes. Complex models provide higher resolution in space and time, and generally higher accuracy; however, they require a higher level of resource commitment for use.

Conclusions reached include the following:

1. At the present time, risk analysis is primarily comprised of screening level evaluations of alternative technologies, sites, exposure pathways and pollution control options, as opposed to site-specific evaluations of proposed facilities.
2. Evaluations are performed to identify information gaps, research needs, and needed regulations.
3. Resource and time constraints often limit the level of effort that can be devoted to the analysis of exposure levels.
4. Expected/allowable risk uncertainties are in the range of one to three orders of magnitude.
5. Because of the complexity of synfuels emissions, the risk analysis evaluates exposure and effects of categories of pollutants, as opposed to specific compounds. The use of representative compounds within each category (RAU) is the procedure, amenable to modeling, currently being utilized.
6. The characterization of expected emissions (i.e. the source term) involves significant uncertainties due to the lack of existing commercial scale synfuel facilities.

7. The exposure analysis is concerned with water-related migration and fate of contaminants contained in both potential point and nonpoint source discharges to waterbodies, and leachates generated by solid wastes and raw materials storage areas.

The second workshop focused on the terrestrial and aquatic food-chain models currently utilized in the process of risk assessment. To put these in perspective, Figure 3, from Breck and Baes (Br85), presents the components of the human health risk assessment methodology for synfuels technologies and shows the relationships of the aquatic and terrestrial food-chain transport with the other major parts of the overall process. Thus, in moving from the synfuel pollution source to the assessment of health risk to man, use is made of atmospheric and aquatic transport models, aquatic and terrestrial food-chain transport models, and models that estimate risks from calculated environmental exposures to synfuels chemicals (dose-response models).

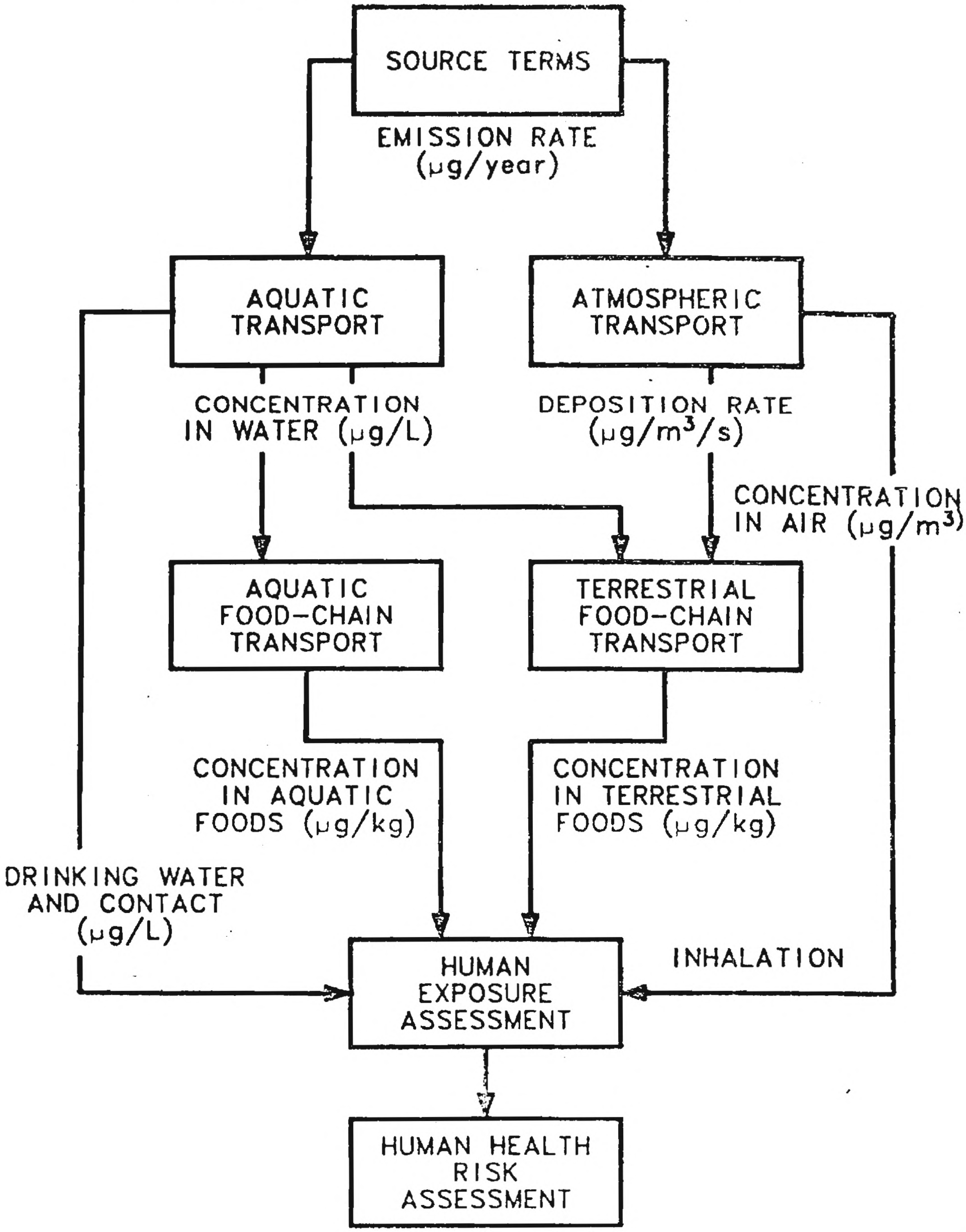
Objectives of the workshop were to obtain the recommendations of experts on:

1. Terrestrial and aquatic food-chain models best suited to synfuels risk analysis.
2. Data sources and parameter estimation methods best suited to synfuels risk analysis.
3. Major limitations on existing data and methods.

FIGURE 3

COMPONENTS OF THE OVERALL HUMAN HEALTH RISK

ASSESSMENT METHODOLOGY FOR SYNFUELS TECHNOLOGIES



Conclusions and major observations of the workshop participants included the following:

1. A simple concentration factor approach is appropriate in aquatic food-chain modeling of chronic low-level releases of synfuels effluents.
2. In terrestrial food-chain models there is a need for greater model complexity to account for location-specific variations in agricultural practice (of course, concentration factors can be used to estimate terrestrial transport).

3. For aquatic and terrestrial models, field data are the best basis for estimating concentration factors. When field data are not available, laboratory data can be used. If no data exist for a particular compound or class of compounds, estimates can be made using partition coefficients based on structure-activity relationships.
4. There exists a need to estimate the uncertainty associated with particular model output.
5. The terrestrial food-chain model needs to include a consideration of a good contamination pathway via foliar absorption and translocation to edible produce parts.
6. The model should consider use of soil degradation kinetics which may be predicted from structure/activity relationships. These would be discerned from examination of the pesticide data base.
7. The model should consider using a prediction of the synfuel compound concentration in the soil solution. This would allow the prediction of the traditional soil/plant concentration factor from hydroponic data and provide a means for assessing the impact of synfuels compounds on crops.
8. A careful consideration of the effects of food processing (especially cooking) on human exposures should improve the model.
9. Consideration of several additional areas which need to be included to define the food-chain model:
   a. inclusion of animal products other than beef and milk

b. accounting for differences in transfer coefficients resulting from livestock management practices

c. water and soil ingestion by livestock (in addition to food)

d. addition of irrigation water as a source term

e. capability to model acute exposures and sensitive populations

f. estimation of uncertainty associated with model predictions

10. Validation is the method not only to ensure that the assessment model is both appropriate and accurate but also to specify definitively the uncertainty associated with model predictions.

XI. PEER REVIEW

The Peer Review process has been used extensively in the U.S. Environmental Protection Agency and is, in essence, an integral part of scientific research. The Integrated Health and Environmental Risk Analysis Program for Synfuels utilized this important process as an essential and continuing function of its research efforts. Not only was the overall program reviewed periodically but also individual peer reviews were conducted on major program elements.

Peer Review Groups were established from time to time to review the entire program and were populated by outstanding experts in the field. Although members varied, there was always continuity represented by several individuals.

In an analogous manner, Peer Review Panels were formed to review major components of the programs such as Health Effects, Food-Chain, etc. These panels were usually smaller than the Peer Review Group and frequently had a member of the group as a participant in its review and evaluation.

Peer Review Groups and Peer Review Panels usually met for one to two days and produced a draft report at the conclusion of each meeting. This was followed up by submission of a final report submitted by the chairman to the EPA Project Officer on behalf of the members.

These meetings were preceded by the reading of pertinent reports and other written material. At the meetings, which were held at strategic locations, the group or panel was briefed by the individual researchers in accord with a predetermined agenda. There was discussion and interaction between researchers and peer reviewers. The procedure was then concluded by an executive session of the peer reviewers in which a draft report was formulated for prompt delivery to the EPA Project Officer. This was promptly followed by submission of the final peer review report.

In addition to the peer review members and the pertinent researchers, these meetings were attended by EPA program officials, the EPA Project Officer, users from relevant EPA organizational components, the Peer Review Group Executive Director, and small numbers of interested observers.

The users are of special importance as these were representatives from the EPA offices which would be involved in establishing and implementing a regulatory program for synfuels technologies.

The schedule of the various peer review meetings and other relevant information are presented in Figure 4, whereas pertinent detail on the composition of the Peer Review Groups and Peer Review Panels and their reports are included in Section XIV, Appendix.

This was an extremely important and useful procedure as it effectively helped guide the research and made numerous, beneficial suggestions and recommendations which were incorporated into the several scientific research efforts.

FIGURE 4

MEETINGS OF PEER REVIEW GROUPS AND PANELS

IDENTIFICATION	CHAIRMAN	DATES	LOCATION
Peer Review Group	Dr. N. C. Rasmussen	Nov. 18-19, 1981	Knoxville, TN
Peer Review Panel on Human Health Effects	Dr. A. C. Upton	May 6, 1982	Brookhaven National Laboratory, Upton, NY
Peer Review Panel on the Food-Chain	Dr. B. E. Vaughan	May 18, 1982	Comparative Animal Research Laboratory, Oak Ridge, TN
Peer Review Group	Dr. S. M. Greenfield	March 29-30, 1983	Alexandria, VA
Peer Review Panel on the Food-Chain	Dr. M. W. Carter	Oct. 27-28, 1983	Environmental Research Laboratory, Corvallis, OR
Peer Review Panel on Kosovo Study	Dr. J. Whittenburger	Nov. 9, 1984	Brookhaven National Laboratory, Upton, NY

XII. CONCLUSIONS

This Section presents in concise form the major conclusions which have been derived from the research conducted under the EPA Integrated Health and Environmental Risk Analysis Program for Synfuels. Other conclusions and various technical and scientific decisions are included in the text.

1. There are several raw materials, available in abundance, from which synfuels can be produced by a number of synfuels technologies. These technologies are producing synfuels in a number of countries whereas they are mainly in the pilot-plant stage in the United States with the exception of the Great Plains Coal Gasification project in Beulah, ND.
2. When synfuels technologies are developed for commercial operation in the United States, there will be a concurrent requirement for environmental and health protection programs to ensure protection, have environmental acceptability, assure a high degree of meeting regulatory requirements, and put in place a plan to monitor environmental and health related emissions.
3. A comprehensive evaluation of synfuels requires assessment of the occupational workers during the technology conversion process, the health and environmental effects from synfuels technologies, and the health and environmental effects from the uses of synfuels.
4. There is such a variety of complex chemicals associated with synfuels that it is necessary to establish a manageable system to deal with this wide spectrum of materials. The Risk Assessment Category (Risk Assessment Unit), consisting of some 38 categories of materials, was established for this purpose.

5. The approach taken to produce needed field and laboratory data to provide needed input into the risk analysis of health and environmental effects of synfuels was effective. Thus, laboratory and field research was integrated into the assessment models utilized for the evaluation of health and environmental effects.
6. There are a number of benefits which can be derived from having a close cooperative working relationship between two similar Federal agency programs. This type effective agreement was maintained between the U. S. Department of Energy Health and Environmental Assessment Program and the Integrated Health and Environmental Risk Analysis Program for Synfuels.
7. The occupational assessment of a surrogate study group, the coke oven workers, supplied useful information as to the protocols and procedures needed to effectively evaluate synfuels workers and technologies.
8. The Kosovo Coal Gasification Plants' work atmospheres are extremely variable. Samples from personnel are the only way to obtain meaningful exposure results and even then care must be taken when these results are interpreted as representative of a job classification or a group of workers performing the same job.
9. The occupational health evaluation of the Kosovo coal gasification plant workers shows that worker exposures to a wide variety of coal gasification airborne workplace contaminants are usually below occupational exposure limits such as the guidelines of the American Conference of Governmental Industrial Hygienists.

10. A number of chemicals, representative of particular RAU/RAC, are readily transferred to and found in various edible animal products such as milk, eggs, and meat.

11. Hydroponic system results indicate a transfer of many synfuels chemicals (representative of RAU/RAC) into plants.

12. Research in aquatic ecosystem effects of process waters produced by synfuels technologies shows a very wide variation in the toxicity of various waste waters.

13. Risk analysis is a valuable and useful methodology in the understanding and evaluation of environmental and health effects of synfuels. It will be an effective tool in the regulatory decision making process.

14. The availability of toxicity data for synfuels has increased appreciably during the last several years and this research program contributed appreciably to this data base.

15. The concept of using generic environments for synfuels risk assessments is useful, since commercial synfuels technologies are not in operation in the United States.

16. Specific adverse ecological endpoints have been developed and quantified for use in the assessment of environmental risks.

17. The User's Manual for Ecological Risk Assessment presents the only risk assessment methodology available for the effects of synfuels on non-human biota, and this methodology can be applied to other types of environmental contaminants.

18. The opportunity to study and evaluate health and environmental effects of synfuels, prior to large-scale use of synfuels technologies on a commercial basis in the United States, is recognized as a real advantage.

19. There is a variety of short-term screening tests, such as in vitro assays using bacteria and cultured mammalian cells to detect toxicity, mutations, chromosome damage, and recombination, as well as long-term studies using whole animals to evaluate reproductive effects, inhalation toxicology, skin carcinogenicity, neurobehavioral toxicology, and teratology and developmental toxicology, available for assessing biological and health effects of synfuels.

20. Six predictive models, including three statistical and three stochastic models, were used to evaluate health effects and the uncertainties associated with them for "unit discharges" from synfuels technologies.

21. The several predictive models were utilized to produce population exposure estimates by Risk Assessment Category and by selected pathways, namely air, water, and food chains, for effluents from various synfuels technologies.

22. The Users Manual produced by Brookhaven National Laboratory, BNL 373220, summarizes health effects research and provides necessary information to use the developed technology in extension of synfuels work or in other appropriate assessments of different technologies.

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XIV. APPENDIX

Report of the Peer Review Group for the Integrated Health and Environmental Risk Analysis Program.

Report of the Peer Review Panel on Human Effects of Synfuel Production.

Report of the Peer Review Panel on the Food Chain Transport of Synfuels.

Report of the Peer Review Group on the Integrated Health and Environmental Risk Analysis Program for Synfuels.

Report of the Peer Review Panel on the Food Chain Transport of Synfuels.

Report of the Peer Review Panel on Human Health Effects of Exposure in a Coal Gasification Plant.

These reports have been retyped for inclusion in this Report. The purpose was to make the formats more consistent.