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The future commercialization of a synthetic fuels indus in the United States requires careful consideration of variety of technical, economic, environmental safety, health problems. One consideration involves identifying controlling any novel safety hazards that may be associa with the design, siting, operation, and decommissioning complex synthetic fuels facilities. This assessment exami whether there may be potentials for unconventional saf hazards in the development of a synthetic fuels industry, whether the current and proposed safety control practices adequate to protect the worker and the environment. analysis focuses on technologies for producing synthetic fu from coal and oil shale for which pioneer plants are un construction or design and appear therefore to have greatest potential for being commercialized in the Uni States by the year 2000. These technologies incl gasification and liquefaction processes for coal, and ab ground retorting processes for oil shale. A chapter provid a technological overview of these technologies is followed an examination of safety, health and environmental haza potentially associated with such synfuels plants. Where c permit,. safety control practices are evaluated. Chapt identifying those areas where further R&D is needed to impr component reliability and performance, environmer monitoring and worker health and safety and some mechani that might aid in the generation of such data complete report.

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Safety Issues Related to Synthetic Fuels Facilities

Final Report of the
Committee on Synthetic Fuels Facilities Safety
Commission on Engineering and Technical Systems
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for the report were chosen for their special competences and with regard to appropriate balance.

This report has been reviewed by a group other than the author's according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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COMMITTEE ON SYNTHETIC FUELS FACILITIES SAFETY

STANFORD S. PENNER, Director, Energy Center and Professor of Engineering Physics, University of California at San Diego, *Chairman*.

WILLARD R. CHAPPELL, Director, Center for Environmental Sciences and Professor of Physics, University of Colorado at Denver.

WILLIAM R. EPPERLY, General Manager, Synthetic Fuels Department, Exxon Research and Engineering Company, Florham Park, New Jersey.

HAROLD W. GUTHRIE, Private Consultant, Santa Monica, California.

JOHN W. LANDIS, Senior Vice President, Stone & Webster Engineering Corporation, Boston, Massachusetts.

KEVIN L. MARKEY, Colorado Representative, Friends of the Earth, Denver, Colorado.

BLAINE C. McKUSICK, Assistant Director, Haskell Laboratory for Toxicology and Industrial Medicine, E.I. du Pont de Nemours & Company, Wilmington, Delaware.

RAFAEL MOURE, Industrial Hygienist, Health and Safety Office, Oil, Chemical, and Atomic Workers International Union, Denver, Colorado.

KENNETH E. PHILLIPS, Associate Engineer, Management Sciences Division, The Rand Corporation, Santa Monica, California.

ERIC H. REICHL, Private Consultant, Greenwich, Connecticut.

JASWANT SINGH, Vice President/Technical Director, Clayton Environmental Consultants, Inc., Marsh & McLennan, Inc., Southfield, Michigan.

RICHARD STEGEMEIER, Senior Vice President for Corporate Development, Science & Technology Division and Energy Mining Division, Union Oil Company, Los Angeles, California.

WILLIAM E. WALLACE, Jr., Energy Team Leader, Division of Respiratory Disease Studies, National Institute for Occupational Safety and Health, Morgantown, West Virginia.

DENNIS F. MILLER, Acting Executive Director,
Energy Engineering Board
PATRICIA L. POULTON, Staff Officer,
Committee on Synthetic Fuels Facilities Safety
HELEN D. JOHNSON, Administrative Assistant,
Energy Engineering Board
JULIA W. TORRENCE, Secretary
CHERYL A. WOODWARD, Secretary

PREFACE

The future commercialization of a synthetic fuels industry in the United States requires careful consideration of a variety of technical, economic, environmental, safety, and health problems. One consideration involves identifying and controlling any novel safety hazards that may be associated with the design, siting, operation, and decommissioning of complex synthetic fuels facilities. To this end, the Environmental and Safety Engineering Division of the U.S. Department of Energy (DOE) requested that the National Research Council examine whether there may be potentials for unconventional safety hazards in the development of a synthetic fuels industry, and whether the current and proposed safety control practices are adequate to protect the worker and the environment. In addition, DOE stressed the importance of evaluating safety hazards that might occur due to a short-term catastrophic event.[1] The Commission on Engineering and Technical Systems through its Energy Engineering Board established the Committee on Synthetic Fuels Facilities Safety to carry out these tasks and to identify the specific safety areas where further research and development (R&D) are needed.

The committee's efforts focused on technologies for producing synthetic fuels from coal and oil shale for which pioneer plants are under construction or design and that appear therefore to have the greatest potential for being commercialized in the United States by the year 2000. These technologies include gasification and liquefaction processes for coal, and aboveground retorting (AGR) processes for oil shale; the committee does not expect *in situ* techniques for shale oil recovery to play as large a role during this time. Processes for extracting oil from tar sands and from heavy oil sources are not addressed in this study since the committee judged

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[1]The causes of catastrophic events can be natural--earthquakes, windstorms, flash floods, tornadoes--or man-made--sabotage, bombing.

them to be well demonstrated and believed they would not present unconventional safety and health risks--at least not on the order of those that might be associated with a developing oil shale and coal conversion industry. In pursuing its charge, the committee held a two-day workshop during January 1982 to receive input from groups such as academic researchers; program planners representing agencies whose responsibilities include plant safety; plant design companies; labor unions; environmental groups; and representatives from the chemical, oil shale, and coal industries. The material received by the committee at the workshop--through the presentation of formal papers, general participant discussions, and briefings provided by DOE--supplied the background material (much of which is in the Appendix) for the committee's report.

It is important to note that the primary emphasis in this document is on hazards that could endanger worker safety and health, such as acute exposures to toxic substances, fires, explosions, and disabling and fatal accidents. However, the committee also believed it important to note acute hazards that might cause latent and chronic occupational health problems and long-term detriment to the environment. Thus, safety is broadly defined, although this document reflects DOE's interest in having the committee address primarily hazard- and safety-related issues.

ACKNOWLEDGMENTS

This report was prepared by the Committee on Synthetic Fuels Facilities Safety under the chairmanship of Stanford S. Penner. The committee itself is solely responsible for the report's findings and conclusions, but a number of individuals made important contributions to the committee's deliberations.

The committee was fortunate in having the able counsel of two advisors, August D. Benz, Manager, Process and Environment Department, Research and Engineering Operation, Bechtel Group, Inc.; and Laurence M. Holland, Deputy Division Leader, Life Sciences Division, Los Alamos National Laboratory.

The committee extends its thanks to those individuals who participated in the two-day workshop held on January 18 and 19, 1982. They provided briefings, data, and materials that helped the committee understand the safety issues confronting the synfuels industry. Thanks are also given to the personnel of the U.S. Department of Energy who provided guidance and information at the outset of the study and made presentations at the workshop.

The final preparation of the report was guided by comments from anonymous reviewers designated by the Commission on Engineering and Technical Systems, under the direction of its executive director, David C. Hazen. The committee is indebted to Renee G. Ford, who served as editor for its report.

The director of the study was Dennis F. Miller. Patricia Poulton, committee staff officer, joined the staff in March 1982 and was a great help in assisting the committee in the preparation of its final report. Special recognition is due Helen D. Johnson, administrative assistant to the Energy Engineering Board, and to Julia W. Torrence and Cheryl A. Woodward, who provided secretarial assistance to the committee and who served the committee with dedication.

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SUMMARY

SUMMARY OF FINDINGS

- The anticipated production rate of the U.S. synthetic fuels industry during the next decade is 30,000 to 50,000 barrels per day (BPD) for coal utilization with an equivalent amount of shale liquids. This slow industrial development provides an opportunity to develop from first-generation plants (a) effective technological implementation and (b) safe and environmentally acceptable designs. Operating experience with first-generation plants should be used to assess air quality risks, waste disposal and control systems, plant vulnerability, regional development programs, and long-term and larger-scale socioeconomic dislocations. The initial plants should be carefully monitored in all of these areas.
- In general, parallels exist between synthetic fuels technologies and convential energy processes, and thus commonalities exist in potential hazards and demonstrated control methods and strategies. Yet, there are significant technological extensions that must be carefully monitored and evaluated. The associated health and safety hazards are highlighted in this report. While the ultimate growth of the industry will represent major materials handling and disposal problems, special areas of vulnerability to sabotage and natural disasters were not identified. In synthetic processes using coals, the gasifier or liquefier represents only 15 to 20 percent of total investments while other components involve tested technologies. Scale-up of aboveground shale oil recovery plants does not appear to indicate unusual technological risks.
- Careful attention should be paid, particularly during the deployment of the first generation of synfuels plants, to (a) industrial hygiene characterization of occupational hazards; (b) medical surveillance, including biological and epidemiological monitoring; (c) toxicological investigations, including synergisms; and (d) interfacing (a) through (c) in an occupational health program.

- A committee of experts in the health field, policymakers from the concerned companies, and experts from universities and government agencies should determine what health and exposure data should be collected for a registry for each synfuel worker and for each synfuel industry, how the data should be stored and used, and who should have access to such data.
- In view of expected longer-term growth of an industry with very substantial mining operations, improvements should be sought in mine safety and mining technology.
- Particular attention must be paid to the management and training of competent workers in order to assure the safe and reliable operation of synfuels plants.
- Regulatory requirements affecting health and safety for both construction and operation should adequately safeguard the work force and the environment and should accurately reflect the best available current information.

SUMMARY OF ISSUES, INFORMATION NEEDS, AND POLICY OPTIONS

The design, siting, construction, operation, and decommissioning of coal gasification, coal liquefaction, and oil shale facilities could present safety risks both to synfuels workers and to the environmental system unless careful controls are exercised. Many of these hazards are expected to be similar to those associated with conventional mining, mineral processing, coking operations, and refining of petroleum. However, because of the chemical and physical properties of coal and shale and their products, the types of technologies to be employed, and the scales of their operations, it has been suggested that unconventional hazards may occur.

The following issues summarize the deliberations and work of the Committee on Synthetic Fuels Facilities Safety in evaluating the various technologies and their potentials for unconventional safety hazards as described in Chapters 2 and 3 of the report. Their suggestions for research and development (R&D) to further improve the safety and reliability of future synfuels plants (Chapter 4) and the mechanisms that might aid in the generation and gathering of such data (Chapter 5) are presented.

Issues

Which Technologies Are Expected To Significantly Affect Domestically Produced Synthetic Fuels During the Next 20 Years?

The mining and processing technologies expected to significantly affect domestically produced supplies of synthetic gaseous and liquid fuels by the year 2000 include: coal gasification, direct and indirect coal liquefaction, and oil shale recovery using aboveground retorting (AGR); modified in situ (MIS) and true in situ (TIS) processes are not expected to play a large role during this period.

How Large Will a Synthetic Fuels Industry Be by the Turn of the Century?

A goal for synthetic fuels was set in 1980 under the Energy Security Act: the goal was for an industry that would convert coal, oil shale, peat, and tar sands to synthetic fuels that could be used as substitutes for natural gas and petroleum (including crude oil), petroleum products, and chemical feedstocks to be producing the equivalent of at least 500,000 BPD of crude oil by 1987, increasing to 2 million BPD by 1992. However, the 1987 and 1992 goals now appear unrealistic; it is unlikely that an industry producing 500,000 BPD will be seen at the earliest before the mid-1990's. Nevertheless, it is appropriate to view the 1980's as the decade for the construction of commercial pioneer plants prior to large-scale commercialization during the 1990's and the next century.

Are There Similarities and Differences Between Synfuels Technologies and Existing Energy Conversion Technologies?

Unconventional aspects of the synthetic fuels technologies include the gasifiers for coal gasification, and in some processes the gas processing or cleaning systems. The coal liquefaction units are all of novel design. The combination of high temperatures and pressures in hydrogen-rich environments, and flowing erosive and corrosive materials, may pose unusual stress on certain equipment utilized in direct or indirect coal liquefaction facilities. For oil shale recovery, the raw shale dust, spent shale, and retort gases produced in both AGR and MIS processing have some novel characteristics.

Some aspects of oil shale underground mining differ from other mining. While some mines use large openings and high extraction rates and some operate under gassy conditions, only oil shale mines and some salt mines operate under all three conditions simultaneously. In addition, the fact that in MIS recovery mining and retorting are both taking place underground at unprecedented levels at the same time introduces a set of circumstances not previously experienced in other underground commercial-scale mining activities.

Those areas where synfuels technologies are comparable to existing energy conversion technologies and those aspects which are unconventional are highlighted in Table 1.

TABLE 1 Similarities and Differences Between Synfuel and Existing Conventional Energy Conversion Technologies

Synfuels Technologies	Similarities to Existing Energy Conversion Technologies	Unconventional Aspects of Synfuels Technologies
Coal Gasification (Surface)	Many unit operations and processing steps similar to those employed in oil refineries, power plants, and coke ovens.	The gasifier itself; and in some processes the gas processing or cleaning systems (e.g., the tar knock out unit operation).
Indirect Coal Liquefaction	Essentially similar to coal gasification techniques.	
Direct Coal Liquefaction	Overall operation parallels conventional petroleum refineries.	The ability of equipment to contain process under high pressures and temperatures in hydrogen-rich environments at commercial scale, e.g., the potential for flange leakage and the adequacy of process components such as slurry pumps to handle slurry streams. The ability of vessels to withstand hydrogen attack and to maintain safe operating temperatures at commercial scale.
Oil Shale Recovery	Basic mining technology comparable to that employed for recovery of coal, iron, and copper.	Unprecedented scale of mines for large-scale operations could require different approach in regard to materials handling, mining engineering, and design and fabrication of equipment. Use of larger than usual diesel-powered equipment underground.
Aboveground Retorting	The processes involved in retorting and upgrading (e.g., materials handling, crushing, solids heating and cooling, waste disposal, and the handling of liquids) are similar to those used in other operations such as mineral processing and conventional petroleum refining.	Characteristics of raw shale dust, spent shale, and retort gases associated with both aboveground retorting and modified _in situ_ processes.
Modified _in Situ_	Same as for aboveground retorting except for underground retorting.	High temperatures and fires involved in modified _in situ_ processes; mining and retorting both taking place underground at unprecedented levels at same time. Process not tested over long period of time at significant scale. Leaching requires further study to achieve effective control.

What Potential Safety and Health Hazards Associated with Coal Conversion Facilities Require Controls?

The potential safety and health hazards associated with coal gasification and liquefaction facilities include fires and explosions, and possible exposure to various process emissions and wastes which are toxic. In particular the possibility exists for exposures to known mutagens or carcinogens and to a wide range of organics which may be genetic toxins. Many of these hazards are routinely managed in comparable industrial facilities. The following risks are noted as having unconventional aspects which, if not properly anticipated and if appropriate control strategies are not designed and followed, have the potential to cause new safety and health risks.

Fires and explosions are noted as hazards because compressed oxygen (O_2) may be used in the gasification of coal or the gasification of residual material from direct coal liquefaction. In general, the higher the compression, the greater the hazard. The presence of small quantities of O_2 in the recycled, inverted, hot gas during coal pulverizing and drying is also a potential cause of fire or explosion. A further possibility of explosion results from the presence of large amounts of coal dust. While the occurrence of a fire or explosion due to such hazards is not unique, an occurrence in a coal conversion facility with large amounts of potentially flammable and explosive materials under high pressures and temperatures could pose a hazard of unconventional magnitude.

Toxic gases, such as hydrogen sulfide (H_2S) and carbon monoxide (CO), are a hazard because they may be produced in higher concentrations than in existing, commercial-sized energy conversion facilities. Coal tars from gasification are hazardous if not properly handled, because they contain large amounts of known carcinogens. The likelihood of exposure to other potentially toxic residues of coal gasification and liquefaction is also of concern, and precautions must be taken to protect both operating and maintenance personnel from excessive contact with these materials. Since indirect coal liquefaction involves coal gasification as part of the process, many of the hazards are similar.

In direct coal liquefaction, there is a high potential for leaks to occur under the high operating pressures and temperatures, thus releasing hot concentrated toxic and carcinogenic materials (for example, oil-solid slurries and H_2S) which could result in burns and other contact injuries. The potential for worker exposure to highly toxic substances is also considered a major hazard.

What Are the Potential Safety and Health Hazards Associated with Oil Shale Recovery Prior to Control?

The similarity of oil shale open-pit and underground mining to conventional mining industries makes it possible to project likely occupational safety and health risks. These are largely identified as due to fires, explosions, and respiratory illnesses.

Nevertheless, some aspects of shale mining which have the potential to increase safety and health risks differ from those of other mining. Such risks include concerns relating to the scale-up of safety equipment for the size of diesel-powered equipment used in underground shale mines and the very large inventories of explosives which might lead to technical detonation problems. Also the potential for silica-dust-induced fibroses or for synergistic exposure effects from oil shale dust and diesel exhaust products has not been fully determined.

Spent shale containing silica dust will also be generated during retorting operations. Unless properly managed, the handling of spent shale might pose hazardous respiratory exposures. While little statistical information is currently available on the health and safety effects of shale oil retorting and refining, the risks are expected to be comparable to those in industries using similar technologies.

What Measures Will Be Taken During the Development of the Synthetic Fuels Industry To Reduce Safety, Health, and Environmental Risks?

Some combination of the following measures, which while common to most industrial operations will necessarily vary in synthetic fuels facilities because of site-specific, technology-specific, and material-specific differences will be taken: (a) careful site selection to minimize ramifications to the total environmental system; (b) the design and maintenance of safe working conditions; (c) the selection of process and pollution control technologies and strategies to reduce the release of airborne emissions, aqueous effluents, and solid wastes; (d) the institution of industrial hygiene and worker training programs; (e) health surveillance, including exposure monitoring and record keeping; and (f) emergency plans and procedures.

Can Safety Risks Be Minimized Effectively During Both Normal and Catastrophic Conditions in First-Generation Synthetic Fuels Facilities?

A certain level of uncertainty and risk is introduced where technology extensions (specially designed or modified equipment, for example) are needed and where new development approaches are being considered; also where control technologies and strategies have not yet been tested at commercial scale, on comparable waste streams, or for prolonged periods of time. However, in general, due to the large number of parallels noted between synthetic fuels facilities and conventional energy conversion plants, and thus similarities in both their potential hazards and the proposed control strategies, there appears to be every reason to believe that first-generation synthetic fuels facilities can be designed and built in accordance with established standards and practices and will comply with existing regulatory requirements. Moreover, if conservative planning and design efforts are applied to synthetic fuels plants the probability of process upsets from natural disasters would likely not be any greater than those experienced in established industries. In fact, these facilities should have a less-than-average susceptibility to damage from earthquakes or hurricanes because of their inland locations. In addition, security risks for synthetic operations are expected to be comparable to security risks for similar mining or petroleum-related operations.

Yet, it is essential that the first generation of synthetic fuels plants be carefully evaluated and monitored with respect to their reliability and safety, and that R&D be directed toward areas of limited experience and uncertainty. Experience gained and information gathered during the construction and operation of these first-generation facilities will provide the foundation needed for a technologically sound, as well as safe, synthetic fuels industry.

Information Needs

The anticipated slow development of synfuels technologies provides the opportunity to clarify the potential for safety hazards to the work force, to the environment, and to the public. Although the committee believes that adequate data currently exist to proceed with commercial projects, it did suggest areas where additional R&D could be directed toward further improvements in the safety and reliability of future synfuels plants.

Technological R&D

Two main areas were identified relating to technological R&D for future synthetic fuels facilities. These relate to component areas that involve the modification or redesign of commercially available equipment to fit more severe service requirements and the adequacy of existing mine safety technologies for the safe design and operation of large-scale mining activities associated with the production of shale oil. Research priorities should be directed toward improvements in these two areas, both of which are critical to maintaining continuity of process operations and involve the highest risk potential to workers.

Environmental R&D

While the establishment of control technologies and strategies for synthetic fuels facilities has been based on either technology transfer from conventional energy facilities or pilot plant characterization and demonstration, the committee perceives the need to monitor their performance in first-generation synthetic fuels plants. Such research would be typical of that required to monitor or proof test any first-of-a-kind system and should address the monitoring and long-term reliability and operability of both individual and integrated control technologies, as well as the continued assessment of the potential effects of pollutants on the environment. Specific R&D recommendations were grouped under the following areas: solid waste management, transport of pollutants, and potential effects of pollutants on the environment.

Health Effects R&D

The health concerns associated with the development of synthetic fuel processes were thought to be of greater concern for workers in the synthetic fuels industry than for the general public. Medical surveillance of workers, monitoring worker exposures, instituting engineering controls, training competent workers, providing education about health and personal hygiene, maintaining strict industrial hygiene standards, instituting a worker registry for the earliest possible identification of manifest health effects, and evaluating the toxicity of process emissions and product streams are all key areas that form the basis for a program that guards against potential adverse health effects in synthetic fuels facilities. The committee stressed that ongoing programs directed toward assessing health effects associated with shale oil, coal gasification, and direct coal liquefaction should continue to receive research emphasis, as should evaluations of worker training facilities and personal protective equipment.

Policy Options

Some mechanisms for generating and gathering R&D data warrant consideration. These are highlighted below.

The Need for Sharing Commercial Plant Data

While a considerable amount of environmental and health data has been developed from pilot-scale efforts and will be further refined by ongoing research programs, the most crucial data are those that will be obtained from the large-scale demonstration and commercial units anticipated to be built in the next decade. It will be with these commercial units that an understanding can be developed of the emissions, effectiveness of environmental control technologies, worker environments, and various hazards. Thus, the committee believes it is vital that industry, the government--local, state, and federal--and the research community take full advantage of the research opportunities offered by the gathering and analysis of data related to environmental and health effects of these first-generation facilities. The basic issues that need to be resolved include: how such a research program should be put together, who should fund it, where the data should reside, who should have access to such data, and what the procedure for sharing the findings should be.

The committee concluded that, since so many issues are involved, perhaps it would be appropriate to set up a working group or committee to devise a mechanism for developing and sharing data among countries, companies, government agencies, researchers, labor, various interest groups, and the public. This plan might include such things as workshops, international conferences, international committees, and so forth. It is assumed that such a group would be in contact with synthetic fuels companies, agencies, scientific societies, and individuals, not only in the United States but also abroad, in order to build a consensus on the proper approach to this complex problem.

Health Surveillance

A mechanism that would aid in the gathering and analyzing of safety and health information would be a synthetic fuels health registry or registries for the health records of workers in the industry. Such a registry could be extremely beneficial for the accurate identification of occupationally induced diseases with a long latency period. Also, a registry would provide the data for case-control studies and cross-sectional medical studies, and would allow the rapid identification of unexpected problems.

The power of epidemiological studies to detect work-related health hazards increases with the number in a group being studied. Therefore, it is desirable for the various companies to collect the same data in the same format by the same procedures so that epidemiological studies can be carried out on employees in similar jobs across the industry. Accordingly, a committee of experts (particularly epidemiologists, physicians, industrial hygienists, and toxicologists) and policymakers from concerned companies, universities, and government agencies should consider the timing for establishing a registry, as well as determining what data should be collected for each worker and for each industry, how the data should be stored and used, and who should have access to such data. The format for recording the data and the length of time the data are to be retained should also be established by this committee. In addition, the committee should establish procedures for preserving

INTRODUCTION

OVERVIEW

Over the past several years considerable debate has taken place regarding the most appropriate path to assuring secure energy supplies. An important step in developing new energy supplies relates to evolving a comprehensive policy that reduces demand through conservation. However, there are limits to the savings that can be accomplished through any conservation efforts. It is because of this fact, among others, that the United States has also adopted a policy of exploring and developing energy alternatives. Many alternatives are being considered, including enhanced oil recovery, expanded coal development, solar-thermal energy utilization and photovoltaics, wind energy, ocean-thermal gradients, increased nuclear fission for power generation, nuclear fusion, biomass combustion, and the production of synthetic liquid and gaseous fuels by the conversion of coal, tar sands, biomass, and oil shale. A potentially important step in this move toward secure energy supplies was made when former President Carter signed into law the Energy Security Act of 1980. The program that emerged ranged from promoting the conservation of all energy sources to more specific targets of creating increased energy supplies from newly discovered fields of oil and gas. It stressed the use of renewable resources, along with the determination to develop abundant domestic fossil fuel sources such as coal. In addition, financial support was provided--via the newly created Synthetic Fuels Corporation--for developing synthetic oil and gas from the huge domestic deposits of coal, oil shale, and tar sands.

In addition, a goal for synthetic fuels was set in 1980: an industry that would convert coal, oil shale, and tar sands to liquid fuels should be producing the equivalent of at least 500,000 barrels per day (BPD) by 1987, increasing to 2 million BPD by the turn of the century. However, the goal is now unrealistic and it is unlikely that an industry producing 500,000 BPD will be seen at the earliest before the mid-1990's. Nevertheless, it is appropriate to view the 1980's as the decade for the construction of commercial pioneer plants prior to large-scale commercialization during the 1990's and the next century. This relatively slow rate of growth provides an opportunity to develop from first-generation plants effective technological implementation of safe and environmentally acceptable designs.

REPORT ORGANIZATION

The remaining chapters of this study are organized as follows:

- Chapter 2--"Technological Overview" discusses synthetic fuels development in the United States. Coal gasification, coal liquefaction, and oil shale recovery processes considered most likely to be commercialized by the year 2000 are described. Similarities and differences are noted between each specific technology and other energy conversion facilities. Unconventional aspects of the technologies that might affect worker health and safety and the environment are highlighted.
- Chapter 3--"Plant Hazards and Occupational Safety and Health" first identifies the unconventional safety, health, and environmental hazards potentially associated with coal gasification, coal liquefaction, and oil shale recovery techniques prior to the application of control mechanisms. The remainder of the chapter deals with approaches currently used or proposed to identify and reduce hazards that might occur during the early phases of the synfuels industry. Where data permit, the pollution control equipment, engineering controls, maintenance practices, monitoring procedures, worker training programs, and general industrial hygiene programs are evaluated with respect to their effectiveness in reducing or eliminating the safety risks previously identified.
- Chapter 4--"Information Needs." This chapter identifies those areas where further R&D is needed to improve component reliability and performance, environmental monitoring, and worker healtn and safety.
- Chapter 5--"Policy Considerations." This discussion presents some mechanisms that might aid in the generation and gathering of needed R&D information, such as that highlighted in Chapter 4.

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2

TECHNOLOGICAL OVERVIEW

INTRODUCTION

The mining and processing technologies that are expected to significantly affect domestically produced supplies of synthetic gaseous and liquid fuels by the year 2000 are discussed in this chapter. These technologies are: coal gasification, direct and indirect coal liquefaction, and oil shale recovery using aboveground retorting (AGR); modified *in situ* (MIS) and true *in situ* (TIS) processes are not expected to play a large role in this time scale. Aspects of these technologies may affect the safety and health of workers in these synfuels industries, as well as the physical environment.[1] The following subjects are presented as background to the analysis presented in subsequent chapters of this report:

- Brief summaries of the history and status of each of the three technologies--with emphasis on U.S. projects.
- Descriptions of the process technologies.
- Summaries of the technological readiness of each particular process, highlighting those aspects of the technologies that are similar to existing energy conversion facilities and those aspects that are unique to synfuels activities.

[1]These health and environmental concerns are being addressed during the technical development of each process by major research programs funded by both government and private developers. A data base is being generated from this research based on the operation of large-scale pilot plants (and in some cases, commercial plants) to permit the design of appropriate environmental controls and safeguards to meet regulatory requirements. As discussed in Chapter 3, experience gained from comparable industries should be applicable in helping to define safeguards and engineering controls that will be required to reduce the occurrence of potential safety, health, and environmental hazards.

HISTORY AND STATUS OF U.S. SYNFUELS PROJECTS

Coal Gasification

Coal gasification plants have been commercially operated abroad for many decades. Prior to 1945, commercial gasifiers were also widely operated in the United States. Since that time, because of the increasing availability of cheap natural gas, the number in use has decreased to the point where only a few small industrial gasification facilities are now operating in this country.[2] However, increasing costs for natural gas and major technological advances in coal gasification, along with a desire to provide diversified sources of energy, have led to renewed interest in coal gasification technologies. At present, one commercial utility-sized facility is under construction and should be in production by the mid-1980's. Developed by the Great Plains Gasification Association in Mercer County, North Dakota, it is expected to produce 137.5×10^6 standard cubic feet per day (SCF/D) of high-Btu gas by 1984.[3] In addition, a number of smaller-scale gasification plants are in operation. These include, for example, the Tennessee Valley Authority's "Ammonia-from-Coal" Texaco gasifier demonstration plant located in Alabama, and eight low-Btu gasifiers located in industrial plants in Pennsylvania (including Hazelton Brick, Caterpillar Tractor, Glen Gery Operations).[4] It is interesting to note that some authors have predicted that by the year 2000, about 27 percent of the potential gas supply produced synthetically will come from coal gasification.[5]

Coal Liquefaction

There are two major categories of liquefaction processes--direct and indirect. In the direct processes, the coal is heated and hydrocracked under various conditions in order to convert its organic content to liquids which are subsequently separated from the product

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[2]J. A. Robinson, "Property Loss Prevention Criteria as Applied to Coal Gasification Projects," paper presented at a conference on the Prevention of Fire and Explosions in the Hydrocarbon Industries, sponsored by the Institute of Gas Technology, Chicago, Illinois, June 7, 1979, p. 1.

[3]National Coal Association, Coal Synfuel Facility Technology (Washington, D.C.: National Coal Association, November 1981).

[4]Ibid.

[5]Robinson, op. cit., p. 10.

stream containing solids. In the indirect process, the coal is first gasified. After the gases produced are purified, they are converted catalytically to a variety of liquid products.

Direct liquefaction was in commercial use in Germany during the 1930 to 1945 period. Some 90,000 barrels per day (BPD) of gasoline were produced in some ten synthetic fuels plants. Indirect coal liquefaction was first practiced commercially in Germany prior to World War II. In recent years, it has been extensively commercialized for liquid fuel production in South Africa. The SASOL process is available under license. Indirect liquefaction has been used in the United States largely to provide feedstock for the chemical industry prior to World War II. However, coal liquefaction for the production of synthetic fuels requires a far greater production capacity, and thus larger plants. Consequently, a new generation of direct and indirect liquefaction technologies is being developed.

Direct Coal Liquefaction

In the 1950's, the Bureau of Mines operated a small direct liquefaction plant, 60 tons per day (TPD), in Louisiana, Missouri, modeled after World War II German synthetic fuels plants. The Missouri facility in one continuous three-month run produced one million gallons of gasoline (equivalent to 265 BPD).[6] At the same time, a 300-TPD direct liquefaction plant was operated briefly by Union Carbide Corporation.

There are a number of direct coal liquefaction pilot plants in operation in the United States. Processes utilized include the catalytic Hydrocarbon Research process known as H-Coal, the Exxon Donor Solvent (EDS) process,[7] and the Solvent-Refined Coal (SRC-1) process. Should support be forthcoming from the Synthetic Fuels Corporation, a large commercial-sized facility--Ashland Oil's H-Coal

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[6]J. P. McGee, "Notes on Coal Synfuel Facility Hazards," Correspondence to the Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, January 1982 (see Appendix, Paper J).

[7]Exxon Research and Engineering Company announced in January 1982 that the EDS coal liquefaction technology had been successfully demonstrated with Illinois coal in their 250-TPD pilot plant. The technology was judged a success after more than 5,000 hours of tests were conducted on 47,000 tons of Illinois high-sulfur bituminous coal. See Exxon Research and Engineering Company, "EDS Technology Successfully Demonstrated on Illinois Bituminous Coal," press release (Florham Park, New Jersey: Exxon Research and Engineering Company, January 28, 1982).

Project, Breckenridge County, Kentucky--may begin construction for production in the late 1980's.[8] Pioneer plant development of the SRC-II process has been deferred because of cost escalations, but plans are proceeding for the development of a plant utilizing the SRC-1 process.

The International Energy Agency (IEA) has recently (March 1982) recommended undertaking the design of several direct coal liquefaction plants of commercial scale as the next logical step; government support for such a program will be required.

Indirect Coal Liquefaction

The largest indirect coal liquefaction facility in the world is the SASOL-2 plant in South Africa. It is designed to produce 40,000 BPD of transportation fuels, including gasoline and jet and diesel fuels, plus 20,000 BPD of chemical feedstocks.[9] A twin of this unit, SASOL-3, is under construction. Together with the 30-year-old SASOL-1 plant the three units will supply over half of all liquid fuels for South Africa. No commercial-sized indirect liquefaction plants for the production of fuel are operating in the United States today. (Until recently, a 7,000-BPD facility operated in Brownsville, Texas, converting natural gas to gasoline using a process similar to that of indirect liquefaction. However, it was not successful.)

Shale Oil Recovery

Oil shale is a fine-grained sedimentary rock containing an organic material kerogen that yields a synthetic oil and gas during pyrolysis or retorting. Oil has been produced from oil shale since before 1900 in many parts of the world (for example, Australia, Spain, South Africa, France, Germany, Sweden, Scotland) including the United States. Today, oil shale operations exist in the Soviet Union (which has the largest currently active oil shale industry in the world), China, and Brazil.

A very large concentration of high-grade shale oil is located in the Green River Formation, a geologic entity underlying some 34,000 square miles of terrain in northwestern Colorado, southwestern Wyoming, and northeastern Utah.[10] As shown in Figure 1, the

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[8] National Coal Association, op. cit.

[9] Ibid.

[10] Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), pp. 88-90.

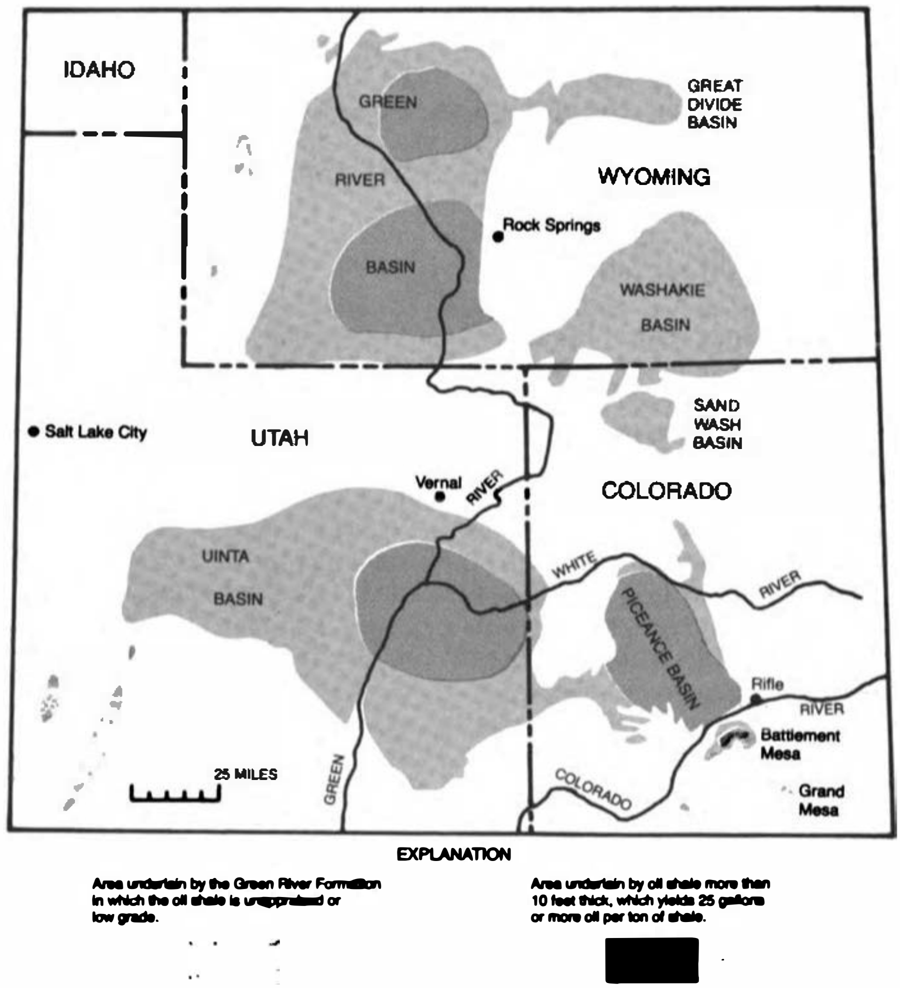

Figure 1 Oil shale deposits of the Green River Formation.

SOURCE: D. C. Duncan and V. E. Swanson, Organic-Rich Shales of the United States and World Land Areas, U.S. Geological Survey Circular 523, 1965.

principal oil shale deposits are found in the Piceance, Uinta, Green River, and Washakie Basins. These areas, especially the Piceance Basin, are among the most intensely explored geologic regions in the United States. Moreover, the majority of U.S. oil shale development activities are taking place in the Piceance Creek Basin.

There are three generic types of oil shale technology: conventional mining with AGR; MIS recovery; and TIS. The largest aboveground retorts that have been tested at Colorado sites are the semiworks of the Union Oil "A" directly heated device and the TOSCO II indirect hot solids retort that are about one tenth of the size of planned commercial retorts of these companies.[11] Developers in Utah, including the White River, Sand Wash, and Paraho-Ute projects, also plan to utilize the AGR approach.

A few projects may be developed using MIS technology, but these will represent only a small fraction of total production by the end of the century. According to one earlier estimate, a total production of about 450,000 BPD is projected by 2000, with somewhere between 300,000 and 350,000 BPD from AGR and the remaining divided between MIS (some 100,000 BPD) and several small projects testing different TIS technologies--the most undeveloped of the three approaches.[12] The principal MIS development efforts have been conducted in conjunction with the Rio Blanco and Cathedral Bluffs projects in Colorado. There are also two small TIS projects, one in Utah (Geokinetics) and one in Colorado (Equity Oil).

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[11]Colorado Energy Research Institute and Colorado School of Mines Research Institute, Oil Shale 1982: A Technology and Policy Primer (Lakewood, Colorado: Colorado Energy Research Institute, November 1981), p. 36.

[12]Synfuels Project Directory: Shale (Washington, D.C.: Pasha Publications, March 1982); and Colorado Energy Research Institute and Colorado School of Mines Research Institute, op. cit., pp. 41-57.

SYNTHETIC FUELS TECHNOLOGY[13]

Coal Gasification[14]

Description of Process

Coal gasification is carried out in a gasifier, which is a fixed-bed, a fluidized-bed, or an entrained-flow reactor. Gasifiers of various designs are commercially available, with modified designs expected to enter the market in the future. Coal gasification involves reactions of coal with steam and oxygen to produce a synthesis gas containing carbon monoxide (CO) and hydrogen (H_2), as well as minor amounts of carbon dioxide (CO_2), low molecular weight hydrocarbons (HC), and, in some gasifiers, higher molecular weight organic compounds. Raw synthesis gas also contains a variety of coal-derived contaminants. These include ammonia (NH_3), hydrogen cyanide (HCN), hydrogen sulfide (H_2S), organic sulfur compounds, trace elements, and entrained particulate matter. Gasifiers may be categorized according to the amount of heavy organics or coal tars (coal devolatilization products) in the synthesis gas they produce.

Support Facilities

A full-scale commercial coal gasification facility to supply utility sector fuel will process on the order of 12,000 to 30,000 TPD of coal and will yield products with energy contents equivalent to 20,000 to 50,000 BPD of oil. For economic reasons, such facilities are likely to be located on or adjacent to a captive coal mine. Industrial fuel gasification plants may be a fraction of this size; for example, the

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[13]For detailed discussions of technological aspects of these processes, see the following reports by the U.S. Department of Energy, under Contract No. DE-AC01-79ER1007: Assessment of Long-Term Research Needs for Coal-Gasification Technologies (Fossil Energy Research Working Group I (FERWG), April 1979); Assessment of Long-Term Research Needs for Coal-Liquefaction Technologies (FERWG Group-II, March 1980); and Assessment of Long-Term Research Needs for Shale-Oil Recovery (FERWG Group-III, March 1981). Also see C. Y. Wen and E. S. Lee (eds.), Coal Conversion Technology, (Reading, Massachusetts: Addison Wesley, 1979); and R. Probstein and R. E. Hicks, Synthetic Fuels (New York, New York: McGraw Hill, 1981).

[14]W. E. Corbett, W. C. Thomas, and E. H. Reichl, "Factors Affecting the Safety of Coal Gasification Facilities," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper D).

proposed Memphis gasification industrial park facility will consume 3,200 TPD of coal.

Large oxygen plants and relatively large auxiliary power plants (200 to 500 megawatts electrical [MWe]) will be associated with commercial utility-sized gasification facilities. In addition, the substantial make-up water requirements vary with the gasifier used and the design of the water management system.

The removal of contaminants requires processing of the gaseous products downstream of the gasifier. This procedure involves gas quenching and cooling (with heat recovery where possible) and acid gas removal with sulfur recovery. Catalytic steps to convert the purified synthesis gas into gaseous or liquid products may be used in other facilities. Products that can be made include nearly pure H_2 or CO, methane (CH_4), methanol (CH_3OH), gasoline, and many other chemicals.

Many of the unit operations and processing steps involved in coal gasification are similar to those used in other energy conversion facilities such as oil refineries, power plants, and coke ovens. However, some facility-specific differences will occur because of the gasifier itself and downstream cleaning of gases rich in H_2S, minerals, and in some cases tars.

Indirect Coal Liquefaction

Description of Process

Indirect coal liquefaction to produce synthetic fuel first involves gasification of the coal, as described in the previous section, to yield synthesis gas which is then converted to liquid fuels under pressure and in the presence of suitable catalysts. One type of process, the Fischer-Tropsch-type reactor, is presently in commercial operation at the SASOL-2 plant in South Africa.[15] Large-scale commercial applications of zeolite catalysts for synthesis are under development without U.S. government support and may well be in operation by the end of the decade.

Facilities

Figure 2 is a flow sheet for the process proposed by the Tri-State Synfuels Project. This project, which has completed a feasibility study, is now in a two-year cooperative agreement financed by a Department of Energy grant.[16] While this is largely a coal

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[15]National Coal Association, op. cit.

[16]A. de Leon, Manager, Public Relations, Tri-State Synfuels Company, Houston, Texas, April 30, 1982; personal communication.

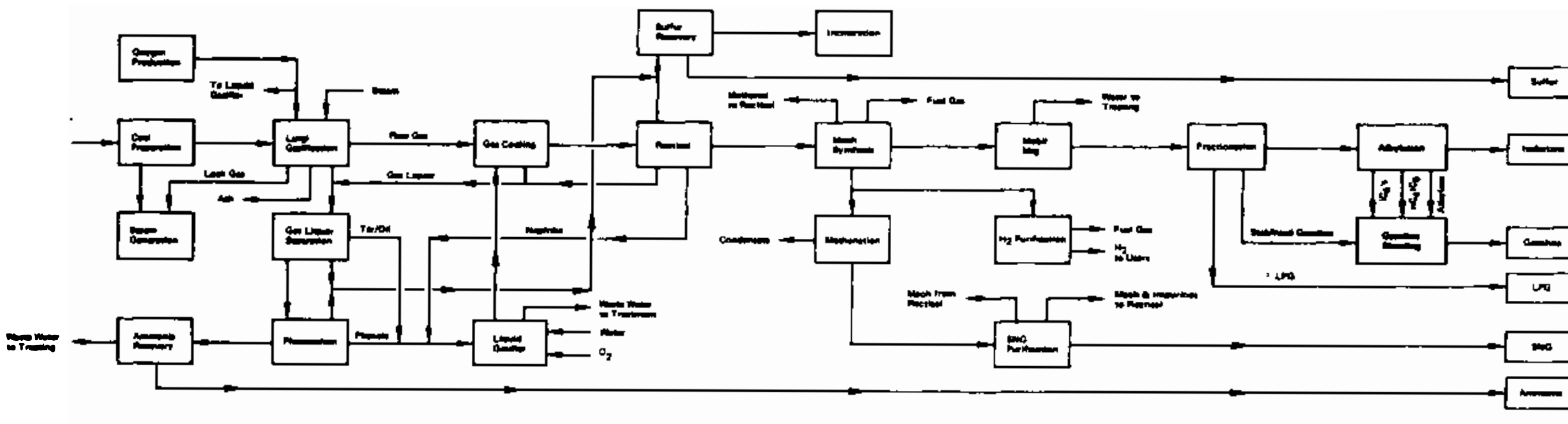

Figure 2 A preliminary process flow diagram for the Tri-State Synfuels Project. In the methanol-to-gasoline process subbituminous coal is fed into fixed-bed Lurgi gasifiers. The coal is gasified by injection of steam and oxygen which reacts with the coal at high temperatures and pressures to produce raw gas. The hot gases are cooled and sent to the Rectisol unit. Tars, phenols, and other liquids produced in the gasification process are sent to a liquid gasifier where more raw gas is recovered, sent to gas coolers and then to the Rectisol unit where the raw gas is stripped of undesired elements. From the Rectisol unit the syngas is processed in a methanol synthesis unit. Approximately half of the syngas is moved to the methanization unit, then purified and recovered as substitute natural gas. The methanol produced in the synthesis unit is moved to the Mobil methanol-to-gasoline facility. In this process the methanol is converted to gasoline and small amounts of liquefied petroleum gas (LPG).

SOURCE: Tri-State Synfuels Company, Houston, Texas, March 1982.

gasification facility, it is shown for the proposed production of methanol to gasoline. However, because of the present unfavorable economic climate for this synfuel project, it has been deferred indefinitely as of April 1982.

Direct Coal Liquefaction[17]

Description of Process

The operation of direct coal liquefaction facilities generally parallels that of conventional petroleum refineries except for two areas of technology extension. Such extensions are necessary due to the handling of solids in high-pressure environments.

All processing sequences used for direct hydrogenation in the production of coal-derived liquids involve the following steps: (1) addition of hydrogen to supply the needed constituents for the required increase in hydrogen-to-carbon ratio; (2) cracking of the coal in the presence of hydrogen (hydrocracking) to produce compounds of reduced molecular weight; (3) removal of sulfur- and nitrogen-containing compounds (such as H_2S and NH_3) that have been formed by hydrocracking, as well as removal of water produced by reaction with oxygen atoms contained in the coal; and (4) appropriate processing of the tar and coal residues (bottoms) and separation of the desired liquids from the ash and from any remaining unreacted coals.

A generalized flow diagram for direct coal liquefaction is shown in Figure 3. It contains the major process steps that take place in the Gulf Oil Company Solvent-Refined Coal procedure (SRC-II), the Exxon Donor Solvent process (EDS), and the catalytic Hydrocarbon Research process (H-Coal).

Support Facilities

The support facilities required for integrated and self-contained direct coal liquefaction constitute the largest portion of the overall plant (for example, the direct liquefaction process steps of a commercial-sized EDS plant represent only about 14 percent of its total erected cost). They are needed for such purposes as

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[17]The material on this process was drawn from the following: C. W. de George, "Safety of Synthetic Fuels Plants, Direct Coal Liquefaction," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper E).

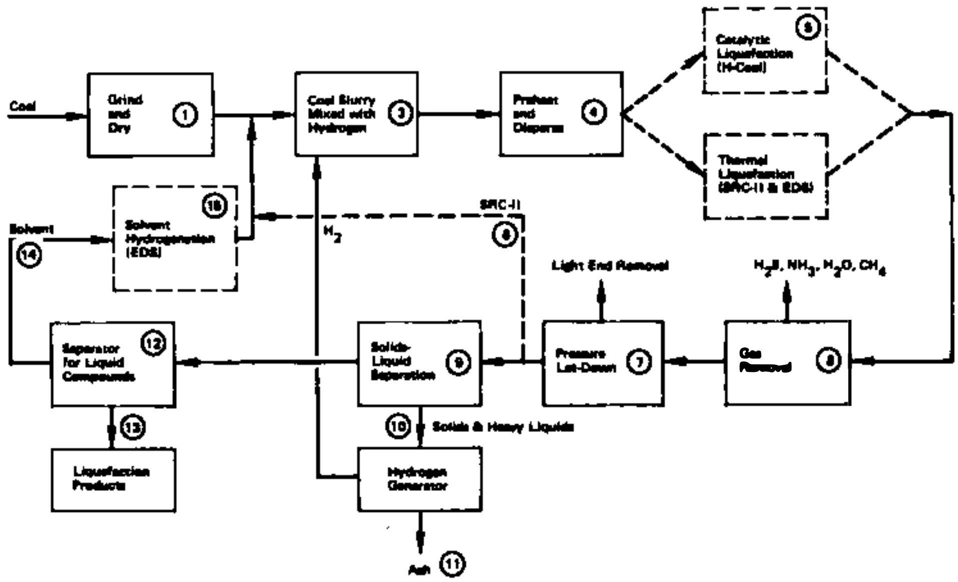

Figure 3 A generalized flow diagram for direct coal liquefaction. The raw coal is first dried and ground (1) to produce the feed coal that is mixed (2) with a (recycled) solvent to produce a coal slurry to which hydrogen feed is added in appropriate amounts (3). The liquid mixture of coal, solvent, and hydrogen is then heated and dispersed (4) before entering the liquefaction unit (5). The liquefier may be a catalytic reactor (as in the H-Coal process) or a thermal reactor (as for the SRC-II and EDS processes). Because of the necessary presence of mineral matter, both in the coal and in the (recycled) solvent, the so-called thermal liquefaction of the SRC-II and EDS process will also involve catalyzed reactions. After liquefaction, the reaction products undergo a series of separation steps, beginning with gas removal (6) and pressure reduction or let-down (7) during which low molecular weight hydrocarbons (light ends) are separated. At this point, some of the solvent may be recycled to the feed slurry as in the SRC-II process (8). However, most of the heavier remaining material is now subjected to one or more processing steps to separate the principal liquid products from heavy liquids and solids (9). The latter may be partially pyrolyzed to generate feed hydrogen (10) and ash (11) while the principal liquefaction products enter a separator (12) from which both desired liquefaction products are recovered (13) and recycled solvent is bled (14) for prior solvent hydrogenation in the EDS process or for direct reuse in the coal slurry (as in a version of the SRC-II process).

SOURCE: Fossil Energy Research Working Group-II, Assessment of Long-Term Research Needs for Coal-Liquefaction Technologies, Contract No. DE-AC01-79ER10007 (Washington, D.C.: U.S. Department of Energy, March 1980).

effectively using ash bottoms, producing hydrogen, treating waste-water streams, upgrading the liquid products, producing steam, and storing and transporting coal. These support facilities are generally similar to the technology currently used by petroleum refineries and utility power plants, with the exception of the units for processing bottoms and for producing hydrogen.

Depending on coal type, operating conditions, and the process used, 50 to 70 percent of the coal feed is directly converted to gaseous and liquid HC products, leaving a residue of undistillable tar, unreacted coke, and ash bottoms. The effective utilization of the carbon present in these bottoms is desirable to improve the thermal efficiency and economic attractiveness of a direct coal liquefaction plant. There are several possible alternatives for processing bottoms: direct combustion of fuel; partial oxidation to produce a synthesis gas for use as fuel or for subsequent upgrading to hydrogen; and separation of the solids to increase the recovery of the nondistillable tar.

Equipment

Direct coal liquefaction facilities employ the commercially available types of equipment used in petroleum processing facilities, with some exceptions. The need for specialized technology is related to two characteristics common to all direct coal liquefaction processes: (1) high pressure levels and (2) the presence of solids. (For a detailed discussion of these characteristics, see Position Paper E in the Appendix).

Shale Oil Recovery[18]

Description of Mining Processes

Aboveground Both AGR and MIS retorting technologies require mining the oil shale, with mining requirements for MIS reduced by 75 to 85 percent for equivalent production. Open-pit mining may be feasible in areas where the deposits are relatively close to the surface (several hundred feet or less). This procedure would involve removing the overburden (which is saved for future reclamation) in a steplike manner to prevent the steep, deep mine sides from crumbling. For commercial-sized oil shale plants, surface mines

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[18]The material on this process was drawn from the following: Office of Technology Assessment, op. cit., pp. 137-153; Colorado Energy Research Institute and Colorado School of Mines Research Institute, op. cit., pp. 25-36; and Fossil Energy Research Working Group III, op. cit., pp. 1-30.

could be as large as the largest iron or copper mines in the world. (See Figure 4.) In areas where the overburden is thinner than 200 feet (as in some areas of the Uinta Basin) strip mining may be employed, using technology developed for surface coal mining operations.

Underground To recover deep deposits of oil shale, underground mining is required. Room-and-pillar mining is the most advanced method used to date. Only about 60 percent of the oil shale can be recovered in the initial mining program by this method since some must be left to support the mine roof. Underground mines that must provide as much as 100,000 tons of rock each day to support a 50,000-BPD production schedule would be among the largest of this type in the world. (See Figure 5.) It should be noted, however, that the initial project due for commercialization will mine 12,000 TPD of high-grade ore to produce 10,000 BPD of syncrude.

Description of Retorting Process

Aboveground Retorting The majority of U.S. companies currently involved in the construction of oil shale demonstration plants are using aboveground processes, which are closer to commercialization than either MIS or TIS. Aboveground retorts are of two types: directly heated retorts use heat generated inside the retorting vessel (as in the Paraho direct process; see Figure 6) while indirectly heated retorts use heat generated outside the vessel (as in the Union B, TOSCO II, and Lurgi-Ruhrgas processes).

In the direct process, heat is transferred by flowing gases generated within the retort as a result of the combustion of carbonaceous retorted shale and pyrolysis gases. This process produces a spent shale low in residual carbon and also low-Btu gas when air is used for burning. An example of one type of directly heated retort was the Paraho Direct system developed by the Paraho Development Corporation.

In the indirect process, combustion does not occur inside the retort. There are at least two versions of this process. In one, heat is transferred by gases heated outside the retort vessel. These retorts produce a carbonaceous spent shale and also high-Btu gas. Examples include the Union B (see Figure 7), Paraho Indirect, and Superior processes. In a second version, heat is transferred by mixing hot solid particles with the oil shale. These retorts form spent shale that may or may not contain carbon, and also high-Btu gas. Examples include the TOSCO II (see Figure 8) and Lurgi-Ruhrgas processes (see Figure 9).

Modified in Situ Retorting In order to create permeability in the underground oil shale deposits, a portion (15 to 25 percent) of the deposit is mined and removed by conventional methods. The remaining

Figure 4 Bingham Canyon Open-Pit Copper Mine, belonging to Kennecott Mineral Company (near Salt Lake City, Utah). Kennecott Copper's Bingham Canyon mine in Utah removes about 390,000 tons/day. By comparison, the U.S. Bureau of Mines, which considered 10 different mining scenarios described a representative shale mine to produce 450,000 tons of rock and 180,000 BPD. It was assumed that 2.5 tons of rock would produce 1 barrel of oil. A mine of that scale was determined to be about 2 miles long, 1.5 miles wide, and 2,000 feet deep.

SOURCE: Colorado Energy Research Institute and Colorado School of Mines Research Institute, Oil Shale 1982: A Technology and Policy Primer, November 1981, p. 26.

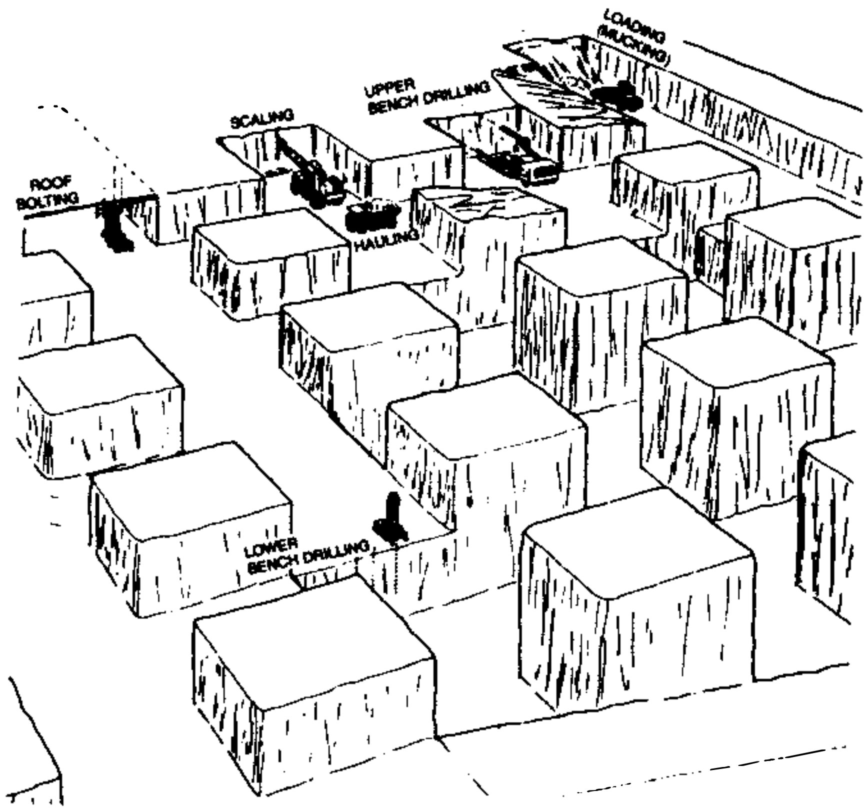
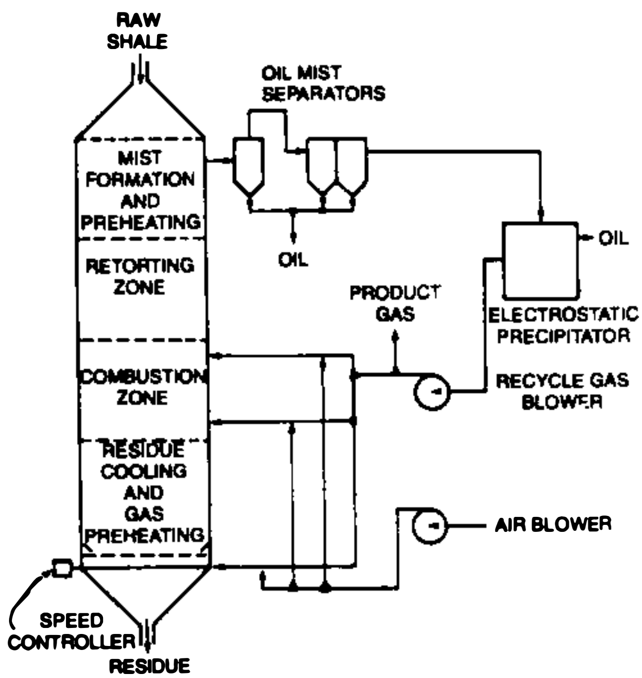


Figure 5 Room-and-pillar oil shale mining method, cutaway view. The room-and-pillar mine depicted above is the mining plan proposed for Colony Development's 46,000-BPD facility in the Piceance Creek Basin. The rooms are 60 feet wide; the pillars are 60 feet square; the mine roof is 50 feet high. Mining is conducted in two 30-feet high benches. The upper bench is mined first by drilling blastholes into the walls of a production room and breaking the shale loose with explosives. The broken shale is carried by trucks to crushers, where it is crushed to the size required by the TOSCO II aboveground retorts. The walls and roof of the new room are then "scaled" to remove shale that was loosened by the blasting but did not fall. Holes are drilled into the floor of the upper bench, and additional roof bolting is not needed. The cycle of drilling, was designed to produce about 60,000 tons per day of shale. About 60 percent of the shale in the mining zone was to be removed for processing the aboveground retorts. The rest was to remain in the support pillars.

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C. U.S. Government Printing Office, June 1980), pp. 126-127.



A. Direct Heating Mode

Figure 6 The Paraho Retorting Process using a direct heating mode. This system is similar to the older gas combustion design. Raw shale is fed to the retort through a rotating distributor at the top. It descends as a moving bed along the vertical axis of the retort. The shale is heated to pyrolysis by a rising stream of hot gases. Oil and gas produced goes to collecting tubes and then to separating equipment. Residual carbon is ignited to produce heat for pyrolyzing the raw shale.

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), p. 142.

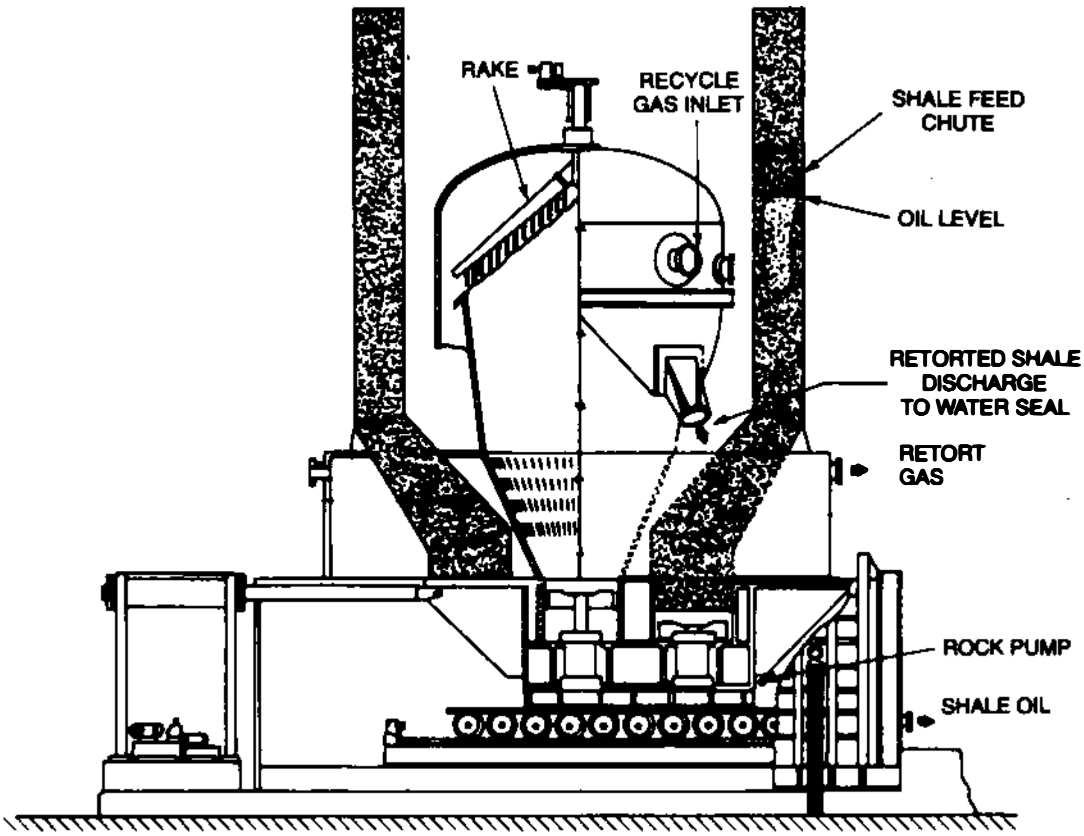


Figure 7 Union B Process, showing indirect heating of shale. This system, which has not been field tested, feeds shale through the bottom of the inverted cone vessel. Hot gases enter the top of the retort and pass down through the rising bed, causing kerogen pyrolysis. Shale oil and gas flow down, with the oil accumulating at the bottom. A portion of the gases produced is used to induce additional kerogen pyrolysis and to reheat the furnace.

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), p. 144.

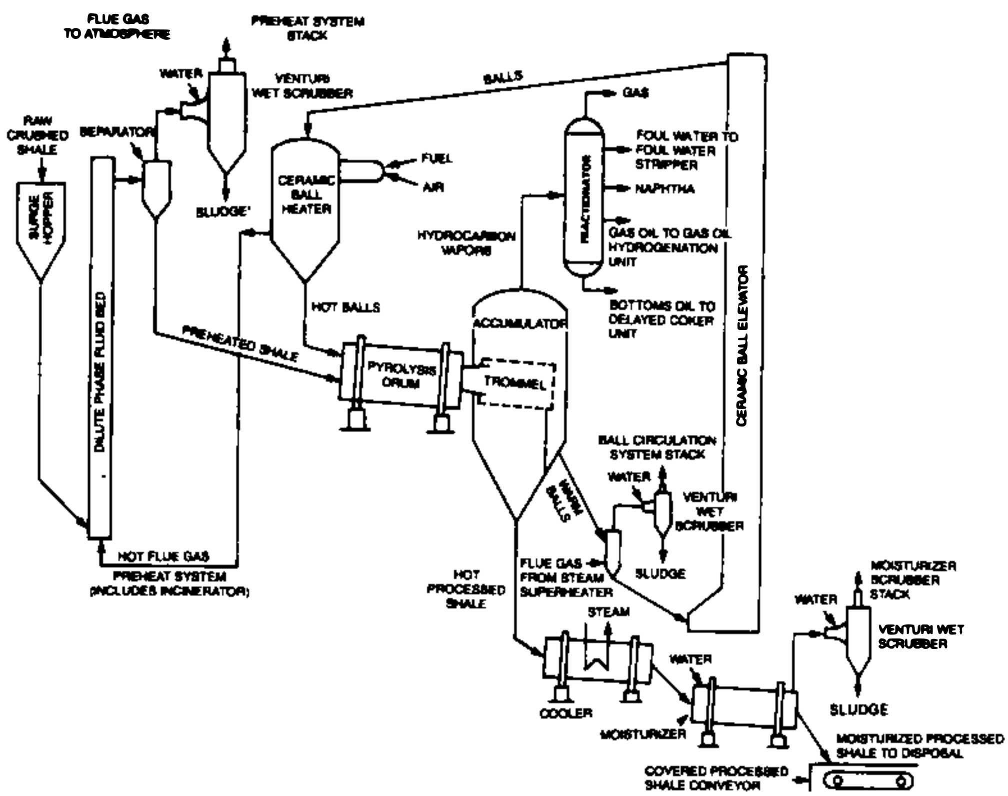


Figure 8 The TOSCO II process for oil recovery from oil shale. The TOSCO II system uses hot ceramic balls to carry heat to finely crushed oil shale. As the shale and balls come into contact with each other, the shale is heated to about 950°F (510°C) which induces retorting. After oil vapors and gases are withdrawn, the oil is condensed. Some of the gases are burned to reheat the ceramic balls to about 1,200°F (650°C).

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), p. 149.

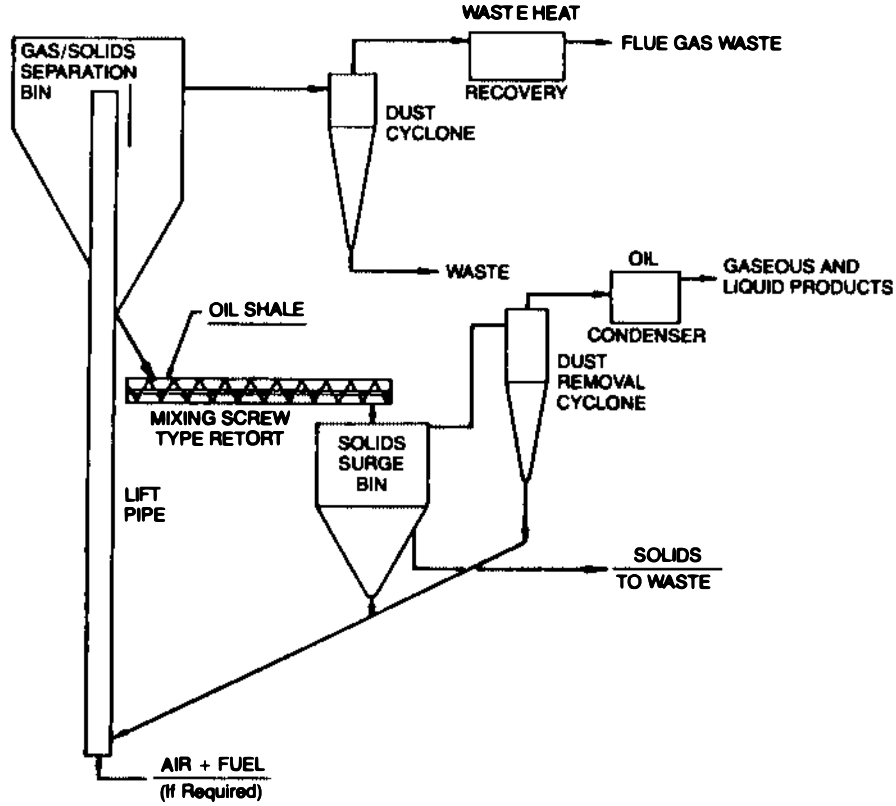


Figure 9 Lurgi-Ruhrgas Process for producing hydrocarbons from oil shale. The Lurgi-Ruhrgas retorting system mixes hot, retorted shale with finely crushed raw shale. Retorting takes place in a mechanical mixer in which gas and shale oil vapors are withdrawn. Retorted shale leaves the mixer, is heated to about 1,100°F (595°C), and is returned to the mixer where the retort process begins again.

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), p. 152.

shale is blasted into small fragments that fill the mined-out areas. The rubble is then retorted and the freed liquids and gases are pumped from the underground retort to the mine surface. (See Figure 10.)

True in Situ Retorting No shale is mined in TIS processes. The shale is first fractured and then retorted underground after preheating to pyrolysis temperatures. The released liquids and gases are then pumped to the surface. Because this developmental approach is in its infancy, it is not expected to significantly affect the production of synthetic fuels by the year 2000. For this reason, TIS is not discussed further in this assessment.

Description of Upgrading and Refining Processes

Systems for upgrading and refining shale oil are comparable to those used in conventional petroleum refineries, except that heavy metals and nitrogen must be removed from the crude shale oil and more hydrogen must be used than is required with some conventional crude oil.

CONCLUSION

As can be seen from the foregoing discussion of the synfuels technologies most likely to be commercialized within the next decade, they vary both with respect to their resemblance to existing technologies and with respect to their perceived differences. (See Table 2.)

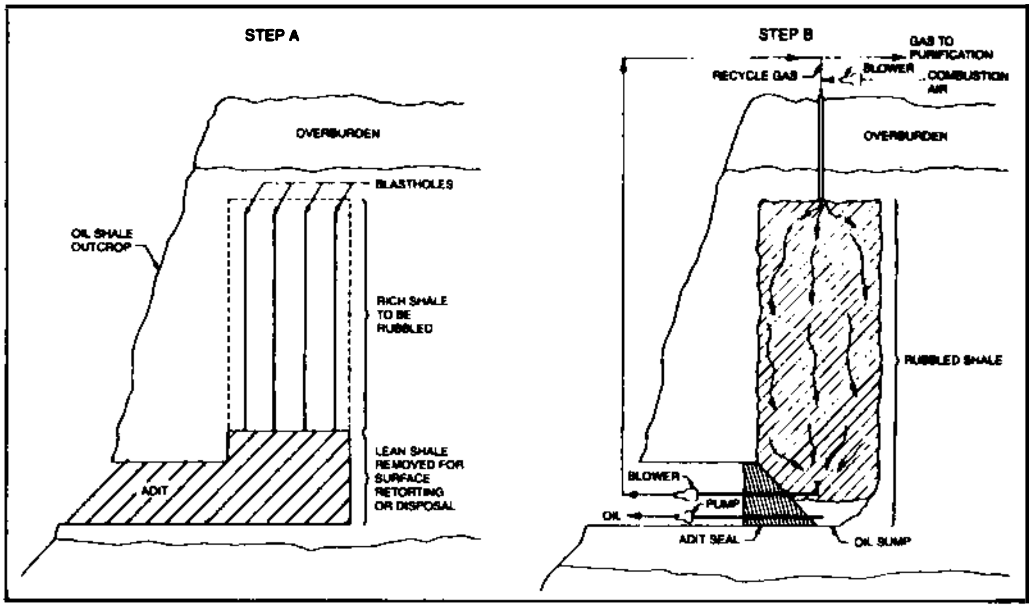


Figure 10 Modified in situ retorting. In MIS processing there are two major steps, as shown above. In the first step, a tunnel is dug to the bottom of an oil shale bed, and enough shale is removed to create a room with the same cross-section area as the future retort. Holes are drilled through the roof of the room to the desired height of the retort. They are packed with explosives that are detonated in the second step. A chimney-shaped underground retort filled with broken shale results. The access tunnel is then sealed, an injection hole is drilled from the surface (or from a higher mining level) to the top of the rubble pile. The pile is retorted by injecting air and burning fuel gas, and heat from the combustion of the top layers is carried downward in the gas stream. The lower layers are pyrolyzed, and the oil vapors are swept down the retort to a sump at the bottom from which they are pumped to the surface. The burning zone moves slowly down the retort, fueled by the residual carbon in the retorted layers. When the zone reaches the bottom of the retort, the flow of air is stopped, causing combustion to cease.

SOURCE: Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980), pp. 131-132.

TABLE 2 Similarities and Differences Between Synfuel and Existing Conventional Energy Conversion Technologies

Synfuels Technologies	Similarities to Existing Energy Conversion Technologies	Unconventional Aspects of Synfuels Technologies
Coal Gasification (Surface)	Many unit operations and processing steps similar to those employed in oil refineries, power plants, and coke ovens.	The gasifier itself; and in some processes the gas processing or cleaning systems (e.g., the tar knock out unit operation).
Indirect Coal Liquefaction	Essentially similar to coal gasification techniques.	
Direct Coal Liquefaction	Overall operation parallels conventional petroleum refineries.	The ability of equipment to contain process under high pressures and temperatures in hydrogen-rich environments at commercial scale, e.g., the potential for flange leakage and the adequacy of process components such as slurry pumps to handle slurry streams. The ability of vessels to withstand hydrogen attack and to maintain safe operating temperatures at commercial scale.
Oil Shale Recovery	Basic mining technology comparable to that employed for recovery of coal, iron, and copper.	Unprecedented scale of mines for large-scale operations could require different approach in regard to materials handling, mining engineering, and design and fabrication of equipment. Use of larger than usual diesel-powered equipment underground.
Aboveground Retorting	The processes involved in retorting and upgrading (e.g., materials handling, crushing, solids heating and cooling, waste disposal, and the handling of liquids) are similar to those used in other operations such as mineral processing and conventional petroleum refining.	Characteristics of raw shale dust, spent shale, and retort gases associated with both aboveground retorting and modified in situ processes.
Modified in Situ	Same as for aboveground retorting except for underground retorting.	High temperatures and fires involved in modified in situ processes; mining and retorting both taking place underground at unprecedented levels at same time. Process not tested over long period of time at significant scale. Leaching requires further study to achieve effective control.

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3

PLANT HAZARDS AND OCCUPATIONAL SAFETY AND HEALTH

OVERVIEW

A strong environmental protection program has been developed in the United States over the past two decades as a consequence of the passage of comprehensive pollution control legislation. These laws include: the Clean Air Act, the Clean Water Act, the Safe Drinking Water Act, the Surface Mining Control and Reclamation Act, and the Resource Conservation and Recovery Act, along with numerous pollution control laws and regulations passed at the state and local levels. While the laws are not specifically directed toward synthetic fuels facilities, developers of such facilities must meet all these current legal environmental requirements.

Moreover, federal laws and standards have also been designed to ensure occupational safety and health. Requirements passed under the Occupational Safety and Health Act of 1970, the Federal Mine Safety and Health Amendments of 1977, and the Toxic Substances Control Act of 1976 include specific provisions for: developing health standards that limit worker exposure to hazardous chemicals and to physical hazards such as noise; wearing and providing personal protective equipment; mandatory health and safety training programs; specifications for fire protection equipment; frequent inspections and investigations of mines; and monitoring the manufacturing, processing, distribution, use, and disposal of chemical substances in commerce. If these requirements are not met, permits may not be issued to build and operate the plant, or the plant could be closed down once operations begin. While the level of enforcement may vary to some degree among the states and municipalities, a specific level of control has been established by statute for enforcement by the U.S. government. (It is also important to note that other regulations and standards may be forthcoming--for example, technology effluent standards for the synfuels industry--which would further safeguard the environment and the worker.)

Thus, in order to comply with such regulations and to increase the probability that synfuels facilities will operate reliably for long periods of time,[1] developers of coal conversion and shale oil plants will employ a variety of approaches to minimize safety risks to the worker, the plant, and the physical environment. Many methods for minimizing hazards can be adopted from those used in other existing full-scale energy conversion facilities. At the same time certain unconventional aspects of the synfuels technologies discussed in this report may require the modification of existing safety controls and practices or the development of new ones.

This chapter first identifies some of the unconventional safety, health, and environmental hazards potentially associated with coal gasification, coal liquefaction, and oil shale recovery technologies in the absence of the application of proper control mechanisms. The remainder of the chapter examines the approaches currently used or proposed to anticipate or reduce hazards that might occur during the early phases of the synfuels industry. In addition, coal conversion and shale oil recovery plants will be compared with conventional fuel operations to assess inherent risks from the standpoint of plant reliability and susceptibility to natural disasters, sabotage, site-specific risks, and technology-specific risks.

[1]The capital costs of commercial plants (25,000-BPD equivalent) should be very high, in excess of $\$2 \times 10^9$ each. Such a heavy financial commitment requires the expectation of reliable process operations for prolonged periods of time. Thus, to protect this investment developers should make every effort possible to assure the construction of hazard-free and safe operating plants.

IDENTIFICATION OF POTENTIAL HAZARDS ASSOCIATED WITH SYNFUELS FACILITIES PRIOR TO CONTROL[2]

It is recognized that there have been several decades of industrial experience with processes, materials, and fuels identical and similar to those encountered in synfuels processes. Thus, many of the potential hazards associated with synfuels operations are the same as those routinely managed in comparable industrial facilities. Certain synfuels processes, however, have novel aspects that have the potential to cause new safety and health hazards unless they are adequately controlled. Major activities, unit operations, and critical components of the overall synfuels technology cycle that may entail some occupational or environmental hazards are outlined below. Many of the risks noted in the following discussion will be controlled if they are properly anticipated and if appropriate control strategies are designed and followed. If there are catastrophic failures in the control systems during or after plant operation, damage could be severe and long lasting. The control and mitigation practices currently in place or proposed to address identified hazards are examined later in this chapter.

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[2]For a thorough discussion of potential occupational and environmental hazards and risks associated with synfuels facilities, see R. Brown and A. Witter (eds.), Health and Environmental Effects of Coal Gasification and Liquefaction Technologies, a Workshop Summary and Panel Report for the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Contract No. DOE/HEW/EPA-03 MTR-79W00137 (McLean, Virginia: The MITRE Corporation, May 1979); R. Brown (ed.), Health and Environmental Effects of Oil Shale Technology, a Workshop Summary and Panel Report for the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Contract No. DOE/HEW/EPA-02 MTR-79W00136 (McLean, Virginia: The MITRE Corporation, May 1979); IWG Corporation and the Center for Environmental Sciences, University of Colorado, Health and Environmental Effects Document for Oil Shale--1981 (Washington, D.C.: U.S. Department of Energy, November 13, 1981); JRB Associates, NIOSH Occupational Hazard Assessment: Coal Liquefaction, Vols. I & II, prepared for National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services (Washington, D.C.: U.S. Government Printing Office, March 1981); Office of Technology Assessment, U.S. Congress, An Assessment of Oil Shale Technologies (Washington, D.C.: U.S. Government Printing Office, June 1980); and O. White (ed.), Proceedings of the Symposium on Assessing the Industrial Hygiene Monitoring Needs for the Coal Conversion and Oil Shale Industries, NTIS BNL-51002 UC-41 (Health and Safety-TID-4500), March 1979.

Coal Conversion Processes

The presently available coal conversion processes all involve components at high temperatures and pressures, containing hydrogen, toxic gases, and corrosive and erosive liquids and solids. Acute exposure of workers to intermittent high fugitive emissions would occur without precautions and controls in the following events: mechanical failure of process equipment and of related control and monitoring components.[3] Furthermore, the generated waste streams contain substances that must be controlled to prevent harmful effects on the environment. Severe exposures could also result from sabotage or natural disasters, as they would in any similar facility.

Acutely hazardous exposures to toxic or suffocating gases and chronic major exposures to genetic toxins with a latent response are critical occupational hazard concerns for the synfuels facility primary reactor and primary product cleanup unit operations. Fixed-bed coal gasification and direct coal liquefaction produce intermediate products and substantial amounts of by-products, before cleaning and refining, that are mutagenic in a variety of *in vitro* tests.[4] Some of these materials have also been shown to be carcinogenic in animal exposure tests. These processes, as well as other coal gasification technologies (for instance, entrained and fluid-bed gasification) also produce toxic sulfur- or nitrogen-compound gases and CO.[5]

Coal Gasification

Occupational Safety Concerns Coal gasification processes have been in existence for many years and a number of the points vulnerable to accidents are obvious and well known. Gasification technology combines elements similar to blast furnaces, coke-oven recovery plants, and those utilized in conventional petroleum refinery processes (such as synthetic ammonia plants). Similarities pertain to the total energy potential contained in the plant (inventory), the

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[3]C. W. de George, "Safety of Synthetic Fuels Plants, Direct Coal Liquefaction," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper E).

[4]Brown and Witter, op. cit.

[5]J. P. McGee, "Notes on Coal Synfuel Facility Hazards," correspondence to Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, January 1982 (see Appendix, Paper J).

temperatures and pressure levels, and the gas-, liquid- and solids-handling equipment and controls. Most individual hazardous materials are well controlled in conventional refining or other industries. However, special research efforts are needed in the early deployment of the synfuel industry to identify and assure the control of novel or unusual combinations of toxic, corrosive, or erosive materials or processes which might result in exaggerated or unexpected hazards.

It will be important, therefore, that the experience gained in comparable industries be properly incorporated during every stage of a synthetic fuels project, beginning with process design, detailed engineering construction, training of workers, and ultimately operation. The high cost and complex nature of synthetic fuels facilities suggest that the organizations ready to undertake such ventures will have ready access to--and will rigidly apply--the proper measures to safeguard their workers and their investment.

Occupational Health Concerns Potential specific health hazards from coal gasification plants result from silica, metals, benzene, phenolics, polynuclear aromatic hydrocarbons (PAH), heterocyclic compounds, aromatic amines, sulfur compounds, and CO. Although much work has been done in documenting the existence of these compounds in the process streams, there are few data available on fugitive emission quantifications of worker exposure levels at various facilities.[6] Major sources of personnel exposure could occur from coal storage and handling, uncontained emissions from the gasification process and the cleanup system, and waste disposal.[7] Entrained gasification generally requires a dry, finely pulverized coal feedstock. The health concerns associated with the handling of this fine coal in gasification plants are comparable to those encountered in other coal utilization technologies and are routinely recognized.

Small leaks in the gasification and cleanup system are unavoidable, particularly during the start-up, because of many reactor and pipeline connections, sample ports, and instrumentation installations.[8] These leaks could endanger worker health unless continued attention is paid to proper housekeeping. Fugitive process

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[6]J. Singh, D. Lazarevic, and E. F. Vandergrift, "Survey of Worker Exposures at a Fluidized Bed Coal Gasification Facility," paper presented at The American Industrial Hygiene Association's annual meeting, Houston, Texas, 1980. Paper made available to the Committee on Synthetic Fuels Facilities Safety, January 1982 (see Appendix, Paper Q).

[7]Ibid.

[8]Ibid.

gases can be divided into toxic gases such as H_2S, CO, SO_2 (sulfur dioxide), and CS_2 (carbon disulfide); and nontoxic gases such as H_2, CH_4, CO_2, and N_2 (nitrogen).[9] The toxic gases may damage lungs and body tissues; severe enough doses could cause death (for example, a small breach could result in a fatal concentration of H_2S). The nontoxic gases, while not damaging to the lungs and tissues, may cause death by displacing the necessary oxygen supply.[10] Moreover, since many of the emissions streams that might be released contain considerably higher concentrations of CO and H_2S than are produced in existing commercial facilities, such as refineries, they could affect worker health negatively unless carefully planned for and controlled.[11]

Gasification wastes that might pose hazardous handling situations are: process condensates from quenching and water scrubber operations that may contain aromatic organics, toxic trace elements, and dissolved gases; sludge from biological oxidation units that may contain adsorbed toxic trace elements or organics; and spent catalysts that may contain a number of toxic trace elements.[12] In particular, measures to protect workers who are involved with handling, storage, and transportation of carcinogenic coal tars will be an important component of an overall control program.[13] Routine maintenance or maintenance operations following unplanned or catastrophic plant failure could result in significant exposures of the involved work force to chemical mutagens and carcinogens. In some cases, these maintenance operations are subcontracted, so relevant health effects might not be readily identified.

Societal and Environmental Concerns Important sources of emissions are fugitive losses from the gasification and processing steps. Because gasification facilities are closed and usually pressurized systems, these fugitive losses may be the major source of emissions. The emissions may contain high concentrations of CO and H_2S, and

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[9]McGee, op. cit.

[10]Ibid.

[11]W. E. Corbett, W. C. Thomas, and E. H. Reichl, "Factors Affecting the Safety of Coal Gasification Facilities", paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper D).

[12]McGee, op. cit.

[13]Corbett, Thomas, Reichl, op. cit.

these toxic gases cause breathing difficulties, lung damage, and even death, depending on the extent of exposure.

All coal gasification facilities (just as any power plant) will produce large masses of solid materials that require disposal. These solid wastes include ash in various forms, process additives, and incompletely processed products. Components of these solid wastes may include toxic trace elements and water treatment sludge. If these pollutants migrate through the water table or are released to the atmosphere through transpiration or wind erosion, surface vegetation and drinking water supplies could become contaminated. Moreover, contaminated water could harm or kill aquatic biota and, if used for the irrigation of crops, could introduce toxic substances into the food supplies. Avoidance of these contaminations, to the extent they are known, must be built into all plants. Moreover, the extent of these effects, if any, must be carefully monitored as the first commercial synthetic fuels plants are built and operated.

Coal Liquefaction

Occupational Safety and Health Concerns[14] Although parallels clearly exist between the safety and health problems anticipated for the developing direct coal liquefaction industry and those typically accepted and experienced by the petroleum refining and chemicals industry, certain aspects of the technology (identified in Chapter 2), where technology extension has occurred, might present unconventional safety and health hazards that are not yet fully identified. For example, the composition of the raw liquid products derived from direct coal liquefaction differs markedly from that of petroleum crude oils and distillates. Prior to upgrading, coal-derived liquids have a high concentration of aromatic (benzene-like) compounds containing heteroatoms (for example, sulfur, nitrogen, and oxygen), PAHs, and polycyclic organic material (POM). This difference in composition is an area of occupational concern, particularly with respect to toxicity levels. Primary, unrefined coal liquefaction products have been shown to be much more highly mutagenic than conventional crude oil or petroleum products, and also more highly mutagenic than processed or unprocessed shale oils.[15]

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[14]For a detailed discussion of the toxicological safety issues associated with direct coal liquefaction, see G. K. Vick, "The Toxicology Data Base and Research Program Plans for Direct Coal Liquefaction," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper S).

[15]Brown and Witter, op. cit.

Another hazard associated with any use of coal is the possibility of coal dust explosions in the coal-handling system. This is the same hazard existing in all coal-fired utility plants and an important safety consideration for coal liquefaction plants as well.[16]

The erosive and corrosive nature of the processing solids and slurries is a further specific problem area. Processing of abrasive slurries, particularly at high temperatures and pressures, accelerates erosion and corrosion that may cause leaks in process equipment. Leaks increase the potential for worker skin contact with process materials, for inhalation exposure, for burns, and for fires. The most common medical problems experienced at pilot plants have been dermatitis, eye irritation, and thermal burns.[17]

Problems such as erosion, corrosion, and the plugging of valves have required special equipment and careful monitoring and maintenance procedures in pilot facility operations.[18] Attrition, plugging, or fouling of these components constitute potential unconventional sources of hazardous process upsets or fugitive emissions and require special consideration in the design of safety relief lines and safety valves.[19]

A major hazard to operators and maintenance workers in direct coal liquefaction plants is the high level of maintenance required to assure operation of slurry-carrying process equipment. The necessity for frequent disassembly and reassembly of this equipment can expose these workers excessively to highly carcinogenic slurry streams. Maintenance workers involved in plant turnarounds or in activities following plant shutdown after process failures or catastrophes could receive substantial exposure to such streams.

The several preceding potential hazards for coal liquefaction processes have been summarized in Table 3.

Societal and Environmental Concerns Potential risks to society and to the total environmental system associated with the direct liquefaction of coal will be similar to those described for coal gasification facilities.

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[16]de George, op. cit.

[17]JRB Associates, op. cit., Vol. I, p. 3.

[18]McGee, op. cit.

[19]de George, op. cit.

TABLE 3 Potential Occupational Hazards in Coal Liquefaction Plants

System, Unit Operation, or Unit Process	Potential Hazards
Coal-handling and preparation system	Coal dust, noise, fire, explosion, asphyxia (nitrogen and carbon monoxide), gases, burns
Liquefaction system	Phenols, ammonia, tars, thiocyanates, PAHs, carbon monoxide, hydrogen sulfide, hydrocarbons, fires, explosions, burns, high pressure, noise, ash, slag, mineral residues, primary aromatic amines
Separation system and upgrading and gas purification	Same as above
Shift conversion[a]	Tar, naphtha, hydrogen cyanide, fire, catalyst dust, burns, hot gases (carbon monoxide, hydrogen)
Fischer-Tropsch or methanol synthesis unit[a]	Carbon monoxide, methane, nickel carbonyl, spent catalyst dust, fire, burns
Waste-treatment facilities	Hydrogen cyanide, phenols, ammonia, particulates, hydrocarbon vapors, sludges, spent catalysts, sulfur, thiocyanates, tars

[a]Indirect liquefaction.

NOTE: Occupational Safety and Health Administration (OSHA) has standards for various chemicals that have been identified in the process streams of coal liquefaction pilot plants. Exposure limits have been established for individual chemicals. In most cases, the substances present in coal liquefaction plants will be complex mixtures of these and other compounds.

SOURCE: JRB Associates, NIOSH Occupational Hazard Assessment: Coal Liquefaction, Vol. II, prepared for National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services (Washington, D.C.: U.S. Government Printing Office, March 1981), p. 13, modified here by the Committee.

Shale Oil Recovery Processes

Occupational Safety Concerns

Mining The similarity of oil shale open-pit and underground mining to conventional mining industries (coal, trona, salt) make it possible to project likely occupational safety risks. During mining, accidents can result from electrocution, explosions and fires, rock and roof falls, bumps, falls, heavy mining equipment, vehicular traffic, and flooding. Mining is a high-risk occupation (in 1978, fatality rates were seven times higher in mining and quarrying than in manufacturing, and the disability injury rates were twice as high).[20] An examination of accident reports compiled by the Mine Safety and Health Adminstration between 1979 and 1980 indicated that the accident rate in underground oil shale mines was 90 percent higher than that of other nonmetal mining operations.[21] Yet, it should be noted that the limited statistical data base is inadequate for purposes of reliably predicting future performance of an oil shale industry. Furthermore, surface mining operations are considered to be two to three times less dangerous than underground operations.[22]

Nevertheless, some aspects of oil shale underground mining differ from other mining. While some mines use large openings and high extraction rates and some operate under gassy conditions, only oil shale mines and some salt mines operate under all three conditions simultaneously.[23] This combination might present novel safety hazards as yet unknown to the mining industry. For example, the size of diesel-powered equipment used in oil shale mines, when

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[20]IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 6-15.

[21]Kay Kreise, "Injury Experience in Nonmetallic Mining," paper presented at the Fourth Annual Rocky Mountain Center for Occupational and Environmental Health (RMCOEH), Occupational and Environmental Health Conference: Health Issues Related to Metal and Nonmetallic Mining, Park City, Utah, April 1982 (in press).

[22]IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 6-15.

[23]P. A. Rutledge, "Mining Problems Unique to Oil Shale," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper N).

they reach commercial scales of operation, will be several times larger than those currently available. It may not be possible simply to scale up the temperature controls, flame arrestors, and emission controls from the smaller units. If leaks were to occur due to ineffective pollution control devices, especially in gaseous mines, explosions and fires might result. Moreover, due to the size of the mining operations, very large inventories of explosives will be stockpiled or manufactured on site and employed. Unless properly controlled, their presence might lead to technical detonation problems during use which would exacerbate the currently low level of risk associated with the use of explosives in conventional mining. In addition, there is also concern for roof and pillar structural integrity under the assault of nearby massive use of explosives.

Underground mining, in conjunction with MIS retorting, might expose miners to safety risks not experienced in other underground mining activities.[24] For example, the increased potential for explosions and fire from the burning of retorts underground while operations continue in another part of the mine could make this approach particularly hazardous to the safety of the worker; recent statistics, based on industry-wide accident rates, suggest that this concern is likely to be valid.[25] For example, a major safety issue of the MIS process is the possibility that gas from the retort could leak into the mine if the negative pressure system on a retort malfunctions. A gas leak from an active retort could present an acute toxicity hazard or could be catastrophic if it were to spread to an area of the mine being developed with explosives.

Retorting and Refining Because full-scale, commercial oil shale retorting is a new technology in the United States and has only been operated at the pilot test stage, no data on accident statistics are available. However, the accident rate is expected to be comparable to that of an industry that uses similar technology (for example, limestone calcining, roasting of taconite and copper ores, and conventional petroleum refining).[26]

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[24]Skelly and Low, Engineers and Consultants, R&D Needs for Oil Shale Mining and Health/Safety Technology: Final Report (Washington, D.C.: U.S. Department of Energy, June 1980), p. 1.

[25]IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 6-22.

[26]IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 6-23.

Occupational Health Concerns[27]

Mining Several potential health hazards might be associated with the mining of oil shale: (1) lung disease resulting from the inhalation of oil shale dust generated from blasting, drilling, and vehicle traffic; (2) skin disease and colon and respiratory cancers resulting from carcinogens and trace elements that might be produced in mining; and (3) loss of hearing and potential neurological damage caused by excessive levels of noise and body vibrations as a result of drilling, blasting, and vehicle traffic at the mine site. These hazards could pose substantially greater risks to underground oil shale miners than to those involved in surface operations. Health problems caused by mining activities, unlike injuries caused by safety problems, can take much longer to become manifest (sometimes over 20 years).

Limited epidemiological studies of domestic oil shale experience have identified a higher than normal incidence of respiratory cancer and cancer of the colon.[28] However, a correlation of the cancer incidence with oil shale occupational exposures was confounded by smoking, with which there was a positive correlation,[29] and by the past uranium-mining experience of many of the workers. Case-control follow-up studies of the excess colon cancer incidence have not been performed. These domestic studies have shown a positive correlation

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[27]For a detailed discussion of the toxicological safety issues associated with oil shale recovery, see the following: A. M. Kaplan, "U. S. Oil Shale Industry: Health and Environmental Effects," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper G); L. M. Holland, "Health Effects of Oil Shale Development," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper F); B. C. McKusick, "Toxicological Safety Issues," material prepared for the Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, February 1982.

[28]J. Costello, "NIOSH Studies of Oil Shale Workers," paper presented at the Fourth Annual Rocky Mountain Center for Occupational and Environmental Health (RMCOEH) Occupational and Environmental Health Conference: Health Issues Related to Metal and Nonmetallic Mining, Park City, Utah, April 1982 (in press).

[29]J. Costello, "Retrospective Mortality Study of Oil Shale Workers 1948-1977," Thirteenth Oil Shale Symposium Proceedings (Golden, Colorado: The Colorado School of Mines Press, April 1980), pp. 369-379.

of actinic keratoses to oil shale worker exposures.[30] Limited medical studies of oil shale workers have identified the existence of pneumoconioses in some which are radiographically distinct from silicosis and coal workers' pneumoconiosis.[31] In nondomestic oil shale experience studies, the Institute of Occupational Medicine in Edinburgh is now pursuing studies of occupational health effects associated with the now-defunct Scottish oil shale industry. Those efforts, sponsored in part by the Department of Energy, will follow up recently reported preliminary studies of respiratory cancer in a limited number of ex-workers.[32]

It is important to note that respiratory illnesses are common to miners throughout the world. Green River oil shale contains a high percentage of silicon dioxide (approximately 12 percent), and the disabling lung disease silicosis could be caused by the inhalation of free silica.[33] The potential for dust-induced fibroses or for synergistic exposure effects on the oil shale worker from oil shale dust and diesel exhaust products has not been fully determined.

Less is known about the possible exposure to carcinogens and trace elements in oil shale mining. Although some of the materials produced during the mining of oil shale have been linked to skin disease, many more data are needed to reach conclusive results.

Noise, while a potential safety problem, is not uncommon in other mining operations. However, uncertainties exist about whether the unusual size of the oil shale mining operations, coupled with the use of percussive drills, pumps, turbines, blowers, and large pieces of diesel equipment, will result in excessive noise exposures for miners.

Retorting and Refining Production of hazardous materials during oil shale retorting depends in large measure on the effective retort

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[30]J. Costello, M. D. Attfield, J. A. Burkhart, et al., "Morbidity Study of Oil Shale Workers Employed at Anvil Points, Colorado, During 1948-69," (to be published).

[31]W. E. Wright and W. N. Rom, "A Preliminary Report: Investigation for Shalosis Among Oil Shale Workers," Chapter 34 in Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980).

[32]A. Seaton, D. Lamb, W. Rhing Drown, et al., "Pneumoconiosis of Shale Miners," Thorax, Vol. 36 (1981), pp. 412-418.

[33]IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 6-7.

temperature.[34] Hotter retort temperatures produce higher yields of gas and coke, PAHs, and trace elements than those produced at lower temperatures. Many PAHs have been shown to be carcinogenic. The amount of potentially carcinogenic material the worker might be exposed to depends in part on the design of the retort.

Spent shale will be generated during the retorting operation of any oil shale facility. Trace elements, including heavy metals, are expected to be present in the spent shale. Unless properly managed, the handling of spent shale might pose hazardous dermal or respiratory exposures to potentially toxic PAHs and heteroatomic organics or silicaceous minerals.

The level of risk is expected to be higher for retorting work and its associated activities than for the refining of shale oil. The health-related problems associated with shale oil refining should be comparable to those found in conventional petroleum refining.

Decommissioning of Facility Once an oil shale facility has ceased operations, appropriate caretaking will be required to monitor abandoned MIS retorts, spent shale waste piles, and reclamation sites. Maintenance workers involved in these tasks may be exposed to yet undefined health risks which should be identified and monitored.

Societal and Environmental Concerns

A number of the air pollutants that might be generated are respiratory irritants, and others such as particulates might contain PAHs and can be carcinogenic. Qualitatively, the air pollution concerns for sulfur- or nitrogen-compound emissions are the same as for other synfuels. Leachates from aboveground disposal areas and burned-out *in situ* retorts could, unless properly monitored and controlled, increase the concentrations of dissolved solids in parts of the Colorado River and also could pollute surface water and aquifers that are major sources of drinking water. In addition, wildlife resources of the area will be affected without proper precautions, and the topography of the land will be altered.

APPROACHES TO RISK REDUCTION

The following are some of the approaches which should be used during the development of a synthetic fuels industry to reduce safety, health, and environmental risks: careful site selection to minimize

[34]P. A. Boguvski, "Carcinogenic Substances in Estonian Oil Shale Industry," *16th International Congress of Occupational Health*, 1976, p. 658.

effects on the total environmental system; the design and maintenance of safe working conditions; the selection of process and pollution control technologies and strategies to reduce the release of airborne emissions, aqueous effluents, and solid wastes; the institution of industrial hygiene and worker training programs; health surveillance, including exposure monitoring and record keeping; and emergency plans and procedures. While these approaches are common elements of most industrial operations, methods for reducing risk in synfuels facilities will necessarily vary because of site-specific, technology-specific, and material-specific differences. Specific practices employed or proposed to minimize potential hazards associated with coal conversion and shale oil recovery facilities are noted below.

Project Siting Considerations

Synfuels facility siting is similar to other industrial facility siting in that once the basic site requirements have been defined (that is, plant production rate, raw materials, market, process technology, potential emissions levels), the actual site selection study is undertaken. Such a study reviews all identified potential sites, evaluating each against common criteria in order to identify the most suitable location. Of critical importance to synfuels plant siting are those criteria that relate to the control of air emissions, aqueous effluents, hazardous substances, leachate from mines and waste piles, and so forth. Methods currently undertaken by developers prior to and during the siting process to avoid or minimize potential environmental and safety hazards are noted in detail in the Appendix.[35]

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[35]For a more thorough discussion of considerations involved in the siting of synthetic fuels facilities, see: A. D. Benz, "Synthetic Fuels Facility Safety Plant Siting Considerations," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper A); P. A. Rutledge, "Oil Shale Facilities Siting: Geologic and Environmental Considerations," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper O); and B. Brodfeld, "Environmental Regulations in Relation to the Synfuels Industry," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper B).

Plant Design and Maintenance Procedures

The separation of major plant operating areas, the use of noncombustible materials in construction, the implementation of safety-oriented instruments and controls, and the undertaking of routine metallurgical inspections are just a few engineering controls and practices that can minimize safety hazards in synfuels facilities.[36] Specific practices for reducing fires and explosions, for preventing leaks, and for limiting worker exposure to hazardous gases, liquids, and solids in coal conversion facilities are highlighted in the Appendix in Position Papers E and J. Many of these approaches are based on experience gained in oil refineries and coal-fired power plants.

Comparable design and maintenance practices are also employed or proposed for limiting risks that might occur during shale oil recovery operations. For example, some design and maintenance features for safe mining operations include: the use of standard safety apparatuses for the plant (such as guard rails or warning signs) and for the worker (such as respiratory and hearing protection devices and protective clothing, footwear, gloves, and hard hats); well-maintained mining equipment; adherence to safety regulations and sound safety practices (for instance, the use of explosion-proof electrical systems); training the new worker and providing refresher courses for workers throughout their careers; and developing effective face ventilation systems for large mine openings.

In addition, precautions can be taken in the design phase to protect the facility and worker from damage that might be caused by a natural disaster or sabotage. By following construction codes that consider worst-case possibilities to determine what wind loads and earthquake severities must be withstood during plant operational life, developers can overbuild their facilities to minimize safety hazards from such sources.[37] Also, standard security procedures (for example, a chain-link perimeter fence with limited access points, security guards stationed at access points, intrusion detection equipment, employee training programs) can assist in limiting the potential for sabotage.[38] To protect against damage

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[36]J. A. Robinson, "Property Loss Prevention Criteria as Applied to Coal Gasification Projects," paper presented at a conference on the Prevention of Fire and Explosions in the Hydrocarbon Industries, sponsored by the Institute of Gas Technology, Chicago, Illinois, June 7, 1979.

[37]de George, op. cit.

[38]Ibid.

or disruption of operations from lightning, the tallest process equipment can be enclosed in a steel framework and grounded.[39] Careful siting practices, as previously noted, can also be effective in avoiding and controlling impacts that might result from catastrophic events.

Pollution Control Technologies and Strategies

The amounts of pollutants ultimately emitted from synfuels facilities will depend on the effectiveness of the control methods used to meet environmental regulations. Developers plan, whenever possible, to employ control methods tested in analogous commercial-scale energy conversion facilities. Yet, a number of characteristics of the potential synfuels industry require extrapolating control measures beyond the present levels of knowledge. These include: the expected scale of operations, the physical characteristics of the coal and shale, the nature of the waste streams, and areas where technology extensions have occurred.

Specifically, one of the most significant questions facing the designers of coal conversion facilities is the effectiveness and reliability of waste-water treatment systems.[40] Individual treatment technologies such as solvent extraction, steam stripping, and biological oxidation are commercially available. Many of the commercially available devices have been found to provide an adequate degree of control, but few have been operated commercially with waste waters from such facilities.[41]

Uncertainties also exist with respect to the handling of solid wastes from nonpoint sources (such as leachates) from oil shale facilities. The efficacies of control strategies after site abandonment are even less certain, but this problem is not unique to synthetic fuels plants. Long-term monitoring and custodial care may be required to assure that contaminants are not released from catchment basins, for example, as a result of dam failure or extraordinarily heavy rainfall or snowfall, during the life or after shutdown of synfuels plants. Nevertheless, control technologies and strategies appear to be fairly well developed, and should be adaptable to the first-generation synfuels plants.

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[39] McGee, op. cit.

[40] Corbett, Thomas, Reichl, op. cit.

[41] Ibid.

Health Surveillance and Exposure Monitoring

The safety programs associated with synthetic fuels facilities will include medical surveillance of workers in order to limit any adverse health effects. Normally, surveillance involves preplacement, periodic, and termination examinations. Such exams usually include gathering information on work histories, which are important since past exposures may predispose the worker to adverse effects.[42] Exposure monitoring is used to determine whether worker exposure to chemical and physical hazards is within the limits set by the Occupational Safety and Health Administration (OSHA) and other standards-setting agencies, and whether corrective measures are needed. However, no exposure limits have been established for many substances that may contaminate the work place in coal conversion and shale oil facilities.[43] Currently, the programs implemented in different synthetic fuels facilities vary in regard to both input and output data and in their approaches to record keeping. The feasibility of and potential designs for an industry-wide oil shale worker registry for epidemiology studies are currently under discussion by some state and federal government agencies, the American Petroleum Institute, and some oil companies. The use of advanced medical surveillance techniques such as blood or urine assays for mutagenic materials or their metabolites or for early biological effects such as leukocyte chromosomal aberrations or sister chromatid exchange requires further research.[44] But these can in some cases provide a basis for early indication of genotoxicity hazards to workers.[45] Also, the physiological or radiological criteria for determining the onset and stages of pneumoconioses for oil shale miners must be defined.

Emergency Plans and Procedures

Developers of synthetic fuels facilities, like other industrial operators, must develop emergency plans and procedures for fires, explosions, and rescues. Such plans establish lines of

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[42]JRB Associates, (Vol. I), op. cit., p. 6.

[43]Ibid.

[44]B. J. Dabney, "The Role of Human Genetic Monitoring in the Workplace," Journal of Occupational Medicine, Vol. 30, No. 9 (1981), pp. 626-631.

[45]J. D. Fabricant and M. S. Legator, "Etiology, Role, and Detection of Chromosomal Aberrations in Man," Journal of Occupational Medicine, Vol. 23, No. 9 (1981), pp. 617-625.

responsibility and make it clear to personnel where they should be and how they should act in the event of a major process upset or natural disaster[46]. The aftereffects of a natural disaster or sabotage can be handled by procedures similar to those that would be used should a catastrophic equipment failure result from a process malfunction.[47] Elaborate safety shutdown signals and isolation capabilities are typically provided within petroleum refineries and should be similarly provided within commercial-scale synfuels facilities.[48]

EFFECTIVENESS OF METHODS TO MINIMIZE SAFETY RISKS UNDER NORMAL AND CATASTROPHIC CONDITIONS

Pilot plant operating experience to date indicates that certain siting practices, engineering controls, pollution control techniques, and worker safety practices already demonstrated in mining, petroleum refining, and the chemical industry can be transferred, with some modifications, to these plants to address some known environmental and safety problems. For example, the severe operating conditions that exist in direct coal liquefaction are also experienced in petroleum refineries, though not necessarily in the same combinations. Hydrogen-rich environments up to 3,000 pounds per square inch (psi) are encountered in hydrocracking, and synthesis of ammonia and the handling of erosive gas and liquid streams containing solids is well demonstrated in fluidized-bed catalytic units.[49] However, the combination of high concentrations of H_2S, CO, and other toxic gases, high hydrogen pressures, high temperatures and pressures, and flowing erosive and corrosive materials may pose unusual possibilities for hazards or hazardous exposures in synfuels facilities.

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[46]Guidelines for developing emergency procedures have been published in the Federal Register (e.g., Fire Protection, Means of Egress, Hazardous Materials Final Rule) and by DOE (Chapter 0601, Emergency Planning Preparedness and Response Program) and will be useful for developing an emergency plan for synfuels facilities.

[47]de George, op. cit.

[48]Ibid.

[49]Ibid.

Moreover, if conservative planning and design efforts (such as using construction codes that typically consider worst-case possibilities) are applied to synfuels plants, the probabilities of process upsets from natural disasters would not likely be any greater than those experienced in established industries. (Past oil refinery and chemical storage catastrophes have shown that proper facility design can avoid or control the impact of natural disasters.) In fact, these facilities should have a less-than-average susceptibility to damage from earthquakes or hurricanes because they will not tend to be located in coastal regions.[50] (It is also interesting to note that hydrogenation plants operated by the Germans during World War II were not severely damaged even during extensive Allied bombings. Although on-site storage facilities were ruptured, causing minimal leaks of stored liquids, and lines and couplings were broken, the retort vessels themselves remained substantially intact.[51] However, since the siting of synfuels facilities in the United States will undoubtedly follow a different pattern, it would appear that no parallel can be drawn.)

While such occurrences as temperature extremes, lightning, severe blizzards, thunderstorms, and flash floods could adversely affect a particular plant's operation, their subsequent effects would not be expected to be so severe that they could not be anticipated and planned for. Security risks for synfuels operations are expected to be comparable to security risks for similar mining or petroleum-related operations.[52] All require a moderately high level of security, and no security risks requiring unusual precautions for coal conversion and shale oil recovery operations are apparent at this time.[53]

Yet, a certain level of uncertainty and risk is introduced where technology extensions have occurred and where new development approaches are being considered (for instance, in MIS oil shale retorting). This is also true where control technologies and strategies have not yet been tested at commercial scale, on comparable waste streams, or for prolonged periods of time. Problems that might result from these factors are neither so trivial as to be

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[50]Corbett, Thomas, Reichl, op. cit.

[51]McGee, op. cit.

[52]Since publicity is a factor in the motivation of many acts of terrorism or sabotage, the first several synthetic fuels facilities built in the United States may be more susceptible to this problem than more established energy conversion facilities.

[53]R. J. Stegemeier, "Risks of Shale Oil Recovery," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper R).

ignored, nor so large as to preclude the construction of the first generation of synthetic fuels plants. At the same time, it is essential that these plants be carefully evaluated and monitored with respect to their reliability and safety, and that R&D be directed toward areas of limited experience and uncertainty. Experience gained and information gathered during the construction and operation of this first series of facilities will provide a better opportunity to build technologically sound, hazard-free, and safe operating commercial-sized synfuels plants in the future.

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INFORMATION NEEDS

INTRODUCTION

Insights into identifying the safety, health, and environmental risks that might be associated with the commercialization of a synthetic fuels industry in the United States have been obtained from laboratory large-scale pilot plants, and in some cases commercial demonstration plants, and from experience in related industries. Nevertheless, additional measurements and R&D programs would be useful in order to reduce the level of uncertainty and risk associated with areas where technology extensions have occurred, where new development approaches are being considered, and where control technologies and strategies have not yet been tested on comparable processes, unit operations, or components for prolonged periods of time. The anticipated slow development of synfuels technologies--to an approximate 80,000 BPD by the late 1980's (30,000 to 50,000 BPD from coal utilization and an equivalent amount from shale liquids)--provides the opportunity to clarify the potential for safety hazards to the work force, to the environment, and to the public.

One method for clarifying such risks would be the definitive monitoring of the initial set of commercial coal conversion and shale oil recovery facilities. Preparation for such monitoring should include the review of data generated during pilot plant operations and the initiation of additional safety, health, and environmental R&D programs and monitoring activities. Areas where additional research and surveillance should be focused during the initial stages of commercialization are identified in this chapter.

TECHNOLOGICAL R&D

Two main areas relating to technological R&D for future synthetic fuels facilities have been identified. These relate to component areas that involve the extension of commercially available equipment to more severe service requirements and the adequacy of existing mine safety technologies for the safe design and operation of large-scale mining activities associated with the production of shale oil. Research priorities should be directed toward improving these elements which are critical to maintaining continuity of process operations, and which involve the highest risk potential to workers.

Component Design in Areas of Technology Extension

Coal liquefaction facilities in particular would benefit from research directed at improved component technology. As noted previously, such facilities generally use commercially available equipment types intended for petroleum processing facilities. The risk and safety concerns are related to the degree of extrapolation required to make this equipment suitable for the processing severities unique to direct coal liquefaction and not to the uncertainties of workability or operation for brand new equipment types.[1] While much of the direct coal liquefaction pilot plant effort currently in progress deals with the demonstration of commercially available petroleum-type equipment, additional research focused on areas where technology extensions exist would materially improve the operability and safety of coal liquefaction facilities. These areas are well defined with emphasis placed on the ability to contain high-pressure process fluids at high temperatures in hydrogen-rich environments, to handle solids containing slurry process-streams adequately, and to protect operating personnel from possible toxic exposures due to the compositional make-up of coal liquids.

Table 4 indicates some broad areas of component design that should receive continued attention. For example, improved components

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[1]C. W. de George, "Safety of Synthetic Fuels Plants, Direct Coal Liquefaction," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper E).

TABLE 4 Component Research Areas for Direct Liquefaction Processes

- Reliable materials performance in slurry-handling system.
- Improved understanding of hydrogen attack and temperature embrittlement of 2 1/4 Cr-1 Mo steels.
- Elevated temperature properties, fabrication, and inspection techniques of thick weldment (> 8 in.) for pressure vessel construction.
- Vessel designs that reduce the shell design temperature below that of the operating environment.
- Continued development of components for slurry services, e.g., control and block valves, pumps, seals and flushing systems, instrumentation, heat-transfer equipment.
- Continued development of design criteria for the prevention of flange leakage.

SOURCE: C. W. De George, "Safety of Synthetic Fuels Plants Direct Coal Liquefaction," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982, (see Appendix, Paper E).

for slurry service would improve the operation of the plant by reducing downtime, limiting the number of maintenance turnovers, and decreasing the health hazard to maintenance personnel.[2] Similar component reliability characterization and improvement are recommended for coal gasification-based processes, especially for ball valves used to control feed, product, or by-product two-phase and three-phase flows. There should be continued work to determine failure modes and rates of critical process operations and components subject to representative corrosive and erosive mixed solid-fluid flows and hydrogen or temperature embrittlement, and to analyze failure modes for synfuels production systems under routine and upset conditions. Information generated could assist in quantifying the probability and effects of events having high-consequence, low-occurrence rates. Such data could provide a basis for improved design and inspection criteria and techniques.

Priority should also be given to designing equipment to meet the needs of large-scale underground oil shale mining operations. For example, research is suggested in order to develop larger-than-conventional diesel-powered mining equipment. Of particular interest is the design of a flame arrestor and cooler that will be effective given the gassy conditions of some oil shale mines.[3] Research should also be continued in the work directed toward improving rapid tunneling equipment, drilling technology, and haulage systems.

Moreover, a system must be established for obtaining reliable accident/source/term data in order to identify the factors that cause accidents and to recommend preventive measures. Efforts should be directed toward those unit operations thought to expose the worker to the highest level of risk, and toward those areas where there is no previous experience for judging accident potential (for example, areas where technology extensions have occurred) at commercial-scale plants.

Continued Safety Research for the Mining of Shale

Oil shale underground mining and MIS retorting present higher levels of risk to the safety and health of the oil shale worker than either the aboveground retorting of shale or the shale oil refining operation. Therefore, improvements should be sought in mine safety and mining technology. Safety R&D needs should be directed toward the following critical areas:

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[2] J. P. McGee, "Notes on Coal Synfuel Facility Hazards," correspondence to Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, January 1982 (see Appendix, Paper J).

[3] P. A. Rutledge, "Mining Problems Unique to Oil Shale," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, January 1982 (see Appendix, Paper N).

- Mine Fires and Explosions. Priority should be given to determining the ignitability of oil shale dust clouds, identifying the fire hazard of oil shale dust layers on a hot surface, investigating the flammability and spontaneous combustion potential of coarse oil shale, and determining the most effective means of extinguishment.[4]
- Ventilation. Work should include the development of an effective face ventilation system for the large-sized rooms expected in oil shale underground mining operations.[5] Special ventilation needs and controls for upset conditions in MIS oil shale retorting should be researched.
- Ground Control. Rock mechanics and the structural stability of pillars, particularly the cumulative impact of extensive blasting on pillar stability and the effect of multilevel mining on mine stability, should continue to be addressed.
- Instrumentation. The effectiveness of existing equipment to detect and monitor fires and hazardous gases in commercial-scale oil shale mines should be assessed.
- Explosives.[6] Additional research in this area might include: a program for monitoring dust, methane, and explosion products during the blasting of oil shale; and development of acceptable practices to allow for a more diverse range of explosives and larger charge sizes than are permitted in other underground mining.[7]
- Emergency Response. Research here would involve examining existing equipment and systems for their adequacy to respond during a mine emergency. For example, an assessment could be made of the adequacy of existing fire-fighting systems and ventilation equipment.

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[4]Ibid.

[5]Ibid.

[6]It is important to note that while oil shale mining will entail the use of large quantities of explosives, it will only increase the current usage of explosives by an incremental amount, not by a multiple. The amount used at a particular site may be large, but not larger than at certain U.S. sites for mining copper or iron ore, as previously noted. Most of the explosives will be ammonium nitrate in the form of an aqueous emulsion or a water gel. These widely used explosives are particularly safe forms. For example, they cannot be detonated by a simple blasting cap, which makes them safer than dynamite.

[7]B. C. McKusick, "Future Use of Explosives by the Shale Oil Industry," correspondence to the Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, February 1, 1982.

ENVIRONMENTAL R&D

While the necessary control technologies and strategies for synthetic fuels facilities have been established based on either technology transfer from conventional energy facilities or pilot plant characterization and demonstration, a need does exist for monitoring their performance in first-generation synfuels plants. Such research should address systems capable of monitoring the long-term reliability and operability of both individual and integrated control technologies, as well as the continued assessment of the potential effects of pollutants on the environment. The principle of monitoring or proof-testing of first-of-a-kind systems is well established within all disciplines of science and engineering. Critical areas include solid waste management, the transport of pollutants, and potential effects of pollutants on the environment. These are highlighted below.

Testing of Control Technologies for Prolonged Periods of Time

As part of near-term demonstration of commercial-scale synfuels processes, programs should be initiated to confirm the continuous performance of the environmental control technologies. For example, as discussed in Chapter 3, one area where additional research is suggested relates to the reliability of integrated waste-water treatment trains in coal gasification and coal liquefaction commercial applications.[8] While such work has been undertaken and is currently conducted to investigate the performance and reliability of both individual and integrated control technologies, further research would nevertheless be useful.

Solid Waste Management

A basic issue surrounding solid waste management in coal conversion and particularly in shale oil recovery relates to the direct or indirect environmental effects of waste disposal. Specific R&D needs include:

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[8]W. E. Corbett, W. C. Thomas, and E. H. Reichl, "Factors Affecting the Safety of Coal Gasification Facilities," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper D).

- Evaluating the effectiveness of solid waste disposal plans over the short and long term and also under normal and catastrophic conditions. In addition, hazardous waste disposal areas should be designed in case such areas will be required in the longer term.
- Developing reliable models and testing them under simulated worst-case conditions, such as massive failures of a containment structure due to sabotage or a natural disaster.
- Continuing work in the area of geotechnical engineering, both at a basic and applied level, in order to lessen the chance of solid waste disposal pile failure.[9]
- Studying leachates--in particular, their ability to penetrate the linings of disposal ponds and catchment basins.

Modeling and Monitoring Pollutant Release

Although much work has been done in the important area of modeling and monitoring pollutant release, this work should continue. For example, industrial hygiene monitoring in large pilot plant operations has in part determined the character and composition of fugitive releases from coal liquefaction subprocesses in the work place. However, accurate models to predict levels of these releases at the plant perimeter need to be developed. Other areas where special monitoring should be provided include: measuring particulate and dust release and the amount of sulfur oxides emitted at each site; characterizing the hydrocarbons and trace elements that are emitted; and analyzing the effects of altitude and terrain on the chemistry and transport of pollutants.[10] In addition, work should continue in the refinement of dispersion modeling and monitoring techniques, as well as in evaluation of those techniques used in the monitoring of surface and ground waters.

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[9] W. R. Chappell, "Some Policy Issues Related to Synthetic Fuels Facilities Safety," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper C).

[10] IWG Corporation and the Center for Environmental Sciences, University of Colorado, Health and Environmental Effects Document for Oil Shale--1981 (Washington, D.C.: U.S. Department of Energy, November 13, 1981), p. 7-10; and R. D. Brown, testimony before the Subcommittee on Energy Development and Applications and on Natural Resources, Agriculture Research and Environment, of the Committee on Science and Technology, U.S. House of Representatives, 96th Congress, September 28, 1981, Washington, D.C.

Continued Assessment of Potential Impacts of Pollutants on the Environment

While a great deal of knowledge has been gained about the potential effects of synfuels facilities on the physical environment, more can be learned from the first set of commercial plants. Such work should address impacts that might occur both during the operation of a facility and after the facility's useful lifetime. Specific areas of study might include:

- Evaluating pollutant increases and effects (where data permit) on air quality, water quality, and so forth, due to the clustering of synfuels facilities in a relatively confined geographical area.[11]
- Monitoring the effect of long-term, chronic exposure of natural biota, agricultural crops, plants, and grazing animals to low levels of pollutants unique to synthetic fuels, especially the effect on biotic systems (for instance, semiarid desert biota and grasslands) that usually have not been put under stress by humanly-induced pollutants.[12]

HEALTH EFFECTS R&D

The health concerns associated with the development of synthetic fuels processes relate more to the synfuels worker than to the general public. Medical surveillance of workers, industrial hygiene, monitoring of worker exposures, engineering controls, work practices, personal hygiene, health education, and toxicity evaluations of process emissions and product streams are key areas that form an integral program for guarding against potential adverse health effects in synthetic fuels facilities. Ongoing programs in assessing health effects associated with shale oil and direct coal liquefaction and coal gasification-based processes should continue to receive research emphasis, as should worker training and the effectiveness of personal protective equipment.

Continued Assessment of Health Effects Associated with Shale Oil Recovery Processes

The health concerns associated with the development of shale oil recovery processes relate more to the occupational worker than to the

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[11]The Prevention of Significant Deterioration increment provisions of the Clean Air Act will limit to a certain extent the clustering of synfuels facilities.

[12]Brown, op. cit.

general public. The available toxicity data suggest that crude shale oil may be slightly more mutagenic and carcinogenic than is crude petroleum and that in situ shale oil may be more mutagenic and carcinogenic than surface-retort shale oil.[13] However, acute and short-term toxicity tests do not indicate a significant difference between shale oils and some shale oil middle distillates on the one hand and equivalent petroleum-derived substances on the other.[14]

Historical evidence from foreign oil shale development and recent data generated from demonstration and pilot plants do not indicate that respiratory tract tumors are a major concern.[15] At the same time, the limited nature of current information and the increased incidence of some forms of cancer and dermal diseases seen in domestic oil shale pilot facility workers recommend that medical surveillance programs should carefully monitor for respiratory problems as well as for skin diseases in the occupational population.[16]

Exposure to the general public from pollutant release may occur primarily as a result of end-product use, fugitive emissions, spills, and waste disposal. As noted in Chapter 3, the physical and chemical properties of upgraded crude shale oil suggest no significant difference or increased hazard during transportation and refining when compared with those of crude petroleum. Nevertheless, more work would be desirable with respect to any adverse health effects that might result from environmental release.[17]

In conjunction with continuing analysis of data generated from pilot plant operations, further research efforts should be directed toward the following problem areas in health effects R&D: confounding variables, inadequate monitoring strategies, poor resolution among toxic constituents, inability to translate bioassay information into human health effects, and insufficient exposure

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[13]A. M. Kaplan, "U.S. Oil Shale Industry: Health and Environmental Effects," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper G).

[14]Ibid.

[15]L. M. Holland, "Health Effects of Oil Shale Development," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper F).

[16]Ibid.

[17]Kaplan, op. cit.

dose-response data for risk assessment.[18] Due to the paucity of information, cause-effect relationships have been difficult to establish.[19] Effective coordination of monitoring and characterization studies, exposure dose-response and transport and metabolism studies, and medical surveillance efforts can remedy many of these areas of uncertainty. Specific R&D is needed in the following areas:[20]

- Basic Toxicology Research. Adequate toxicology data are not yet available to quantify the occupational respiratory disease hazard of exposure to respirable oil shale dust in combination with diesel exhaust materials. This should be the topic of a specific research effort.
- Basic Health Research. Efforts should be continued to identify further the chemical composition and changes in composition that occur as a result of shale oil upgrading techniques. Also, investigations should be continued on potential phototoxicity and dermatoxicity.
- Oils and Refined Products. Toxicity testing should be carried out on product streams following upgrading and refining and on end-products to identify any potential health hazard to the consumer. Such work should include analyses of emissions resulting from the combustion of end-products where appropriate. In all cases, toxicity testing should include equivalent petroleum-derived materials as controls.
- Epidemiological Studies. Studies should be done on past experience with oil shale exposure (for example, in Scotland and Estonia) and on present (current oil shale worker) exposures to oil shale.[21]
- Airborne Effluents. Experiments must be continued in order to better evaluate the toxicity of gas and vapor emissions alone and in combination with particulate emissions. Industrial hygiene monitoring and sampling with chemical characterization should certainly continue. Moreover, baseline meteorological data including seasonal variations need to be established.

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[18] R. D. Brown (Project Coord.) Health and Environmental Effects of Synthetic Fuels Technologies: Research Priorities, a report to the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, under contract DE-AC01-79-EI0018 MTR-80W348, April 1981.

[19] IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit., p. 7-10.

[20] Research needs are drawn from Kaplan, op. cit., unless otherwise indicated.

[21] IWG Corporation and the Center for Environmental Sciences, University of Colorado, op. cit.

- Aqueous and Solid Effluents (Wastes). There must be continued evaluation of surface retort waters after standard impoundment and of currently available cleanup techniques prior to disposal. Work should also continue on chronic studies with retort waters and on laboratory and field studies of leachates and waste waters on aquatic organisms, and on the effect of these effluents on aquifers and on the mobilization of potentially toxic, naturally occurring trace elements. Moreover, a baseline needs to be established.

Continued Assessment of Health Effects Associated with Direct Coal Liquefaction

Toxicology research programs associated with the H-Coal, SRC-II, and EDS processes are well under way. These programs include state-of-the-art testing technology and in some cases go beyond that into experimental procedures.[22] Thus it appears that a sound data base on acute toxicity will be generated. Nevertheless, as with R&D on shale oil health effects, it is desirable to generate and assess more data to connect the composition of coal conversion streams with occupational health criteria quantitatively.[23] Additional and improved data should be sought to determine what, if any, significant threshold-level values should exist for suspected carcinogens, and whether present or planned medical surveillance and industrial hygiene procedures can be strengthened.[24] Activities where further research could prove beneficial include the need to:[25]

- Quantify the carcinogenic potency of high-boiling fractions.
- Define developmental and reproductive effects and quantify them as necessary.

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[22]For a summary of these ongoing research programs, see C. K. Vick, "The Toxicology Data Base and Research Program Plans for Direct Coal Liquefaction," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper S).

[23]R. D. Brown, Health and Environmental Effects of Synthetic Fuels Technologies: Research Priorities, op. cit.

[24]O. White (ed.), Proceedings of the Symposium on Assessing the Industrial Hygiene Monitoring Needs for the Coal Conversion and Oil Shale Industries, NTIS BNL-51002 UC-41 (Health and Safety TID-4500), March 1979.

[25]Research needs are drawn from Vick, op. cit., unless otherwise indicated.

- Define the level of upgrading at which products become biologically equivalent to current products.
- Determine if combustion products from raw coal liquids differ from those from current fuels and, if so, how.
- Explore chronic exposures in a broader range of species under conditions as representative as possible of human exposures (except for dose levels that may have to be proportionately higher to compensate for the relatively small number of test animals).
- Ensure that the present coke-oven/coal tar and petroleum experience has been adequately examined for clues to potential effects.
- Evaluate personal hygiene practices in order to determine the best cleaning methods for skin areas, including burns and wounds, and to develop ways to determine that cleansing has been effectively accomplished.[26]
- Develop a simple method for biologic monitoring of significant exposure to coal liquids, since at present it is difficult to evaluate the extent of exposure from skin contamination.[27]
- Undertake epidemiologic studies--both past and prospective--on exposures to coal and coal liquids. Once commercial plants are operating, long-term prospective studies of worker populations should be conducted to assess effects and to continue to quantify these effects.
- Continue to carry out on a regular basis detailed industrial hygiene surveys so that worker exposure can be characterized over time. Such surveys will help to identify any problems with the engineering controls or work practices.[28]

Coal-gasification-based processes that use a gasifier with substantial amounts of coal tar by-products (for example, fixed-bed gasifiers) pose similar mutagenic and carcinogenic health hazards. These same toxicology, industrial hygiene, and epidemiology assessments are similarly recommended to clarify health effects associated with gasification systems.

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[26]JRB Associates, NIOSH Occupational Hazard Assessment: Coal Liquefaction, Vol. II, prepared for National Institute for Occupational Safety and Health, U.S. Department of Health and Human Services (Washington, D.C.: U.S. Government Printing Office, March 1981) p. 95.

[27]Ibid.

[28]JRB Associates, op. cit., p. 96.

Evaluation of Personal Protective Equipment

No matter how effective engineering controls and worker safety practices are, contamination of workers' clothing will occur. Thus, it is important to test and evaluate the effectiveness of personal protective clothing against those materials produced during synfuels operations which are known to present a potential hazard. This is particularly important for the protection of workers involved in scheduled or unscheduled maintenance or repair work.

Evaluation of Worker Training Facilities

Worker education is already an important component of standard industrial operations. Such programs include the initial training and refresher courses required by OSHA and the Mine Safety and Health Administration (MSHA). Initial training includes informing the employees about known occupational safety and health hazards and familiarizing them with emergency procedures and practices. Periodic sessions are undertaken to ensure that workers are familiar with potential hazards and the proper use of protective equipment and that they have a sound understanding of good personal hygiene. Also, training might be necessitated by changes in equipment or modes of operation. Experience with worker training programs has shown that they contribute to the safe and reliable operation of synfuels facilities because the knowledge imparted can lessen the occurrence of potential hazards due to human error or ignorance.

As a result of the importance of such programs, and given the large number of workers that will have to be trained prior to the commercialization of a large number of synfuels facilities, it is important to assess the adequacy of existing training facilities (for example, vocational schools, mining engineering programs, industrial in-house programs) to meet the anticipated demand.[29]

SUMMARY

Adequate data exist now to proceed with commercial projects. The areas previously discussed are suggested R&D to improve further the safety and reliability of future plants. Areas highlighted for further investigation and attention include:

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[29]Chappell, op. cit.

Technological R&D

- Component design in areas of technology extension.
- Continued safety research in the mining of shale.

Environmental R&D

- Testing of control technologies for prolonged periods of time.
- Continued work in the area of solid waste management.
- Modeling and monitoring pollutant release.
- Continued assessment of potential effects of pollutants on the environment.

Health Effects and Occupational Safety R&D

- Continued assessment of health effects associated with shale oil recovery processes.
- Continued assessment of health effects associated with direct coal liquefaction and gasification.
- Evaluation of personal protective equipment.
- Evaluation of worker training facilities.

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POLICY CONSIDERATIONS

INTRODUCTION

The following discussion sets forth some mechanisms that might aid in the generation and gathering of R&D information. Special attention is given to information needs highlighted in Chapter 4.

THE NEED FOR SHARING COMMERCIAL PLANT DATA[1]

While a considerable amount of data has been developed from pilot-scale efforts and will be further refined by ongoing research programs, the most crucial data are those that will be obtained from the large-scale demonstration and commercial units anticipated to be built in the next decade. It will be with these commercial units that an understanding can be developed of the emissions, effectiveness of environmental control technologies, worker environments, and various hazards. It is vital that industry, government (local, state, and federal), and the research community take full advantage of the research opportunities offered by these early facilities. It is essential that the research effort be perceived as being credible by various interest groups as well as by the general public. Thus, the gathering and analysis of data related to environmental and health effects of synfuels facilities should involve, in appropriate ways, a wide variety of groups and individuals. It is also important that the research effort continue to be coordinated among the various agencies and companies. Moreover, data should be exchanged and compared on an international as well as a national basis.

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[1]Information in this section is based on W. R. Chappell, "Health and Environmental Data Needs and Management," correspondence to the Energy Engineering Board's Committee on Synthetic Fuels Facilities Safety, February 10, 1982.

Thus, the basic issues to be resolved include: How is such a research program put together? Who funds it? Where does that data reside? Who has access to such data? And how are the findings shared? These are complex issues and were not resolved during the course of this study.

Since so many issues are involved in considering a mechanism for gathering and analyzing these data, perhaps it would be appropriate to constitute a group or committee that would devise a mechanism for developing and sharing data among countries, companies, government agencies, researchers, labor, various interest groups, and the public. This plan might include such things as workshops, international conferences, international committees, and so forth. It is assumed that such a group would make contact with synfuels companies, agencies, scientific societies, and individuals not only in the United States but also abroad in order to build a consensus on the proper approach to this complex but important problem.

HEALTH SURVEILLANCE[2]

A mechanism that would aid in the gathering and analysis of safety and health information would be a synfuels health registry or registries for the health records of synfuels workers. The potential for measuring the occupational health effects of the commercialization of synfuels technologies requires the planning and implementation of a record-keeping method (that is, a registry) that would integrate work environment characterization with medical screening capable of quantifying health effects. An occupational health program that links the toxicological characterization of occupational pollutants in the coal conversion and shale oil recovery industries has largely been accomplished. Thus, toxicology has

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[2]Information in this section is based on the following sources: R. Moure, "Establishing a Registry of Workers Involved in Oil Shale and Coal Liquefaction Demonstration and Commercial Plants," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper K); D. A. Savitz, "Potential Uses of a Synthetic Fuels Worker Registry," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper P); R. N. Ligo, "Du Pont's Occupational Health Program," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper H); and C. W. Stallard, "A System for Data Collection and Computer Processing in Occupational Health Programs: The SOHIO Health Information Center," paper presented at U.S. EPA/DOE Symposium on Health Effects Investigation of Oil Shale Development, Gatlinburg, Tennessee, June 23, 1980.

provided the industrial hygiene discipline with the basis to implement a sampling strategy.

Before setting up a registry, it is essential to recognize what a registry can and cannot do. A registry can be extremely beneficial for the accurate identification of occupationally induced diseases with a long latency period, such as cancer. A registry allows for detailed consideration of exposure as well as confounding variables in relation to a temporally distant health outcome. The possibility of a single, extremely high dose causing disease cannot be dismissed, but the emphasis here is on long-term, low-dose exposure.

Second, a registry would provide the data for case-control studies and cross-sectional medical studies. Active surveillance might be possible if, for example, a potent teratogen or skin carcinogen was discovered. A registry could be indispensable in following up acute, catastrophic exposures with delayed health effects.

Finally, a registry can rapidly identify unexpected problems. A continuing but unrecognized exposure, catastrophic to health in the sense that asbestos was, could be recognized in this way. Access to detailed exposure histories could provide a quick identification of "real" (that is, exposure-caused) epidemics versus spurious (random) clustering.

Gulf Oil, SOHIO, du Pont, and NIOSH have all had experience with worker registries and with long-term epidemiology studies such as the U.S. Public Health Service prospective studies of several thousand uranium miners.[3] Based on that information, the general features of an effective registry can be stated. The system will provide access to the kinds of information listed below:

- Basic Employee Data. These include name, social security number, birth date, last known address, job titles, job locations.
- Results of Medical Examinations. Common practice is a preplacement exam with subsequent periodic exams. More frequent exams may be warranted by a particular exposure hazard. The exams commonly include a health history questionnaire that may include a question on smoking; examination by or under the supervision of a physician; posterior-anterior chest X-ray; urinalysis; white blood cell count and hemoglobin; audiogram;

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[3]F. E. Lundin, J. K. Wagoner, and V. E. Archer, "Radon Daughter Exposure and Respiratory Cancer Qualitative and Temporal Aspects," Joint Monograph #1 NIOSH and NIEHS, Public Health Service (Washington, D.C.: U.S. Public Health Service, 1971).

visual acuity test; blood chemistry (for example, SMA-12); electrocardiogram, with frequency dependent on age; and pulmonary function tests. Employees are reevaluated at each exam for signs of adverse health effects which could be related to the job.

- Work-Related Illnesses or Injuries. These are treated by the plant physician who refers the employee to his or her personal physician when further evaluation or treatment is required.
- Special Medical Monitoring. This can be either physical or biological monitoring and is for employees exposed to specific toxic agents. For example, employees potentially exposed to a substance capable of causing kidney damage might receive special physical exams periodically to look for signs of such damage.
- Special Files. Examples are a file of sickness-related absences; a file of deaths among active and retired employees; a file of cancer cases; and a file of coronary heart disease.
- Exposure Data. These are the data gathered by industrial hygienists to determine whether exposure limits are being met.
- Information on smoking habits. What is smoked, in what amounts, and for how long.

Using the several kinds of information listed above, epidemiologists can periodically analyze disease incidence at various employment sites to determine whether an excess incidence of a disease or cause of death has occurred at a site. In addition, studies can be conducted on groups of employees who have been exposed to certain substances at various exposure levels in order to determine whether the substances are causing adverse health effects.

The power of epidemiological studies to detect work-related health hazards increases with the number in a group being studied. Accordingly, it is desirable that the various companies collect the same data in the same format by the same procedures so that epidemiological studies can be carried out on employees in similar jobs across the synfuels industry. A committee of experts (especially epidemiologists, physicians, industrial hygienists, and toxicologists) and policymakers from the concerned companies, universities, and government agencies should determine what data should be collected for each synfuel worker and for each synfuels industry, and how the data should be stored and used, and who should have access to such data. The format for recording the data and the length of time the data are to be retained should also be established by this committee. In addition, the committee should establish procedures for preserving the confidentiality of medical data and safeguarding proprietary information. Each participating company should be encouraged to collect the data prescribed by the committee.

Whenever it is decided to study some segment of synfuels workers, the data on the workers from each company needed for a particular study should be transferred to the organization that will perform the study, following the established procedures for preserving the confidentiality of medical data and safeguarding proprietary information.

COST-BENEFIT ANALYSIS[4]

Adequate consideration of health and safety issues implies potential costs that could significantly influence the social benefits from the commercial production of synthetic fuels. The trade-offs between the reduction of health risks and the market competitiveness of synthetic fuels should be considered. Cost analysis methodology should be developed from a solid data base. Key areas include:

- Health Effects Research. Epidemiological and toxicological studies to develop relationships between health effects and exposure levels to toxic materials.
- Research on Plant Performance and Toxic Exposure. The development of relationships to link technical measures, plant performance, and the duration of worker exposure to toxic process streams during plant repairs.
- Research on Cost and Performance Trade-offs. The development of relationships linking product costs to improvements in plant performance.

Data generated from this research will provide input for developing the appropriate model. Available literature on equipment failures can help identify candidate variables to predict performance levels. Previous studies of plant maintenance levels can help suggest variables for measuring toxic exposure potential during repair and servicing. These links between health effects research, regulatory policy, and product costs must be incorporated into a method to stimulate policy decisions.

A dialogue should be encouraged among researchers involved in health effects studies and those investigating engineering and economic issues. Collaboration through conferences and committees represents a feasible option.

CODE FOR HANDLING EXPLOSIVES IN SHALE MINES

Special regulations concerning explosives should be developed for oil shale mines. Such standards might allow for the use of ANFO, dynamite, and similar nonpermissible explosives. The rationale for such regulations is based on some speculation that the slow-burning

[4]Information in this section is based on K. E. Phillips, "Research Needs for Assessing the Costs of Health and Safety Compliance In a Synthetic Fuels Industry," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper M).

nature of permissible explosives could result in the combustion of shale rubble, gilsonite, or other carbonaceous materials present in a shale mine.[5] Moreover, a means for using explosives currently classified as nonpermissible must be developed if proven mining methods are to be used in oil shale mines.[6]

COMPENDIUM OF DATA RELATING TO ACCIDENTS

An industry-sponsored group might be established to develop germane statistical data to determine the causes of actual accidents in a developing synfuels industry and to recommend preventive measures for consideration by the industry. Those activities are currently carried out within the hydrocarbon-processing industry by a variety of organizations such as the American Society of Mechanical Engineers, the American Institute of Chemical Engineers, and the National Safety Council.[7] However, a formalized industry-sponsored group would focus efforts on developing accident-source information for synthetic fuels facilities.

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[5]Skelly and Loy, Engineers and Consultants, R&D Needs for Oil Shale Mining and Health/Safety Technology: Final Report, (Washington, D. C.: U. S. Department of Energy, June 1980), p. 23.

[6]P. A. Rutledge, "Mining Problems Unique to Oil Shale," paper presented at the committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982 (see Appendix, Paper N).

[7]C. H. Vervalin, "Know Loss-Prevention Information Resources," Hydrocarbon Processing, March 1981, pp. 222-236.

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APPENDIX

PAPERS PRESENTED AT THE COMMITTEE'S

WORKSHOP ON SYNTHETIC FUELS FACILITIES SAFETY

LA JOLLA, CALIFORNIA

JANUARY 1982

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INTRODUCTION

This Appendix contains 19 position papers prepared by members of the Committee on Synthetic Fuels Facilities Safety and by invited experts. They were presented at the committee Workshop held on January 18-19, 1982 in La Jolla, California. They represent a summation of the committee's deliberations on various aspects of safety problems in a developing synfuel industry that appear to warrant specific consideration. The topics covered by these papers range from a description of the synfuels facilities themselves to a delineation of safety, health and environmental issues uniquely associated with synfuels facilities and operations. These papers are the principal source of information for the committee's final report.

It should be noted that the views expressed in these papers are those of the authors and do not necessarily reflect those of the Committee on Synthetic Fuels Facilities Safety.

POSITION PAPER A

SYNTHETIC FUELS FACILITY
SAFETY PLANT SITING CONSIDERATIONS

August D. Benz
Bechtel Group, Inc.

Site selection for major new industrial projects such as refineries, chemical plants, power plants, and metallurgical facilities requires a thorough evaluation of technical, economic, social, and ecological factors to permit selection of preferred sites and site development plans. Siting decisions for synthetic fuels facilities are made somewhat more difficult because of their large size and complexity, and because of uncertainties associated with the developing technologies involved.

For all major projects, worker and public safety must be protected and environmental regulations must be met. Typically, control of air emissions, aqueous effluents, hazardous substances, and leachates from mines and waste piles are critical considerations in synfuels plant siting. Other socioeconomic and environmental aspects of synfuels plants are also important. This paper discusses safety and environmental considerations that affect synfuels plant siting.

Compliance with regulatory requirements is a major consideration. At this time, the regulatory situation relative to synfuels is still evolving (as is the technology itself and the political climate relative to synfuels). Future regulatory trends in the synfuels area are difficult to predict.

When analyzing alternative plant sites, technical, economic, social, and ecological factors must all be evaluated in terms of cost-benefit trade-offs, both economic and environmental. Failure to analyze properly all of the diverse technical and regulatory issues in siting a synfuels facility can lead to unforeseen environmental control costs, inability to obtain necessary permits, and costly project delays. Choices of sites are seldom obvious and decisions often involve evaluation of hidden costs and intangible factors.

SYNFUELS PLANT CHARACTERISTICS AND BASIC SITE REQUIREMENTS

Before discussing specific plant siting criteria, it is useful to review the general characteristics of synfuels facilities. Various synfuels facilities differ appreciably and these differences affect basic site requirements and siting opportunities significantly.

Typical characteristics of generic coal gasification, coal liquefaction, and surface retort oil shale facilities are listed in Table 1. Typical synfuels project development schedules are shown on Figure 1. No attempt has been made to report typical emission or effluent levels or to list hazardous residuals involved in the various types of synfuels plants, since these are highly variable depending on coal or oil shale characteristics, synfuels process technology, and the pollution control technology applied.

Synfuels project characteristics that exert a major influence on basic site requirements include synfuels production rate, raw material supply, market location, facility process technology, and potential emissions level.

As can be seen from Table 1, all synfuels plants are characterized by the very large quantities of solid materials which must be handled. The location of the raw materials supply (mines) relative to the process facility site can affect operating costs as much as any other single factor, making mine-mouth facility siting attractive in many cases. Mine-mouth plants are considered normal for oil shale projects, tar sands projects, and low rank coal conversion projects. Similarly, water availability, transportation availability (pipelines, railroads, etc.), or local markets for syngas or syncrude products and by-products influence differential site cost significantly. Process water availability can easily become a limiting consideration.

Process technology selection also affects basic site requirements significantly since the different technologies each exhibit different product yields, raw materials quality requirements, by-product quantities and properties, waste materials production, and potential emission rates. For example:

- Certain coal gasifiers and shale retorts have strict limitations on raw materials size, resulting in added feed preparation facilities and/or disposal requirements for fine mesh particles.
- Oil shale retort operating conditions vary widely between processes, resulting in spent shale properties that require different disposal techniques.
- Heavy tar and phenolic oil production is significant with some coal gasifiers, while others produce essentially none of these by-products.

Synfuels production rate affects basic site requirements primarily because of potential environmental "costs" rather than construction and operating costs. As output increases, the gas and water effluents tend to increase proportionally. For large plants, effluent levels could exceed allowable increments for regulated

TABLE 1 Typical Synfuels Project Characteristics

Synfuel Project	Coal Gasification	Coal Liquefaction (Direct)	Oil Shale (Surface Retorts)
Product	Substitute natural gas	Synthetic crude oil	Synthetic crude oil
Production rate	250 X 10^6 cu ft/day	50,000 bbl/day	50,000 bbl/day
Feedstock (coal/shale)	15-25,000 tons/day	20-30,000 tons/day	60-90,000 tons/day
Water consumption	6-25 X 10^6 gal/day	6-15 X 10^6 gal/day	8-20 X 10^6 gal/day
Solid waste (ash/spent shale)	1-5,000 tons/day	2-8,000 tons/day	40-70,000 tons/day
Cost (1981 dollars)	\$1.5-2.5 X 10^9	\$2-3 X 10^9	\$2-3 X 10^9
Land requirements (excluding mine)	300-500 acres	300-500 acres	500-700 acres
Labor requirements			
construction staff	2,500-4,000	3,500-5,000	3,500-5,000
operations staff	800-1,200	1,00-1,500	1,000-1,500

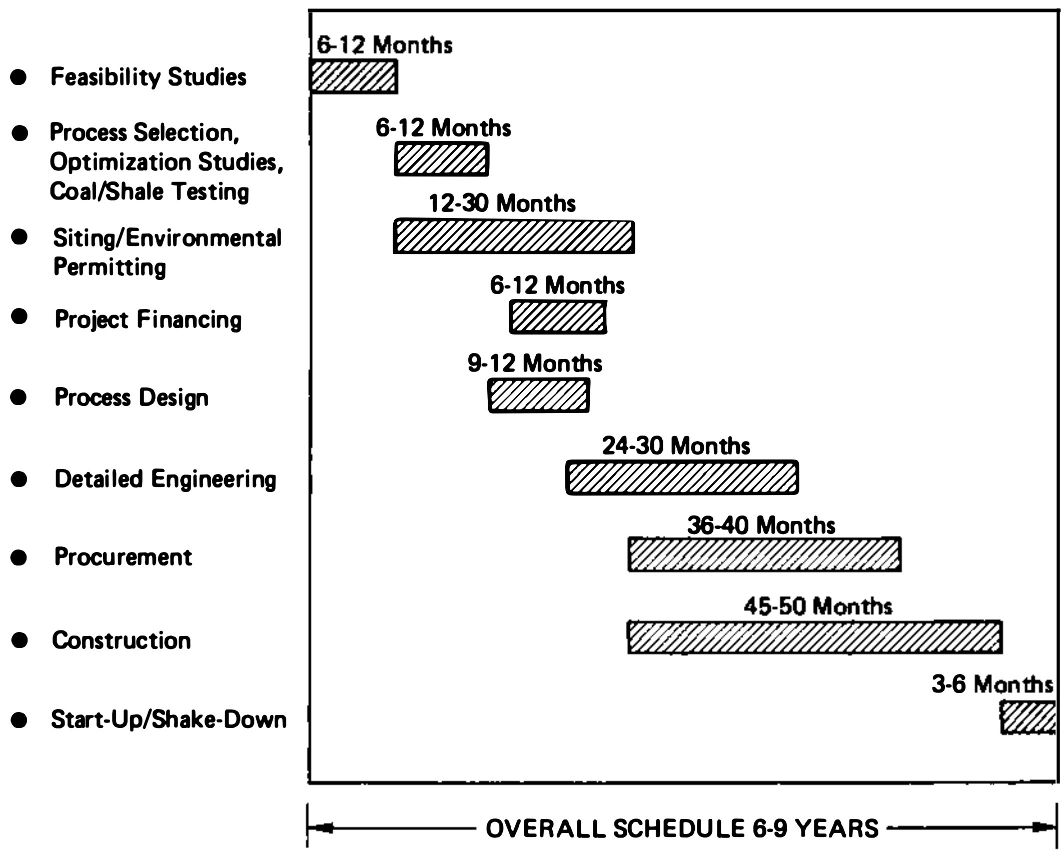

Figure 1 Major synfuels project schedule.

pollutants, even though best available control technology is applied. Plant siting within certain areas of degraded air quality or within nonattainment areas may be unsuitable because of uncertainties or extreme costs associated with offsets for obtaining increments in prevention of significant deterioration (PSD).

As mentioned, the potential emissions level of a particular synfuels plant varies significantly with the process technology utilized and the raw material characteristics. Many studies have been performed for various combinations of synfuels technologies and raw materials, and they have generally concluded that currently available pollution control technology is adequate to handle the known environmental problems of the synfuels industry. These existing control technologies have been proven in commercial application within the oil refinery, chemical, mining, and metallurgical industries. It is believed, therefore, that lack of acceptable pollution control technology will not preclude development of the synfuels industry, although pollution control costs will have an important effect on synfuels production costs.

Review of Figure 1 shows the extended time period involved in planning, designing, and building a major synfuels project. Note that siting and environmental permit efforts can be expected to involve up to two and a half years.

MAJOR PROJECT SITING CRITERIA

When the basic site requirements of a major industrial project have been defined (plant production rate, raw materials, market, process technology, and so on), a site selection study can proceed. The study will review all identified potential sites, evaluating each against common criteria in order to identify the most suitable. Synfuels siting is similar to other industrial facilities siting in this regard.

For these evaluations, the major site criteria include techno-economic, socioeconomic, and environmental factors. Table 2 lists the major criteria normally used in facility siting studies for major projects of all types. During a major facility siting evaluation, all of the criteria in Table 2 must be considered. Many of these criteria are self-evident in their importance to plant siting decisions. Particularly important criteria in synfuels plant siting are discussed further in the following sections.

Techno-Economic Criteria

Compatibility with Soils, Geology, and Seismology

In addition to the obvious requirements of suitability for foundations and structures, the soils, geology, and seismology are

TABLE 2 Generic Siting Criteria

TECHNO-ECONOMIC

- Maximum compatibility with soils, geology, and seismology
- Maximum compatibility with existing air quality levels and regulations
- Maximum compatibility with surface and ground water resources
- Maximum labor force availability
- Maximum property availability
- Maximum site access
- Maximum expansion potential
- Minimum technical risk
- Minimum construction impact mitigation
- Minimum site development
- Minimum proximity of hazards
- Minimum transportation costs

SOCIO-ECONOMIC

- Maximum compatibility with productive lands and water
- Maximum compatibility with existing and proposed land use
- Maximum compatibility with regional economics (municipal services, labor markets, cultural aspects, housing markets, zoning, taxes)
- Maximum public acceptability
- Minimum disruption of social institutions
- Minimum visual and audible impacts on existing and proposed residential and recreational areas
- Minimum population displacement

ENVIRONMENTAL

- Minimum adverse air quality impact
- Minimum adverse impact on hydrological resources
- Minimum adverse impacts on wildlife habitats and populations
- Minimum adverse impacts on aquatic ecosystems
- Minimum soil erosion
- Minimum adverse noise impacts

important considerations because of the need to reclaim mined lands and solid waste disposal areas, and to prevent contamination of the local ground water regime with leachate from solid waste storage. Local geological and ground water regime are particularly relevant to synfuels siting because of the need for solid (possibly hazardous) waste disposal sites. The presence of a high water table, highly permeable geological conditions, or unstable seismic conditions could preclude the location of waste disposal sites near the facility.

Compatibility with Existing Air Quality Levels

Current air quality regulations impose severe constraints on the siting of synfuels plants. In some areas, existing degraded air quality makes it necessary to reduce emission levels and to make trade-offs that considerably increase plant cost. Alternately, regulations may prohibit development because minimum feasible emissions exceed permissible limits. To date, uncertainties in the air quality regulatory climate have hindered efforts to develop a generalized approach to synfuels siting. Ultimately, each potential site must be evaluated with regard to existing federal, state and local requirements and existing ambient air quality at the time permits are sought. The degree of emission control and the emission control technology will depend on basic facility characteristics such as process technology, plant size, and raw material characteristics, in addition to the existing air quality in the site area.

Compatibility with Surface and Ground Water Resources

Water can be a critically limiting factor for development of synfuels plants--particularly in the western United States where water resources are scarce and conflicting demands for its allocation can exist. Synfuels siting must take into account water availability, cost, and dependability, and the risk of these factors changing significantly. Plant operating costs can vary considerably depending on trade-offs between the cost of water and the costs of water-saving technology.

The availability of sufficient water depends on more than the physical presence of water. Other critical factors, especially in the West, include economic competition from other uses; the political acceptability of diverting water for energy-related uses; a body of law controlling water rights, which is still developing; and environmental regulations. Major impediments to developing a generalized approach to synfuels siting with regard to water availability are:

- Lack of conservative use of water resources for agricultural uses, engendered by cheap rates.

- o Unadjudicated water rights in many western river basins, and lack of knowledge of the total water allocations available in many basins.
- o Increasing exercise of water rights by Indian tribes and uncertainties with regard to ultimate water requirements of the Indian reservations.
- o Inadequate laws regarding ground water allocations and use.

Technical Risks

It must be recognized that most synfuels technologies are relatively unproven in large-scale commercial practice at this time. As a result, uncertainties exist in many important areas such as trace contaminant levels in products and by-products, dust loadings or other pollutant levels in vent and waste streams, process operations stability and tendency to upset, unusual emissions and health hazards encountered during shutdowns or maintenance activities, large-scale mining technology, and so on. These uncertainties affect overall project siting and safety evaluations. Careful evaluation of these and other technical risks are particularly important for the "first-of-a-kind" commercial synfuels plants planned for the next decade. In addition, continuing evaluation of synfuels plant safety and health hazards must be maintained during initial operation of these plants, until an adequate commercial data base is developed for each of the specific process technologies. In other words, it will be necessary to provide conservative initial plant designs for the synfuels industry to ensure that worker and public health and safety as well as the environment are adequately protected.

Other Techno-Economic Criteria

The influences on synfuels siting considerations of the remaining techno-economic criteria listed on Table 2 are largely self-evident.

Socioeconomic Criteria

Disruption of Social Institutions

Considering the large size of synfuels plants, full-scale commercial synfuels production may cause major social and economic effects, particularly in rural areas. Proximity to urban centers can be attractive because the influx of labor and the industrialization associated with facilities development are buffered by existing urban facilities and conditions. Synfuels development in rural areas may lead to boom town phenomena--rapid build-up of a large construction labor force followed by a sharp decline to a smaller operating work force. Because of the location of major coal and oil shale resources in rural areas, facility siting must take into account the potential for serious disruptions of the local communities and the potential costs of mitigating such effects.

Visual and Audible Impacts

Because of noise associated with such operating facilities, visual and auditory impacts can be disruptive to local residents. Locating facilities at some distance from residential areas can reduce noise complaints. Locating facilities in designated industrial areas is preferable to rural locations because of reduced visual or aesthetic disruption. Alternately, use of "green belts" or "setbacks" can help reduce such visual and audible effects.

Compatibility with Productive Lands and Water

When possible, facilities location in designated industrial areas would reduce conflicts inherent in using productive agricultural, range, or timber lands for industrial purposes. Similarly, sites with water resources allocated to energy uses are more suited to synfuels siting than areas such as in the western states where water allocations either have not been made or have been designated to agricultural uses.

Other Socioeconomic Criteria

The effect on synfuels siting of the remaining socioeconomic criteria listed on Table 2 is largely self-evident.

Environmental Criteria

Air Quality Effects

Assuming that controlled emissions comply with air quality standards, effects of air emissions would result from toxic residuals, or pollutants that are not controlled during plant upsets or equipment failures. The existence of sensitive ecosystems, sensitive species, or sensitive agricultural or silvicultural crops on or near a site would render the site less compatible with synfuels facility siting.

Effects on Hydrologic Resources

The potential for adverse effects of water withdrawal on existing surface or ground water resources is particularly important to synfuels siting in the western states as discussed previously.

Waste-water streams generated by synfuels processes require a variety of treatments either to achieve zero discharge or to satisfy effluent standards. Generally, existing water treatment technologies can be adapted to treat contaminated synfuels waste-water streams, although only limited experimental data are available. Typically, about one third of the total waste water is "sour water" containing hydrogen sulfide, ammonia, phenolics, cyanides, thiocynate, metals, and polycyclic aromatic hydrocarbons. Cooling tower "blow-down" usually accounts for another third of the total waste water, with miscellaneous process streams and raw material storage, sanitary wastes, and landfill leachates making up the balance.

Synfuels siting must take into account the potential receiving water classification in determining whether zero discharge is necessary. Although new source performance standard (NSPS) effluent discharge limitations for synfuels have not been promulgated, it is assumed that the National Pollutant Discharge Elimination System (NPDES) requirements would be applicable to any point and nonpoint sources of effluents. NSPS would likely be similar to those established for refineries and steam electric power plants. In the West, zero discharge with recycling of the waste-water streams is more cost-effective because of the need to conserve water resources. In the East where discharge of effluents is possible, the ambient water quality of the receiving waters must be considered when siting a facility.

With regard to ground water quality, potential adverse effects would derive from solid or hazardous waste storage areas. In siting a facility, ground water uses and the ground water and geologic regimes on and near waste storage sites must be evaluated with regard to potentially leachable contaminants.

Other Environmental Criteria

The remaining environmental criteria listed on Table 2 are largely self-evident in their influence on synfuels site studies.

SUMMARY AND CONCLUSIONS

The basic site requirements for synfuels projects arise from specific project characteristics such as production rate, raw material characteristics, and process technology. An actual synfuels plant site which provides all of the basic requirements, meets all regulatory requirements, and fulfills other necessary economic, social, and environmental criteria can be selected using normal major project site selection techniques.

There is every indication that synfuels facilities can be designed and built in accordance with established standards and practices, and can comply with appropriate air, water, noise, health and safety, waste disposal, and other regulatory requirements. Pollution control techniques and worker safety practices are already believed to be demonstrated in the mining, petroleum refining and chemical industries and will prove adequate to handle environmental problems in the synfuels industry. Unplanned occurrences can present risk to both worker and public safety, and conservative planning and design efforts will be required to ensure that the probability of these occurrences in the synfuels industry will be no greater than that experienced in established industries. This may be somewhat more difficult when dealing with the first-of-a-kind synfuels projects expected within the next decade, but there is no indication that these initial plants will present insoluble problems.

In conclusion synfuels plant siting requires careful study of complex technical, environmental, and socioeconomic factors. The prospects for acceptable siting of synfuels facilities appear to be good, although they depend on specific environmental regulatory restrictions which have not been fully defined as yet. The most important synfuels siting considerations appear to be potential for compliance with air, water, and solid waste environmental regulations. Any attempt to site a facility must be performed case-by-case working with federal, state, and local agencies. The environmental, socioeconomic, and health effects of synfuels development have been studied in depth by both public and private sectors. Potential impacts are neither so trivial as to be ignored, nor so large as to preclude development of synfuels facilities. Cognizance of the issues, careful study of the costs and trade-offs, and up-front planning with both local communities and with all responsible regulatory agencies can lead to successful siting and development of synfuels facilities.

POSITION PAPER B

ENVIRONMENTAL REGULATIONS IN RELATION TO THE SYNFUELS INDUSTRY

Bruno Brodfeld
Stone and Webster Engineering Corporation

Environmental considerations will significantly influence the development of the synfuels industry in the United States. For one thing, environmental requirements affect the siting, cost, and permitting of synfuels plants. For another, environmental issues can provide a vehicle for opposition to the development of a synfuels industry.

This paper discusses environmental regulatory requirements applicable to the design, construction, and operation of synfuels plants. It was prepared as a basis for discussion during the January 18-19, 1982 workshop organized by the Committee on Synthetic Fuels Facilities Safety.

The main applicable laws and regulations controlling environmental impacts at the federal level include the following:

- The Clean Air Act (CAA) of 1977 regulates the release of air pollutants by means of National Ambient Air Quality Standards, Prevention of Significant Deterioration Increments, and New Source Performance Standards. These are being established for 42 separate source categories, of which seven may apply to specific sections of synthetic fuel plants. In addition, the Clean Air Act requires the development of National Emission Standards for Hazardous Air Pollutants.
- The Clean Water Act (CWA) of 1977 regulates the release of liquid effluents by the establishment of effluent standards including standards for toxic pollutants, and by a permitting structure embodied in the National Pollutant Discharge Elimination System. Effluent standards are being established for 28 source categories, of which five may apply to liquid effluents from synthetic fuel plants.
- The Resource Conservation and Recovery Act (RCRA) of 1976 governs the generation, transportation, and disposal of

hazardous solid wastes, and requires all states to develop criteria for disposal of all other solid wastes.

- The Surface Mining Control and Reclamation Act (SMCRA) of 1977 regulates surface coal mining practices through Environmental Protection Standards and the requirement of comprehensive Reclamation Plans.
- The Rivers and Harbors Act of 1899 requires that a permit be obtained from the Chief of the Army Corps of Engineers for any construction in a navigable waterway, which would include docking or intake facilities.
- The Safe Drinking Water Act of 1979 requires that any primary drinking water source be maintained at a level of quality determined by water quality standards defined as a result of the act. Consequently, any synthetic fuels facility, like any other industrial facility, must ensure that any drinking water sources are not contaminated by facility operation. In addition, any synfuels plant using deep-well waste disposal systems requires an Underground Injection Control Permit under this act.
- The National Environmental Policy Act of 1969 requires the lead federal agency designated by the Federal Council on Environmental Quality to produce an Environmental Impact Statement (EIS) when a major federal action is taken. All new synthetic fuels plants are expected to require such an EIS.
- The Toxic Substances Control Act of 1976 requires that all new chemicals be tested prior to their use in commerce. This premanufacture notice procedure requires that toxic substances be controlled to ensure public health and safety. Once a chemical has gone through this procedure and is found nontoxic, then no further testing for new projects is required. This would mean that each new synfuels product would have to go through such a procedure but this would not be necessary for subsequent projects designed to produce similar products.

The CWA, CAA, RCRA, and SMCRA require states to prepare implementation plans for regulating permissible effects at the state level. If state regulatory agencies prepare plans that are approved by the Environmental Protection Agency (EPA), then permitting responsibility is delegated from the federal to the state level. Under current administration policies, the trend is to increase state control of the permitting programs over that experienced in the past. In addition to these federally delegated programs, states have passed environmental statutes that closely parallel federal concerns, supplement them with state-specific considerations, and in some cases, have promulgated standards that are more stringent than federal standards. For example, while oil shale mining is not controlled by federal statute, it is stringently regulated at the state level.

The above discusson on laws and regulations illustrates the already existing wide array of regulatory requirements that synfuels projects must comply with.

In this context, it should be mentioned that in 1979, the EPA announced a program for preparation of Pollution Control Guidance Documents (PCGD's) for the stated purpose of decreasing regulatory uncertainty in the absence of new source performance standards for synfuels production facilities. They were intended to develop current technical information on air emissions, liquid effluents and solid wastes from synfuels plants, available control technologies, and expected ranges of achieveable control levels. It was anticipated that such guidance documents would be developed during a two-year period for various synfuels technologies including indirect coal liquefaction, low Btu coal gasification, medium and high Btu coal gasification, direct coal liquefaction, and oil shale. Recent information indicates that this EPA effort has been discontinued.

It is important to recognize that, while state-of-the-art review documents such as PCGD's may assist regulatory agencies in project assessments, they should not be used to inhibit development of innovative control technologies or to enforce preferred control methods.

In assessing the likely effect of environmental regulations on the development of the synfuels industry it should be emphasized that most environmental issues associated with synfuels projects are quite similar to the issues associated with any large and complex industrial facility. In fact, many of the processes and systems within a synfuels plant use conventional technologies that have been used for years in the refinery, chemical, metallurgical, and power industries. With regard to major pollutants and resource requirements, synfuels plants are not expected to produce environmental impacts or hazard levels greater than those achieved in many large plants in various industries, as long as proper environmental control technologies are applied.

The effect of environmental regulations on the synfuels industry is likely to be primarily related to the siting of synfuels plants. Among the various laws and regulations mentioned, those dealing with water resources, air quality, and toxic and hazardous substances are critical.

In arid western states, availability of water rights is a major issue affecting the siting of synfuels plants and therefore it may control the development of the synfuels industry in those regions. As a practical matter, this issue should be considered primarily a state, rather than a federal concern.

While in the case of water, regulations emphasize resources and quantity, in the case of air, regulations emphasize quality. Current CAA provisions critically affect the synfuels plants.

For example, in developed areas such as in the East and Midwest, the requirements related to nonattainment areas may significantly affect the siting of synfuels plants. These requirements contained in the state implementation plans may make the development of a synfuels project contingent on the project owners' being able to offset their emissions.

In undeveloped areas in general and in the western states in particular, the most important requirements relate to the prevention of significant deterioration (PSD) and to visibility impairment. PSD requirements for pristine areas could effectively prevent construction of large synfuels plants in some of these areas and even of modest-sized facilities in other areas. Similarly, the visibility impairment requirements, in the absence of reliable methods for predicting visibility effects, can represent an uncertain factor in permitting synfuels plants near pristine areas.

It should be mentioned that in certain cases, the stringency of air quality restrictions can be a factor favoring the development of a synfuels project. For example, in proximity of pristine areas, where increases in air pollution are limited to very small increments and "air rights" are the limiting factor for energy development in the area, coal gasification plants can have an inherent advantage due to the low level of sulfur emissions. In such cases, electric utilities may prefer to use coal gas fuel instead of direct coal combustion for power generation as a means for facilitating their own siting problems.

Currently discussions are taking place related to legislative action on CAA. In this context, it is important for the scientific and technical community to emphasize the need for reliable scientific evidence before specific requirements are added to the act, particularly as related to acid precipitation and carbon dioxide emissions. Appropriate research programs in these areas are required, as evidenced by Congress mandating an Acid Precipitation Program and a Carbon Dioxide Study in the Energy Security Act of 1980. It should be pointed out that the synfuels industry, more than other industries, has at its disposal the technological means for better control of carbon dioxide and sulfur emissions.

Another regulatory activity that can significantly affect the synfuels industry is the setting of standards for toxic and hazardous air, water, and solid waste pollutants. It is essential that any such standards and classifications of pollutants as toxic or hazardous be based on comprehensive scientific data coupled with appropriate risk assessment.

The consequences of environmental regulations on the synfuels industry will depend not only on the regulations themselves, but also on industry's ability to present a persuasive case to regulatory agencies whenever permits are applied for. The strength of an industrial applicant's case depends many times on the thoroughness of environmental impact analyses, the degree of sophistication of analytical and modeling techniques, and the extent of monitoring programs before and after construction of a plant. While expansion of such activities can add a certain cost element, it can often contribute to a streamlining of the permitting process. Therefore, it is important for industry to initiate and carry out appropriate research and development efforts related to environmental impacts, risk assessment analyses and when required development of comprehensive modeling of environmental effects. Such activities should have an accepted place within industry's efforts related to the development of synfuels technologies.

POSITION PAPER C

SOME POLICY ISSUES RELATED TO SYNTHETIC FUELS FACILITY SAFETY

Willard R. Chappell
University of Colorado

In spite of the "oil glut of 1981," many observers agree that an energy crisis still exists. The United States and allies depend upon countries with a high potential for political instability for a large share of the liquid hydrocarbons that power the defense and industry of the free world. The recent experience of Iran is ample evidence that a major disruption could occur that would endanger the flow of oil from the Middle East. If the threat were great enough, military intervention by the Western countries would be inevitable and the spread of the conflict beyond the Middle East (in view of the strategic position of the Soviet Union) possible. Even without such an event, the continued draining of the capital of the United States and its allies poses a major concern for the vitality of the economies of these countries. Therefore it seems prudent if not necessary to move away from the present dependence on foreign oil.

Over the past several years the most appropriate path to energy independence has been actively debated. Numerous studies have been performed by government, industry, and the research community; the results have been contradictory, controversial, and confusing. Perhaps the lesson to be learned from all this confusion is that energy is so interwoven into the fabric of society that it defies any simple analysis. In addition to our inability to analyze the energy problem, the situation is compounded by the fact that numerous value judgments are involved in deciding on the best path to energy independence. Important values such as jobs, health, the environment, and the quality of life are at stake. Moreover, even if we knew and could agree upon the "best" course, we (the United States and its allies) do not have complete control over our energy destiny. Some believe that Saudia Arabia and other OPEC countries have a deliberate policy of pricing their oil at a level that makes other alternatives (such as synthetic fuels) uneconomical.

It is perhaps because of the high level of uncertainty and frustration that the United States has de facto adopted a policy of exploring and developing numerous alternatives. While debate goes on over the appropriate mix and emphasis, some progress is being made on numerous fronts including solar, conservation, fusion, and synthetic fuels. In 1980 a potentially important part of this progress was initiated when the President signed into law the Energy Security Act (P.L. 96-294). Title I of this act establishes national goals for the production of synthetic fuels in the United States of at least 500,000 barrels of crude oil equivalent per day by 1987, increasing to 2 million barrels per day by 1992. The corporation is empowered to provide financial assistance to permit the achievement of these goals. The total authorization over the 12 years from 1980 to 1992 is $80 billion. The size of such an industry will be immense. If oil shale were the complete source of the 2 million barrels per day, it would require the processing of roughly 1200 million tons of ore per year--twice the size of the present coal industry. The total capital cost is difficult to estimate, but could be $100 to $300 billion (in 1981 dollars).

Thus, the undertaking is perhaps the largest in history. An enterprise of this magnitude has the potential for numerous ramifications, harmful and beneficial, and many of which are difficult to predict in advance. There are policy decisions that can influence the nature and magnitude of the efforts, both beneficial and adverse. The purpose of this paper is to briefly discuss some of the issues relating primarily to synthetic fuels facilities safety.

SURFACE MINING AND UNDERGROUND MINING

A considerable amount of the nation's coal and oil shale reserves are amenable to surface mining. Much of the surface-mineable coal is in the western part of the nation as is most of the high grade oil shale. This leads to a concern expressed by many people over the disturbance of lands that have scenic or agricultural value and that are relatively difficult to reclaim because of the low precipitation levels. As a result, the highly controversial Surface Mine Act was passed to attempt to assure adequate protection of these land values. In the case of oil shale many people in the environmental community have expressed opposition to extensive surface mining.

On the other hand, from the points of view of safety, resource conservation, and economics, surface mining has many positive benefits. Underground mining is two to three times more hazardous to the worker than surface mining. Recovery of the resource accessible to surface mining is essentially 100 percent, whereas, for example, underground mining can recover less than 50 percent of the oil shale because of the necessity to leave pillars to avoid subsidence. Finally, surface mining is cheaper than underground mining and this consideration is particularly important in the case of synthetic fuels where the economics is considered by many to be marginal at best.

In the case of the modified in situ process the worker safety issue becomes particularly paramount because of the presence of miners underground while retorts are burning. While the probability of a serious accident which could communicate hot, ignitable, and toxic gases from a burning retort to an area where workers are present is difficult to calculate, such accidents are possible and could result in death or injury to a few hundred workers.

It is clear that the values involved compete in assessing the appropriateness and desirability of surface versus underground mining. Some people believe that the risks posed to miners are voluntary on the part of the miner and therefore not a factor to be considered. Others argue that workers' injuries and deaths are costly to the nation in terms of both suffering and economic cost, and therefore a legitimate concern to the nation as a whole.

The mining approach used could be influenced in a variety of ways, if the nation could agree through its political process, on whether surface or underground mining is more desirable. Indeed, the approach could conceivably vary with the location of the site.

Of all the issues of concern, the mining issue is one of the most immediate since mining begins early in a project and because it affects site selection. Thus, if the nation wishes to influence the direction taken, policy decisions will have to be made soon.

SOCIOECONOMIC IMPACTS

One of the toughest issues involved in people-intensive development on any scale is the socioeconomic aspect. This term encompasses a wide variety of problems which include economic shortfalls from the necessity to provide facilities such as schools and jails before a tax base is available, and the increase in crime, divorce, mental illness, alcoholism, and other social problems found in booming communities. A potential effect on facility safety results from a possible decrease in workers' alertness due to stresses not directly job-related (e.g., marriage problems) or from the high worker turnover found in such areas. In addition, it is conceivable that sabotage attempts by disgruntled workers could increase due to such stresses. Such planned or accidential events could lead to an increased risk of death and injuries to the workers and, perhaps, nearby communities.

The debate is ongoing and this may be an appropriate time to examine the relationship to facilities safety more closely in order to ascertain whether this is a significant issue and whether specific measures can be taken to mitigate this concern.

SOLID WASTE DISPOSAL

The recent collapse of a coal spoil bank that resulted in considerable property damage and a death in a Colorado community illustrates one of the hazards of waste disposal that is not frequently raised as an issue. While knowledge of the geotechnical properties of materials has increased considerably, phenomena such as creep and piping are still not well understood and pose problems to pile stability. Moreover, natural phenomena such as earthquakes, mudslides, floods, and tornadoes as well as man-made events such as sabotage present a potential threat to piles of solid waste. (In the case of oil shale, the waste piles will be extraordinarily large--hundreds of millions of tons and hundreds of feet thick.)

Clearly the need to increase our knowledge of geotechnical engineering both at a basic and applied level is great. But, there are also some ways of reducing the risk due to catastrophic pile failure without improving present technology. One such approach would be to choose appropriate sites where events that could cause failure (e.g., floods) are less likely or where the consequences of such failure are fewer. It might be appropriate to review existing regulations to see if they contain adequate criteria for judging site appropriateness on these grounds.

The volumes of solid waste generated by a 2-million-barrel-per-day synthetic fuel industry are phenomenal. Clearly, with the large numbers of piles generated by such an industry, pile failures will occur from time to time, but site selection and better research have the potential for significantly reducing the frequency and consequences of such events.

WORKER TRAINING

The creation of a 2-million-barrel-per-day industry is going to require tens of thousands of workers in various dangerous jobs. Clearly proper job training can reduce the risks of these jobs. But, will facilities for proper training be available?

A variety of incentives have been used in the past to successfully train people in jobs considered essential to national security. The adequacy of training facilities (vocational schools, mining engineering programs, and so on) must be evaluated to determine if such incentives need to be created.

RESEARCH SUPPORT

The Energy Security Act clearly defines a national goal of 2 million barrels per day by 1992. Congress has authorized $20 billion to be used, with a subsequent installment of $68 billion planned to help achieve this ambitious goal. While some research on the environmental and health effects of such an industry has taken place, this research has not been performed on a commercial scale because none exists in the United States. It is clear that the federal government has an essential role in funding such research. Not only can this research lead to new understandings which can save lives and reduce the environmental threat, but our experience with nuclear energy shows that lack of a program that can assure the public of the safety of these facilities could slow or even stop the development of a synthetic fuel industry.

In view of the hundreds of billions of dollars (including the $88 billion in the Synthetic Fuels Corporation) at risk in meeting the national goal and the potential risks involved in this giant enterprise, an investment of even a billion dollars in environmental research would not seem very large to help ensure that the national goal is met in a cost-effective and an environmentally acceptable manner.

POSITION PAPER D

FACTORS AFFECTING THE SAFETY OF COAL GASIFICATION FACILITIES

William E. Corbett and William C. Thomas
Radian Corporation
and
Eric H. Reichl
Consultant

This position paper identifies and discusses safety risks associated with coal gasification facilities. Risks relating to five general categories are addressed:

- o natural disasters,
- o sabotage,
- o plant reliability,
- o site-specific risks, and
- o technology-specific risks.

The focus of this paper is on risks unique to coal gasification facilities. In addition to these unique risks, all of the subject facilities will pose the same types of risks as those associated with any full-scale energy conversion facility such as an oil refinery or coal-fired power plant.

The initial portions of this paper present some background information on coal gasification facilities, including a brief discussion of the subject technology and an identification of the waste streams that could be generated. This information is pertinent to the risk discussions that follow because in many instances the characteristics of the technology and its waste streams are dominant factors in determining the presence and the magnitude of the risks posed.

TYPE OF FACILITIES

Producing synthetic fuels from gasification of coal involves the reaction of coal with steam and oxygen to produce a synthesis gas containing CO and H_2 as well as minor amounts of CO_2, low molecular weight hydrocarbons, and, for certain types of gasifiers, higher molecular weight organics. In addition, raw synthesis gas also contains a variety of coal derived from constituents normally considered to be contaminants. These contaminants include NH_3, HCN, H_2S, organic sulfur species, trace elements and entrained particulate matter.

A number of gasifiers are commercially available or nearly at a commercial stage of development. These gasifiers can be categorized as fixed-bed, fluidized-bed, or entrained-flow reactors. With respect to many safety issues however a more meaningful method of categorizing gasifiers is according to whether or not they produce a synthesis gas that contains heavy organics (coal devolatilization products). In general, the greatest producers of heavy organics or coal tars are those gasifiers which operate at relatively low temperatures and are fixed-bed reactors. The Lurgi gasifier is an example of this type of reactor. Whether coal tars are produced is significant because coal tars contain known carcinogenic compounds and hence present health and safety risks to both plant workers and the environment.

In their simplest form, coal gasification facilities produce a gaseous product which consists of CO and H_2 as well as CO_2 and light hydrocarbons. Processing steps downstream of the gasifier which may be required to remove raw gas contaminants include gas quenching and cooling (with heat recovery where possible), and acid gas removal and sulfur recovery. More complex gasification facilities use a catalytic step(s) to convert the purified synthesis gas into gaseous or liquid products. Products that can be made include nearly pure H_2 or CO, substitute natural gas (CH_4), methanol, and gasoline.

Full-scale commercial facilities of the type just described will frequently be located on or adjacent to a captive coal mine. This is desirable because these facilities will process on the order of 12,000 to 30,000 tons per day (TPD) of coal in order to produce products with an energy content equivalent to 20,000 to 50,000 barrels per day (BPD) of oil. Associated with gasification facilities of these sizes will be large oxygen plants and relatively large auxiliary power plants (200 to 500 MW equivalents). Makeup water requirements will vary depending on the particular gasifier used and the design of the facility's water management system. However, all coal gasification facilities will consume large quantities of water.

Coal gasification facilities have been in commercial operation abroad for many decades. Prior to 1945, they were widely used in the United States. As a result of this experience, some information has been obtained concerning the safety records of these facilities. However, most of this information is not publicly available.

No large-scale commercial gasification facilities operate in the United States today from which safety information can be obtained. Thus, it is likely to be some time before a good data base is available that would allow some of these issues to be addressed directly. However, many of the unit operations and processing steps that comprise a coal gasification facility are very similar to those used in existing energy conversion facilities. Fortunately, most of these types of facilities, such as oil refineries, power plants, and coke ovens, have been widely used in the United States, and as a result, much U.S. experience with the safety aspects of these facilities has been obtained.

A fairly large number of specific gasification processes and downstream processing equipment options will be used in future U.S. coal gasification facilities. In general, the safety issues associated with any of these facilities are similar though specific safety issues vary from facility to facility. Thus, the subject of gasification-related safety issues can be addressed to a large extent in a general manner. Where appropriate, technology-specific issues are discussed.

SAFETY ISSUES ASSOCIATED WITH THE WASTE STREAMS FROM COAL GASIFICATION FACILITIES

Gaseous Emissions

One of the most significant sources of gaseous emissions from a coal gasification facility will be the acid gases removed from the raw synthesis gas. These gases will consist predominantly of CO_2 and H_2S, with lesser amounts of organic sulfur compounds (COS, CS_2 and mercaptans) and low molecular weight hydrocarbons. Processes for removing the sulfur-containing species from these gases and converting them into an elemental sulfur by-product are in commercial use. As a result, no major new control or safety problems are expected. The tail gases from sulfur recovery will comprise a large CO_2-rich waste stream. This stream will be vented to the atmosphere in most coal gasification facilities, although some of these CO_2-rich streams may find use as stimulants in enhanced oil recovery.

Another major gaseous emission from any large coal gasification facility will be the flue gases from the auxiliary power plant. As mentioned previously, this unit could contain as large as a 500 MW equivalent power boiler in a typical commercial-size synfuel facility. Pollution control requirements for this emission source will vary depending on the boiler fuel characteristics, whether or not the boiler must comply with the utility boiler new source performance standards (NSPS), local environmental conditions, and other factors. In almost all cases though, some type of particulate, SO_2, and NO_x controls will be required.

Most large gasification facilities are expected to use gasifiers that operate at elevated pressures (up to 1000 psi). Therefore the coal must be pressurized prior to its being introduced into the gasifier. For almost all of the gasifiers currently available, the coal-feeding mechanism will produce a gaseous emission. While the bulk of these gases can be recovered, some residual amounts will be released. The composition of the residual gases will vary depending on the design of the coal-feeding mechanism and on the pressurizing gas used. In all cases, some raw synthesis gas, that is, CO, H_2, particulate matter, H_2S, hydrocarbons, NH_3, HCN, and, if the gasifier operates at relatively low tempatures (e.g., the Lurgi gasifier), high molecular weight organics, will be released with the coal-feeder gases.

Gasifier start-ups and shutdowns will generate gases that will require disposal because they do not meet specifications. These gases will be similar to combustion flue gases during the early phases of start-up. During shutdown or the later phases of start-up, they will resemble raw synthesis gas.

Potential safety risks associated with coal-feeder and start-up and shutdown gases are numerous. Some of these gases may need to be released directly to the atmosphere. As mentioned above, some gasifiers produce a synthesis gas that contains high molecular weight organics. Tests conducted on a Lurgi-type gasifier indicate that some of these organics are PNAs. In the coal-feeder gases (lockhopper gases), the PNAs were found as aerosols and as condensed liquids or entrained particulate matter. Depending on the design and operation of the coal feeder, some control of entrained particulates and aerosols may be required.

There will be a number of fugitive-type emissions from coal gasification facilities, including: process fugitives (containing hydrocarbons, CO and H_2S) from valves, pump seals, and flanges; fugitive coal dust from coal storage and handling; and emissions from storage of hydrocarbon liquids. Controls for these types of emissions are commercially available and hence fugitive emissions from coal gasification facilities do not appear to present any new or unique problems. On the other hand, many of the potential sources of fugitive emissions in gasification facilities will be streams containing high concentrations of CO and H_2S. As a result, process fugitive emissions will contain CO and H_2S in addition to hydrocarbons. Thus, need for control of process fugitives may be greater than is commonly found in commercial practice (for example, in refineries) in order to ensure workers' safety.

Solid Wastes

A number of solid wastes will be generated by coal gasification facilities, but by far the largest volume of waste will be gasifier ash. Other large volume sources of solid wastes are the auxiliary boiler (bottom ash if the boiler is coal-fired) and the boiler flue gas pollution control equipment (fly ash and, if a nonregenerable FGD system is used, FGD sludge or dry solids). Available data from tests conducted on a number of gasification-derived ashes indicate that these wastes would be classified as nonhazardous according to current Resource Conservation and Recovery Act (RCRA) guidelines and test procedures. Of course, each gasification facility must present data to support this classification. However, disposal of these wastes is not expected to pose any unique problems or risks.

Other solid wastes that may be generated by coal gasification facilities include raw water treatment sludge, spent catalysts, and sludges and dry solids from the facility's waste-water treatment system. Raw water treatment sludge should not pose any new or unique handling or disposal problems. This material will consist primarily of removed suspended solids and precipitated calcium salts and, as such, will probably be considered a nonhazardous waste.

Spent catalysts may pose more significant problems than the other wastes discussed. Some will contain a number of toxic trace elements and as such could be classified as hazardous according to RCRA. Fortunately, the presence of those trace elements also makes them candidates for resource recovery. Many catalyst suppliers are willing to buy back (or at last take back at no cost) spent catalysts in order to recover their metals content for reprocessing into new catalysts. Thus, the risks associated with disposing of spent catalysts may be much less than otherwise anticipated.

The degree of risks posed by waste-water treatment sludges and solids will depend on the characteristics of the waste waters being treated. Sludge from biological oxidation units may contain absorbed trace elements or toxic organics. Whether the presence of these constituents will be cause for concern is not fully known at this time. Similarly, solids produced from a forced evaporation unit or recovered from an evaporation pond may contain high concentrations of toxic trace elements or organics. Ultimately, the risks associated with handling and disposing these types of wastes must be identified and dealt with case-by-case.

Aqueous Wastes

The two major sources of waste waters from coal gasification facilities will be process condensates and "blow-down" from the cooling water system. Unless contaminated waste waters are used, the cooling water system will not pose any unique waste water stream treatment or disposal problems. On the other hand, process condensate will be a waste water unique to gasification facilities.

Process condensate will be generated in gasification facilities when the raw synthesis gas is quenched and cooled. Since the quenching liquor and condensate will have been in intimate contact with the raw gas, it will potentially contain any of the components present in the raw gas. Of major potential concern will be the presence of organics, trace elements, and dissolved gases. The organics will consist of a wide variety of compounds if the gasifier operates at moderate temperatures (as the Lurgi gasifier does). Data obtained from tests on process condensate from a Lurgi-type gasifier indicate very high levels of BOD, COD, and TOC. Phenolics were the major class of organic compounds identified, but benzene and benzene derivatives, nitrogen-containing organics, and PNAs were also found.

A second source of process condensate will be the final product synthesis step. For most of the product slates mentioned previously, water will be a by-product of product synthesis. This waste water will be relatively clean except for those facilities that produce liquid products (e.g., gasoline). In this case the waste water will be contaminated with relatively low molecular weight, oxygenated, aliphatic organics.

Treatment requirements for gasification process waste waters will depend to a large degree on the availability of raw water, local environmental constraints, and the design of the integrated facility's water management system. In areas where water is not a scarce resource, a treatment system adequate to allow discharge of the treated effluents may be optimal. In areas where water is scarce or other constraints prohibit discharging treated waste waters, the facility's water management system may be designed to maximize water recycling and reuse and to operate in a "zero discharge" mode. Several alternative approaches to zero discharge are available. In arid parts of the country, solar evaporation ponds can be used as a final disposal technique. Underground injection is also a viable ultimate disposal method in most parts of the country. Forced evaporation is a third alternative if waste energy is available or if the volume of water to be evaporated is small. Combinations of these approaches are also feasible.

One of the most significant questions facing the designers of gasification facilities is the operability and reliability of the facility's waste water treatment system. Individual treatment technologies such as solvent extraction, steam stripping, and biological oxidation are commercially available. However, experience regarding the reliability of integrated treatment trains in gasification applications is lacking. A good deal of research is currently being conducted to investigate the performance and reliabilty of both individual treatment technologies and integrated systems.

Coal Tar from Gasification

Certain, but not all, gasifiers yield coal tar as a minor by-product. The use of these tars will vary widely, including recycling to extinction, use as internal fuel for the auxiliary power plant, and sale as fuel or chemical feedstock.

Coal tars are currently articles of commerce. However, gasification-derived coal tars will have a somewhat different composition than coke-oven tars (which supply the approximately 50,000 BPD used in the United States). Coal tars contain more carcinogens than comparable petroleum-derived fractions, but gasifier tars and coke-oven tars do not differ much in this regard. Thus, measures should be taken to protect workers who are involved with the handling, storage, and transportation of coal tars.

SPECIAL SYNTHETIC FUEL PLANT RISKS

In broad terms, synthetic fuel plants will present many of the same types of risks as those encountered in any large, complex energy conversion facility. Since many of these facilities will use technologies or combinations of technologies for which current commercial experience is limited, the dominant risks associated with these facilities will tend to be technology- or performance-related rather than safety- or health-related. These concerns will be reflected in uncertainties in the economic viability of proposed projects and these economic uncertainties can be expected to limit the rate of commercialization of coal gasification technology in the United States.

This paper is not intended to comprehensively address all of these issues. Rather, the comments presented below focus on the unique characteristics of synthetic fuels plants that affect their inherent risks from the standpoint of: susceptibility to natural disasters, sabotage, plant reliability, site-specific risks, and technology-specific risks.

Susceptibility to Natural Disasters

This issue should be addressed in conjunction with the site-specific risk category because the potential susceptibility of synthetic fuels plants to many types of natural disasters is closely related to geographical location. First, assume that the majority of the gasification facilities to be built in the United States will be located fairly close to large proven reserves of coal. This has been the case with most of the facilities which have been announced to date. These facilities should have a less-than-average susceptibility to damage from earthquakes or hurricanes because they will not tend to be located in coastal regions. Their susceptibility to damage from flooding, tornadoes, or other natural disasters would depend upon other site-specific characteristics.

Sabotage

The same considerations as those mentioned above apply here with a number of possible exceptions. It should be noted that one of the main risk factors to be considered with any synthetic fuel plant is a large inventory of fossil fuel. In a gasification facility, a large fraction of this inventory is represented by a coal pile which is not subject to the same level of risks as a large oil tank farm or a nuclear reactor. Thus, plant sabotage may succeed in forcing plant shutdown or even reconstruction, but the relative threat to the work force or the public would be less than that represented by either of the two sources mentioned above.

A different type of concern is represented by the problem of public visibility; the recent attempt at sabotaging the SASOL plant received world-wide publicity. Since publicity is a factor in the motivation of many acts of terrorism or sabotage, the first several facilities of this type to be built in the United States may be more susceptible to this problem than more established energy conversion facilities. Were this to occur, however, the main risk would be to the in-plant work force since these facilities will tend to be placed in remote locations and because their inherent susceptibility to sabotage (as discussed above) is not great.

Plant Reliability

Consistent with the factors discussed previously, plant reliability is really more of a threat to economic performance than plant safety. However, any large coal-oxygen flame operating under pressure presents potential reliability-related safety problems. These risks are probably greatest in pressurized, oxygen-blown systems, operating at high temperatures.

Solids-handling problems will affect the reliability of all coal-based synthetic fuel plants. The use of commercially proven processes will be the best protection against this risk. This is particularly true of systems in which solids must be handled under pressure, since the reliability of this type of equipment has never been as good as that associated with the handling of gases and liquids.

Another potential problem worthy of mention here is that many plant-reliability concerns will result not from the individual process units or technologies employed in these facilities, but rather from new or unique combinations of those processes. One example of this kind of problem is created by the obvious incentives to conserve water in facilities located in water-scarce areas such as the Great Plains.

Water conservation in such a facility will most likely be accomplished by cascading or reusing treated waste waters in various water-consuming units in the system. As a result of this arrangement, the performance of critical pieces of process equipment and ultimately the performance of the whole facility will become very dependent upon systems which are normally used only as "end of the pipe" treatment processes. In a facility that employs a high degree of process integration, it will be critical to identify those components likely to be the least reliable so that steps can be taken to separate these units from critical pieces of process hardware. In the case of the waste water treatment example, this would require that a sufficient quantity of treated waste water be maintained to satisfy plant needs during periods of waste water treatment system upsets or downtime; and that facilities be provided for segregating and storing waste water that does not meet specifications for recycling and further treatment.

Site-Specific Risks

It seems obvious that sites known to be subject to earthquakes, floods, hurricanes, dense population, approaches to airports, or other stresses should be avoided. Again, however, these factors are already considered in siting of other types of large energy conversion facilities, so no unique differences can be found that would make synfuels facilities inherently more susceptible to these risks. Like all types of large-scale coal processing facilities, synfuels plants will handle large quantities of coal and produce substantial quantities of solid wastes (primarily, boiler and gasifier ashes and slags). With these factors in mind, synfuels facilities should be sited such that a significant area suitable for disposal of solid waste is available.

Technology-Specific Risks

Technology-specific risks associated with coal gasification facilities can be discussed in two parts. The first type is those posed by the normal operation of the plant and its environmental discharges. These risks and their uniqueness to coal gasification facilities were discussed in the first part of this paper. For the most part, none is thought to be unique.

The second type of technology-specific risks relates to the potential for adverse effects from abnormal or upset conditions. Generically, coal gasification facilities do not differ from other energy conversion facilities with respect to the types of upsets that might occur. Of course, specific technical risks will vary from facility to facility depending on the specific equipment used and on the processing sequence selected. However, no risks unique to coal gasification facilities seem to stand out at this time.

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POSITION PAPER E

SAFETY OF SYNTHETIC FUELS PLANTS--DIRECT COAL LIQUEFACTION

C.W. DeGeorge
Exxon Research and Engineering Company

Safety aspects and risks associated with the developing of a direct coal liquefaction industry are discussed. Direct coal liquefaction facilities and conventional petroleum refineries are compared with the conclusion that the industries closely parallel each other. Safety and risk evaluations should be focused for the direct coal liquefaction industry upon those areas where technology extensions are required beyond petroleum experience. These areas have been well defined by the industry and numerous investigative programs are already in place with various industry groups, technical societies, and government agencies.

GENERALIZED DESCRIPTION OF DIRECT COAL LIQUEFACTION

A generalized flow diagram for direct coal liquefaction is shown in Figure 1. This diagram contains the major process steps that occur in the Gulf Oil Company solvent-refined coal procedure (SRC-II), the Exxon donor solvent process (EDS), and the Catalytic Hydrocarbon Research process known as H-Coal. The flow diagram and the following description were used as background for previous DOE-sponsored work on the assessment of long-term research needs for coal-liquefaction technologies.[1]

All processing sequences used for direct hydrogenation in the production of coal-derived liquids involve the following steps: addition of hydrogen to supply the needed constituents for the required increase in hydrogen-to-carbon ratio; cracking of the coal in the presence of hydrogen (hydrocracking) to produce compounds of

[1]Fossil Energy Working Group-II, Assessment of Long-Term Research Needs for Coal-Liquefaction Technologies, Contract No. DE-AC01-79ER10007 (Washington, D. C.: U. S. Department of Energy, March 1980), pp. 2, 4, 5.

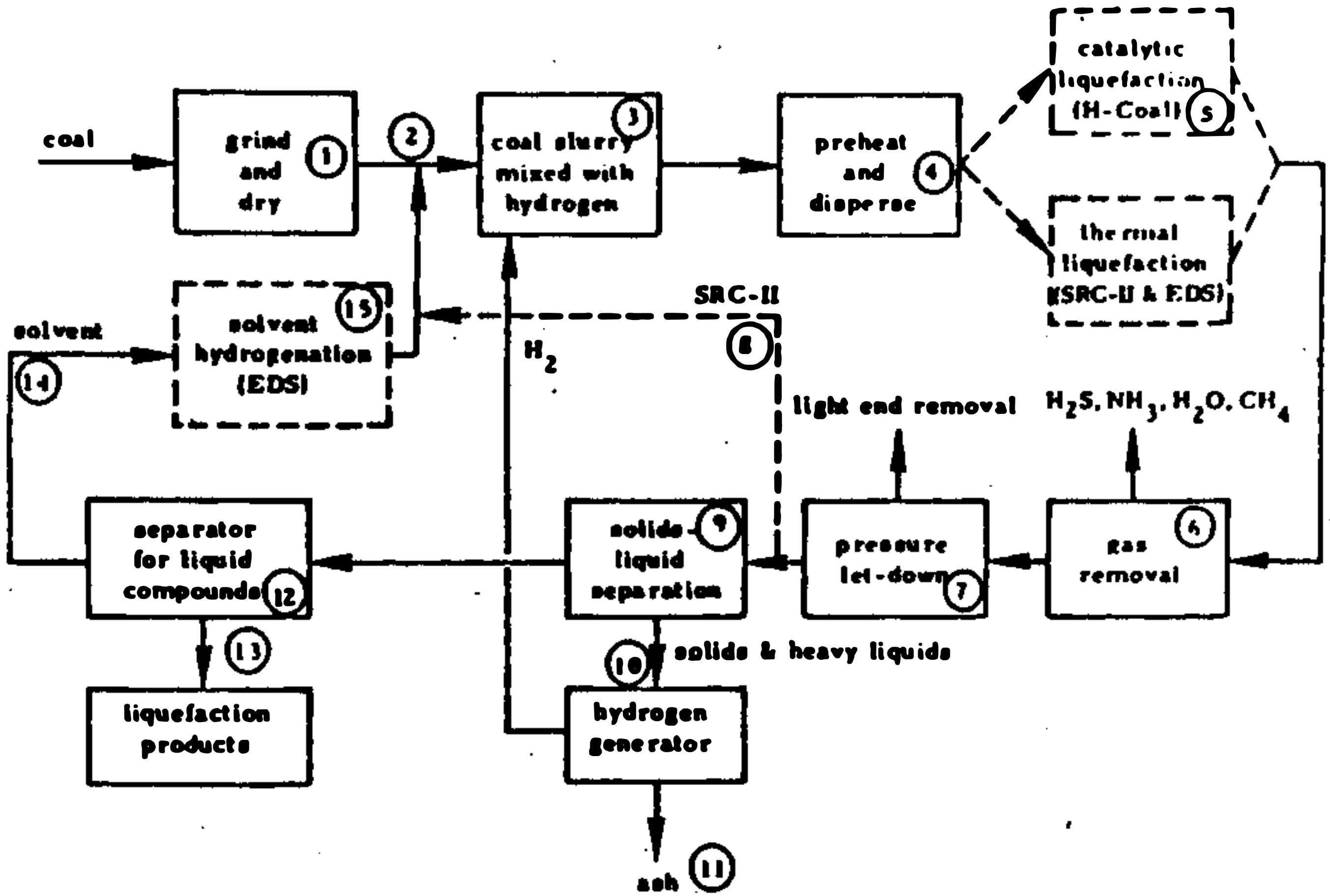

Figure 1 A generalized flow diagram for direct coal liquefaction.

reduced molecular weight; removal of sulfur- and nitrogen-containing compounds (e.g., H_2S, NH_3) that have been formed by hydrocracking, as well as removal of water produced by reaction with oxygen atoms contained in the coal; and appropriate bottoms processing and separation of the desired liquids from ash and any remaining unreacted coals.

Reference to Figure 1 shows the following processing features. The raw coal is first dried and ground (1) to produce the feed coal that is mixed (2) with a (recycled) solvent to produce a coal slurry to which hydrogen feed is added in appropriate amounts (3). The liquid mixture of coal, solvent, and hydrogen is then preheated and dispersed (4) before entering the liquefaction unit (5). The liquefier may be a catalytic reactor (as in the H-Coal process) or a thermal reactor (as for the SRC-II and EDS processes). Because of the necessary presence of mineral matter, both in the coal and in the (recycled) solvent, the so-called thermal liquefaction of the SRC-II and EDS processes will also involve catalyzed reactions. After liquefaction, the reaction products undergo a series of separation steps, beginning with gas removal (6) and pressure reduction or let-down (7) during which low molecular weight hydrocarbons (light ends) are separated. At this point, some of the solvent may be recycled to the feed slurry, as in the SRC-II process (8). However, most of the heavier remaining material is now subjected to one or more processing steps to separate the principal liquid products from heavy liquids and solids (9). The latter may be partially pyrolyzed to generate feed hydrogen (10) and ash (11) while the principal liquefaction products enter a separator (12) from which both desired liquefaction products are recovered (13) and recycle solvent is bled (14) for prior solvent hydrogenation in the EDS process or for direct reuse in the coal slurry (as in a version of the SRC-II process.)

DIRECT LIQUEFACTION PLANT SUPPORT FACILITIES RESEMBLE PETROLEUM REFINING TECHNOLOGY

Integrated and self-contained direct liquefaction plants require substantial support facilities. The processing facility for liquefaction of the coal typically represents a small portion of the overall plant facilities. For example, the direct liquefaction section of a commercial-size EDS plant represents only 14 percent of the plant's total erected cost.[2] The remaining facilities are required to allow effective utilization of the tar and coal residue,

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[2]U.S. Department of Energy, EDS Commercial Plant Study Design Update--Illinois Coal, Vol. 1, FE-2893-61, Cooperative Agreement DE-FC01-77ET10069 Distribution Category UC-90D (Washington, D. C.: U.S. Department of Energy), pp. 1-ES-16.

to produce hydrogen, to treat waste-water streams, to upgrade liquid products, to produce steam, and to store and transport coal. Except for the bottoms processing unit, these support facilities generally resemble technology typically found in petroleum refineries or utility power plants. As such, they are not anticipated to require any unusual research effort to guarantee their safety within a direct coal liquefaction plant.

PROCESSING BOTTOMS FROM DIRECT COAL LIQUEFACTION

Depending on coal type, operating conditions, and direct coal liquefaction process, 50 to 70 percent of the coal feed is directly converted to gaseous and liquid hydrocarbon products. A residue of undistillable tar, unreacted coal, and ash remains which can be termed bottoms. Effective utilization of the carbon in bottoms is desirable to improve the thermal efficiency and thereby the economic attractiveness of the direct coal liquefaction plant.

Bottoms require special handling and the need for such facilities should be recognized. If processed in the molten form, bottoms should be handled with care similar to that practiced for all other liquid products or internal streams in direct coal liquefaction plants. If bottoms are solidified before further processing, respirable dust emissions must be controlled similar to handling coal. Bottoms also tend to contain more extractable material than coal. From an environmental health and industrial hygiene standpoint, the standards for control of fumes from bottoms should likely approach the standards used for coal-tar pitch volatiles. Additional comment on this issue is left to positional papers that concentrate on toxicology of the direct coal liquefaction industry.

There are several potential alternatives for bottoms processing. These include direct combustion as fuel, partial oxidation to produce a synthesis gas for use as fuel or for subsequent upgrading to hydrogen, and solids separation to increase recovery of the nondistillable tar. The problems and research needs for bottoms processing will differ for each technology and are independent of liquefaction process safety. For example, the bottoms processing technologies that gasify the carbon in the bottoms residue closely resemble developing processes in the coal gasification area. Risks or safety-related concerns with these processes should be dealt with individually.

DIRECT LIQUEFACTION FACILITIES

Direct coal liquefaction facilities generally utilize commercially available types of equipment used in petroleum-processing facilities. The risk and safety concerns are related to the degree of extrapolation required to make this equipment suitable for the peculiarities of direct coal liquefaction and not to the uncertainties of workability or operation for brand new equipment types. Much of the current direct coal liquefaction pilot plant efforts deals with the demonstration of modified petroleum-type equipment (for example, slurry pumps and letdown control valves). A workshop on critical coal conversion equipment held in October 1980 concluded that "hardware availability will not delay construction and operation of demonstration plants, but may result in non-optimum process equipment configurations.[3]

Each direct liquefaction developer is the most appropriate party to identify areas where new equipment development is required due to process-related specifics. For example, ebullating pumps are required within H-Coal reactors but not for other direct liquefaction processes. Such nongeneric developmental requirements and their associated risk and safety concerns are outside the realm of this discussion. It should be noted, however, that many of these new equipment items represent areas where large-scale pilot plant demonstrations are desirable. Advancement of technology in these areas is adversely affected to a large extent as funding restrictions due to federal budget cuts become more stringent.

THE NEED FOR TECHNOLOGY EXTENSIONS

Areas of technology extension common to all direct coal liquefaction processes can be identified. They are:

- Pressure Levels. Conditions to achieve conversion of coal molecules into liquid products are severe. Pressure levels up to 3000 psig are required at high temperatures in hydrogen-rich, corrosive, and erosive environments.

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[3]Workshop on Critical Coal Conversion Equipment, Huntington, West Virginia--October 1-3, 1980, FE-2468, Contract No. EF-77-C-01-2468 (Washington, D.C.: U.S. Department of Energy, January 1981), p. iii.

- Presence of Solids. The handling of slurry streams is a requirement of direct coal liquefaction processes. The presence of solids results in erosion concerns, control measurement difficulties, and increased plugging potentials.

- Coal Liquid Compositions. Raw liquid products derived from direct coal liquefaction differ markedly from petroleum crude oil and distillates. Raw products prior to upgrading are highly aromatic with high heteroatom concentrations for sulfur, nitrogen, and oxygen. The effect of these compositional differences relative to petroleum-derived products is an area of concern particularly as it relates to toxicity.

High Pressure Levels

Direct coal liquefaction requires operation at high pressures and temperatures in hydrogen-rich environments. At typical direct coal liquefaction conditions, hydrogen attack of carbon steel and many alloy steels is a concern. Hydrogen attack occurs when atomic hydrogen permeates the steel or alloy and reacts with metal carbides to form methane. The methane collects in internal voids and cannot diffuse out of the metal. The resulting high internal stresses can ultimately lead to cracking of the metal at the grain boundary. Once attack has occurred, the metal cannot be repaired and must be replaced.

Hydrogen attack is avoided by selecting steels for construction that contain carbide stabilizing elements of which the most important is chromium. All austenitic (18 Cr-8 Ni) stainless steels are resistant to attack because of their high chromium content. However, technical and economic considerations obviate the use of solid stainless steel for major vessel construction. The lower chrome alloys typically used in hydrogen environments are selected according to empirically derived Nelson curves published by the American Petroleum Institute.[4] The Nelson curves define acceptable operating regions for low alloy steels as a function of temperature and hydrogen partial pressure. The opinion that the Nelson curves are valid for direct coal liquefaction environments is supported by a majority of materials specialists and researchers in the field.

The Nelson curves are plotted based on all available data points where damage to the metal has been detected. Since their inception in 1949, the Nelson curves have been modified in a few instances in

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[4]American Petroleum Institute, Steels for Hydrogen Service at Elevated Temperatures and Pressures in Petroleum Refineries and Petrochemical Plants, Publication No. 941 (Washington, D.C.: American Petroleum Institute).

the direction of greater conservatism as long-term data have become available. Current research by the API, the Metal Properties Council, and others is directed at further evaluation of the Nelson curves and improving fundamental understanding of the mechanism of hydrogen attack on pressure vessel steels.

The material most likely to be used for reactor vessel construction in commercial direct coal liquefaction plants is 2 1/4 Cr-1 Mo. The 2 1/4 Cr-1 Mo curve on the Nelson chart was added in 1970 and is based on an interpolation of only two data points. Commercial applications other than direct coal liquefaction which operate near the 2 1/4 Cr-1 Mo Nelson curve limits are few. As a result, extensive data that support or disagree with the 2 1/4 Cr-1 Mo Nelson curve may only come with experience from the direct coal liquefaction industry. Based on current knowledge, 2 1/4 Cr-1 Mo would be an acceptable material and could be used with confidence in a pioneer direct coal liquefaction plant. However, recognition of the possibility of hydrogen attack is important so that appropriate monitoring and inspection programs can be applied within pioneer commercial facilities.

Other than 2 1/4 Cr-1 Mo, what economically acceptable construction materials are available? The 3 Cr steels offer improved hydrogen resistance, however, world-wide commercial experience in fabrication of 3 Cr steel vessels is limited and virtually none comes from the United States. In addition, 3 Cr steels are weaker with lower allowable stress values than 2 1/4 Cr-1 Mo. As a result, thicker vessels would be required if made of 3 Cr steel which imposes additional technical problems in the achievement of acceptable metal properties and in the construction of already-thick vessels. No obvious alternative to 2 1/4 Cr-1 Mo steel has currently been identified and this concern is understood by a large number of industry groups, technical societies, and government agencies involved in coal liquefaction materials development. Metallurgical research should continue in an effort to better understand hydrogen attack.

An alternative approach to a problem solution for hydrogen attack other than identification of new materials involves research aimed at developing an acceptable vessel design for coal liquefaction environments which reduces the skin temperature of the vessel shell below that of the operating environment. Use of internal refractory linings is one option. Development work in this area should be directed at improving the integrity and reliability of the lining. Attendant problems involve the ability to gas-free refractory linings following exposure to the process environment so that safe inspection and maintenance of the lining is possible.

Use of layered vessel shell construction as opposed to solid wall design represents another option. In such designs, only the inner pressure-tight layer requires hydrogen resistance since the outer layers are vented to the atmosphere. The inner layer would be made of stainless steel, similar to the weld overlay provided for 2 1/4 Cr-1 Mo solid wall vessels for corrosion resistance to H_2S.

Problem areas related to this type of construction include the difficulties associated with providing side-entering nozzles, the likelihood that field fabrication would not be acceptable for quality control, and difficulties in inspection and repair. In addition, the internal stainless steel layer must be joined to the outer transition sections which requires the use of ferritic weldments and presents problems similar to those discussed for 2 1/4 Cr-1 Mo solid wall construction.

The consequences of hydrogen attack, while not acceptable, would be unlikely to result in catastrophic rupture of the equipment piece. Rather a fissure or small gap would likely appear with a resulting nonmassive release of contained material.

Related to the area of materials adequacy for vessel construction is the exothermic nature of direct coal liquefaction reactions. The extent of temperature rise depends on the liquefaction process and the operational controls available to maintain the exotherm at desirable levels. The presence of an exotherm is widely recognized and extensive control instrumentation is provided to prevent operating temperatures from exceeding materials design temperatures. Should the operating temperature approach the design limit the control instrumentation typically includes automatic safety shutdowns to eliminate heat input to the system as well as automatic introduction of emergency quench gas or quench oil.

Other after-effect problem areas of high pressure can be identified. The problem of fabricating the thick walls required for the vessels can be overcome, although not entirely in a cost-effective manner, by providing two parallel equipment vessels of smaller size instead of one. Reducing the vessel diameter allows a reduction in wall thickness since thickness is proportional to the internal vessel diameter.

The high pressure levels required for direct coal liquefaction also could compound the difficulties of emergency control forces in response to failure of equipment pieces. Any release of contained fluids would perhaps be magnified due to the driving force provided by the high pressures. An example that illustrates this point would be the anticipated fluid release and subsequent problems created by a 6-inch split tube in a 500-psig furnace relative to a 6-inch split tube in a 3000-psig furnace.

Presence of Solids

The movement of solids within a direct coal liquefaction facility is generally accomplished by slurrying the solids with liquid hydrocarbons. These slurry streams present a number of problems not generally found in commercial petroleum facilities. Ongoing demonstrations at large-scale direct coal liquefaction pilot plants are addressing these problems and experimenting to find methods of overcoming or controlling their ramifications.

Slurry erosion results in metal loss. Severe metal loss can result in leaks of contained fluids and create potentially dangerous situations. Erosion in machinery which requires tight tolerances can cause efficiency declines which eventually necessitate shutdowns. Protection against erosion is possible through judicious materials selection, use of erosion resistant linings, and use of special design features. Frequent inspection monitoring at troublesome locations, such as areas of direct high velocity impingement, also is recommended so that potential trouble can be identified and repaired before it becomes a real problem.

The presence of solids also creates difficulty in control measurements for direct coal liquefaction processes. In particular, measurement of flow, level, and pressure are problems due to the tendency of solids to plug the sensing taps. Flushing the sensing taps is one solution to the plugging problem although interference with the variable measurement often occurs. Other alternative solutions involve use of instrumentation which does not require direct exposure to the solids-containing fluid. Examples include flow measurement devices which work acoustically or through use of conductivity information and level measurement through use of low-level radiation. Development efforts are under way to improve these measurement techniques for control of the process to prevent unsafe conditions that could result in equipment failure and potential emergency situations. "In spite of clearly defined needs in the instrumentation and control (I&C) areas, program managers generally believe that the existing recognized deficiencies will not prevent successful operation of pilot and demonstration plants."[5]

The presence of solids also contributes to potential plugging problems for lines within the direct coal liquefaction facility. Solids can saltate in areas of low velocity and eventually create a flow restriction which leads to a line plug and probable unit shutdown. Proper design to eliminate low-flow areas can overcome this problem. However, unit shutdowns which stop process flows also can result in saltation and difficulty in refluidizing the process fluid. Proper operating procedures are necessary in such instances which result in flushing of these potentially troublesome lines with available process liquids.

Related to the problem of solids plugging is the recognized need to maintain open flow paths to and from safety valves in slurry service. Since the connecting lines to these safety valves have zero flow rates except in emergency situations, they have a greater tendency to plug through solids deposition or solidification of high boiling point components than other process lines which have continuous flows. Provision of a continuous flushing medium to purge these lines of solids and recognition that particular care is required when installing heat tracing to prevent solidification is

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[5]Fossil Energy Research Working Group-II, op. cit., p. 56.

recommended and should be considered in the detailed design of such services.

Coal Liquid Compositions

The difference exhibited by raw direct coal liquid products relative to petroleum products is well recognized. Numerous studies are under way to better define the toxicity of raw coal liquid products and the appropriate control and handling procedures required to minimize any attendant occupational safety and health risks. Included among the studies are the evaluations of upgrading options which hydrotreat the raw coal liquids into finished products using processing facilities commonly found within petroleum refineries. Toxicological assessments are not discussed within this document but are left for consideration within other positional papers.

HAZARDS ARE COMPARABLE TO EXISTING EXPERIENCES

Major questions as to mechanics and construction materials must be satisfactorily resolved before commercial direct coal liquefaction plants can be operated with the same degree of safety and reliability as the hydrocarbon processing industry. The major uncertainties center on the processing steps outlined in Figure 1, the design of which will be based on pilot plant experience as opposed to conventional commercially available systems.

Pilot plant operating experience to date has been favorable in that no major fires or explosions have occurred. This attests to the adequacy of existing national concensus engineering and safety standards used as criteria for the design and construction of the various pilot plant facilities. These standards include those of the National Fire Protection Association, American Standards Institute, American Society of Testing and Materials, as well as others. Operator training and plant safety programs based on refinery and chemical plant experience have also contributed significantly to the safe operation and maintenance of the pilot plants.

The severe operating conditions that exist in direct coal liquefaction are well bracketed by refining experience. Hydrogen-rich environments up to 3000 psig are encountered in hydrocracking, and the handling of erosive gas and liquid streams containing solids is well demonstrated in fluidized bed catalytic units. Table 1 lists typical hazards where failure has been experienced from the operation of such processes. The list, while not all-inclusive, is instructive from the standpoint that similar hazards can be identified in the design, operation, and maintenance of the processing facility for liquefaction of the coal.

TABLE 1 Typical Hazards That Could Result in Release of Process Materials

Hazard	Mitigation Practices[a]
1. Hydrogen attack of reactor shell	1. Selection of shell material based on Nelson curves; operating temperature control and shut-down system; frequent inspection and close monitoring of shell for hydrogen attack.
2. High pressure furnace tube rupture	2. Furnace relief and shutdown and fire protection system; inspection of tubes to determine tube life.
3. Flange leakage	3. Minimize flanges; strict flange makeup and tightening procedures; periodic inspection and tightening.
4. Piping or vessel leak due to erosion or corrosion	4. Erosion and corrosion-resistant materials; valving to permit isolation; periodic non-destructive testing, inspection, and monitoring.
5. Increase in metal transition temperature due to temper embrittlement	5. Selection (and testing) of materials to assure ductile behavior during initial component pressure testing; special operating procedures to assure heating of vessel prior to pressurization in service.

[a]Design; operation; maintenance

The control of these hazards is widely practiced within the refining industry.[6]

One hazard which lies outside refining experience is the possibility of coal dust explosions in the coal feed system to the coal liquefaction plant. This hazard persists in coal-fired utility plants and therefore is an important safety consideration.

NATURAL DISASTERS AND SABOTAGE

Natural disasters result from uncontrollable forces and cannot be prevented. However, careful site selection and appropriate design procedures can be used effectively to avoid or control their consequences. For example, site selection to avoid flood plains and earthquake faults should be practiced wherever possible. Construction codes typically consider worst-case possibilities to determine what wind loads and earthquake severities must be withstood during a plant's operational life. Sabotage is also difficult to absolutely control although standard security procedures could be strengthened if warnings of sabotage attempts could be obtained. However, no guarantees of absolute protection could ever be made.

Standard security procedures would include surrounding the direct coal liquefaction plant by a chain-link perimeter fence with limited access points. Security guards would be stationed at the access points and would only admit authorized personnel. Although scaling the perimeter fence would be relatively easy, transport of large quantities of sabotage equipment onto the site would be more difficult. Once on-site, the sabotage forces would require time to move undetected while they accomplished their goals. The operating plant personnel would question any unrecognized and unauthorized movement within an operating area. Operating personnel are also typically equipped with hand-radios which allow communication with the process control house and with security forces as necessary.

New and innovative security systems which offer a scientific approach to security have recently been advanced as concerns relating to terrorist and extremist group activities have mounted.[7] Components of these security systems include intrusion detection equipment, a comprehensive resource protection program, current threat analyses, employee training programs, and sound contingency

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[6]American Petroleum Institute, "Conditions Causing Deterioration or Failures, "Guide for Inspection of Refinery Equipment, Chapter II (Washington, D.C.: American Petroleum Institute).

[7]F. G. Spranza, "Improve your Plant Security System," Hydrocarbon Processing (September 1981), pp. 331-338.

plans for situations such as man-made and natural disasters, labor unrest, and power failures. The management of the security system develops plans, operations, and programs to effectively integrate these functions into a comprehensive overall protection plan.

The after-effects of a natural disaster or sabotage would be handled by procedures similar to those used in case of catastrophic equipment failure due to maloperation. Elaborate safety shutdown signals and isolation capabilities are typically provided within petroleum refineries and will similarly be provided within commercial direct coal liquefaction plants. For example, should a furnace tube rupture, immediate actions would automatically include elimination of fuel gas and pilot gas flow to the burners, discontinuation of feed pump and treat gas compressor operation to eliminate entering process flows, and remote operation of isolation block valves to segregate the furnace from other equipment that contains combustible fluids. Remote operation of valves to supply snuffing steam to the firebox to smother the resulting fire would also be possible. The immediate impact of a process fluid release into the firebox would be handled by specially designed explosion doors which would direct the release skyward away from operating personnel or other equipment. In addition, at the design stage, isolation spacing requirements would have been followed for the furnace which serve to segregate it from other contributors to combustion and which allow access by fire-fighting equipment.

EQUIPMENT SPARING PHILOSOPHIES AND MULTIPLE TRAIN DESIGN APPROACHES

Plant reliability, not considering the implications of catastrophes caused by such occurrences as natural disaster, can be guaranteed by applying appropriate philosophies at the design stage. Equipment pieces where failures are periodically expected, such as high-pressure slurry feed pumps, would be spared with a redundant unit so that loss of one unit would not result in shutdown of the process. A similar approach, but on a larger scale, involves modular construction of parallel plant processing units. For example, a plant designed to normally produce 60,000 B/SD of liquid product would include four parallel direct coal liquefaction modules, each capable of providing 15,000 B/SD. Loss of one module due to failure of nonspared equipment pieces would then only result in a 25 percent loss in overall plant capacity.

Other design procedures that can be applied to increase overall plant reliability include oversizing of selected processing support facilities with provision of intermediate storage facilities. Failure of a support facility, for example a sour water treating unit, would then not require the shutdown of the remaining plant facilities. Sour water would be stored in tankage and eventually be processed using the treating unit's excess capacity following completion of necessary repairs.

Judicious use of such philosophies can result in capacity factors which approach 90 percent. Capacity factor is defined as the ratio of the expected annual coal throughput of the plant to the theoretical yearly coal throughput (at normal operation with no outages).

SITE-SPECIFIC RISKS

Site-specific risks should be considered during site selection. If unacceptable risks can be identified, an alternate location would become necessary. Evaluation of any site-related risks requires identification of a location and therefore must be addressed case by case. Items that should be evaluated during site selection include consideration of the mining-to-plant interface, ramifications of remote site locations, unusual problems created by local weather patterns, and ability to adequately man construction forces and operations teams for a grass-roots facility.

The mining interface must be considered since an unreliable supply of raw material would limit the plant's design capacity factor. Multiple mines, particularly for direct coal liquefaction plants, which are designed to process bituminous coal from underground mines, are typically required to feed commercial-sized facilities. The processing plant's location should be intermediate between the supply mines but more importantly should be situated so that access routes of coal to the plant are guaranteed and have minimal chance for interruption. Labor unrest can also lead to disruption of coal feed to a plant. Protection against long-term feed disruptions can be accomplished by following the utility plant practice of storing long-term "dead coal" piles containing a 90-day supply of feed.

Remote sites may affect the ability to attract and the cost of a labor force, both short-term for construction and long-term for plant operations. Extremely remote locations may require development of planned housing communities which means that the thoughts and concerns of local government planning organizations must be evaluated. The financial investment in remote locations can also be significant and the availability of adequate tools for cost estimates at the planning stages is a necessity to avoid major cost overruns which could challenge the economic viability of a project.

Severely inclement weather can adversely affect the construction schedule and lead to major cost increases if not considered in advance. Once a plant is operational, weather patterns that can isolate plant personnel for various periods of time should be evaluated and, if necessary, temporary living quarters may have to be provided at the site.

Development of a large-scale grass-roots direct coal liquefaction industry will require the training of a large, highly skilled labor force capable of operating and maintaining the facilities. The ability to attract and hold trained personnel should be considered. Unattractive remote locations may result in large turnover ratios of employees if incentives, perhaps of a monetary, residential, and cultural nature, are not provided

RISKS ASSOCIATED WITH DIRECT COAL LIQUEFACTION PLANTS

A number of parallels have related the safety aspects and risks for a direct coal liquefaction industry to those usually considered and accepted within the petroleum refining or chemical industries. That the direct coal liquefaction industry has drawn heavily on such experience is partly attributable to the backgrounds of the companies involved in developing synthetic fuels processes. However, direct coal liquefaction equipment and operating requirements have very close younger-brother-type relationships to these industries and such a parallel evaluation seems reasonable.

Areas where safety and risk evaluations should be focused for the direct coal liquefaction industry include those that require technology extensions. These areas are well defined and emphasize the ability to contain high-pressure process fluids at high temperatures in hydrogen-rich environments, to adequately handle slurry process streams, and to protect operating personnel from possible toxic exposures due to the compositional makeup of coal liquids. Research emphasis should continue to be given high priority in the following broad areas of component design:

- Reliable materials performance in slurry handling system.
- Improved understanding of hydrogen attack and temper embrittlement of 2 1/4 Cr-1 Mo steels.
- Elevated temperature properties, and fabrication and inspection techniques of thick weldment (>8") for pressure vessel construction.
- Vessel designs that reduce the shell design temperature below that of the operating environment.
- Continued development of components and slurry services, for example, control and block valves, pumps, seals and flushing systems, instrumentation, heat transfer equipment.
- Improved understanding of causes of dust explosions in coal-handling systems and methods for monitoring.
- Continued development of design criteria for the prevention of flange leakage.

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POSITION PAPER F

HEALTH EFFECTS OF OIL SHALE DEVELOPMENT

Laurence M. Holland
Los Alamos National Laboratory

ABSTRACT

Information on the potential health effects of a developing oil shale industry can be derived from two major sources: (1) the historical experience in foreign countries that have had major industries and (2) the health effects research that has been conducted in the U.S. in recent years. Both are useful because the recent work applies modern scientific approaches to many of the generic questions while the experience in foreign countries offers more data on the long-term results of human exposure. The information presented here is divided into two major sections: one dealing with the experience in foreign countries and the second dealing with the more recent work associated with current oil shale development in the United States.

FOREIGN EXPERIENCE WITH HEALTH EFFECTS OF OIL SHALE

Oil shale has been used as a source of energy and liquid products in a sustained manner in only two areas of the world: Great Britain and Estonia. The recent Brazilian industry provided no significant production until mid-1972 when the first Petrosix retort was completed.[1] Of the three foreign countries intermittently involved in shale oil production, the Soviets (Estonia) offer the most in the way of significant experimental and epidemiological data. The Scottish experience is historically important because of its effect on the general field of industrial hygiene and occupational medicine.

Because the Brazilian industry is new it will not be examined here. This analysis emphasizes the Estonian effort followed by a summary of the major problems identified by Great Britain's experiences.

[1]G. L. Baughman, Synthetic Fuels Data Handbook, 2nd ed. (Denver, Colorado: Cameron Engineers, Inc., 1978), p. 80.

Oil Shale-Related Health Effects Observed in the Soviet Union

History

The Soviet oil shale industry is the largest currently active one in the world. Development of the resource has taken place in a nearly continuous fashion under three governments. Beginning in 1920, Estonia began research which resulted in the development, after 5 years, of a so-called Pintsch retort which produced town gas. This 200-ton-per-day facility became the basis for the Kiviter gas generator currently in use in the Estonian SSR. In 1939 Estonia was taken over by Russia and then occupied by Germany as part of the general invasion of all Soviet territories in 1941. At that time the Estonian industry had reached over 800,000 tons per year. As the Russians retreated, they dismantled the industry and while the Germans planned an expansion, very little production took place before Russia regained the area in 1944. Apparently the reconstruction of the industry moved slowly until the refinement of the Kiviter process and the development of the Galoter process took place in the early 1960's. Historically, the principal use of Estonian shale has been for the production of low-Btu town gas and for direct combustion in power-generating plants.[2] Vosamae mentions the use of oil shale (as a solid fuel) in domestic stoves and furnaces.[3] This private use of shale has probably been common far longer than the industry has existed. The use of Baltic or Estonian shale for the production of liquid fuel or chemical feed-stock has been a comparatively recent development, beginning in the early 1970's. It is important to recognize that both the Soviet shale and the extraction methods applied to it differ significantly from the U.S. resource and technologies.

The Resource (USSR)

The Baltic or Estonian shales are known as kukersite, and are extremely rich in recoverable organic components. Most Estonian ore

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[2]Baughman, op. cit., p. 76; and I. A. Veldre and H. J. Janes, "Toxicological Studies of Shale Oils, Some of Their Components and Commercial Products, "*Environmental Health Perspectives*, Vol. 30 (1979) pp. 141-146.

[3]A. I. Vosamae, "Carcinogenicity Studies of Estonian Oil Shale Soots," *Environmental Health Perspectives*, Vol. 30 (1979), pp. 173-176.

assays more than 40 gal/ton and is located very near the surface.[4] Kung describes the chemical analysis of kukersite and states that organic constituents account for 37 percent of the total[5]. Green River shales from the intermountain region of the United States average 25 gal/ton or less and about 16 percent organic complexes.[6] Kung further states that Estonian shale is 13 percent SiO_2 of which 42 percent is in the form of quartz. Thus, quartz contributes only about 5.5 percent of the minerals, considerably less than the 15 percent found in the Mahagony zone of U.S. shales. The amount of silica present as quartz is an important factor in the development of the fibrotic and obstructive lung diseases often associated with mining industries.

The rich oil shale deposits are located in the northeastern part of Estonia very near the current border with Russia and about equidistant from Leningrad and Tallinn. The major industrial town of Kohtla-Jarve is at the approximate center of the oil shale region. The countryside is typical of a low costal area, with numerous lakes, rivers, and small swamps. Located at nearly 60^o north latitude, the terrain resembles the lake region of northern Minnesota (author, personal observation). The depth of the shale rock varies but probably averages less than 100 ft with some areas having an overburden of less than 25 to 30 ft.

Two types of mining are carried out: strip mining in the shallower regions and underground mining in the deeper areas. Apparently in situ techniques have never been tried, either because of ready accessibility of the shale or because it occurs in an alternating seam pattern. Strip mining is accomplished with large machinery and the shale rock is transported to processing plants by both truck and train. Restoration of terrain and reforestation are practiced but the extent of this effort is not known. The underground mine "Estonia," located near Kohtla-Jarve, is probably the largest in the country and consists of a series of very long major drifts (up to 2 to 3 miles) served by an extensive lateral drift system. The dimensions of the rooms and drifts are considerably smaller than those found in U.S. oil shale mines, and constructed roof support systems are more evident. Apparently all underground equipment is electrically powered (author, personal observation).

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[4]Baughman, op. cit., p. 78.

[5]V. A. Kung, "Morphological Investigations of Fibrogenic Action of Estonian Oil Shale Dust," Environmental Health Perspectives, Vol. 30 (1979), p. 153.

[6]Baughman, op. cit., p. 14.

Energy Production Technologies (USSR)

It should be emphasized that until very recently the main use of Baltic shale has been for direct combustion in power-generating stations and for the production of low-Btu town gas.[7] Gas and oil production has been carried out in tunnel ovens, solid-heat transfer retorts, and chamber ovens.[8] Tunnel ovens, which are a variation of a moving grid system, are the oldest of the Soviet technologies and are apparently still in limited use. The tunnel oven approach uses a train of hopper cars, loaded with shale, which are drawn through a long tunnel where hot gases are passed through the shale driving off the oil vapors and gas.[9] The solid-heat-transfer process is called the Galoter retort and closely resembles both the TOSCO II and the Lurgi-Ruhrgas retorts. Spent shale is used as the heat-carrier agent. The older Kiviter process (chamber oven) is similar in function to the Gas Combustion, Paraho, Petrosix, and Union retorts. Both the Galoter and Kiviter processes are available in the United States under license from Resource Sciences Corporation of Tulsa, Oklahoma.[10]

In general, the modern oil and gas producing plants in the Estonian SSR combine the Kiviter and Galoter techniques since each process requires a different size shale; the former uses a feed-stock ranging from 1 to 5 in. while the latter requires fine pieces up to 1 in. in diameter. A combined screening and flotation process separates the ore according to size after crushing (author, personal observation). An increasing proportion of the industrial population is employed in plants employing one or both of these techniques.

It should be noted that epidemiological data presented later in this report make no distinction among the several recovery techniques uses in Estonia, and that workers are included who are to have been exposed to more than one process including the direct-combustion power-generating operations.

Experimental Results (USSR)

Direct Toxicity Veldre and Janes reported on the relationship among boiling point, volatility, and toxicity of several shale

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[7]Ibid., p. 76.

[8]Veldre and Janes., op. cit., p. 141.

[9]Baughman, op. cit., p. 76.

[10]U.S.S.R. Oil Shale Presentation (Tulsa, Oklahoma: The Resource Science Corporation, 1975).

oils and selected fractions.[11] In general, it appeared that those oils or fractions which originated from low temperature extraction processes or were marginally volatile at low-temperature were the least toxic of the materials tested. The most toxic material tested was the diesel oil fraction. In this same article, the authors state unequivocally that the activity of the phenols determines the toxicity of Estonian shale oil. In both acute and chronic toxicity experiments the symptoms described are attributable to disturbance of the central nervous system. Long-term exposure led to a variety of systemic changes including anemia, leukopenia, reduction in blood glucose levels, and changes in certain liver and kidney functions. Long-term oral exposure (0.1 g/kg/day) in rats resulted in a decrease in primordial ovarian follicles in females and a reduction of normal spermatogonia in males.

Veldre found no correlation between the toxic and carcinogenic properties of any of the shale oil materials tested. She further states that many of the products resulting from the use of shale oil as a petrochemical feedstock possess toxic potentials that are not necessarily different than those derived from other basic organic fuels. Soviet experimentation had led to the conclusion that the intensity of the skin effects of these end-use products correlates with the degree of inhalation toxicity.

In another report, Blinova classifies the oils from the various retorts according to their skin irritating effect. He found the oils produced at higher temperature (generator chamber oven and tunnel oven) were more irritating than oil from the lower-temperature solid-heat-transfer system (Galoter process).[12]

<u>Carcinogenicity</u> The Soviets have studied the carcinogenicity of oil shale products since 1951.[13] Bogovski has been the principal experimenter in the field and published a book on the subject in 1961.[14] The major conclusions he draws from his experimentation are: (1) Higher carcinogenic activity occurs in the products resulting from higher temperature processing; (2) benzo(a)pyrene (BaP) is a major factor in the enhanced carcinogenicity of many but not all, of the products and their fractions; and (3) aliphatic

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[11] Veldre and Janes, op. cit., pp 141-146.

[12] E. Blinova, I. Veldre, and H. Janes, <u>Toxicology of Shale-Oils and Phenols</u> (Valgus, Tallin, 1974).

[13] P. A. Bogovski and F. Vinkmann, "Carcinogencity of Oil Shale Tars, Some of Their Components, and Commercial Products," <u>Environmental Health Perspectives</u>, Vol. 30 (1979), pp. 141-146.

[14] P. A. Bogovski, <u>The Carcinogenic Effect of Estonian Oil-Shale Processing Products</u>, English Summary (Tallinn, 1961).

hydrocarbons may potentiate the carcinogenic effects of the aromatic compounds. The preoccupation with the presence of BaP in shale oil products led to assumptions by early experimenters which have since proven to be misleading. Bogovski reports the identification, by Eisen in 1959, of other known or suspected carcinogens such as 1,2-benzanthracene and 2-methylbenzanthracene in shale oils. Some of these materials were low in BaP content and proved to be highly carcinogenic in experimental animals.

Vosamae studied the carcinogenic effect of oil shale ash, or soot, resulting from either direct combustion of kukersite or from combustion of mazut (fuel oil). Benzene extracts of both materials were used and the results indicate that the soot resulting from direct combustion of kukersite showed a marked carcinogenic action and that the extract of soot from oil shale fuel oil was carcinogenic but that the effect was considerably less than that of the direct combustion material. These experiments emphasized the unreliability of BaP content as a measure of carcinogenicity since the fuel oil soot, which was less carcinogenic, contained the most BaP (1200 ppm) while the more carcinogenic direct combustion soot contained less (14 ppm).[15]

Vosame also performed intratracheal experiments in rats to determine the carcinogenic action of the various solid materials and their extracts in the lung. She could not demonstrate a significant increase in lung neoplasia over the incidence in controls for any of the solid materials. When tars derived from solids, were instilled under conditions that favor the penetration of tissues by carcinogens (for example, in detergents) a nearly 50 percent incidence resulted.

While Veldre found that besides process temperature, the phenolic content of the products and by-products was an important factor in direct toxicity,[16] Bogovski was unable to demonstrate serious carcinogenesis attributable to the phenols found in shale oil or certain of its products.[17] He used both direct (single-stage) testing and promotion (two-stage) schemes.

Summary In summary, the Soviet experimentalists have defined the biological activity of most of the materials associated with the Estonian oil shale industry. They draw several major conclusions from their years of experimentation:

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[15] Vosamae, op. cit.

[16] Veldre and Janes, op. cit.

[17] P. A. Bogovski and H.I Mirme, "Cocarcinogenicity of Phenols from Estonian Shale Tars (Oil)," Environmental Health Perspectives, Vol. 30 (1979), pp. 177-178.

1. Direct toxicity is more pronounced with higher process temperatures and also to a lesser extent with degree of volatility.
2. Direct toxicity can be approximately estimated from the phenol content.
3. The intensity of skin effect correlates with the degree of inhalation toxicity.
4. Higher process temperatures produce more carcinogenic products and by-products.
5. BaP is an important carcinogen in many products and by-products.
6. The presence of BaP is not a reliable indicator of carcinogenic potential.
7. The solid wastes (soot) possess carcinogenic potential which depends on their source.
8. Heating of commercial products derived from oil shale may increase their hazard.

Effects on Worker and Regional Health (USSR)

The Soviet experience with management of industrial health problems related to an oil shale industry is the most extensive one that extends into modern times. Purde and Rahu have published some findings related to cancer incidence in the Estonian oil shale region.[18] They report that the incidence of stomach and lung cancer is higher than that found in the general population of Estonia but attribute this increase to migration into the industrial district from other republics in the Soviet Union. Apparently over 70 percent of the Kohtla-Jarve stomach cancer patients have immigrated from areas where stomach cancer incidence runs 1.6-2.5 times higher than that of native Estonians. However, in this same study they cannot explain the high incidence of gastric cancer in the rural populations of the same district (low migration factor). Veldre has found that analysis of water, soil, and vegetables for BaP was not significantly different from control (non-oil shale) districts.[19]

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[18] M. Purde and M. Rahu, "Cancer Patterns in the Oil Shale Area of the Estonian S.S.R.," Environmental Health Perspectives, Vol. 30 (1979), pp. 209-210.

[19] I. A. Veldre, A. R. Itra, and L. P. Paalme, "Levels of Benzo(a)pyrene in Oil Shale Industry Wastes, Some Bodies of Water in the Estonian S.S.R. and in Water Organisms," Environmental Health Perspectives, Vol. 30 (1979), pp. 211-216.

Preliminary results of a study involving 2069 oil shale workers who had been in the industry for 10 to 20 years and had been followed for 20 years failed to show an incidence rate for lung and stomach cancer that exceeded that found in the general population. However, the study did reveal an increased incidence of skin cancer among women who had spent between 10 and 20 years in the industry. Purde and Rahu do not distinguish among the several possible job categories involved although it is probable that the population under study excludes miners. Of the 2069 workers studied, 89 individuals with diagnosed cancers were identified. Of these, 23.6 percent had stomach cancers, 15.7 percent skin cancers, 13.5 percent lung cancers, and 13.5 percent tumors of the uterus. Except for uterine tumors these numbers are offered without any distinction between the sexes or any reference to the age of the patients although it must be assumed that most of the population were in or near a general retirement age (55 for women and 65 for men).

The Soviets appear to have expended considerable effort in determining the health effects related to oil shale mining. Akkerberg states that the dust concentrations in underground mines ranges from 2 to 30 mg/m^3 with a much tighter range in the drifts (6 to 9 mg/m^3).[20] The difference may be related to the process wherein some of the initial crushing procedures and considerable rock dumping takes place underground (author, personal observation). Kung cites Feokistor in regard to the relatively fine nature of the mine dust, 80 percent of which is made up of particles under 2μm in size. This is a remarkably small, highly respirable dust which, even at low concentrations, might lead to eventual respiratory impairment. Salzman observed signs of pneumoconiosis and fibrotic disease during radiographic examination of workers exposed for many years to mine dust.[21] Kung reported the pathological changes observed during examination of autopsy materials from workers associated with oil shale mining. He stated that coniotic fibrosis from long-term inhalation develops slowly and is of a mild, diffuse nature. Much of the inhaled material is transported to the hilar lymph nodes and typical silicotic nodules are found in bronchopulmonary nodes. Significantly, both focal and diffuse emphysema were noted in many specimens, and signs of chronic bronchitis were observed.[22] Kung concludes that inhalation of oil

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[20] I. Akkerberg, et al., Problems of Occupational Hygiene in Oil ShaleIndustry of the Estonian S.S.R. Vol. 2, Tallinn, (1955), pp. 61-85.

[21] S. M. Salzman, In: Problems of Occupational Hygiene in Oil Shale Industry of the Estonian S.S.R, Vol. 1, Tallinn, (1953), pp. 127-39.

[22] V. A. Kung, "Morphological Investigations of Fibrogenic Action of Estonian Oil Shale Dust," Environmental Health Perspectives, Vol. 30 (1979), pp. 153-156.

shale dust causes chronic bronchitis, mild pneumoniosis, and emphysema, but that the incidence is low. He attributes this relatively low incidence to the low content of free silica in kukersite and to the low concentration of dust in the mines.

Luts described the incidence of occupational disease of the nasal portion (including the major sinuses) of the respiratory tract. He reported that 7.2 percent of the oil shale miners observed suffered from chronic hypertrophic rhinitis often accompanied by sinusitis and nasal polyps. These changes are attributed to the high humidity and cold temperatures (8 to 9°C) in the mines and are not considered occupational diseases. Apparently a distinction is made between the microclimate of the mines (temperature and humidity) and the concentration of raw shale dust. Contact with oil shale ash (soot), on the other hand, is responsible for a 7.6 percent incidence of atrophic rhinitis. Luts attributed these more severe changes to the nature of the ash and the additional insult of fugitive gases, an effect he equated to the clinical pattern seen after inhalation of superphosphate or cement. The changes described as related to shale ash are undoubtedly partly due to simultaneous exposure to gases and vapors and points to the need for adequate respiratory protection for U.S. workers who may be associated with working retorts and spent shale as part of their job.[23]

Bogovski described the general problem of occupational skin tumors and suggested several steps to be taken to achieve adequate worker protection and develop epidemiological records.[24] Among measures he listed are: compulsory analysis of occupational and medical histories at frequent intervals; imposition of adequate prophylactic measures and industrial hygiene practices; detection of carcinogenic substances in current and new products; instigation of new experiments to identify the carcinogenic potential of industrial products; and detailed evaluations of the state of health of significant blocs of workers in several production plants.

In summary, several conclusions may be drawn from Soviet reports on human health effects:

1. The incidence of stomach and lung cancer is higher in the general population of the oil shale districts.
2. This higher incidence is, at least partly, attributed to the immigration of workers from republics where the background incidence is higher.

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[23]A. E. Luts, Methods for Investigation of the Mucous Membrane of the Nose for Early Detection of Occupational Diseases in Shale Industry Workers, Monograph, unedited translation (Tallinn, 1976).

[24]P. A. Bogovski, "Occupational Skin Tumours Induced by Products of Thermal Treatment of Mineral Fuels," Vopr. Onkol., Vol. 5, No. 10 (1959), pp. 486-497. (English Translation.)

3. The higher incidence of stomach cancer in rural populations of the same regions is unexplained, but does not appear to be associated with elevated levels of BaP in the environment (i.e., soil, water, vegetables, etc.).
4. An increased incidence of skin cancer has been observed among female workers.
5. Mine dust concentrations are low, much of the dust is highly respirable, and the percentage of free silica is low.
6. Chronic bronchitis, mild forms of pneumoconiosis, and emphysema are observed in miners.
7. Diseases of the mucous membranes of the nasopharynx as a result of exposure to raw shale dusts and to a mixture of shale ash and gases and vapors are observed.

Oil Shale-Related Health Effects Observed In Great Britain

History

The Scottish oil shale industry and the English textile industry, which used products derived from shale oil, provided much early information regarding shale oil-related diseases of the skin. Scrotal cancer among Scots retort men, and English "mule spinners" and skin tumors among Scots paraffin workers were among the first occupational diseases for which compensation was provided.

Occupational Diseases (UK)

An early and thorough investigation of occupational disease was the study of paraffin workers and oil workers associated with the Scottish oil shale industry performed by Alexander Scott in 1923.[25] Scott described, in great detail, the various manifestations of skin disease found among oil shale workers and discussed the etiology, anatomical locations of lesions, and pathology and suggested prophylactic measures. Seven distinct occupational dermatoses were described: occupational comedones (acne), folliculitis and follicular dermatitis, pustular dermatitis, papular dermatitis, erythema simplex, dermatitis erythematosa, and

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[25]A. Scott, "The Occupation Dermatoses of the Paraffin Workers of the Scottish Shale Oil Industry: With a Description of the System Adopted and the Results Obtained at the Periodic Examinations of These Workmen," Eighth Scientific Report on the Investigations of the Imperial Cancer Research Fund, (London, England: Taylor and Francis, 1923).

epithelioma (paraffin workers cancer). Of these, papular dermatitis and follicular dermatitis (destruction of hair follicles) were the most common, and epithelioma was the most important because of the life-threatening potential.

In 1922 Scott described occupational cancer among Scottish oil shale workers and stated that the incidence was approximately 1.5 percent over a 22-year period.[26] This incidence rate is given as a percent of workers observed without a description of the total industrial population or calculation of the years of exposure, although a selected group of workers had a minimum of 18 years of service. Scott pointed out three important factors in the occurrence of occupational cancer among shale workers: age at first observation, length of service, and influence of job assignment upon location of lesion. From his observations, it is apparent that most skin cancers occurred in workers over 40 years of age with more than 18 years of service. The influence of work assignment on anatomical location of the lesion is illustrated by his data which show a predominance of arm, hand, head, and neck neoplasms among paraffin shed workers compared with a high incidence of scrotal cancers among oil workers, retort men, and still workers. Scott concluded that direct contact with paraffin was largely restricted to the upper parts of the body while contact with the ash, coke, and other "gritty material" experienced by the oil workers was less restricted. He considered that difficulty with, or lack of, personal hygiene was an important factor in the high incidence of scrotal cancer. While paraffin workers' cancer was recognized as an occupational disease by the British Workmen's Compensation Act of 1906, the Scottish oil shale workers were not officially included until 1920.

Scott described the neoplastic conditions he observed as epitheliomata, and included both benign and malignant tumors. The fatal cases in this series were apparently due to local invasion rather than distant metastases, although the investigative techniques of the day may have precluded precise diagnosis.

In 1922, Southam and Wilson described the prevalence of scrotal cancer among "mule spinners" in the British textile industry. The lubricating oils used were of the "paraffin series," largely derived from shale oil, and saturated the clothing of the inguinal region of the workers.[27]

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[26]A. Scott, "On the Occupation Cancer of the Paraffin and Oil Workers of the Scottish Shale Oil Industry," British Medical Journal, (1922).

[27]A. H. Southam and S. R. Wilson, "Cancer of the Scrotum: Etiology, Clinical Features and Treatment of the Disease," British Medical Journal, Vol. 2 (1922), p. 971.

In 1926, White discussed occupational dermatoses and stated that the (natural) "petroleums do not usually inaugurate neoplasms" but that in oil shale workers the prospect of developing cancer is 0.5 percent.[28]

Experimental Results (Great Britain)

Twort and Twort designed skin-painting studies in mice to test the relative carcinogenic potency of several oils, and developed an arbitrary scale based on their experiments.[29] They ranked shale oil (Scottish) as having a potency of 1 and California petroleum with a potency of 3. Some coal-derived materials were considerably higher than shale oil. In a later experiment they showed the process temperature dependency of carcinogenic potential.[30] Leitch also described positive skin-painting experiments with certain fractions of Scottish shale oils.[31]

In 1943, Berenblum and Schoental suggested that the carcinogenic constituents of shale oil were similar to those found in coal tar, and that although blue shale oil contained 3:4 benzpyrene some fractions apparently devoid of benzpyrene induced skin tumors in mice.[32] In 1944, they compared a chloroform extract of finely ground raw shale with shale oil in a mouse skin-painting scheme. While they could induce no tumors with the raw shale extract, they caused a 60 percent tumor incidence in 18 weeks and a latency to first tumor of only 7 weeks with shale oil.[33]

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[28]R. P. White, "Modern Views of Some Aspects of the Occupational Dermatoses," Journal of Industrial Hygiene, Vol. 8, No. 9 (1926), pp. 367-381.

[29]C. C. Twort and J. M. Twort, "The Relative Potency of Carcinogenic Tars and Oils," Journal of Hygiene, Vol. 29 (1930), pp. 373-379.

[30]C. C. Twort and J. M. Twort, "The Carcinogenic Potency of Mineral Oils," Journal of Hygiene, Vol. 30 (1931), pp. 204-226.

[31]A. Leitch, "Paraffin Cancer and Its Experimental Production," British Medical Journal (1922), p. 1104.

[32]I. Beremblum and R. Schoental, "Carcinogenic Constituents of Shale Oil," British Journal of Experimental Pathology, Vol. 24 (1943), pp. 232-238.

[33]I. Berenblum and R. Schoental, "The Difference in Carcinogenicity Between Shale Oil and Shale," British Journal of Experimental Pathology, Vol. 25 (1944), pp. 95-96.

Summary

In summary, several observations can be made from the British experience with oil shale-related occupational disease:

1. Most of the occupational diseases identified as being associated with the oil shale industry were the result of skin exposure.
2. Length of exposure and age of the worker are important factors in industrially related skin cancers.
3. Adequate protective measures, routine in modern industry, could have greatly reduced the risk of occupational cancer.
4. Process temperature was identified as a contributing factor to the relative carcinogenicity of products.

CONCLUSIONS DRAWN FROM FOREIGN EXPERIENCE

Oil shale industries producing a variety of products have existed in both the United Kingdom and the Soviet Union for periods exceeding 50 years. During the years of active production (which continues in the Soviet Union) a substantial body of information involving both experimental data and occupational disease incidence has been developed. From this body of data several conclusions can be drawn as follows:

- Most occupational diseases affected the skin.
- Observed skin diseases included contact dermatoses as well as benign and malignant neoplasms.
- Age and length of service were important factors in the incidence of skin cancers.
- Sound industrial and personal hygiene practices could have prevented or greatly diminished occupational disease.
- Neoplasia in organ systems other than the skin has not been frequently reported as an occupational disease.
- The incidence of stomach and lung cancer is higher in the oil shale producing areas of the Estonian SSR, but this may be, at least partly, due to migration from other districts.
- Nonneoplastic lung diseases are not a serious problem among oil shale miners and other workers in Soviet industry.
- Chronic bronchitis, mild forms of pneumoconiosis (silicosis), and emphysema are observed.
- Diseases of the nasopharynx occur in more severe forms among workers exposed to combinations of ash and gas and vapor effluents.
- A mature shale oil industry is a relatively recent development in the Soviet Union with current technologies existing since 1920 or after. Observation times may be too short for definitive epidemiological conclusions.

- Experimental data from the Soviet Union indicate that both direct toxicity and carcinogenicity may be process related.
- Direct (systemic) toxicity is more pronounced with higher process temperatures.
- Direct toxicity may increase as phenol content increases.
- Carcinogenicity of products is related to higher process temperatures.
- The presence of BaP is not a reliable indicator of carcinogenic potential.
- Oil shale dusts have not been shown to be carcinogenic *per se*.

CURRENT RESEARCH INTO THE HEALTH EFFECTS OF OIL SHALE DEVELOPMENT

A mature oil shale industry, located in the intermountain region of Colorado, Utah, and Wyoming will probably consist of a mix of extraction technologies chosen partly on the basis of local geology. Certain health hazards, both occupational and public, can be predicted in the generic sense, however, technology-specific information is crucial to an understanding of the eventual hazards of a truly scaled-up industry. Basically, the technologies can be divided into three major categories: surface retorting (with mining and crushing), modified *in situ* and true *in situ* (with rubbling from the surface and no mining). Each of these categories present certain unique hazards with even more technology-specific questions arising within the surface retorting category.

In additon to the potential hazards of a large regional extraction industry, consideration must be given to the further processing and eventual public use of the refined products. Health and environmental research has therefore begun to address not only the extraction issues but the refining and end-use of the resource. This research extends from site-specific industrial hygiene studies through an array of chemical and biological assays of relevant materials to biological testing of final industrial and consumer products. In some instances workers involved in the oil shale industry have been examined in attempts to either establish the health status of the small population of current workers or to retrospectively determine the existence of specific long-term effects.

The most meaningful way to organize the existing information is to base it on the materials involved rather than on the test systems used. This allows the reader to compare the results of several levels of testing on one class of materials at a time and, in general, to follow the resource from original extraction through end-use. The three major materials categories are: airborne effluents (dusts, vapors, gases); oils and refined products; and aqueous effluents (retort waters, leachates). Most potential health hazards can be placed in these categories, however, certain questions may be common to all three material categories. Included here is an array of inorganic and organometallic complexes which may be formed and mobilized during extraction and processing.

Airborne Effluents

Within the last two or three years, three in situ retorting techniques and one surface retort have been demonstrated at pilot scale. In each case, field studies with extensive sampling efforts have been conducted to define both the occupational environments and certain more general site-specific problems. One of the in situ sites utilizes a horizontal burn method in which rubbling is performed from the surface with no true mining. Other than road dust and particulates created during blasting there is very little problem with dusty conditions.

The other two modified in situ (MIS) sites depend on considerable underground mining with the attendant problems of dust control. In addition to the particulates associated with nearly continuous mining, the air of large MIS mines may contain fugitive gases and vapors from the burning retorts as well as the ubiquitous diesel exhaust (also a particulate). Surface retorting requires mining (usually room and pillar), crushing, and stockpiling of ore before retorting. A commercial-sized surface retort may consume as much as 100,000 tons of shale ore in one day and produce a like amount of spent shale (equivalency in weight is not exact however volume is often increased). Surface techniques, therefore, have the additional problem of large volumes of spent material to be disposed of on the surface. Although several surface retorting techniques have been demonstrated, only one, the Paraho process at Anvil Points, Colorado, has been operated to any extent within the last few years. It is from this production run (1977 to 1978) that most of the currently available materials for testing have become available.[34]

Particulates

No threshold limit values (TLV) have been established for either raw or spent shale dusts per se and any current regulations will have to be based on standard formulas for silica-bearing rock.[35] Dust

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[34] R. N. Heistand, "Paraho Operations," Health Effects Investigation of Oil Shale Development (Ann Arbor, Michigan: Ann Arbor Science, 1981).

[35] "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment," American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1976.

exposure becomes an important concern when the relatively high free-silica content of raw and spent shale (8 to 15 percent) is considered along with the complex organic materials involved. The presence of free-silica, the chemical availability of organics, and the particle size (respirability) are the most important factors in establishing the potential hazard of dusts of this type. Both raw and spent shale dusts have been analyzed for the availability of total hydrocarbons and certain polycyclic aromatic hydrocarbons as a function of particle size. It was found that chemical availability (and presumed bioavailability) of total hydrocarbons rose as particle size decreased.[36]

Long-term studies of rodents exposed to respirable oil shale particulates have failed to produce pulmonary cancers.[37] These same studies do, however, indicate a potential risk from pulmonary fibrosis and obstructive lung disease similar to that associated with other hard rock mining endeavors. The number of pulmonary experiments is so far too meager to establish a dose response or to identify pathological changes representing a specific shale miner's pneumonoconiosis.

Small groups of oil shale workers employed during the infrequent activities at Anvil Points, Colorado, have been examined for pulmonary pathology but results were inconclusive. In one report oil shale pneumoconiosis (or shalosis, the author's term) could not be confirmed because of the complicated work and smoking histories of the subjects.[38] Another study, which examined workers during the 1977 to 1978 Paraho production run, revealed pulmonary changes with a strong correlation to smoking, but no relationship to

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[36]W. D. Spall, "Analytical Chemistry of Respirable Size Oil Shale Dusts," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR (Los Alamos, New Mexico: Los Alamos National Laboratory, January 1981); and L. M. Holland et al., "Inhalation Toxicology of Oil Shale Related Materials," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980).

[37]Holland et al., op. cit.; R. A. Renne et al., "Morphologic Effects of Intratracheally Administered Oil Shale in Rats," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980); and L .M. Holland et al., "Inhalation and Intratracheal Exposures to Oil Shale Dusts," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

[38]W. E. Wright and W. N. Rom, "A Preliminary Report: Investigation for Shalosis Among Shale Workers," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980).

oil shale work history.[39] Both studies involved only small populations that worked at the same site during different periods of production. Industrial hygiene surveys and sampling activities have been performed at most of the recently active sites. These field studies include the previously mentioned Paraho run; the Occidental development at Logan Wash, Colorado; the Rio Blanco development on Colorado's C-a tract; and the Geokinetics operation near Vernal, Utah. Measurements of dust levels at each site have varied enormously and reflect the experimental nature of some operations, and illustrate the job assignment or operational specificity of particulate contamination.

In both MIS operations, the measured in-mine dust levels averaged far below an assumed TLV of 2.5 mg/m^3 (based on 10 percent quartz content). Dust levels associated with surface retorting were much more operation-dependent, and the highest levels were noted in areas where machinery was remotely operated. In areas around the retort with intermittent worker activity, the dust levels were low (generally less than 1 mg/m^3 of respirable particulate). However, some remotely operated activities generated several hundred mg/m^3 of total dust at times. In either case the occupational hazard is low; nevertheless based on these findings, controls will have to be imposed on a scaled-up industry to prevent regional problems. There was a somewhat higher dust level in the mine serving the surface retort than in the two MIS mines.[40] Actual mining conditions could not be compared between MIS and the surface procedures since sampling was not conducted under similar operational circumstances. Gas and vapor concentrations of selected organic compounds have been measured in both types of extraction procedures, and levels detected were generally below established TLV. Samples included CO, CO_2, NO_2, NH_3, H_2S, SO_2, CS_2, HCN, HCHO, HNO_3, arsine, benzene, toluene, phenols, aliphatic amines, and total hydrocarbons. Once again, detectable levels were operation-specific and factors contributing to local work environments were usually multiple (including diesel equipment, blasting, retorting).

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[39]J. Rudnick and G. L. Voelz, "An Occupational Health Study of Paraho Oil Shale Workers, "Health Implications of New Energy Technologies, op. cit.

[40]L. L. Garcia, H. J. Ettinger, and H. F. Schultz, "Paraho Industrial Hygiene Survey," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.; M. I. Tillery and M. Gonzales, "Air Sampling at Occidental Oil Shale Facility at Logan Wash," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op cit.; and M. Gonzales et al., "Air Sampling During Anvil Points Fire Extinguishment," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

Analysis of fugitive emissions will be a continuing and site-specific need as the technologies develop since each extraction technique and each mine will vary considerably in specific ways. The problems of respiratory or skin contact with organic vapors and gases by themselves or in combination with particulates have not been adequately studied. These are important generic questions which cannot be answered by the usual combination of field study and laboratory experimentation. In both surface retorting techniques and in situ approaches the possibility of exposures combines particulates and organic vapors. For instance, a 50,000 bbl/day MIS facility would require a minimum of 25 large in-place retorts at various stages of retorting to be combined with an equal number of retorts being prepared in adjacent mine complexes. Retort integrity and ventilation will have to be nearly fail-safe to control potential exposures. Fugitive vapors and gases may also combine with both raw and spent shale particulates in connection with surface retorts.

The only active true-in-situ operation presents some specific problems. Because the shale has a minor overburden in this formation, blasting to create uniform rubble is performed from the surface with no mining. Creation of a sufficient void volume depends on surface uplift which also creates surface cracks. Crack sealing is performed with varying success with the result that gases and vapors can escape during the retort "burn." A similar situation has occurred twice in recent years when raw shale storage or fine piles have been ignited accidentally. This phenomenon could have an impact on both industrial and regional populations if similar incidents are frequent. Measurements of selected compounds have been made during one recent fire of this type. Measurements taken at fissure openings indicated CO and SO_2 levels as high as 1000 ppm, H_2S as high as 500 ppm, and total hydrocarbons up to 1000 ppm. However, concentrations detected at an approximate breathing zone (5 to 6 ft) were within safe limits indicating rapid dispersal of the emissions. Combustible gases as high as 20 percent of the lower explosive limit (LEL) were detected at ground level but were also quickly dispersed.[41]

Long- and short-term animal studies addressing these complicated mixed exposure conditions are only beginning.[42] Both acute and chronic toxicity must be considered if an adequate definition of hazard is to be developed.

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[41]Gonzales et al., op. cit.

[42]L. M. Holland et al., "Development of a Laboratory Retort for Inhalation Experiments," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

Product Oils and Refined Fuels

Nearly all fossil-derived liquids can be shown to be carcinogenic. Because of historical evidence, the question of carcinogenicity in connection with product oils and their refined daughter products has become one of the central health concerns associated with shale oil extraction. Standardized upgrading procedures, practiced to simplify transportation and refining, may significantly reduce the carcinogenic potential of the oils, and modern refinery techniques should minimize occupational exposure. Even with the assumption of modern protective practices several questions remain; namely the relationship of carcinogenic potency and process chemistry, the comparative tumorigenicity of synfuel products in general and with natural petroleums, the identification of the factors involved in the apparent reduction of carcinogenicity by hydrotreatment, and a comparison of the inflammatory potential of the crude products and by-products. Ultimately, the products reaching individual consumers or employed as chemical feedstocks must also be measured for toxic and carcinogenic potential.

Because shale oil along with other fossil liquids is a highly complex mixture, the results of many of the shorter-term assays for mutagenesis (and putative carcinogenesis) have been equivocal. Reliance on such tests for definitive risk data is inappropriate and obscures their great usefulness as first-step screens and for indicating trends. Careful studies combining chemical analysis and fractionation with mutagenesis assays can help to identify the active components in fossil fuels and define the generic and process factors that contribute to activity.

Crude oils from most of the recent retorting operations have been tested for mutagenicity using several methods, but principally the Salmonella/mammalian microsome assay of Ames.[43] While a number of bacterial strains have been used, most of the results are based on histidine reversion phenomena in either TA98 or TA100 test strains of Salmonella. Testing has been carried out both with and without the addition of rat liver homogenate (S9-metabolic activation). Considerable interference by cytotoxicity has been experienced when testing most of the shale-derived fuels. This reaction appears to be somewhat process specific and is more pronounced in the only hydrotreated product tested to date.[44] Cytotoxicity may have some

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[43] B. N. Ames, J. McCann, and E. Yamasaki, "Methods for Detecting Carcinogens and Mutagens with the Salmonella/Mammalian-Microsome Mutagenicity Test," Mutation Research, Vol. 31 (1975).

[44] J. Nichols and G. F. Strniste, "Ames/Salmonella Mutagen Assay of Shale Oil," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

relationship to the inflammatory properties observed after repeated skin applications (see below).

Because of unequal cytotoxicities it is sometimes difficult to compare the results of oils from different processes. An added complication is the variation in amount of hydrocarbons extracted in the medium-compatible solvent (usually DMSO). Based on research performed so far, the much-tested Paraho crude oil has been shown to be mutagenic for TA98 with S9 activation although the results with TA100 have varied from no activity to quite high revertant frequencies.[45] There is general agreement that the hydrotreating of this highly active oil reduces the mutagenicity anywhere from three to tenfold.

Mutagenic activity has been further defined by testing major fractions of the oils and it has been shown that most of the activity lies in the basic and neutral fractions as derived in the most common separation techniques.[46] Experiments utilizing mammalian cell systems to identify mutagenic activity in the various oils have been performed both with and without exogenous metabolic activation. The cellular toxicity of the highly complex mixtures again interferes with straightforward analysis of mutagenic activity.[47] The enhancing properties of near-ultraviolet (NUV) have been studied with both the crude oils and certain process waters.[48] While photo-induced mutagenicity was reduced by hydrotreating, phototoxicity was not affected. This observation may be important in considering industrial situations where exposure to sunlight and crude oils may be difficult to prevent.

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[45]Ibid.; H. Timourian et al., "Comparative Mammalian Genetic Toxicology of Shale Oil Products Assayed In Vitro and In Vivo," Health Effects Investigation of Oil Shale Development, op. cit.; and T.K. Ras et al., "Short-term Microbial Testing of Shale Oil Materials," Health Effects Investigation of Oil Shale Development, op. cit.

[46]Rao et al., op. cit.; and Oil Shale Task Force, Environmental Research on a Modified In Situ Oil Shale Process, Contract No. DOE/EV-0078 (Washington, D.C.: U.S. Department of Energy, 1980).

[47]R. T. Okinaka and G. F. Strniste, "Exogenous Metabolic Activation of Shale Oils in Mammalian Cell Culture," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report. op. cit.

[48]G. F. Strniste, E. Martinez, and D. J. Chen, "Light Activation of Shale Oil Byproducts," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

Cytogenic studies, have revealed structural changes in chromosomes or actual aberrations in connection with several oils[49]. The cytogenetic assay measuring sister-chromatid exchange (SCE) can be performed both in vitro and in vivo. Timourian[50] found no increase in SCE in mice treated with either crude or hydrotreated shale oil until doses approaching the mean lethal dose (LD_{50}) were used, while others using a cultured mammalian cell (CHO) observed a significant dose-related SCE induction with crude oil. Response to hydrotreated crude oil was of less magnitude, however normalization of the data according to the amount of extractable material (DMSO extraction) revealed an SCE induction rate nearly equal to that of the parent crude. When actual chromosome breaks were measured after exposure of mice to crude shale oils or hydrotreated crudes, the frequency of aberrations observed with oils from different processes was about the same while the upgraded oil showed a similar trend but a lower frequency rate.[51]

Intact animal testing, focused mainly on skin cancer potential, has been performed by a number of investigators. The principal method used has been the repetitive direct application of materials to mouse skin.[52] All of the crude shale oils tested in recent experiments have exhibited a carcinogenic effect in the mouse system.[53] Certain of these experiments have also demonstrated the

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[49]Timourian et al., op. cit.; E.W. Campbell, R.A. Ray, and L.L. Deaven, "Effect of Oil Shale on In Vitro Induction of Sister Chromatid Exchange," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.; and J. Meyne, "Cytogenetic Effects of Shale-Derived Oils and Related Byproducts in Mice," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

[50]Timourian et al., op. cit.

[51]Meyne, op. cit.

[52]J. H. Weisburger, "Bioassays and Tests for Chemical Carcinogens," Chemical Carcinogens American Chemical Society, ACS Monograph 173 (Washington, D.C.: American Chemical Society, 1976).

[53]J. M. Holland, D. A. Wolf, and B. R. Clark, "Relative Potency Estimation for Synthetic Petroleum Skin Carcinogens," Environmental Health Perspectives (in press); S.C. Lewis, "Carcinogenic Bioassay of Shale Oil Refinery Streams and Downstream Products," Health Effects Investigation of Oil Shale Development, op. cit.; L. M. Holland, J. S. Wilson, and M. E. Foreman, "Comparative Dermotoxicity of Shale Oils," Health Effects Investigation of Oil Shale Development, op. cit.; and L. M. Holland and J. S. Wilson, "Long-term Epidermal Carcinogenicity Studies of Shale Oil," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

carcinogenic potential of coal-derived liquids, natural petroleums, and upgraded (hydrotreated) shale oils as well as certain shale-derived refinery products. From this accumulated body of work several preliminary conclusions or trends can be identified: carcinogenic potential is common to most fossil liquids; crude shale oils appear to be more carcinogenic than most natural petroleums; hydrotreating reduces carcinogenic potential markedly; among shale oils, potency may be process specific; coal-derived liquids equal or exceed the potency of shale oils; and none of the distillates has been shown to induce skin tumors in the mouse system.

Along with tumor occurrence and latency, the phlogistic or irritant properties of the oils have been demonstrated. Various forms of acute and chronic dermatitis (nonneoplastic) may be at least as important among occupational diseases as skin cancer. The irritant properties of shale oils have been demonstrated in several of the studies that identified the tumorigenic potential. It has been shown that within certain limits, frequency of exposure is the major factor in severe inflammation. Frequency of exposure also has a noticeable effect on tumor latency. Sustained heavy and frequent exposure of mice cannot be considered analogous to industrial exposure but the observations nevertheless illustrate several important points: occasional exposures, even if heavy, will probably not lead to a long-term effect; sustained intermittent exposure may eventually lead to neoplasia but the latency (time to tumor occurrence) is probably lengthened as the frequency of exposure is diminished; and inflammatory phenomena are usually related to frequent, repeated exposures.

Observations on the cutaneous effects of shale oil in humans have been reported in nearly every country where an industry has existed. (See section, Foreign Experience with Oil Shale Production.) Limited studies on U.S. oil shale workers have shown no relationship between the observed skin lesions and the degree of exposure to shale oil. The contributing factors of age, complexion, sun exposure, and other occupational variables complicate any retrospective studies of skin disease. To date, the U.S. populations have been too small for adequate analysis.[54]

Systemic toxicity resulting from cutaneous exposure must also be considered with materials of this nature. An apparent nephrotoxicity in mice has been reported following sustained high-dose skin applications of certain distilled refinery products.[55] Similar

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[54]J. J. Zone, "Cutaneous Effects of Shale Oil," Health Implications of New Energy Technologies, op. cit.

[55]L. M. Holland et al., "Chronic Dermal Toxicity of Paraho Shale Oil and Distillates," Health Effects Investigation of Oil Shale Development, op. cit.

kidney lesions have been observed in male rats following oral exposure to naval jet fuel derived from either shale oil or natural petroleums.[56] It should be borne in mind that skin exposure in animals can lead to oral exposure (because of self-grooming) and that systemic effects may therefore be the result of more than one exposure route.

Waters

One of the least understood health implications of an oil shale industry is the possible effect on the waters of the region. Water contamination is possible in a variety of ways, but because of the uncertainties as to the number of extraction facilities to be built and what processes will be involved, it is difficult to accurately predict contamination scenarios. The question is further complicated by an incomplete understanding of the temporal aspects of aquifer contamination (that is, when will MIS retorts be allowed to reflood, at what rate will contaminants be transported, and so forth). Contamination can come from two principle sources: as a product of the retorting process (so-called process or retort waters), and from contact between retorted shale and "natural" waters (leaching of spent shale piles or reflooding of burned-out retorts). In addition, retort process waters, perhaps as many as 3 barrels of water for every gallon of oil produced, may be used to abate dust. Under certain circumstances, this could compound the effect by causing leaching of spent shale with already-contaminated water. However, most process waters from aboveground retorts are likely to be impounded and subjected to cleanup techniques before disposal or industrial use within the plant itself.

Positive mutagenicity in the Ames assay has been shown in one aboveground retort process water.[57] This water would be industrially described as "tank bottoms" and represents a worst-case situation which would nonetheless have to be addressed in designing cleanup techniques. The organic compounds or compound classes that are responsible for this activity have yet to be determined. This same water has been shown to contain direct-acting mutagens in assays

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[56] M. J. Cowan and L. J. Jenkins, "Acute Toxicity of Selected Crude and Refined Shale Oil and Petroleum Derived Substances," Health Effects Investigation of Oil Shale Development, op. cit.

[57] J. Nichols and G. F. Strniste, "Ames/Salmonella Mutagen Assey of Oil Shale Process Water," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

using mammalian cells (no metabolic activation required).[58] Prenatal toxicity studies in breeding mice were also performed on this water, and demonstrated no difference in number of pregnancies, maternal weight, number of live fetuses, or average fetal weight. There was, however, an apparently dose-related abnormality of the hard palate and some indication of an increase in preimplantation fetal loss. When the experiments were repeated with the same process waters after about six months of cold storage, fewer significant abnormalities were observed.[59] One possible explanation is that the biological activity was reduced with time, a conclusion which would seem to indicate that standard clean-up techniques such as filtration and impoundment can be useful. Product waters from two _in situ_ processes have been assayed for mutagenic activity by several investigators. Waters from an MIS retort were found to be negative in the Ames assay while process waters from a true _in situ_ retort were marginally positive.[60] When these same waters and the aboveground process water were screened for _in vitro_ induction of sister chromatid exchange, only the surface process water was found to be positive.[61] Earlier investigators had found the MIS process water to be marginally positive for mutagenesis in the Ames assay.[62]

Some attempts at comprehensive chemical analysis of these waters have been made and tentative results indicate that the aboveground retort water is higher in carbocyclic acids, amides, and nitrates.[63] More effort should be expended in chemical analysis of retort waters and the relationship of their chemical make-up to the product oil established on a process-specific basis if predictions of

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[58]D. J. Chen, R. T. Okinaka, and G. F. Strniste, "Determination of Direct Acting Mutagens in Shale Oil Retort Process Water," _The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report_. op. cit.

[59]C. T. Gregg and J. H. Hutson, "The Prenatal Toxicology of Oil Shale Retort Water in Mice," _The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report_, op. cit.

[60]Nichols and Strniste, op. cit.

[61]E. W. Campbell, F. A. Ray, and L. L. Deaven, "Effects of Process Waters from the Oil Shale Industry on _In Vitro_ Induction of Sister-Chromated Exchange," _The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report_, op. cit.

[62]Oil Shale Task Force, op. cit.

[63]W. D. Spall, "Analytical Chemistry of Oil Shale Process Waters," _The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report_, op. cit.

necessary control procedures are to be made. The important question of spent shale leaching either in MIS retort-abandonment procedures or in surface disposal techniques has only begun to be addressed. Several investigators have identified the potential for mobilization of several environmentally important and potentially toxic trace elements. Included here are boron, fluorine, molybdenum, arsenic, selenium, vanadium, nickel, and mercury. Under retorting conditions, such materials as nickel arsenides can also be formed.[64] The temperatures at which nickel, sulfur, and arsenic compounds are known to form are comparable with those seen in most retorting processes.[65] Unfortunately, some of the metallic compounds shown to be carcinogenic are refractory to testing by standard mutagenesis assays.[66]

Aqueous materials somewhat analagous to in situ leachates but referred to as a retort water have been subjected to toxicity testing by several methods.[67] These studies, which include direct toxicity testing in laboratory animals and tests for teratogenesis revealed low toxicity and no apparent fetal toxicity. These so-called retort (or process) waters were highly diluted by infiltrating ground waters and may represent the "best case" situation. With intense development of large in situ facilities, the positive dilution factor may be appreciably diminished in contiguous aquifers.

The potential of water contamination remains the most complex and most ill-defined health-related issue associated with oil shale extraction. Water contamination, if it occurs on any scale, may also

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[64] P. Wagner and E. J. Peterson, "Assessment and Control of Water Contamination Associated with Shale Oil Extraction and Processing," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.; and J. S. Fruchter et al., Report from Symposium on Analytical Chemistry of Tar Sands and Oil Shale (Comparison with Coal and Petroleum), Meeting of the American Chemical Society, New Orleans, Louisiana, March 1977.

[65] L. R. Gurley and M.S. Halleck, "Nickel Arsenide: Potential Biological Hazards in the Oil Shale Retort Process," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, op. cit.

[66] J. Wildenberg, "An Assessment of Experimental Carcinogen-Detecting System with a Special Reference to Inorganic Arsenicals," Environmental Research, Vol. 16 (1978).

[67] D. I. Hepler et al., Animal Toxicity Evaluation of an In Situ Oil Shale Retort Water, Technical Information Center (Washington, D.C.: U.S. Department of Energy, 1979).

have important ramifications for public health in the region--perhaps as important and probably more insidious than reductions in air quality. It will take comprehensive studies combining geochemistry, hydrology, analytical chemistry, and biological assays on both a generic and site-specific basis to determine the potential hazards.

SUMMARY AND CONCLUSIONS

While similarities between the health effects of oil shale development in various countries exist, crucial differences preclude making judgments on the potential effects of a highly developed U.S. industry. Current research, focused on American materials and technology, has begun to identify specific concerns that will be germane to oil shale development in the United States. From a study of both the historical evidence and the results of current research, several observations can be made:

- The major health concerns relate more to the occupational hazards than to regional populations. No evidence shows that a U.S. industry would react any differently.
- Neither the historical evidence from other countries nor the results of current research have shown pulmonary neoplasia to be a major concern. Surveillance for nonneoplastic pulmonary disease should be continued both experimentally and epidemiologically since U.S. materials are much higher in fibrogenic compounds (silica).
- The industry should be alert to the incidence of skin disease in the industrial setting. However, automated techniques, modern industrial hygiene practices, and realistic personal hygiene should greatly reduce the hazards associated with skin contact.
- The entire question of regional water contamination and any resultant health hazard has not been adequately addressed. None of the countries with industrial experience in oil shale has reported overt health hazards from water deterioration. However, the extraction techniques, the geohydrology, and the scale involved in a mature U.S. industry are not comparable with either the Soviet or British conditions.

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POSITION PAPER G

U.S. OIL SHALE INDUSTRY: HEALTH AND ENVIRONMENTAL EFFECTS

A. Michael Kaplan
E.I. du Pont de Nemours & Company

While the United States is unable with its oil and natural gas resources to satisfy present or future projected energy requirements, its desire to be less dependent on imported oil has increased. Consequently, research in and development toward the establishment of a synthetic fuel industry has increased.

Oil shale is a fine-grained, sedimentary rock containing kerogen which yields a synthetic oil and gas after pyrolysis or retorting. The United States has the world's largest and richest known deposits of oil shale. The Green River Formation located in Colorado, Utah, and Wyoming, extends over an approximate 16,000 square mile area. The Piceance Basin in Colorado also contains high-grade shale. In addition, low-grade shale deposits extend over large parts of the eastern and central United States as well as northern Alaska.[1]

Retorting oil shale is not a modern discovery; Australia, Brazil, Canada, France, Germany, New Zealand, Scotland, and the United States all had produced oil from oil shale before 1900. Today, Russia, China, Brazil, and to a lesser extent, Scotland have substantial oil shale operations.[2] A review of the literature indicates that potential dermatologic and respiratory health problems exist for shale oil workers. Historically, the principal human health hazard associated with the oil shale industry has been skin cancer. Massive exposure under very poor working conditions has been associated with increased incidence of skin cancer in man.[3] "Mule spinner's

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[1]N. K. Weaver, and R. L. Gibson, "The U. S. Oil Shale Industry: A Health Perspective," American Industrial Hygiene Association Journal, Vol. 40 (1979), pp. 460-467.

[2]R. M. Coomes, "Carcinogenic Testing of Oil Shale Materials," 12th Oil Shale Symposium Proceedings, (Golden, Colorado: Colorado School of Mines, April 1979).

[3]A. Scott, "On the Occupation Cancer of the Paraffin and Oil Workers of Scottish Shale Industry," British Medical Journal, Vol. 2. (1922), p. 1108.

cancer" associated with worker exposure to crudely refined mineral oils was observed in the British cotton textile industry and resulted in numerous deaths from scrotal cancer among cotton mule spinners.[4] In addition, emphysema, bronchitis, pneumonia, fibrosis and silicotic nodules, catarrh of the upper respiratory tract, and other respiratory illnesses have occurred among oil shale workers.

In the Soviet Union, shale oil workers have contracted various respiratory illnesses as noted above and occupational dermatoses such as dermatitis, eczema, folliculitis, verruca, and sensitization; however, no cases of occupational cancer have been found as of 1961 among shale oil workers in the Soviet Union.[5] More recently, Purde and Rahn[6] reported cancer patterns among urban and rural populations in the oil shale area of Estonia, U.S.S.R. that included stomach, skin, and lung. The authors concluded that the excess stomach and lung cancers may be explained by migration and that the incidence rates for these cancers do not differ significantly among oil shale workers and the general population of Estonia. The preliminary results suggested that the excess skin cancer cases, which occurred only among women, reflects an occupational hazard in the oil shale processing industry.

Only one epidemiological study has been reported in the United States. In 1952, Birmingham conducted a medical survey of workers at the Anvil Point Oil Shale Demonstration Plant of the Bureau of Mines near Rifle, Colorado. Skin lesions were the predominant finding and included the following: telangiectasia, flat warts, seborrheic keratoses, senile keratoses, and pigmentation. The significance of these lesions could not be defined because of the small number of workers and other factors such as age, severity and length of exposure, complexion of worker's skin, and the relationship between shale oil exposure and sunlight. A new mortality and morbidity study is currently in progress.[7]

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[4]N. K. Weaver and R. L. Gibson, op. cit.; and A. Scott, op. cit.

[5]P. A. Bogovski and F. Vinkmann, "Carcinogenicity of Oil Shale Tars, Some of Their Components and Commercial Products, "Environmental Health Perspectives, Vol. 30 (1979), pp. 165-169; and V. A. Kung, "Morphological Investigations of Fibrogenic Action of Estonian Oil Shale Dust," Environmental Health Perspectives, Vol. 30 (1979), pp. 153-155.

[6]M. Purde and M. Rahu, "Cancer Patterns in the Oil Shale Area of the Estonian U.S.S.R.," Environmental Health Perspectives, Vol. 30 (1979), pp. 209-210.

[7]J. Costello, "Morbidity and Mortality Study of Shale Oil Workers in the United States," Environmental Health Prospectives, Vol. 30 (1979), pp. 205-208.

With the current energy situation in the United States it is clear that the development of a synthetic fuel industry must proceed and that an evaluation of the short- and long-term human health and environmental effects associated with the technology of the developing oil shale industry is of utmost importance. Concerning an oil shale industry, the United States is in the unique position of being able to determine the associated toxic properties before establishing it.[8]

SHALE OIL PRODUCTION TECHNOLOGY

Decora and Kerr[9] and Nowacki[10] present overviews of the potential technologies for processing and characterizing shale oil products.

Many extraction and retorting processes for shale oil have been patented in the last half century; however, only a few processes are generally considered to be prime candidates for early commercial use. Shale oil can be produced from oil shale by three types of retorting processes, namely surface, true *in situ* and modified *in situ*. All retorting processes have one fundamental characteristic in common and that is heating to at least the pyrolysis temperature range of 800 to 1000°F. This produces shale oil, gas, and carbonaceous residue.[11] Figure 1,[12] schematically illustrates the shale fuel cycle from extraction to end uses. Figure 2[13] shows in slightly more detail oil shale production and upgrading steps including potential alternate processing sequences.

At the present time, shale oil is not in commercial production in the United States and to complicate matters, available information

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[8] N. K. Weaver and R. L. Gibson, op. cit.

[9] A. W. Decora and R. D. Kerr, "Processing Use, and Characterization of Shale Oil Products," *Environmental Health Perspectives*, Vol. 30 (1979), pp. 217-223.

[10] P. Nowacki, *Health Hazards and Pollution Control in Synthetic Liquid Fuel Conversion*, (New Jersey: Noyes Data Corporation, 1980).

[11] A. W. Decora and R. D. Kerr, op. cit.; and P. Nowacki, op. cit.

[12] IWG Corporation and the Center for Environmental Sciences, University of Colorado, *Health and Environmental Effects Document for Oil Shale--1981* (Washington, D.C.: U.S. Department of Energy, November 13, 1981).

[13] Union Oil Company of California, 1981.

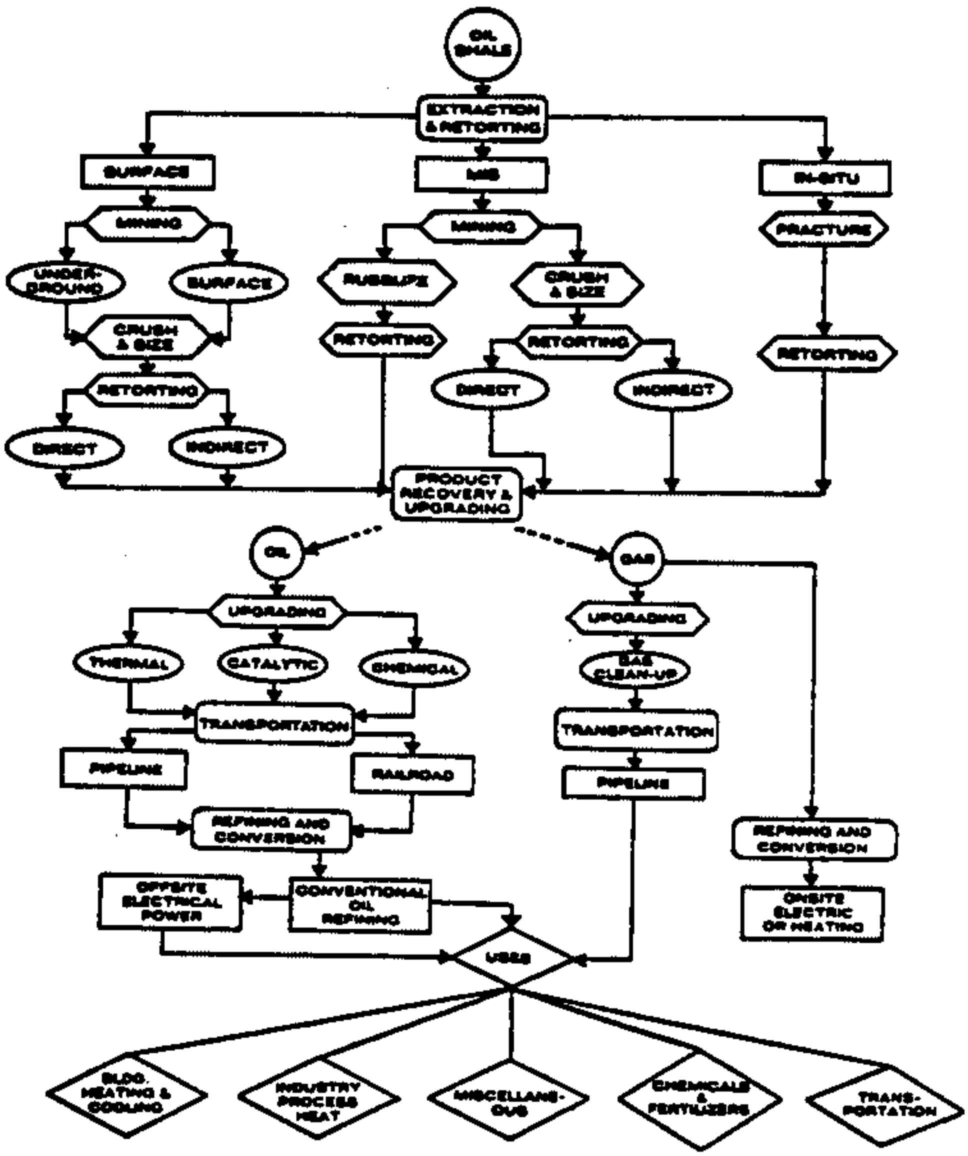

Figure 1 Oil shale fuel cycle analysis flow chart.

SOURCE: IWG Corporation and the Center for Environmental Sciences, University of Colorado, Health and Environmental Effects Document for Oil Shale--1981 (Washington, D.C.: U.S. Department of Energy, November 1981).

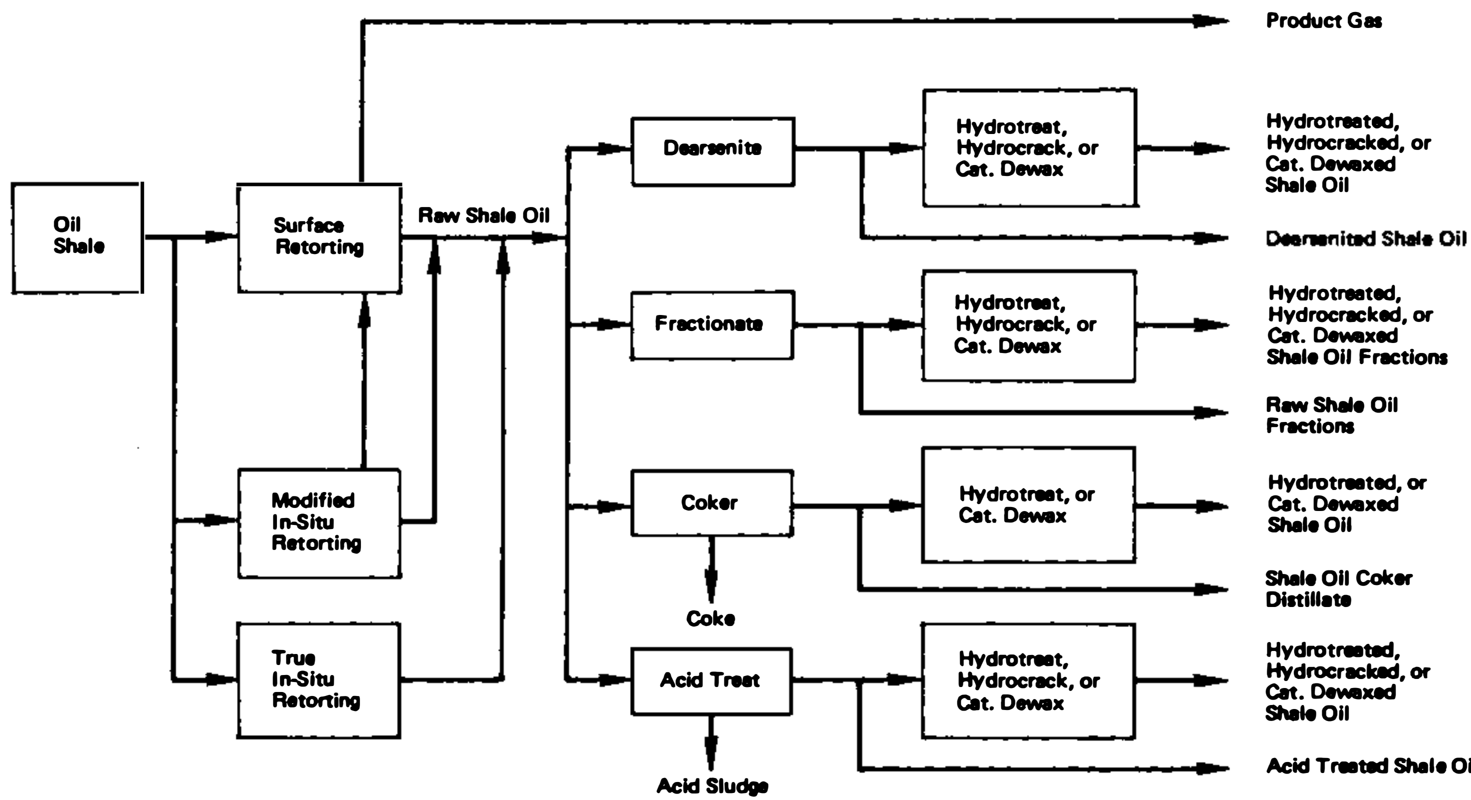

Figure 2 Generalized diagram for shale oil production and upgrading showing alternative processing sequences.

SOURCE: Union Oil Company of California, 1981.

suggests that oils produced by the available retorting processes may differ somewhat with respect to physical and chemical properties.

HEALTH AND ENVIRONMENTAL CONCERNS

Keeping in mind that current U.S. oil shale industrial efforts are at pilot and demonstration levels and cannot be considered identical with full-scale commercial production levels, the fundamental oil shale materials for which there could be potential exposure include: raw oil shale, raw oil shale fines, crude retorted shale oil, upgraded shale oil, process atmospheric effluent (gas and particulate), process or retort water, and spent shale and catalysts. Where true *in situ* shale oil extraction technology is used, potential exposure would include all of the above-mentioned materials except spent shale.[14]

Concern for occupational health and safety can be envisioned in all phases of the currently available technologies. However, beyond the occupational setting, oil shale development will produce changes in the environment and in turn may result in potential public health concerns with respect to food supplies, drinking water, air quality, and a broad range of general environmental concerns. The major health and environmental areas within the oil shale energy cycle are presented in Table 1.[15]

Although reports in the literature concerning foreign oil shale commercial operations have suggested potential areas of concern, continued research is necessary to evaluate the hazards and potential risks to health and the environment.

Within the United States, extensive toxicological investigations have been undertaken by numerous organizations funded by federal, public, and industrial groups. Most of the research to date has focused on potential occupational concerns since the occupational work force would be the first and most intensively exposed population during the development of the oil shale industry; it is hoped that information to address public health concerns as well can be extrapolated.

Following the oil shale energy cycle and based on the three major technology categories (surface retorting, modified *in situ* retorting,

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[14]R. M. Coomes, op. cit.

[15]R. Brown (ed.), *Health and the Environmental Effects of Oil Shale Technology*, a Workshop Summary and Panel Report for the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Contract No. DOE/HEW/EPA-02 MTR-79W00136 (McLean, Virginia: The MITRE Corporation, May 1979).

TABLE 1 Major Health and Environmental Concerns in the Oil Shale Energy Cycle

	PLANNING & DEVELOPMENT	EXTRACTION			CONVERSION			UTILIZATION		
	Mine & Retort Construction	Shale Extraction	Crushing, Grinding	Storage & Handling	Retorting	Upgrading	Waste Disposal	Storage	Final Upgrading & Distribution	Consumption
PHYSICAL										●
Air Quality	●	●	●	●	●	●	●			
Water Quality	●	●	●	●	●	●	●			
Water Supply	●	●	●		●	●	●			
Land Disturbance	●	●					●			
Subsidence		●								
Noise	●	●	●		●					
BIOLOGICAL										
Aquatic	●	●			●		●			
Terrestrial	●	●			●		●			
SOCIETAL										
Occupational Health & Safety	●	●	●	●	●	●	●	●	●	●
Public Health & Safety					●	●	●			●

SOURCE: R. Brown (ed.), Health and Environmental Effects of Oil Shale Technology, a Workshop Summary and Panel Report for the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Contract No. DOE/HEW/EPA-02 MTR-79W00136 (McLean, Virginia: the MITRE Corporation, May 1979).

and true in situ retorting), the easiest and most efficient way to review the existing information, research in progress, and areas requiring additional investigation is to divide the cycle into three major categories: airborne effluents (dust, vapors, gases); oils at various stages of refinement; and aqueous or solid effluents (retort water, spent shale, leachates).

AIRBORNE EFFLUENTS

Industrial hygiene surveys with extensive sampling have been conducted on pilot plant operations for all three retorting processes in attempts to characterize the occupational exposures and to identify site-specific problems. Recognizing the complexity of the composition of oil shale, its derived products and wastes, the following are components of concern with respect to atmospheric contamination: particulates, sulfur oxides, nitrogen oxides, carbon monoxide, hydrogen sulfide, polycyclic aromatic hydrocarbons, silica, and various metals such as nickel, arsenic, mercury, lead, beryllium, cadmium, chromium, selenium and vanadium. The analysis of various metals of raw shale indicate levels of arsenic (about 30 ppm), lead (about 16 ppm), and trace amounts (1 to 2 ppm or less) of the other metals. However, the major concern is the relatively high concentration of silica in raw or spent shale (25 and 40 weight by percent, respectively) suggestive of a pneumoconiosis hazard if dust levels are not controlled.[16]

Studies have been performed to obtain general information on the toxicity of raw shale and spent shale. Five tests were generally used to determine the acute toxicity of these substances, namely, acute oral and dermal LD50's in rats and rabbits, respectively, primary eye irritation and skin irritation in rabbits and dermal sensitization in guinea pigs. The oral and dermal LD50's were >10 g/kg and >20 g/kg of body weight, respectively for both raw and spent

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[16] L. L. Garcia, H. J. Ettinger, and H. F. Schulte, "Paraho Industrial Hygiene Study", The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; M. Gonzales, L. L. Garcia, et. al., "Air Sampling During Anvil Points Fire Extinguishment," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; M. I. Tillery, and M. Gonzales, "Air Sampling at Occidental Shale, Inc. Facility at Logan Wash," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; M. Gonzales, M. I. Tillery, G. Royer and E. Vigil, "Field Sampling-Rio Blanco Oil Shale Project," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; and N. K. Weaver and R. L. Gibson, op. cit.

shale. Raw and spent shale were nonirritating to the skin and both were found not to be skin sensitizers. Raw shale was nonirritating to rabbit eyes while spent shale induced minimal but reversible eye irritation.[17]

Inhalation teratology studies in rats conducted with raw and spent shale were both negative.[18]

Based on the above findings, raw and spent shale can be concluded to have very low or no acute toxic and teratogenic effects in laboratory animals, and they should not present these types of health hazards to humans.

Long-term inhalation and intratracheal instillation studies in rodents with respirable particulates of raw and spent shale have failed to produce pulmonary tumors. However, the results of these studies suggest a potential risk of pulmonary fibrosis.[19] Unpublished chronic inhalation studies in rats sponsored by the American Petroleum Institute (API) at exposure levels of 10 or 30 mg/m^3 showed no evidence of either progressive or fibrotic effects at the highest exposure level despite clear indications of a lung burden that caused some inflammatory reactions.

The above-mentioned surveys collected gas and vapor samples and analyzed for selected compounds namely; CO, CO_2, NO_2, NH_3, H_2S, SO_2, CS_2, HCN, HCHO, HNO_3, arsine, benzene, toluene, phenols, aliphatic amines, and total hydrocarbons. In general, the levels detected were below currently established guidelines.

Based on the currently available industrial hygiene survey results and long-term animal studies, the occupational hazard will be low. The exception -- silica dust -- can be controlled by imposing good engineering design and good industrial hygiene practices as pilot plants are scaled up to commercial production.

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[17] N. K. Weaver and R. L. Gibson, op. cit.

[18] Ibid.

[19] L. M. Holland, D. M. Smith and R. G. Thomas, "Biological Effects of Raw and Processed Oil Shale Particles in the Lungs of Laboratory Animals," Environmental Health Perspectives, Vol. 30 (1979), pp. 147-152; L. M. Holland, W. D. Spall and L. L. Garcia, "Inhalation Toxicology of Oil Shale-Related Materials," Health Implications of New Energy Technologies, (Ann Arbor, Michigan: Ann Arbor Sciences, 1980); R. A. Renne, J. E. Lund, K. E. McDonale, and L. G. Smith, "Morphologic Effects of Intratracheally Administered Oil Shale in Rats," Health Implications of New Energy Technologies, (Ann Arbor, Michigan: Ann Arbor Sciences, 1980); and L. M. Holland, E. A. Vigil, et. al., "Inhalation and Intratracheal Exposures to Oil Shale Dusts," The Los Alamos Integrated Oil SHale Health and Environmental Program Status Report, LA-8665-SR, 1981.

Concerning fugitive emissions resulting from current technology, this is an area of concern which to date has not been adequately examined. Respiratory or skin contact with particulate or vapors and gases by themselves or in combination could easily be envisioned. Currently under development at Los Alamos Scientific Laboratory (LASL) is a laboratory retort that should provide a method to address this area of concern for both acute and chronic exposure.[20]

OILS AND REFINED PRODUCTS

Acute toxicity has been studied by several investigators of selected crude and refined shale oil materials and similar counterparts were derived from petroleum. The studies include acute oral LD50's in rats and mice, dermal LD50's in rats or rabbits, primary eye and skin irritation in rabbits, and dermal sensitization in guinea pigs.

Substances evaluated included the following: retorted (crude) shale oils, hydrotreated shale oil, hydrotreated residue, crude petroleum samples, shale- or petroleum-derived jet fuels (JP-5 and JP-8), and diesel fuel marine samples.

In general, all these materials exhibited very low or no acute toxicity by the various routes of administration. The acute oral toxicity of retorted (crude) shale oils was 8.0 to 10.3 g/kg in rats and 11.3 g/kg in mice. The crude petroleum samples had oral LD50's of >10 g/kg in mice. The acute oral toxicity in mice of hydrotreated-shale oil, hydrotreated residue and the shale or petroleum-derived products was >16 g/kg. The dermal LD50's of all substances tested were either >2 mL/kg or >10 mL/kg and nonirritating to the skin. Crude shale oil and hydrotreated shale oil produce very slight, transient eye irritation in rabbits, but all the other substances tested were nonirritating to rabbit eyes. The dermal sensitization results have ranged from none to moderate.[21]

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[20] L. M. Holland, M. I. Tillery, et. al., "Development of a Laboratory Retort for Inhalation Experiments, The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

[21] N. K. Weaver and R. L. Gibson, op. cit.; A. Scott, op. cit.; P. A. Bogovski and F. Vinkermann, op. cit.; C. L. Gaworski, Evaluation and Comparison of the Irritation and Sensitization Potential of the Jet Fuel JP-5 and Diesel Fuel Marine Refined from Petroluem Oil and Shale Oil, (Washington, D.C.: Department of the Navy, Naval Medical Research Institute, March 24, 1980); and S. D. Allen, Small Animal Toxicity Studies of In Situ Shale Oil and Related Materials, TR-217-001, Utah Biomedical Test Laboratory, 1976.

As was observed for raw and spent shale, the selected crude and refined shale oil substances gave very low or no acute toxicity as tested by the various routes of administration. Further, the data indicate no difference among shale or petroleum oils or derived products.

Inhalation teratology studies in rats with four samples of retorted (crude) shale oil each from different geographic locations were all negative. There was at the highest level (100 mg/m^3) a suggestion of an embryotoxic effect based on a decreased live fetus/implantation site ratio.[22] However, this finding results from very high exposure level, of minor concern.

Crude and upgraded shale oils have been tested by numerous investigators and shown to be carcinogenic in varying degrees to laboratory animals by the dermal route of exposure. In addition, the carcinogenic potential of shale oils varies widely as a function of source, retorting process (that is, temperature) and degree of refining and upgrading of the retorted oil. This is not very suprising since nearly all fossil-derived fuels have been shown to be carcinogenic to some degree.

Extensive mutagenicity testing has been performed as well, on the same samples used for the above-mentioned skin-painting studies.[23] The test systems have been the Salmonella

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[22]N. K. Weaver and R. L. Gibson, op. cit.

[23]N. K. Weaver and R. L. Gibson, op. cit.; J. L. Epler, T. K. Rao, and M. R. Guerin, "Evaluation of Feasibility of Mutagenic Testing of Shale Oil Products and Effluents, " Environmental Health Perspectives, Vol. 30 (1979), pp. 179-184; R. A. Pelroy and M. R. Peterson, "Use of Ames Test in Evaluation of Shale Oil Fractions," Environmenal Health Perspectives, Vol. 30 (1979), pp. 191-203; T. R. Rao, J. L. Epler, J. J. Schmidt-Collerus, et. al., Biological Monitoring of Oil Shale Products and Effluents Using Short-Term Genetic Analyses, (Oak Ridge, Tennessee: Oak Ridge National Laboratory, 1981); J. Nickols and G. F. Strniste, "Ames Salmonella Mutagen Assay of Shale Oil," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; R. T. Okinaka and G. F. Strniste, "Exogenous Metabolic Activation of Shale Oil in Mammalian Cell Cultures," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; E. W. Campbell, F. A. Ray, and L. L. Deaven, "Effect of Shale Oil on in vitro Induction of Sister Chromatid Exchange," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; J. Mayne, "Cytogenetic Effects of Shale-Derived Oils and Related By-Products in Mice," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981; T. R. Rao, J. L. Epler, et. al., "Short-Term Microbial Testing of Shale Oil Materials," Health Implications of New Energy Technologies, (Ann Arbor, Michigan: Ann Arbor Science, 1980); H. Timourian, A. Carrano, et. al., "Comparative Mammalian Genetic ...

assay of Ames, mouse lymphoma assay, and Chinese hamster ovary (CHO) assay, all with and without activation; sister chromatid exchange (SCE); and bone marrow cytogenetics. In general, the results of many of these short-term assays have been mixed or at best equivocal.

Since these shale oils and refined products are highly complex mixtures, methodological problems have been encountered, for example, selection of a compatible solvent, cytotoxicity, and variable factors such as near-ultraviolet light. In the Ames assay, crude shale oils tend to be positive in test strain TA98 with activation; hydrotreatment significantly reduced mutagenic activity. Results of the mouse lymphoma assay were either negative or equivocal, and cytogenetic and bone marrow analyses negative.[24]

In efforts to further clarify the mutagenic potential of crude shale oils, researchers have tested major fractions of the oils derived by solvent extract techniques[25] or fractional distillation.[26] By the solvent extract procedure, most of the mutagenic activity lies within the basic and neutral fractions and by fractional distillation in the high boiler and residual (tar) fractions.

Results of cytogenetic studies using SCE technique conflict ranging from significant dose-related effects[27] to effects only at very high, lethal dose levels.[28] Hydrotreated oils have shown effects of lesser magnitude.

As alluded to earlier, extensive investigations using classical skin-painting techniques with mice have shown that crude shale oils

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23 (cont.)....Toxicology of Shale Oil Products Assayed in vitro and in vivo," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980); R. A. Pelroy and D. S. Sklarew, Comparison of the Mutagenicities of Fossil Fuels, PNL-SA-8812, Pacific Northwest Laboratory, 1981; A. P. Toste, R. A. Pelroy, and D. S. Sklarew, Comparison of Chemical and Mutagenic Properties of a Coal Liquid and a Shale Oil, PNL-SA-8812, 1980; and W. H. Calkins, J. F. Deye, et. al., Mutagenesis and Skin Tumor Irritation by Shale and Coal Derived Oils and Their Distillation Fractions, Final Report No. COO-4758-4, 1981.

24 Ibid.

25 R. A. Pelroy and M. R. Peterson, op. cit.

26 W. H. Calkins, op. cit.

27 E. W. Campbell, F. A. Ray and L. L. Deaven, op. cit.; and J. Mayne, op. cit.

28 H. Timourian, A. Carrano, et. al., op. cit.

from various sources and different retort processes have induced skin tumors in mice. Simultaneously, investigators have tested natural petroleums, coal-derived liquids, hydrotreated shale oils, and a diesel fuel marine precursor and product. Based on currently available data these oils or products rank in order of decreasing potency as follows: in situ shale oil > retort oil > hydrotreated shale oil > diesel fuel marine; and when compared to other fossil-derived fuels, coal derived liquids > shale oils > natural petroleum.[29]

In addition to the occurrence of skin tumors, acute and chronic dermatitis has been observed in mice; the degree of skin irritation may affect the occurrence of tumors and tumor latency as well as nonneoplastic occupational diseases. Basic research is currently in progress to further evaluate the effects of dose and frequency of exposure on dermatoxicity, tumor incidence, and tumor latency.[30]

Recent unpublished studies evaluated the usefulness of initiating and promoting skin-painting procedures with natural petroleum, shale oils, and coal-derived liquids which had been fractionated by distillation; simultaneously using the Ames assay they evaluated them for mutagenicity. The results showed good correlation between mutagenic activity of the various fractions and the occurrence of skin tumors. They ranked in terms of decreasing potency: coal liquids > shale oils > natural petroleum. The data were consistent with the results obtained from classical skin painting.[31] This procedure requires approximately six months rather than two years and eliminates the possible confounding effect of dermatoxicity.

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[29]W. H. Calkins, op. cit.; M. L. Holland, L. C. Gibson, et. al., "Chronic Dermal Density of Paraho Shale Oil and Distillates," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980); S. C. Lewis, "Carcinogenic Bioassay of Shale Oil Refinery Streams and Downstream Products," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980); and L. M. Holland and J. S. Wilson, "Long-Term Epidermal Carcinogenicity Studies," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

[30]L. M. Holland, J. S. Wilson, and M. E. Forman, "Comparative Dermatoxicity of Shale Oils," Health Implications of New Energy Technologies (Ann Arbor, Michigan: Ann Arbor Science, 1980); and J. S. Wilson, Y. Valdez and L. M. Holland, "The Effect of Exposure Conditions on Dermotoxicity," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

[31]W. H. Calkins, J. F. Deye, et. al., op. cit.

One must not overlook consideration of possible systemic toxicity resulting from dermal exposure as evidenced by observations of liver and kidney lesions induced by dermal application of various fossil-derived fuels.[32]

AQUEOUS AND SOLID WASTE EFFLUENTS

This phase of the oil shale cycle has received the least attention among all the research effects over the last five to six years. The extent of possible contamination will vary based on the retorting process and local conditions such as annual rainfall. Contamination can come about by means of retort waters, raw fines, or spent shale when in situ or modified in situ operations are leached or flooded by retort waters or rain.

As already discussed, spent shale and raw fines have not been found to be acutely toxic and mutagenic, and teratological studies, as well as classical chronic skin-painting studies have all been negative.[33]

Mutagenic activity of retort water samples obtained from a surface retort, a modified in situ retort and a true in situ retort have been evaluated in one or more of the following: the Ames assay, CHO mammalian cell culture, SCE assay and human fibroblasts following near-ultraviolet light activation. The surface retort water showed mutagenic activity in all test systems, the modified in situ retort water was negative in the Ames assay (the only assay performed), and the true in situ retort water was either negative or equivocal in the Ames assay and human fibroblast assay.[34]

In the SCE assay, the aboveground and modified in situ retort water samples were positive while the in situ was not different from background rates.[35] Utilizing near ultraviolet light for

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[32]N. K. Weaver and R. L. Gibson, op. cit.; and L. M. Holland and J. S. Wilson, op. cit.

[33]N. K. Weaver and R. L. Gibson, op. cit.

[34]J. Nickols and G. F. Strniste, op. cit.; R. T. Okinaka, and G. F. Strniste, op. cit.; and D. J. Chen, R. T. Okinaka, and G. F. Strniste, "Determination of Direct-Acting Mutagens in Shale Oil Retort Process Water," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

[35]E. W. Campbell, F. A. Ray and L. L. Deaven, op. cit.

activation, mutagenic activity for all three types of retort water was increased but the greatest activity was noted in the above ground retort water sample.[36]

As noted these retort waters are complex mixtures of essentially unknown chemical composition that are extremely cytotoxic. The results suggest that retort waters contain direct-acting mutagens, but considerably more research is needed to gain sufficient understanding of the significance of the results obtained to date. Mutagenicity testing has been used as an indicator of potential carcinogenicity and as a follow-up to these in vitro tests, chronic studies should be performed.

Concerning prenatal toxicity (teratogenicity), conflicting results have been obtained by investigators using aboveground retort water.[37] This discrepancy could be related to nickel arsenide (Ni_5As_2) or some other component(s) in the waste water. Investigations are currently in progress to further define the teratogenic potential of retort water.

Preliminary studies are currently under way to evaluate leachate toxicity. The chances for water contamination from any of the three retort processes are significant and probably the most complex to investigate but the potential for impact on public health does exist.

SUMMARY AND CONCLUSIONS

The development of a U.S. shale oil industry will create the possibility for human exposure and environmental release of crude shale oil and its refined products and residues. The major health concerns relate more to the occupational worker than the general public. The available toxicity data suggest that crude shale oil may be slightly more mutagenic and carcinogenic than crude petroleum and that surface-retort shale oil may be more mutagenic and carcinogenic than in situ shale oil. However, acute, short-term toxicity tests do not indicate a significant difference between shale oils and some shale oil middle-distillates on the one hand and equivalent petroleum-derived substances on the other.

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[36]G. F. Strniste, E. Martinez and D. J. Che, "Light Activation of Shale Oil By-Products," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

[37]C. T. Gregg, and J. Y. Hutson, The Prenatal Toxicology of Oil Shale Retort Water in Mice," The Los Alamos Integrated Oil Shale Health and Environmental Program Status Report, LA-8665-SR, 1981.

Historical evidence from oil shale development in other countries and recent research efforts do not indicate that respiratory tract tumors are a major concern but medical surveillance programs should watch closely for respiratory as well as skin disease in the occupational setting. With modern technology and good industrial and personal hygiene practices, it should be possible to prevent respiratory and skin diseases.

Exposure to the general public from environmental release may occur primarily as a result of end-product use, fugitive emissions, spills and waste disposal. The physical and chemical properties of upgraded crude shale oil (volatility; corrosivity; reduction in nitrogen, sulfur, oxygen, and trace element content) suggest no significant difference or increased hazard during transportation and refining when compared with that of crude petroleum. However, the potential for adverse health effects as a result of environmental release has not been adequately addressed.

Based on the information available the following are areas of concern requiring further research efforts:

Airborne Effluents

- Establishment of baseline meterological data including seasonal variations.
- Evaluation of the toxicity of gas and vapor emissions alone and in combination with particulate emissions.
- Continued industrial hygiene monitoring and sampling with chemical characterization.

Oils and Refined Products

- Toxicity testing of product streams following upgrading and refining and end products to identify any potential health hazard to the consumer. This should include analyses of emissions resulting from the combustion of end products where appropriate. In all cases, toxicity testing should include equivalent petroleum-derived materials as controls.

Aqueous and Solid Effluents (Wastes)

- Establishment of baseline data.
- Evaluation of surface retort waters after standard impoundment and current available cleanup techniques prior to disposal.
- Laboratory and field studies of the effect of leachates and waste water on aquatic organisms; their impact on aquifers and

on the mobilization of potentially toxic naturally occurring trace elements.

- Chronic studies with retort waters.

Epidemiological Studies

- Retrospective
- Prospective

Basic Research

- Continued efforts to further identify chemical composition and changes in composition that occur as a result of upgrading techniques.
- Investigations of potential phototoxicity and dermatoxicity.

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POSITION PAPER H

DU PONT'S OCCUPATIONAL HEALTH PROGRAM

Robert N. Ligo
E. I. du Pont de Nemours & Company

The purpose of this paper is to describe du Pont's occupational health program--its origins, the corporate policies upon which it is based, and its principal components.

The origins of du Pont's medical program can be traced to the first days of the company--to the early 1800's when our founder, E. I. du Pont, put Dr. Pierre Didier, a fellow French refugee, on retainer to the du Pont family. The retainer worked in such a way that if an employee visited Dr. Didier with a problem related to the work place, Dr. Didier would charge the retainer. If the employee's problem was personal, the employee would be billed.

Eventually the du Pont family and the company paid separate retainers. This separation was important. By paying Didier from corporate funds, the company had moved beyond a system of merely assuring the availability of medical care to assuming moral and financial responsibility for the occupational health of its employees.

The Medical Division of the Employee Relations Department was formally started in 1915 when the Executive Committee appointed a full-time medical director and decided that employees should have periodic physical examinations.

During this century, corporate efforts and resources devoted to protecting the health of du Pont employees have steadily increased. These include, among other things, the founding of Haskell Laboratory for Toxicological and Industrial Medicine in 1935 to test the safety of using du Pont chemicals; the establishment of a formal epidemiologic surveillance program in 1956; and the introduction of the computerized Personal Environment Record System (PERS) in 1979 to record employees' work and exposure histories. All of these actions were taken to help carry out du Pont's safety, health, and environmental policy. This policy states that:

1. The company will comply with all applicable laws and regulations related to safety, health, and environmental quality in its manufacturing, product development, marketing, and transportation activities.

2. The company will routinely review its products, processes and control facilities as new information is available for the purpose of making safety, health, and environmental quality improvements beyond those legally required to their cost.

3. The company will determine that each product can be made, used, handled, and disposed of safely and consistent with appropriate safety, health, and environmental quality critera.

The four disciplines that comprise occupational health are toxicology, industrial hygiene, occupational medicine, and epidemiology. There is an order to these with information flowing from one to the next. For example, the results of toxicological tests are used by industrial hygienists when designing and monitoring proper controls for hazardous substances in the work place. Likewise, the results of epidemiological studies are often used to determine the need for more toxicological studies or tighter work place control. In order to understand du Pont's occupational health program, it is necessary to examine how these four disciplines are carried out at du Pont.

Du Pont's toxicologists, for the most part, work at our Haskell Laboratory for Toxicology and Industrial Medicine which was established as part of du Pont's program to protect its employees, its customers, and the public from chemical hazards. At Haskell, toxicologists conduct both long- and short-term animal studies on chemical substances to determine toxic properties ranging from skin irritation to carcinogenicity. An increased emphasis on the effects of chronic exposure to substances, such as the induction of cancer, has been the principal cause of three expansions of the laboratory in the last 14 years.

Approximately 700 substances are tested at Haskell each year to ascertain whether they are hazardous to health or the environment. Haskell's findings are an important and frequently critical factor in management decisions as to whether a chemical should be manufactured.

Haskell Laboratory is also responsible for providing a chairperson for a committee which establishes exposure standards for chemicals made or used at du Pont plants. These standards may be federal Occupational Safety and Health Administration (OSHA) standards, threshold limit values (TLV's), or levels established by du Pont.

Du Pont's industrial hygienists work in different divisions throughout the company--Haskell Laboratory, Safety and Fire Protection Division, Engineering Department, and industrial departments. They use Haskell's toxicological data, along with data from other sources, to develop appropriate hazard controls to be used at du Pont sites, offices, and laboratories.

For example, each du Pont site has industrial hygienists who assist in the regular monitoring of exposure throughout the plant to be sure that exposure limits are being met. If limits are being exceeded, the situation is investigated and corrected. Hygienists also examine work practices to ensure that safe procedures for handling hazardous substances are being followed.

In addition, the occupational health group of the Safety and Fire Protection Divison audits the industrial hygiene programs at each plant. The audit reports emphasize where improvement is needed, and plant management is responsible for acting on the recommendations. Finally, industrial hygienists working at Haskell Laboratory and in the Engineering Service Division of the Engineering Department assist site management in solving difficult exposure problems.

The third group of health specialists, occupational physicians and nurses, is responsible for ensuring that employees and prospective employees can safely perform the jobs to which they are assigned. Our physicians and nurses must therefore:

- Treat any work connected illnesses or injuries;
- Examine employees periodically, looking for adverse health effects which may be due to the job or which may increase the risk from working the job; and
- Assist employees with their personal health care as well as health planning.

The role of the occupational physician in these occupational health and safety programs has grown substantially over the years. Where once industrial medicine was considered an employee relations dividend--a demonstration of concern for people--it is now an integral part of business. Today, du Pont physicians must examine potential health hazards in the work place. They must also look for subtle long-term health effects of substances which in the past have only been known to be acutely toxic. There are about 70 full-time, 50 part-time, and more than 100 fee-for-service physicians at du Pont, and in addition, over 200 registered nurses. The physicians and nurses are assisted by technologists and clerical workers.

Epidemiologists comprise the fourth group of occupational health experts at du Pont. Since 1956, the Medical Division has collected epidemiological data on the causes of diseases and deaths among employees and deaths among pensioners. These data are used to determine if an excess of any disease has occurred at a du Pont site. In addition, du Pont's epidemiologists conduct studies on groups of employees who have been exposed to specific occupational hazards so that any adverse health effects can be detected. This follow-up analysis by epidemiological techniques is believed to be an additional precautionary measure for assessing how effective our occupational health programs have been.

A more detailed description of the du Pont programs which pertain to the last two disciplines, occupational medicine and epidemiology, is appropriate since these are the ones in which the Committee on Synthetic Fuels Facilities Safety has the most interest at this time.

OCCUPATIONAL MEDICINE

Monitoring employee health is an extremely important part of du Pont's occupational health program. To ensure adequate medical surveillance, du Pont employees receive comprehensive preplacement examinations to provide baseline information against which later examinations may be measured. The examinations also provide information used to ensure that an employee is not assigned to a job where his or her physical condition would increase the risk of illness or injury (or would place other employees at increased risk of injury). Employees over age 40 are routinely examined yearly and those 40 years and under every two years. More frequent routine examinations are performed if warranted by the exposure hazard.

The routine examination includes:

- Completion of a health history questionnaire. A comprehensive questionnaire is used for the preplacement examination and an interval questionnaire is used for the periodic examination.
- An examination by or under the supervision of a physician.
- A posterior-anterior chest x-ray.
- A urinalysis.
- A white blood cell count and hemoglobin or hematocrit; differential counts are performed if indicated.
- An audiogram.
- Visual acuity testing.
- Blood glucose, SGOT, alkaline phosphatase, and total bilirubin tests, (in most plants an SMA-12 is performed).
- A stool occult blood test for employees over 50 years of age.
- An electrocardiogram (recommended for the preplacement examination and required at ages 30 and 40 and annually after age 50).
- Screening pulmonary function tests (FVC, FEV_1, FEV_1/FVC ratio).

Employees are reevaluated during each periodic examination to detect signs of adverse health effects which could be due to the job, which may increase the risk from working in that job, or which may cause them to put other employees at increased risk of injury.

Plant physicians treat work-related illnesses or injuries and, where appropriate, provide advice on personal lifestyle factors which may increase the likelihood of disease. If conditions are found which may require further evaluation or treatment, the employee is referred to his or her personal physician. A medical record is initiated for each employee with the preplacement physical examination and is kept at the site where the employee works, under the control of the site physician. Du Pont is in the process of computerizing all medical examination results. The process should be completed for all U.S. sites within the next five years.

Special ongoing medical monitoring programs are conducted at sites for employees who have been or continue to be exposed to certain toxic substances. These fall into two categories.

First, special examinations are given for employees who have been exposed to specific toxic agents. The purpose of these examinations is to identify any health changes that have occurred due to exposure to such agents.

Hexamethylphosphoramide (HMPA), for example, has been shown to cause squamous cell carcinoma of the snout and renal tubular damage in rats. Therefore, all employees assigned to areas where there is potential exposure to HMPA receive physical examinations yearly. Particular attention is given to evaluation for evidence of kidney damage. In addition to the annual physical examination, these employees have a sputum cytology examination every six months, as well as a nose and throat examination.

Secondly, biological monitoring of employees who could have been exposed to toxic substances is performed on a regular basis. These tests serve as a backup for environmental sampling and control measures. Examples are: analysis for lead in the urine of employees potentially exposed to organic lead compounds, and analysis for a metabolite in the urine of employees who are potentially exposed to dimethylformamide (DMF).

It is not always possible to develop valid biological monitoring tests and even when valid tests are possible, developing them is often difficult and costly. It costs about $100,000 just to determine if there is reasonable chance of developing a valid monitoring test.

As part of the occupational medical program, physicians from the corporate Medical Division regularly visit sites to survey medical facilities and programs. These surveys ensure that examination procedures are being properly performed and interpreted, that appropriate actions are being taken in response to test results, and that the principles of good medical practice are being followed.

EPIDEMIOLOGY

Du Pont's program includes four types of epidemiological studies:

- o Routine epidemiological studies that measure morbidity and mortality of employees in the company as a whole and at individual plants, laboratories, and offices;
- o Routine epidemiological studies that measure mortality among pensioners;
- o Special epidemiological studies such as cohort and case-control studies that investigate suspected hazards; and
- o Special epidemiological studies that evaluate the effectiveness of the occupational medical programs.

Most of the data needed to carry out the epidemiological program are contained in four computerized files which were started in 1956:

- o A file of sickness-related absences of employees that result in disability of eight days or more;
- o A file of deaths among active and retired employees;
- o A cancer registry; and
- o A coronary heart disease file.

The methods used to obtain the data for each of these files are described below.

Data on the sickness-related absences are obtained from claims filed according to the company's group accident and health insurance plan. The plan provides for supplementary payment for nonoccupational illness or injury that results in disability of eight or more days. About 95 percent of all employees voluntarily participate in the plan. To be approved, a claim must contain a statement of diagnosis certified by the attending physician.

Mortality data are derived from the claims filed in accordance with the company's group life insurance plan. Since each claim must be supported by a death certificate or "proof of death" statement, processing the claim not only provides a means by which the death is reported to du Pont, but also a means of obtaining the cause of death. The insurance plan covers retired as well as active employees.

The data in these epidemiology files are used for periodic analyses of disease incidence at various employment sites to determine whether an excess incidence of a disease or cause of death has occurred at a site. In addition, studies are conducted on groups of employees who have been exposed to certain substances to determine whether the substances are causing any adverse health effects. For example, in 1977 du Pont conducted a cohort mortality study on acrylonitrile in which the observed number of deaths occurring in a given time period in a group of employees exposed to acrylonitrile was compared with the number of deaths expected in that group for the same time period. Case-control epidemiological studies are also performed on groups of employees who have shown a significant increase in a particular type of illness compared with a control group.

One component of the total epidemiological program is a section devoted solely to cancer epidemiology. The cancer program is designed to measure cancer incidence and mortality among employees, and to identify company sites that have a significant excess of any type of cancer and determine whether the excess could have occurred as a result of exposure to a substance in the work place.

The sickness-related absence and mortality files allow cancer cases that occur among active employees to be tracked for the cancer registry. Information is obtained through insurance claims, which are supplemented by case reports submitted by company physicians. The physicians' reports provide pertinent information that does not appear in the insurance claims, such as work history, smoking history, methods by which the diagnosis was verified, and history on exposure to known or suspected carcinogenic agents.

Important elements of the cancer surveillance program are:

- The routine reporting of cancer cases among employees and of cancer deaths among employees and retirees;

- The maintenance of a cancer registry in which the employee cancer incidence is recorded;

- The routine collection of population statistics by age, sex, and payroll class for all company locations to provide a population base for statistical analyses;

- Periodic analyses of cancer incidence in plants, offices, and laboratories; and

- Cohort studies to investigate cancer mortality among persons who have worked with suspected or known carcinogens.

In summary, du Pont's occupational health program brings together the work of several occupational health specialists including toxicologists, industrial hygienists, occupational physicians, and nurses and epidemiologists.

POSITION PAPER I

ENVIRONMENTAL AND SAFETY IMPACTS CRITICALLY AFFECTED BY OIL SHALE PLANT SITING, FEDERAL LAND MANAGEMENT, AND THE MAGNITUDE AND RATE OF DEVELOPMENT OF THE INDUSTRY

Kevin Markey
Friends of the Earth

The richest oil shale reserves in the United States are located in the 25,000 mi^2 Green River Formation of northwest Colorado, northeast Utah, and southwest Wyoming. Oil shale's geochemistry, its very low grade (and the resulting large scale operations necessary to extract significant quantities of energy), its environmental and social setting, and the many unknowns which still confront its extraction, processing, and use together present a serious environmental and safety threat.

Each oil shale facility will create substantial social and environmental disruption. A single 50,000 barrel per day (BPD) shale oil plant will involve at least 25 million tons of mining volume per year--more than the recent annual production of coal in the entire state of Colorado. However, much more serious than the effects of individual operations are the hazards which may result from a very large mature industry. Musings of a 5-to-8 million BPD shale oil industry are not necessarily idle technological dreaming. The U.S. Congress is now considering changes in the Mineral Leasing Act and the Department of the Interior is now designing a long-term commercial leasing program which could make such an industry a reality if economic and other barriers are overcome.

Any significant energy production from shale oil will involve a sizable industry. What makes shale distinct from other resources is that large reserves are concentrated in a very small area. Even within the Green River Formation the resource is highly concentrated. About two thirds of the Green River shale and almost all of the rich shale is held within the 35-mile by 45-mile Piceance Basin. Because of this geographic concentration, siting, cumulative effects, and rate of development will have an unusual influence on the industry's consequences and its ultimate productivity.

The remainder of this discussion identifies each safety and environmental factor critically affected by siting, resource availability, and rate of growth and how it is affected.

AIR QUALITY

Ambient Air Quality in Critical Airsheds

Flattops Wilderness, Dinosaur National Monument and several other more distant parks and wilderness areas are a stone's throw from the Uinta and Piceance Basins. Flattops is only about 30 miles from the center of the Piceance Basin, for example. A combination of large emission sources and the area's complex meteorology could substantially impare the pristine air quality values of these airsheds.

The air quality effects are highly sensitive to the relative location and total emissions of each oil shale facility. In the near future, the high concentration of facilities on the Roan Plateau in the south of the Piceance Basin could have an adverse cumulative effect on Flattops.

The primitive state of air pollutant dispersion modeling and the uncertainties of emission controls make it particularly difficult to accurately site a plant on the basis of minimizing air quality impacts today.

Ambient Air Quality and Hazardous Emissions Exposures in Urbanized Valleys and Residential Centers

Most existing towns are located in major river valleys--the Colorado, White, and several valleys in Utah. The relatively deep and narrow valleys are subject to serious atmospheric inversions. Both urban emissions from vehicles and secondary industry as well as potentially hazardous emissions from nearby oil shale facilities or secondary industry may be concentrated in unacceptable concentrations in these new urban areas. Recently, Union started construction of its shale oil upgrading unit in the Parachute Creek valley only a few miles north of Parachute and only a few thousand feet from its own on-site residential center ("man-camp"). Most electric generating facilities will be built in such valleys near water sources (including Colorado Ute's recently proposed plant). One existing refinery and possible future refineries could be located in the Grand Valley.

These risks are affected by the location of oil shale and ancillary facilities, industrial siting decisions and mostly local government zoning decisions. The severity of urban-based pollution from vehicles and industrial and residential sources depends on the size of the industry (and thus on resource availability), on the siting of transportation corridors, on the design of new or expanded communities, and on the use of alternative transportation or mass transit.

The major uncertainties in assessing risks or making siting decisions are emission control effectiveness, the pattern of private capital investment in support communities, and the type and magnitude of secondary industrial development attracted to the area.

Regional Loading and Related Air Quality Values

Severe degradation of air quality values in critical airsheds and increased jeopardy to a potentially large urban population by air quality health violations could result from a large industry made possible by uncontrolled access to shale reserves and favorable economics. The risks are largely insensitive to siting and mostly affected by the magnitude of the industry. Uncertainties remain due to enforcement and emission control effectiveness.

WATER QUALITY

Salt Concentration in the Colorado River System

High concentration of total dissolved solids is already a serious problem in the Colorado River, especially in the lower basin and Mexico. Oil shale could exacerbate these problems due to: increased quantities of dissolved solids entering the river system from solid waste (spent shale) leaching and other effluents; and increased concentration of salts in the river system due to higher consumption of the river system's virgin flow, especially if high quality water supplies are used. Risks result to downstream urban users (mainly in southern California, Arizona, and Mexico) due to hypertension or other high salt ailments, and higher costs for agricultural irrigators and industrial water users.

Resource and land management affects these risks in several ways. Siting of aboveground retorting complexes (with surface spent shale disposal) in dry regions with high evapotranspiration may assist in the isolation of salts in solid waste if reclamation is successful. (Unfortunately, these same conditions will decrease the success of long-term reclamation.) Siting of in situ retorting in regions with extensive ground water will increase the likelihood of long-term salt loading of aquifers and eventually surface streams. (Unfortunately, the geographic areas most appropriate for bulk mining and in situ extraction also have extensive aquifers.) The magnitude of the industry and the choice of technologies also affects the solid waste subject to leaching and the consumptive use of water.

Uncertainties remain in the ability to control increased salt concentration through siting because of inadequate information on regional hydrology and the uncertainty of site-specific reclamation. Also, the relative consequences of oil shale activities in Colorado River salinity or its control is affected by other means used to control the river's salt concentration and their effectiveness.

Hazardous Pollutants in Local Water Supplies

Piceance Basin and Uinta Basin surface and ground water are currently put (sparingly) to agricultural and residential uses. As the population in the area increases, especially if it settles in the basins, water demand will grow and excellent sources will be overcommitted, leading to possible increased use of marginal aquifers and water sources. These aquifers are the most vulnerable to pollution by oil shale activities or other industrial development. Pollution sources are solid waste leachates, retort water effluents, and aquifer mixing. Exposure to hazardous substances is possible. Hydrological disturbances also will have an adverse impact on wildlife dependent on springs, seeps, and surface streams.

These risks may be affected by the siting of surface solid waste disposal and, *in situ* operations, as well as the location of future urban development. Presently, urban development is limited to existing towns outside the hydrological basin by local government zoning policies. Man-camps may start to reverse or alter this policy.

ECOLOGICAL, WILDLIFE, AND SYSTEMATIC IMPACTS

Threats to Sensitive or Critical Habitat

Critical wildlife resources of the area will be affected by several problems: habitat disturbance by mining, processing facilities, and solid waste disposal as well as corridors; hydrological disturbances that affect water for wildlife; and total human activity.

Several factors that affect these risks are relevant to siting or resource or land management, especially the siting of facilities and corridors relative to critical habitat and migratory zones, the siting aspects with hydrological consequences, and the design of transportation systems, corridors, and the availability of mass transit for workers. Also, the magnitude of human settlement and activity generated by various sizes of the industry affects the health of wildlife resources.

Total Ecosystem Disruption

Some propose total resource recovery through the use of large-scale open-pit mining and massive retorting complexes. This would involve the total geological, hydrological, and topographic reconstruction of the region. It would jeopardize all existing land uses and the entire existing ecology.

Such a scenario is a decision that can be made only by the federal government, either piecemeal or as a conscious choice of land management. Its success also depends on the economics of such a scheme. The extent of total resource recovery by these means depends on cut off grade of the shale and thus, the economics of shale recovery.

ECONOMIC AND SOCIAL IMPACTS

Continued Diversity of the Regional Economy

Competition for labor, competition for scarce water supplies, agricultural land conversion, and the industry's effect on air quality and ecological values will affect the viability of regional agricultural, tourist, and smaller mining ventures. It could jeopardize the region's existing diversity and make it difficult to recover from any economic depression in the synthetic fuels market. Industry and urban land speculation can outbid any existing users. Also, smaller effects can be multiplied because of the erosion of infrastructure necessary for other industries.

Competition for water is mainly sensitive to the magnitude of the industry. Agricultural conversion is affected by local zoning ordinances and state property tax or land conversion policies. Both facility siting and the magnitude of the industry will affect air quality and ecological values which affect tourism. Competition for labor, once the industry starts, is less sensitive to siting and magnitude of the development since it becomes a problem with very small shale development. (It is already a serious regional problem.)

Boom Town Impacts

The well known problems of energy boom towns result from the rapid influx of new employees and associated population. The problems have serious consequences for the industry's eventual viability as well as serious effects on the existing and new population. Problems are economic and social. Mental health difficulties and social disruption may be the most immediate safety impact of synfuels facilities. The socioeconomic disturbances and dislocations may be overcome by proper financing, but are also very sensitive to the rate of development and the dispersion of the industry.

NATIONAL SECURITY VULNERABILITY

Vulnerability of Continued Energy Production by the Shale Industry

Shale oil production is often justified because of its contribution to reducing the vulnerability of the nation's energy supplies to disruption. But the shale industry's potential vulnerability is seldom discussed.

Any significant energy contribution from shale oil would involve the siting of a highly concentrated industry in a very small region. The vulnerability of such an industry to military or terrorist disruption (even considering its location in the Rocky Mountain region) could be high since it would involve not more than 20 highly complex, large operations within a small 35 by 45 mile zone. Moreover, pipeline transport and supporting critical utilities such as water supply and electricity are equally vulnerable.

Most of these problems are inherent in the industry. The larger the industry becomes, the greater the vulnerability. Other secondary factors relevant to its security are geographic dispersion, corridor and transportation facility design and siting, accessibility and protectability of sites, the choice of technologies, and the size of individual units.

The industry's resilience is particularly low because, depending on the equipment damaged or disrupted, repairs may be a lengthy and costly chore.

POSITION PAPER J

NOTES ON COAL SYNFUEL FACILITY HAZARDS

James P. McGee
Consultant

COMPONENT AND UNIT OPERATION HAZARDS IN A COAL GASIFICATION PLANT

Coal gasification is of major interest since it also is a major part of any liquefaction process.

- o Production of hydrogen for direct liquefaction
- o Production of Syn gas ($CO + H_2$)

Coal gasification is an endothermic process since heat must be added to the coal-steam mixture to promote gasification.

This heat can be added in two modes. Heat can be carried in to the gasifier by some solid which has been heated externally to the gasifier. This can be recycled ash refractory pellets or similar by-products.

The most favored method, however, is to burn a portion of the coal with air or oxygen.

Gasification with air is a much safer process for several reasons:

- o It usually is conducted at essentially atmospheric pressure since this type of operation will only yield a low Btu industrial gas.
- o The oxygen in the air is well mixed with nitrogen so the problem of reacting raw oxygen is non existent.

Gasification with oxygen requires the production and usually the compression of the gas (O_2).

In oxygen production, air is compressed to approximately 90 psig. Large plants use oil-free compressors such as centrifugal or axial. They involve little hazard other than that with any high-speed rotating equipment.

The air compressors are driven with high-speed turbines or electric motors with increasing gears.

The main hazard in oxygen plants is acetylene build-up in the air fractionating column.

Acetylene can also trigger an explosion of any other hydrocarbons present in the column.

Acetylene control is usually accomplished by draw off.

A main source of safety in an oxygen plant is the oxygen compressor.

As O_2 plants have become larger, the oxygen compressors have gone from reciprocating to centrifugal.

These centrifugal compressors require high velocities, which contribute to the explosion or fire hazard.

There are two general types of problems in oxygen compressors:

- Finding materials of construction that will not burn or explode in an oxygen atmosphere.
- Designing a compressor so as to minimize danger due to rubbing, and to keep bearing oil from entering the compressor, and designing seals so that the seal materials will not cause a fire due to rubbing.

In general, it may be said that the higher the pressure of compression the greater the hazard.

Valves and pipes for oxygen can also be a hazard if correct construction materials are not used.

In general copper or copper alloys are highly rated for safety in oxygen use.

In coal gasification, oxygen is always used with steam. The main problem is to effect good mixing of the steam and oxygen since raw oxygen reacting with coal can cause excessive temperatures.

Coal Handling Problems

At the front end of any coal conversion plant, coal must be unloaded, piled, reclaimed, and usually conveyed to coal bunkers.

The problems of coal handling are similar to those of any materials handling.

Yard machinery such as stockers, reclaimers, and bulldozers are the first stage.

Conveyors, elevators, bins, and so on, are the next stage. This type of equipment can be a personnel hazard for both operations and maintenance.

The answer to problems of mechanical handling, operation, and maintenance is in training the people who have to operate and maintain this equipment.

Coal Pulverizing and Drying

All gasification and liquefaction processes require that the coal be reduced in size.

Fixed bed gasification in general can use the largest sized coal, usually lumps up to 2 in.

Fluid bed gasification uses coal in the range of 20 mesh to 1/4 in.

Entrained gasification is usually powerhouse-sized (70 percent through 200 mesh).

Pulverizers or mills for fluid bed or entrained coal usually have a system to dry the wet coal before milling. This is accomplished by carrying the coal in a stream of hot gases. The gases are usually generated in some form of fired heater, and when contacting the wet coal the overall temperature drops to around 250° F.

The main problem is to hold down the oxygen content of the recycled hot gas to limit the risk of fire or explosion.

While there is no definite limit to the oxygen content of the recycled gas it is a good idea to keep it below 7 percent.

Coal stored in bins or fed through lock hoppers should be kept in an inert atmosphere of CO_2 or N_2.

Asphyxiation Hazards Due to Process Gases

Process gases can be divided into toxic gases such as H_2S, CO, SO_2, and CS_2 and nontoxic gases such as H_2, CH_4, CO_2, and N_2.

The toxic gases can cause immediate damage to lungs and other body tissues.

The nontoxic gases can cause death by replacing the necessary oxygen supply.

Toxic gas emissions from compressors, pumps, valves, and flanges must be carefully controlled. Packing and seals are a continuing problem.

Slurry Feeding Problems

Some coal gasifiers and all direct liquefaction processes require feeding coal slurries.

This may be a mixture of coal and water as in the Texaco gasifier or it may be a combination of coal and heavy oil as used in coal hydrogenation plants. Coal-water slurries as a rule are less hazardous than coal-oil slurries, because:

- Coal-water slurries will not burn except in special equipment. Also coal-water slurries should not be carcinogenic.
- Operation of a direct liquefaction plant requires that pulverized or milled coal be mixed with part of the heavy oil from the process.

The resulting coal-oil slurry is highly inflammable and also carcinogenic.

Coal-oil slurry pumps as presently installed have relatively short periods of operation between shut-downs for maintenance. Particular maintenance problems are replacement of packings and bushings. Both of these could be improved to lessen maintenance requirements and health hazards due to the nature of the material passing through the pumps.

Coal-water and coal-oil slurries pumped to high pressure use reciprocating pumps.

Slurries pumped to lower pressures (up to several hundred psi) usually use centrifugal pumps.

The main difference between coal liquefaction plants and commercial oil refineries is the inclusion of solids in the coal hydrogenation plant streams.

Solids of this type to a marked degree are not present in refinery streams.

Solids are present in the feed to coal hydrogenation reactors. These feed streams which must be pumped to a relatively high pressure (2500 to 3500 psi) are a combination of 40 to 45 percent coal in 55 to 60 percent heavy oil from the process.

Although the main source of the solids containing slurries is in the feed system, solids are also in the downstream separation system.

The effect of solids is evident in the operation of the pumps for these streams. Immediate effects on slurry pumps are erosion, corrosion, and packing problems.

All pumps for high-pressure slurry service are reciprocating.

Probably no equipment in coal liquefaction plants varies more from refinery practice and presents more problems in operation and maintenance than these slurry pumps.

It appears that the pumps for slurry duty are standard refinery types which have undergone some modification rather than pumps especially designed for this service. This results in high maintenance and the accompanying health hazards of carcinogenic streams to personnel who must take apart and reassemble such equipment.

Since these slurry pumps are subjected to the most severe duty, and the operation of a liquefaction plant is so dependent upon maintenance-free operation, it seems necessary to design pumps especially for this service.

Some of the parameters that would have to be incorporated in a national slurry pump design are as follows:

1. Long stroke
2. Low rpm
3. Corrosion- and erosion-resistant construction materials
4. Adequate packing lubrication
5. Flush oil system to prevent slurry from working back into the packing
6. Pump valves especially for slurry service, probably ball valves
7. Best available type of plunger packing
8. Relatively low clearance between bushings and plunger

9. Two stages of packing with interstage draw-off
10. Easy access for maintenance

A slurry pump specially designed for this service and giving long life between maintenance periods would materially improve the operation of the liquefaction plant by reducing down-time; limit the number of maintenance turn-overs and decrease the health hazard to maintenance personnel; and offer an excellent operating pump with little or no fugitive emission leakage.

A better design of a pump for oil-solids duty would not only improve the operation of a synfuels plant but would also reduce the health hazards to operating and maintenance personnel.

Sulfur Removal and Recovery Systems

Both coal gasification and direct liquefaction systems require sulfur removal. Since the sulfur must be removed it is usually economical to recover it.

In indirect liquefaction processes the sulfur is removed in the gasification step so that the synthesis is fed sulfur-free gas. This is also true of ammonia and methanol production from coal.

The product gas is usually washed and cooled. If the gas is at a relatively high temperature (1000^{o}F or above) it usually goes to a waste heat boiler before washing.

After washing the gas goes to some sort of sulfur removal system. While there are many types, Benfield or Selexol, for instance, they are basically similar.

They usually consist of an absorber, where the gas is contacted with a solution which removes the H_2S and some or all of the CO_2, and a regenerator, where the acid gas is separated from the absorbent, which is then recycled to the absorber.

The major problem is in the recycled solution. Even the lean solution contains some H_2S. The pumps usually work on the lean solution. Any solution leak could result in flashing of H_2S.

The rich solution is loaded with H_2S and any leakage in valves, flanges, etc., will cause solution leakage and H_2S venting.

Also the H_2S is released in the regenerator at relatively low pressure and may have to have a pressure rise with the attendant problems of H_2S compressor or blower leakage.

Sulfur recovery may be by Claus Plant or Stretford Plant.

In the Claus Plant H_2S is probably burned in air and the combustion gases go through catalyst beds where the sulfur is removed. Although relatively simple in design, leakage is a problem throughout the plant.

The Stretford Plant requires large recirculation of toxic fluids. The plant has many pumps handling these solutions. Leakage at the pump seal liberates not only toxic solution but also H_2S. Pumping problems in sulfur removal and recovery are present chiefly as leakage during operation but are especially severe in maintenance where personnel may be subjected to the streams pumped.

H_2S PROBLEMS IN SYNFUELS PLANTS

All coals and oil shales contain sulfur.

If coal is burned the sulfur is converted to SO_2.

However, in synthetic fuel production both the gasification and synthesis occur in a deficiency of oxygen so the sulfur appears as H_2S.

Equipment Problems with H_2S

All equipment used for handling H_2S (and this is a large percentage of that installed in coal or oil shale conversion processes) can present hazards.

Specific equipment involved includes compressors, pumps, valves, and piping.

Compressors For H_2S

Compressors for H_2S are either reciprocating, centrifugal, or, as a remote possibility, axial.

The main problem with any toxic gas in a compressor is leakage. Leakage in either reciprocating or centrifugal compressors is usually concentrated at the shaft seals.

For high compression ratios and relatively low flows the reciprocating compressor is the preferred type.

Bleed-off from the rod-packing is the recommended method for preventing leakage of toxic gases to the atmosphere. This is a necessary safety precaution for compressors processing an H_2S contained gas.

Buffering of the shaft seal from a nontoxic gas such as nitrogen can also be used.

In general the same methods for controlling H_2S leakage in reciprocating compressors can also be used in centrifugal machines. In addition, the centrifugal offers the possibility of zero leakage by "canning." In this method, both the compressor and its drive (electric motor) are hermetically sealed in a pressure vessel. There are no shaft seals to leak and in general canning is used for low-ratio-of-compression machines such as are encountered in recycle compressors. At the present time it is not known how large canned compressors can be constructed. This type of construction is usually more expensive than conventional compressor types. However, it results in a very safe method for compressing gases containing relatively large amounts of H_2S.

Pumps for Solutions Containing H_2S

The pumps that cause the most problems are those handling the solutions for H_2S removal from process gas.

These pumps operate at elevated pressures and handle amines, potassium carbonate, or some other solution used for the absorption of H_2S.

Again pumps leak at shaft seals.

Any solution leakage at elevated pressure will result in H_2S leakage flashing out of solution at atmospheric pressure.

If these pumps are to be housed in a building where H_2S leakage would be confined then some sort of seal draw-off or buffering is a necessity.

The most critical problem with pumps handling a solution in which H_2S is absorbed is the leaking of the solution and subsequent flashing of the H_2S.

Most leakage occurs at the pump shaft seal.

Three types of pumps are used for solution handling: reciprocating, centrifugal and rotary pumps. Any of these types could be used for solutions containing H_2S.

Reciprocating pumps are used for high pressures and relatively low flows.

Centrifugal pumps are the type most used in the chemical industry and will predominate in large synthetic fuel plants. They can be built for very large flows and can achieve relatively high pressures by adding to the number of stages. Centrifugal pumps will be used for acid gas (H_2S, CO_2) removal in large systems. The Benfield HPC system is a good example. Large amounts of hot potassium carbonate must be circulated at pressures up to 1200 psi. Centrifugal pumps will also be used in sulfur recovery plants such as the Stretford.

Rotary pumps are usually used for special systems. The flows and pressures are usually limited and they would not seem to play a large part in future synfuel plants. Leakage from the pump is restricted by the shaft seal.

There are three general types of shaft seals:

- o Packed seals
- o Single mechanical seals
- o Double mechanical seals

Packed seals are usually used on small low pressure pumps. They are used on reciprocating pumps because mechanical seals are for rotating shafts. This type of seal must be lubricated either by injecting a lubricant in some type of lantern ring or by allowing the seal to leak and so obtain lubrication.

Single mechanical seals utilize two sealing surfaces facing perpendicular to the shaft, one stationary and one rotating. The face surface must be lubricated. Again, this can be accomplished by injecting some form of lubricant or allowing a small amount of leakage. Single mechanical seals operate best on clean liquids. This type of seal does not look promising for handling solutions containing H_2S.

Double mechanical seals are usually two single mechanical seals mounted back-to-back to provide a void space between. Seal fluid is circulated through this void space at somewhat higher pressure than the process stream. Another configuration has the circulating seal fluid at a lower pressure than the process stream. This provides limited flow of the product stream into the sealing fluid. This appears to be a satisfactory arrangement for pumps handling solutions containing H_2S.

Conclusions

For pumps handling solutions in which H_2S is present the preferred type will be the centrifugal.

Because of the toxic nature of the gas in solution double mechanical seals should be used.

Valves for H_2S

The major problem associated with valves which are handling a solution with entrained H_2S or H_2S gas is leakage from the valve stem packing. This problem has been solved in nuclear installations by using "bellows seal valves," which allow no stem leakage as long as the protective bellows is not ruptured.

This type of construction is expensive but it offers the safest type of valve for toxic gases in general and H_2S in particular.

Another method is to use a draw-off stream from the valve packing similar to that used on compressor seals.

It is feasible to construct leak-proof gas systems for handling H_2S. "Canned" compressors, pumps that are also "canned" or equipped with double mechanical seals, and bellows seal valves are all required for leakproof systems. However, it is not known how large "canned" compressors and pumps can be constructed.

EFFECTS OF CATASTROPHES ON SYNTHETIC FUEL PLANTS

Catastrophes which could have impacts on synthetic fuel plants can be classified as follows:

- o due to natural events:
  - Earthquakes;
  - Windstorms such as cyclones and tornadoes;
  - Lightning; or,
- o manmade:
  - Sabotage;
  - Bombing.

It may be well to review past experience in synthetic fuel production.

There are two types of coal synfuel plants--gasification and liquefaction. However, synthetic fuels are usually taken to mean liquid fuels, and this report will concentrate on this type.

Gasification is a requisite for synthetic liquid fuel production. It is required for the production of hydrogen for the coal hydrogenation process and also for the production of synthesis gas ($CO + H_2$) for the Fischer-Tropsch reaction.

The best example of the synthetic liquid fuel industry was the work of the Germans, who literally fought a war on synthetic liquids made from coal.

The primary need for the German war machine was high-octane aviation gasoline and for this product coal hydrogenation was favored.

The other process used for synthetic liquid fuel was the Fischer-Tropsch process or, as it was later known, gas synthesis. This process required reacting a 3-to-1 mixture of H_2 and CO on a catalyst at about 450 psig. This process made a wide spectrum of products, including motor gasoline.

However, the main effort and most production in Germany was coal hydrogenation.

After the war the U.S. Army brought over to the United States the top German synthetic fuel technologists and also loaned the Missouri Ordnance Works at Louisiana, Missouri, to the Bureau of Mines so that synthetic liquid fuel plants could be built at that location.

The Missouri Ordnance works was a 15,000 psig ammonia plant which made that product for the Army during the Second World War. It was ideal for a coal hydrogenation plant, since the equipment already existed for producing hydrogen and compressing it to 11,000 psi.

The coal hydrogenation plant was designed for 160,000 SCFH of hydrogen.

Both a coal hydrogenation plant and a gas synthesis plant were built at the Ordnance Works site. The major effort was on coal hydrogenation.

The team sent over by the Army was composed of coal hydrogenation specialists headed by Dr. Ernest Donath who had been in charge of the coal hydrogenation plants in Germany.

According to Dr. Donath almost half of the German fuels and most of the high octane gasoline was made by the coal hydrogenation plants. The production from these plants was over 100,000 barrels per day.

The Bureau of Mines built a coal hydrogenation plant and a gas synthesis plant basically to German design.

The coal hydrogenation plant operated at 700 atm. (10,000 psi) and required an ongoing program to have American manufacturers build this high pressure equipment. All of the equipment used was of American manufacture.

The gas synthesis plant operated at 450 psig and used essentially standard equipment.

It is of interest that the two synthetic liquid fuel plants built in the United States (the H-Coal and the Exxon Donor Solvent plants) are both coal hydrogenation plants.

It is doubtful that a gas synthesis plant using coal will be built in the United States in the forseeable future, except for production of methanol which is not strictly a synthetic liquid fuel.

Because of the resemblance of coal hydrogenation plants to oil desulfurization plants this type may be of more interest to the oil companies which build the synthetic fuel plants.

Both coal hydrogenation plants and oil desulfurization plants require hydrogenation at 1500 to 3000 psi.

Also, a coal hydrogenation plant has a higher thermal efficiency than a gas synthesis plant.

With this background material we can now look at the problems a major catastrophe could cause to a synthetic liquid fuel plant such as a coal hydrogenation facility.

Synthetic fuel plants are built to withstand the pressure of operation. In coal hydro plants these pressures may vary from 2000 to 3500 psi. But in any case the pressure is such that a sturdy type of construction is mandatory.

In conversations long ago at Missouri with the Germans who had operated the hydrogenation plants during the Second World War, we learned that the effect of Allied bombing on the high pressure equipment was not severe.

These plants by their very nature are built to withstand extreme exterior effects.

Earthquakes

Earthquakes can occur almost anywhere but the regions of the severe ones are rather well-known.

There has been much controversy over the siting of some nuclear plants which are said to be over earth faults.

Synthetic fuel plants will certainly not be located in areas which might be subjected to major quakes.

However, if a synfuel plant is subjected to a major earthquake what would be the supposed results?

1. Due to the rugged construction of the major pieces of high pressure equipment, the damage to this equipment should be minimal. However, pipelines containing gases, liquids, and water would certainly be ruptured. This would result in the escape of process gases and liquids in the plant, which at the

very least would present a major fire hazard. Also light oil, heavy oil, coal slurry, etc., would be released through the plant. Due to the presence of fired heaters, gasifiers, etc., it may be supposed that a major fire would result from the liberation of the inflammable gases and liquids in the plant. Oil tanks, since they are not made to withstand high pressures would be especially vulnerable. A severe earthquake would be a major catastrophe to a synthetic fuel plant.

Winds, Cyclones, and Tornadoes

Due to the rugged construction of synfuel plants and their design for high wind loadings (up to 100 mph), it is doubtful that even a tornado would cause a major breakdown of a synthetic fuel plant.

However, buildings such as offices, shops, and warehouses would probably receive major damage.

The most vulnerable pieces of process equipment in a windstorm are the towers, such as absorbers, regenerators, fractionators, etc.

Each installation would have to be checked for its resistance to wind load.

Lightning

The principal effect of lightning is to cause power outages. If a synfuel plant is buying power from a utility, lightning could disrupt the power supply and stop plant operation.

The chances of a direct hit from a lightning bolt are remote.

Most of the process equipment which stands highest, and is thus most susceptible to lightning, is enclosed in a steel framework which is grounded. This is also true of the towers which are some of the highest structures in the plant.

Any lightning striking a steel framework or tower should be carried to the ground.

In other words the plant equipment should function as a lightning rod.

Sabotage

Here the amount of damage depends on the skill of the saboteur.

In normal times, plant security should be capable of plant protection.

Also, if a relatively few people are involved a certain amount of time would be required which again should give plant security an opportunity to function.

However, in wartime a highly skilled demolition team should be able to completely destroy or put out of commission any synfuel plant.

Bombing

Probably more is known of the effect of bombing on coal hydrogenation plants than any other type of catastrophe.

The German coal hydrogenation plants had a high priority on the bombers' list.

However, according to Donath, when the plants were bombed they would be out of service for several days but repair would begin immediately and the plants would soon be back in operation.

Donath calculated that bombing from the air accounted for about 20 percent downtime.

POSITION PAPER K

ESTABLISHING A REGISTRY OF WORKERS INVOLVED IN OIL SHALE AND COAL GASIFICATION AND LIQUEFACTION DEMONSTRATION AND COMMERCIAL PLANTS

Rafael Moure
Oil, Chemical, and Atomic Workers Union

INTRODUCTION

The exposures encountered in the pilot plant operations of oil shale and coal liquefaction plants have been associated with chronic occupational disease in other industries with similar exposures. For example, exposures to polycyclic aromatic hydrocarbons (PAHs) have been linked with skin malignant neoplasm in a coal hydrogeneration plant,[1] and decrease of pulmonary function after shift has been observed in underground miners exposed only to diesel exhaust fumes.[2] These experiences closely resemble coal liquefaction and oil shale experiences. Coal liquefaction workers in a pilot plant operation (SRC I, II) were reported to be exposed to PAHs exceeding in some cases the OSHA-permitted exposure limits to coal tar pitch volatiles by factors of ten.[3] Sixteen cases of skin neoplasms (two malignant) were identified among 192 workers in a period of four

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[1]R. J. Sexton, "The Hazards to Health in the Hydrogenation of Coal," Archives of Environmental Health, Vol. 1 (1960), p. 181.

[2]J. Gamble, et al., "Acute Changes in Pulmonary Function in Salt Mines," Industry Hygiene for Mining and Tunneling, Proceedings of a Topical Symposium, ACGIH, Denver, Colorado, November 1978.

[3]C. P. Wen, "Epidemiology at SRC," Gulf Science and Technology Company presentation for DOE Health and Environmental Research Conference in Direct Coal Liquefaction, Washington, D. C., July 8-10, 1981.

years of plant operation.[4] The commercial production of oil shale will require the use in underground mining of diesel equipment "several times larger than any available Bureau of Mines-approved equipment."[5] Exposure to NO_X from diesel exhaust concentrations never experienced in underground mining combined with: (a) additional NO_X exposure from extensive use of explosives; (b) oil shale dust exposure during mining; (c) diesel particulates; and (d) SO_X warrant a projection of potential chronic pulmonary disease.

The potential (oil shale) and measured (coal liquefaction) occupational health effects of the commercialization of this technology require the planning and implementation of a record-keeping method (that is, registry) that would integrate work environment characterization with medical screening capable of quantifying health effects. An occupational health program that links toxicological data with industrial hygiene survey needs should precede the establishment of such a registry. The toxicological characterization of occupational pollutants in both industries has largely been accomplished, establishing the basis to implement a sampling strategy.

CHARACTERISTICS OF THE REGISTRY

Data Collection

Demographic data of participants should include: (a) name, (b) job title (codified to specific industry), (c) work location (codified to specific industry), (d) social security number, (e) address (zip code), (f) phone number, and (g) previous job experience (details on dusty occupation and previous exposure to diesels, carcinogens, and so on.)

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[4]R. T. Cheng, "Industrial Hygiene Monitoring Program Detailed Discussions," Gulf Science and Technology Company presentation for DOE Health and Environmental Research Conference in Direct Coal Liquefaction, Washington, D. C., July 8-10, 1981.

[5]P. A. Rutledge, "Mining Problems Unique to Oil Shale," paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982.

An industrial hygiene data retrieval system could be similar to the one used by Gulf Science and Technology Company, Medical and Health Resources Division, on workers in a coal liquefaction SRC pilot plant (see Appendix A). In addition, information on accident frequency, loss time, and absenteeism should be appropriately tabulated in retrieval form.[6]

A computer retrieval data of medical surveillance, including information from biological monitoring and past medical history, should be the data basis for health effects.[7] (See Appendix B.)

Data Analysis

Once the data described in Appendix A are available in computer retrievable form, a series of questions on possible correlations between exposures and effects should be posed. These questions would generate hypotheses of possible correlations to be tested by epidemiologic means (cross-sectional studies, case-control studies, for instance). Definitions of the size of the group to be studied, the comparison group, and the statistical power of the tests to be applied to evaluate such hypotheses would follow the choice of the epidemiological studies to be conducted.

CONCLUSION

The establishment of a registry would include the compatible compilation of different data sources (demographic, industrial hygiene, medical), and the design of specific questions to be tested with the collected data. Failure to design a registry without knowing precisely what specific hypotheses need to be evaluated would result in compiling unnecessary data or missing essential data for future studies.

It is essential that data formats be compatible for use between different operators of the industry. The most appropriate repository of an occupational health registry would be the federal government,

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[6] Wen, op. cit.

[7] R. Moure-Eraso, "Industrial Hygiene and Medical Data Collection in a Coal Liquefaction Pilot Plant," Paper presented at committee's Workshop on Synthetic Fuels Facilities Safety, La Jolla, California, January 1982.

in particular, the agency of the federal government in charge of occupational health research--the National Institute for Occupational Safety and Health (NIOSH). The reasons are multiple:

- NIOSH's exclusive mission is to prevent adverse health consequences of industrial environments without the conflicting burden of simultaneously promoting and developing the industry to be monitored (as is the case with the Department of Energy and the American Petroleum Institute).

- NIOSH has the technical expertise to institute occupational health registries in general (as it has for beryllium, DBCP, aluminum and others), and the specific particular knowledge of the synthetic fuel industry which will enable the institute to design valid protocols for relevant occupational health studies.

- NIOSH would guarantee that the data on a registry would be homogeneous and comparable for operators in the same industry (that is, shale oil and coal liquefaction).

- NIOSH has the industrial hygiene, medical, and epidemiological expertise in-house to design, plan, and implement a scientifically sound occupational health registry.

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APPENDIX A

SOURCE: R.T. Cheng, "Industrial Hygiene Monitoring Program Detailed Discussions," Gulf Science and Technology Company presentation for DOE Health and Environmental Research Conference in Direct Coal Liquefaction, Washington, D.C., July 1981.

EPIDEMIOLOGY AT SRC

1. Clinical Epidemiology

   o Annual mandatory (regulatory, preventive) exam
     - Medical
     - Laboratory results (CBC, SMA, pulmonary function, urinalysis, audiometric test)
     - Physical

   o Preplacement exam

2. Prospective Epidemiology

   o Cancer registry
   o Morbidity-illness and accident reporting
   o Mortality registry

3. Retrospective Epidemiology

   o Cohort study (of active, retired, and terminated employees)
     - Mortality
     - Annual medical history update

4. Reproductive Epidemiology

   o Fertility
   o Birth defects
   o Fetal wastages
   o Perinatal mortality
   o Women in the work place

5. Applied Epidemiology

   o Health services evaluation (cost, quality, process, outcome)
   o Cost-benefit analysis

Records

A medical file is kept on every permanent employee and each contractor or temporary employee who has worked in the process control area more than 30 days. These individual records, as a whole, include:

- Accident reports
- Audiogram
- Authorization for release of medical information
- Blood pressure record
- Dermatology reports
- Hemoccult examination results
- Medical correspondence
- New employee check list
- Personal medical record
- Physician certificate
- Pre-employment report of medical examination
- Pulmonary function test
- Relevant prescriptions
- Signed forms showing that the employee received the pre-employment orientation and understood its components
- Skin examination
- Work history
- Daily medical record
- Summary record of pulmonary and skin abnormalities
- Black-Speck examination sheets
- Completed written test SRC Pilot Plant health protection orientation

Physical Examinations

Preplacement examinations provided to establish baseline data on individuals prior to employment.

Composed of:

a. Family, medical, and work history

b. Physical examination by a medical doctor

c. Audiogram and visual test

d. Chest x-rays (posteroanteror and lateral)

e. Complete blood count and blood chemistries

f. Hemoccult

g. Pulmonary function test

Completed examination forms are sent to the plant nurse for approval, then to the Regional Medical Director for review and filing.

APPENDIX B

SOURCE: C.P. Wen, "Epidemiology at SRC," Gulf Science and Technology Company presentation for DOE Health and Environmental Research Conference in Direct Coal Liquefaction, Washington, D.C., July 1981.

SRC INFORMATION SYSTEM
FIELD INFORMATION
PART ONE

Item		Column
1. FIELD SAMPLE NUMBER		1
2. SAMPLE DATE		10
3. SHIFT		16
4. SAMPLE LOCATION:	4A. AREA CODE	17
	4B. UNIT OR EQUIPMENT CODE	20
5. EMPLOYEE	5A. EMPLOYEE NUMBER	28
	5B. JOB DESCRIPTION	34
	5C. NORMAL JOB LOCATION	36
	5D. MAJOR JOB SITE ON SAMPLING DATE	39
	5E. MINOR JOB SITE ON SAMPLING DATE	42
	5F. SAMPLING TIME ON MAJOR SITE	45
6. PLANT OPERATING CONDITIONS		46
7. AREA OPERATING CONDITIONS		47
8. UNIT OR EQUIPMENT OPERATING CONDITIONS		48
9. WEATHER CONDITIONS		49
10. TYPE OF SAMPLE		50
11. SAMPLING PARAMETER AND METHOD		51
12. WIPE SAMPLES:	12A. WIPE SITE	53
	12B. WIPE TIME	54
	12C. PROTECTION	55
13. CARD TYPE		79 (T 1)

PART TWO: LABORATORY INFORMATION

FIELD SAMPLE NUMBER	LAB SAMPLE NUMBER (10)	ANALYSIS (22)	RESULTS (25)	UNIT (32)	TYPE (79)
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2
					T 2

SRC INFORMATION RETRIEVAL SYSTEM

INFORMATION CODES

PART TWO

Computer Code	Item
01	Gravimetric Weight - Total Particulates
02	Gravimetric Weight - >7.2μ
03	Gravimetric Weight - <7.2μ Respirable Particulate
04	Benzene Soluble Weight
05	α-Quartz
06	Asbestos
07	Cadmium
08	Lead
09	Zinc
10	
11	
12	Total Hydrocarbons as Benzene
13	Benzene
14	n-Hexane
15	Toluene
16	Xylenes (m, ø, p)
17	Process Solvent
18	Plant Light Oil
19	Wash Solvent
20	Aromatics
21	Aliphatics
22	Hydrogen Sulfide
23	Phenol
24	Sulfur Dioxide
25	Carbon Monoxide
26	Carbon Dioxide
27	Total Aromatic Amines
28	
29	Total Polynuclear Aromatic Hydrocarbons
30	Benzo(a)pyrene
31	Anthracene
32	Fluoranthene
33	Pyrene
34	Benzo(a)anthracene

Type of Analysis:

Computer Code	Item
35	Chrysene
36	Coronene
37	Benzo(e)pyrene
38	Dibenz(a,h)anthracene
39	Acenaphthene
40	Fluorene
41	Phenanthrene
42	Benzo(b)fluoranthene
43	1,2,4,5-Dibenzopyrene
44	Benzo(g,h,i)perylene
45	Skin Wash - Total μg
46	Skin Wash - $\mu g/cm^2$
50	Aniline
51	Ortho-toluidine
52	2,4-Dimethylaniline
53	N,N-Dimethyl-para-toluidine

Unit:

Computer Code	Item
1	mg/m^3
2	$\mu g/M^3$
3	ng/m^3
4	%
5	ppm
6	ppb
7	fibers/cc
8	g/m^2/30 days
9	mg/m^2/30 days
0	μg
A	$\mu g/cm^2$

```
ADD RECORD,FILE=61,DCNAME=DATAIN1

FILE TO BE UPDATED : 61
RECORD LENGTH      :   80
BUFFER COUNT       :  100
CARD TYPE FLAG     : Y
RECORD FORMAT      : F
MISC               :
  AUX  0
ENDFILE INPT

END
NUMBER OF RECORDS :      90 ADDED

ENDFILE SYSIN
JOB DONE
```

000103	0	81000103	0306813040				63343481040	Y1113 F5	T1	ADDED
00010345	0	81000103	F81-176-02	45	3.3	0			T2	ADDED
C0010346	0	81C00103	F81-176-02	46	0.68	A			T2	ADDED
000203	0	01000203	0306813040				63343401040	Y1113 E6	T1	ADDED
C0020345	0	81C00203	F81-176-03	45	VOID	0			T2	ADDED
00020346	0	81000203	F81-176-03	46	VOID	A			T2	ADDED
000303	0	81000303	0306813010				46087901010	Y1113 F5	T1	ADDED
C0030345	0	81C00303	F81-176-04	45	3.4	0			T2	ADDED
00030346	0	81000303	F81-176-04	46	0.67	A			T2	ADDED
000403	0	81000403	0306813018				46887901010	Y1113 E6	T1	ADDED
C0040345	0	81000403	F81-176-05	45	0.7	0			T2	ADDED
00040346	0	81000403	F81-176-05	46	0.1	A			T2	ADDED
C00503	0	81C00503	0306813091				78421001051	Y1113 F5	T1	ADDED
00050345	0	81000503	F81-176-06	45	0.6	0			T2	ADDED
C0050346	0	81000503	F81-176-06	46	0.1	A			T2	ADDED
C00603	0	81C00603	0306813091				78421001051	Y1113 E6	T1	ADDED
00060345	0	81000603	F81-176-07	45	0.7	0			T2	ADDED
C0060346	0	81C00603	F81-176-07	46	0.1	A			T2	ADDED
C00703	0	81C00703	0306813020				55062701070	Y1113 F5	T1	ADDED
00070345	0	81000703	F81-176-08	45	VOID	0			T2	ADDED
C0070346	0	81000703	F81-176-08	46	VOID	A			T2	ADDED
000803	0	81000803	0306813020				55062701020	Y1113 E6	T1	ADDED
C0080345	0	81000803	F81-176-09	45	1.4	0			T2	ADDED
C0080346	0	81C00803	F81-176-09	46	0.3	A			T2	ADDED
000903	0	81C00903	0306813081				55703101081	Y1113 F5	T1	ADDED
C0090345	0	81C00903	F81-176-10	45	VOID	0			T2	ADDED
C0090346	0	81000903	F81-176-10	46	VOID	A			T2	ADDED
001103	0	81001103	0306813010				69409601	Y1113 F5	T1	ADDED
C0110345	0	81001103	F81-176-14	45	0.9	0			T2	ADDED
00110346	0	81001103	F81-176-14	46	0.18	A			T2	ADDED
001203	0	81C01203	0306813010				65405601	Y1113 E6	T1	ADDED
C0120345	0	81C01203	F81-176-15	45	8.9	0			T2	ADDED
00120346	0	81001203	F81-176-15	46	0.17	A			T2	ADDED
C01303	0	81C01303	0305813020				312001020	Y1113 F5	T1	ADDED
C0130345	0	81001303	F81-176-16	45	0.9	0			T2	ADDED
C0120346	0	81001303	F81-176-16	46	0.17	A			T2	ADDED
C01503	0	81001503	0306813040				84572301040	Y1113 F5	T1	ADDED
00150345	0	81C01503	F81-176-17	45	21	0			T2	ADDED
00150346	0	81C01503	F81-176-17	46	4.2	A			T2	ADDED
C01603	0	81C01603	0306813040				84572301040	Y1113 E6	T1	ADDED
C0160345	0	81001603	F81-176-18	45	8.5	0			T2	ADDED
C0160346	0	81C01603	F81-176-18	46	0.1	A			T2	ADDED
001703	0	81001703	0306813040				55698301040	Y1113 F5	T1	ADDED
C0170345	0	81001703	F81-176-19	45	0.0	0			T2	ADDED
C0170346	0	81C01703	F81-176-19	46	0.80	A			T2	ADDED
001803	0	81001803	0306813048				55698301040	Y1113 E6	T1	ADDED
C0180345	0	81C01803	F81-176-20	45	1.4	0			T2	ADDED
00180346	0	81C01803	F81-176-20	46	0.28	A			T2	ADDED
001903	0	81001903	0306813081				46997601081	Y1113 F5	T1	ADDED
C0190345	0	81C01903	F81-176-21	45	7.0	0			T2	ADDED
C0190346	0	81001903	F81-176-21	46	1.4	A			T2	ADDED
C02003	0	81C02003	0306813081				46997631081	Y1113 E6	T1	ADDED
C0200345	0	81C02003	F81-176-22	45	0.71	0			T2	ADDED
00200346	0	81C02003	F81-176-22	46	0.15	A			T2	ADDED
C02103	0	81C02103	0306813091				63327701051	Y1113 F5	T1	ADDED
C0210345	0	81C02103	F81-176-23	45	0.8	0			T2	ADDED
00210346	0	81002103	F81-176-23	46	0.2	A			T2	ADDED
C02203	0	81002203	0306813091				63327701050	Y1113 E6	T1	ADDED
00220345	0	81C02203	F81-176-24	45	0.4	0			T2	ADDED
C0220346	0	81C02203	F81-176-24	46	0.09	A			T2	ADDED

POSITION PAPER L

INDUSTRIAL HYGIENE AND MEDICAL DATA COLLECTION IN A COAL LIQUEFACTION PILOT PLANT

Rafael Moure
Oil, Chemical, and Atomic Workers Union

This series of tables presents the industrial hygiene data of a Pilot Coal Liquefaction Operation (SRC I, II) collected by Pittsburgh-Midway Coal, a subsidiary of Gulf Oil Corporation. (Figure 1 provides a layout of the SRC Pilot Plant.) Gulf's Corporate Office of Occupational Health collected occupational health data for the U.S. Department of Energy (DOE) at the Fort Lewis, Washington plant from 1974 to 1981. The evaluation of these data comes from two sources, an Oil, Chemical, and Atomic Workers Union (OCAW) health hazard evaluation conducted by the OCAW Health and Safety Department at the same facilities in April 1981, and the DOE evaluation on occupational and environmental health of the SRC-II program based on the Fort Lewis-Gulf data. This evaluation took place in a DOE-sponsored meeting in July 1981. Most of the conclusions and evaluation of the presentation are based on the evaluation of the Fort Lewis data by teams of experts on toxicology, industrial hygiene, ecology, and environmental control.

AREA DESIGNATIONS

Area	Descriptions
01.0	Coal Preparation Area
02.0	Preheater and Dissolver Area
03.0	Mineral Separation Area
04.0	Solvent Recovery Area
05.0	Gas Recovery and Recompression Area
06.0	Partially Paved Storage Area
07.0	Paved Storage Area
08.1	Product Solidification Area
08.2	Solid Product Storage Area
09.1	Process Waste Water Disposal System
09.2	Tank Farm
09.3	Cooling Water
09.4	Boilers
09.5	Hydrogen/Synthesis Gas and Inert Gas Generation and Desulfurization Units
09.6	Control Building
09.7	Shop and Warehouse Building
09.8	Dowtherm System
09.9	Dry Chemical Storage Building
10.0	Lummus Unit

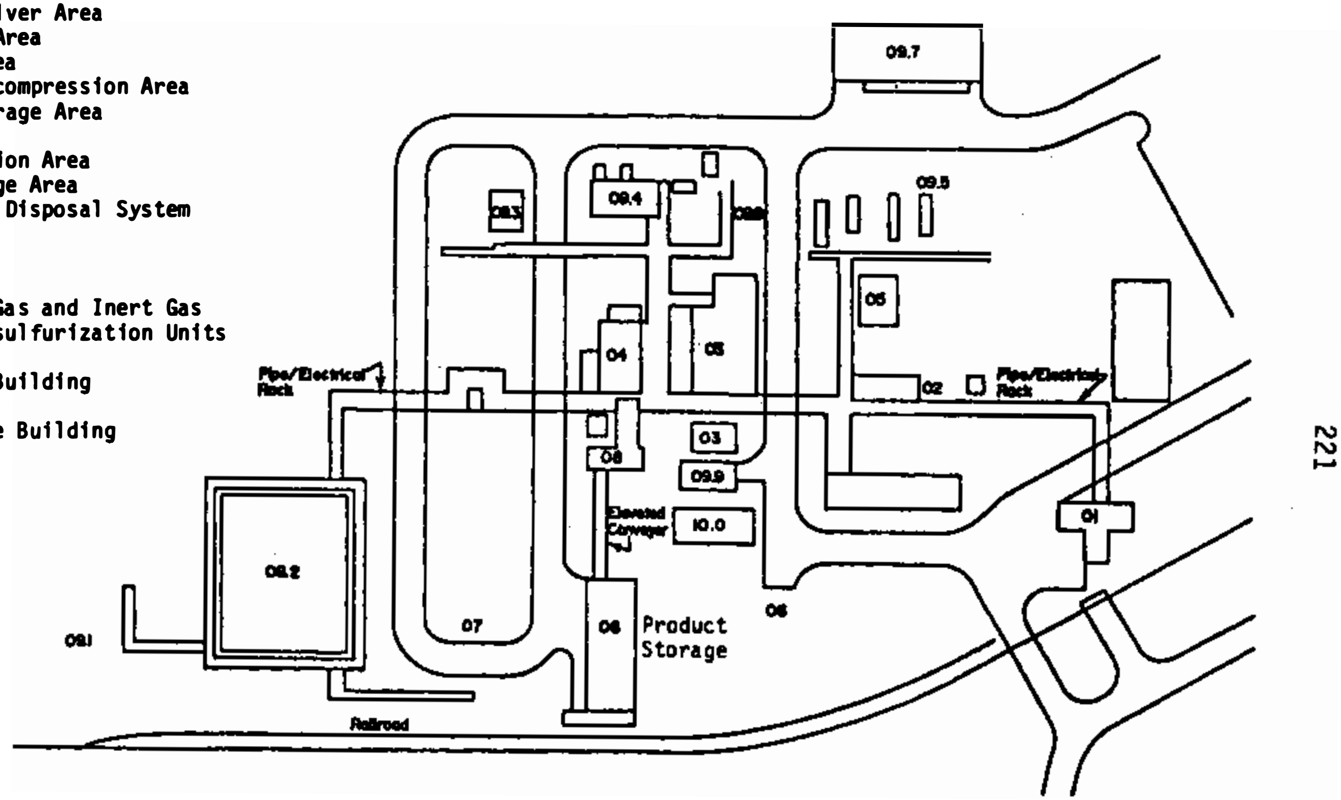

Figure 1 Layout of SRC Pilot Plant, Ft. Lewis, Washington

SOURCE: W. Hubis, "Solvent Refined Coal Pilot Plant and Process, Fort Lewis, Washington," paper presented at DOE Health and Environmental Research in Direct Coal Liquefaction Conference, Washington, D.C., July 8-10, 1981.

TABLE 1 Evaluation of Occupational Health Program, Fort Lewis, Washington, Coal Liquefaction Pilot Plant (Pittsburgh-Midway Coal Co.), by DOE Industrial Hygiene Research Review Team

Positives	Negatives
General	
* Industrial hygiene substantial data collection	* Overall program planning and implementation program not explained
* Aggressive program	* No comprehensive plan
* Innovation (original skin wash technique) instrumentation and evaluation	* Care should be exercised if extrapolating is attempted for other SRC process
	* Apparent low budget misleading (due to DOE subsidies) does not reflect actual cost of program
Exposure Monitoring	
* Extensive number of samples taken for every contaminant	* No sampling strategy defined
	* Oversimplification of exposure picture
	* No information on number of samples exceeding guidelines or standards
	* No special treatment of exposures during extended 12-hour shifts
	* Common exposures to CO and H_2S were serious problems during this operation

TABLE 1 (continued)

Positives	Negatives
	* No evaluation of exposures to catalysts
Medical Health Program (Epidemiology)	
* Good efforts to characterize skin exposure to coal products	* No apparent specificity of medical screening to hazards identified by industrial hygiene surveys (except skin examination)
* Most of the elements to develop dose response relationship present in the program	* No attempt to correlate industrial hygiene data to medical screening results
	* No protocol for prospective epidemiologic studies
	* No attempt to establish a registry of workers

Recommendations

The dual charter of DOE, on one hand to promote and develop energy systems and, on the other, to protect workers against potential adverse consequences, limits the scope of research in occupational health and thwarts initiatives for prevention.

TABLE 1 (continued)

The epidemiologic studies that could be based on the data collected should be conducted or reviewed by the governmental agency in charge of occupational health research. NIOSH is this agency which should be encouraged to promote the interfacing of the data banks and establish a registry on workers involved in the Fort Lewis, Washington operation.

Source: "Industrial Hygiene Research Review," draft from DOE Health and Environmental Research in Direct Coal Liquifaction, 1975-1981: A Case Study (Washington, D.C.: U.S. Department of Energy, 1981).

TABLE 2 Industrial Hygiene Data, Fort Lewis, Washington, PMCM Coal Liquefaction Facility (SRC I)

Air Contaminant Monitored	Number of Samples	Range Concentration	OSHA PEL	Observations
Organic vapors--benzene, toluene xylene (BTX)	120	31-0.02 (ppm)	10 ppm	Five samples above OSHA PEL 04 area and casting SRC slabs. Most concentrations below 0.1 ppm
Particles benzene-soluble fraction	23	1.3-0.0023 mg/m^3	0.2 mg/m^3	Five samples above OSHA PEL. Area samples
Welding fumes	4	0.29-0.001 mg/m^3	Various	No values above OSHA PEL's
Benzene solubles in welding fumes, coal products, contaminated parts	5	0.33-0.13 mg/m^3	0.2 mg/m^3	Four samples above OSHA PEL work on 03 and 031 areas
Asbestos	23	4.9-0.00 f/ml	2 f/ml	One sample above OSHA PEL. Asbestos concentrations greatly decrease when glove box is in use
% Quartz in mineral residue	12	7-3%	--	Average 4.5% quartz
Hydrogen sulfide	34	0.47-000 ppm	20 ppmC	None detected in 21 samples; 5 samples above 0.1 ppm
Sulfur dioxide	42	0.50-0.01 ppm	5 ppm	34 samples below detectable limit

TABLE 2 (continued)

Air Contaminant Monitored	Number of Samples	Range Concentration	OSHA PEL	Observations
Phenol cresol	78	0.04-0.00 ppm	--	72 samples below detectable limit or less than 0.01 ppm
Carbon monoxide	51	10,000-0.00	50 ppm	At least 10 locations in 01 Area and 3 in 050 Area potentially above OSHA PEL. Six samples above 3000 ppm Detector Tube-Area Sample.

Source: R. Moure and L. Rudolph, OCAW Health Hazard Evaluation, Pittsburgh-Midway Coal Mining Company Coal Liquefaction Plant, Fort Lewis, Washington, OCAW Local 1-592, Denver, Colorado: 1981.

TABLE 3 INDUSTRIAL HYGIENE DATA, Fort Lewis, Washington, PMCM Coal Liquefaction Facility (SRC I)

Air Contaminant	Number of Samples	Arithmetic Mean	Range Concentration	OSHA PEL	Observation
SRCI benzene solubles (BS)	9	0.09 mg/m^3	0.26-0.01 mg/m^3	0.2 mg/m^3	01 Area, personal samples, two samples above OSHA PEL
SRC II (BS)	29	0.08	0.60-0.01 mg/m^3	0.2 mg/m^3	01 Area, personal samples, three samples above OSHA PEL
SRC I (BS)	10	0.21	0.78-0.01 mg/m^3	0.2 mg/m^3	04 Area, personal samples, 3 samples above OSHA PEL
SRC II (BS)	7	0.20	1.2-0.01 mg/m^3	0.2 mg/m^3	04 Area, personal samples, one sample above OSHA PEL
SRC I (BS)	9	2.00	7.5-0.23 mg/m^3	0.2 mg/m^3	081 Area, personal samples, all nine samples above OSHA PEL

TABLE 3 (continued)

Air Contaminant	Number of Samples	Arithmetic Mean	Range Concentration	OSHA PEL	Observation
SRC II BS	28	0.66	10-0.01 mg/m^3	0.2 mg/m^3	081 Area, personal samples, 13 samples above OSHA PEL
Hydrogen sulfide	90	--	93,000-0.01 ppm	20 ppmC	Five samples above 1000 ppm (lethal concentration), 8 samples above 2 ppm, total 13 samples above OSHA PEL
Sulfur dioxide	36	--	3.0-01 ppm	5 ppm	One sample 3 ppm, rest on or below 0.01 ppm
Phenol	119	--	0.01-0.00 mg/m^3	101 mg/m^3	Almost all samples below 0.01 mg/m^3

TABLE 3 (continued)

Air Contaminant	Number of Samples	Arithmetic Mean	Range Concentration	OSHA PEL	Observation
Organic vapors BTX (hexane)	158	--	--	Hexane 500 ppm	Eight samples showed break-through
Carbon monoxide	--	--	200-10	50 ppm	Absence of air lock at chute (010 Area) could raise exposure to 5000 ppm

Source: R. Moure and L. Rudolph, OCAW Health Hazard Evaluation, Pittsburgh-Midway Coal Mining Company Coal Liquefaction Plant, Fort Lewis, Washington, OCAW Local 1-592, Denver, Colorado: 1981.

TABLE 4 Overexposures to OSHA-Regulated Substances at PMCM Fort Lewis Plant (DOE Data)

Date	Contaminant	Location Areas	Number of Samples Exceeding OSHA PEL
May 1976	Benzene solubles of total particulate	02,02,06 03,03	5
May 1976	(Welding contaminated metal parts)	06,07,07,07	4
May 1976	Asbestos	Asbestos mixing (no isolation box)	1
May 1976	Carbon monoxide	01,05	10
1977	Benzene solubles of total particulate	08,08,02	3
1977	Benzene solubles of total particulate	04	1
1977	Benzene solubles of total particulate	12,04,04 08,09,12	13
1977	Hydrogen sulfide	04,02,04 07,07,07	13

Source: R. Moure and L. Rudolph, OCAW Health Hazard Evaluation, Pittsburgh-Midway Coal Mining Company Coal Liquefaction Plant, Fort Lewis, Washington, OCAW Local 1-592, Denver, Colorado: 1981.

TABLE 5 Gulf Solvent-Refined Coal Operations and Research

Location	Active Employees	Terminated Employees	Total
Ft. Lewis (since 1974)	199	92	291
Merriam (since about 1962)	32	50	82
P-99 (since about 1975)	22	10	32

Source: C.P. Wen, "Epidemiology at SRC," paper presented at DOE Health and Environmental Research in Direct Coal Liquefaction Conference, Washington, D.C., July 8-10, 1981.

TABLE 6 SRC Final Diagnosis from Physical Examination

		Total No.	%
1.	Infective and parasitic disease	8	6
2.	Neoplasms (benign)	16	13
3.	Endocrine, nutritional and metabolic diseases, and immunity disorders	26	20
4.	Blood and blood-forming organs	3	2
5.	Mental disorders (alcohol)	15	12
6.	Nervous system and sense organs	12	9
7.	Circulatory system	16	13
8.	Respiratory system	8	6
9.	Digestive system	9	7
10.	Genito-urinary system	7	6
11.	Skin and subcutaneous tissue	41	32
12.	Musculoskeletal system and connective tissue	24	19
13.	Congenital anomalies	3	2
14.	Symptoms, signs, and ill-defined conditions	12	9
15.	Injury and poisoning	10	8

Source: C.P. Wen, "Epidemiology at SRC," paper presented at DOE Health and Environmental Research in Direct Coal Liquefaction Conference, Washington, D.C., July 8-10, 1981.

TABLE 7 SRC Physical Examination for Neoplasms

Age	Sex	Diagnosis	
44	M	Benign nevus low back	
40	M	Benign moles; one dark seborrhei-keratosis, benign	
29	M	Benign moles	
26	M	Benign moles	
46	M	Status post left forearm mass excised	
33	M	Right anterior thigh, 3 cm X 1.5 cm Left flank 1.2 X 1.5 cm Left CVA 0.8 cm X 0.5 cm	Probable lipoma. Excision biopsy of one for definitive diagnosis
53	M	Cherry angiomata chest-abdomen	
25	M	Benign nevi base of neck	
29	M	Benign papilloma right groin	
34	M	Benign nevus mid-chest; numerous cherry hemangiomas	
33	F	Benign mole right scapula	
29	M	2½ to 3 years Hx scaling lesion-penis, problem psoriasis, possible carcinoma _in situ_; multiple skin tags	
38	M	Questionable lipoma right pretibial area	
37	M	Warty papilloma left knee	

Source: C.P. Wen, "Epidemiology at SRC," paper presented at DOE Health and Environmental Research in Direct Coal Liquefaction Conference, Washington, D.C., July 8-10, 1981.

TABLE 8 SRC Nonmelanoma Skin Cancer Incidence, 1976-1980

Age	Person-years	Rate*	Expected	Observed	SIR
15 - 24	111.55	2.1	0.002		
25 - 34	474.66	34.4	0.163		
35 - 44	221.64	142.7	0.316	1	
45 - 54	183.63	361.7	0.664		
55 - 64	55.59	662.1	0.368	1	
			1.513	2	1.32

* Rate per 100,000 population based on NCI incidence data from Seattle, Washington for white males, 1977-1978.

Source: C.P. Wen, "Epidemiology at SRC," paper presented at DOE Health and Environmental Research in Direct Coal Liquefaction Conference, Washington, D.C., July 8-10, 1981.

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POSITION PAPER M

RESEARCH NEEDS FOR ASSESSING THE COSTS OF HEALTH AND SAFETY COMPLIANCE IN A SYNTHETIC FUEL INDUSTRY

Kenneth E. Phillips
The Rand Corporation

This paper is submitted to the members of the Commission on Engineering and Technical Systems' Committee on Synthetic Fuels Facilities Safety. It is offered to help identify the research requirements for developing methodologies to assess the costs of health and safety compliance through the life cycle of a synthetic fuels industry. The views expressed are not necessarily shared by the Rand Corporation, but are the sole resposibility of the author.

SUMMARY

This paper identifies issues and research requirements for developing methods to assess the costs of health and safety compliance during the life cycle of a synthetic fuels industry. After examining many factors that could influence the costs of health and safety compliance in energy process facilities, several general conclusions emerge.

Conclusion--Individual Research Programs Require Integration

Developing the capability to assess the costs associated with health and safety compliance in synthetic fuels facilities requires coordinating programs of research in several related areas including:

- Health Effects Research--epidemiological and toxicological studies to develop relationships between health effects and exposure levels to toxic materials.
- Research on Plant Performance and Toxic Exposure--the development of relationships to link technical measures, plant performance, and the time for worker exposure to toxic process streams during plant repairs.

- <u>Research on Cost and Performance Tradeoffs</u>--the development of relationships linking product costs to improvements in plant performance.

Most of the research requirements for developing cost methodology are concentrated in the last two areas. However, findings regarding health effects may well bring about the regulatory policies that affect product costs. Consequently, researchers developing cost methodologies will benefit from the efforts of those investigators engaged in epidemiological and toxicology studies.

Recommendation

Encourage dialogue between researchers involved in health effects studies and those investigating engineering and economic issues. Collaboration through conferences and committees represents a feasible option.

Recommendation

To account for links between health effects research, regulatory policy, and product costs, incorporate methodology to simulate policy decisions.

Conclusion--Costs May Change Over the Industry Life Cycle

The costs of protecting workers from exposure to toxic elements could reduce during the early phase of synfuels industry development because of improvements in plant performance. However, regulatory changes during later phases could drive costs up. The combined effects of these actions could produce the following health and safety cost scenario:

- Initial product costs could decline sometime after technology commercialization and before significant capacity deployment.
- Product costs could reach some minimum level for a short duration while the synfuels industry begins to grow.
- Product costs could then increase rapidly as the industry matures and begins to deploy significant synfuels production capacity.

Recommendation

Structure the research agenda to address life cycle issues in a synthetic fuels industry.

The purpose of this discussion is to identify the key research tasks required to develop the capability to assess the costs of health and safety compliance in a developing synfuels industry. Prior research has identified numerous potentially harmful constituents associated with the process and waste streams of energy plants.[1] Adequate consideration of health and safety issues implies costs that could significantly influence the required selling price of final products. Such ramifications are particularly important for determining the market competitiveness of synthetic fuels, especially when considering the return on investment that private sector firms would require and the associated price supports that might be needed to help establish a synfuels industry.

This paper reviews the likely cost-effects of different options to reduce occupational exposure to toxic elements and public exposure to environmental pollutants; dicusses the methods by which health and safety considerations could force product costs to change during the life-cycle of a synfuels industry; identifies the major research needs for developing cost analysis methodologies; and discusses strategies for undertaking research on the costs of health and safety compliance.

COST EFFECTS RELATED TO HEALTH AND SAFETY COMPLIANCE

Several methods can help reduce worker and public exposure to toxic materials. Short-term options include maintenance-level adjustments to improve plant performance, and production cutbacks to lower pollutant emission levels tied to plant calendar-day operations. Longer-term options include controlling pollution with retrofit devices; controlling pollution by modifying the basic synfuels process, and improving performance--also through changes to the process.

In addition to variability in the methods for reducing exposure levels, the costs associated with these methods also take different forms. Both fixed and variable costs apply. Capital costs, which

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1 Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, Health and Environmental Effects of Coal Gasification and Liquefaction Technologies (McLean, Virginia: The MITRE Corporation, May 1979). See also companion report Health and Environmental Effects of Oil Shale Technology (McLean, Virginia: The MITRE Corporation, May 1979); and Health and Environmental Effects of Synthetic Fuel Technologies: Research Priorities (McLean, Virginia: The MITRE Corporation, April 1981).

are fixed over a short planning horizon, apply mainly to longer term options for reducing toxic exposure. Variable costs, which are readily changeable during a short planning horizon, can apply to both short- and long-term options. Variable costs include maintenance costs, operating costs, and opportunity costs associated with revenue losses from production cutbacks.

Table 1 links the methods of reducing exposure levels to the different cost forms that apply. The methods are grouped into short- and long-term options. As suggested in the table, variable costs appear to provide the greatest number of opportunites to change exposure levels. Furthermore, every method shown affects at least three of the cost forms and these changes in cost often work in different directions. In some cases (such as improving performance through process modification) a single cost form can change in either direction.

Consider the example from Table 1 further. Modifying the process to improve performance most likely requires some form of capital investment. If, for example, an extra process step is added (perhaps to remove abrasive, suspended solids from a high-velocity gas stream) the construction time probably makes this a moderate- to long-term option. With better performance, maintenance costs will most likely decrease. However, net operating costs (related to utilities, feedstock, consumption, and so forth) could increase or decrease. This would depend upon the particular process selected, the process unit configuration chosen during engineering, plus any benefits from cogeneration and other options. Revenue changes in this case would probably increase. This would follow directly from the greater average daily production that an increase in performance would allow. Finally, since the various costs work in opposite directions, the net effects on product cost could move either up or down. Obviously, this would depend upon which individual cost forms register the greatest influence when considered in the context of discounted cash flows, tax liabilities, tax options, rates of return, and other factors.

The various forms of costs, as discussed above, move in different directions depending on the method chosen to reduce exposure levels. Table 1, shows the static interrelationships of cost effects. The next section however examines the possibilities for costs to change incrementally over time.

COST CHANGES DURING AN INDUSTRY LIFE CYCLE

As a synthetic fuels industry develops, two factors could force a change in the production cost curve as the industry moves from commercialization through deployment. First is a gradual improvement in plant performance that should follow from experience gained during plant operations. This factor is expected to lower the costs associated with health and safety issues. The second factor involves the potential for greater restrictions on occupational safety

TABLE 1 Cost Effects of Reducing Occupational and Public Exposure to Toxic Intermediate Process Streams and Environmental Pollutants

FORM OF COST OUTLAY[a]	METHODS TO REDUCE EXPOSURE LEVELS				
	SHORT-TERM OPTIONS		MODERATE-TO-LONG TERM OPTIONS		
	Performance Improvements Through Maintenance Level Adjustment	Pollution Control Through Production Cutbacks	Pollution Control Through Retrofit Devices	Performance Improvements Through Process Modification	Pollution Control Through New Process Design
Capital Costs (Fixed Outlay)	--------	--------	Increase	Increase	Increase
Maintenance Costs (Variable Outlay)	Increase	Decrease	Increase	Decrease	Increase/decrease
Operating Costs[b] (Variable Outlay)	Increase	Decrease	Increase	Increase/decrease	Increase/decrease
Revenue Changes (Variable)	Revenue increase	Revenue loss	-------	Revenue increase	--------
MOST LIKELY NET EFFECT ON PRODUCT COSTS	?	?	Increase	?	?

[a]Additional costs, independent of the method used to alter exposure levels, could involve the cost outlays for workers' protective clothing and the capital costs of instrumentation and monitoring devices to provide continual updates of worker health effects.

[b]Includes feedstock costs, utilities, etc. Feedstock costs increase with better plant performance except for oil shale plants that process lease shale.

regulations and ambient environmental standards. This factor is expected to work against the potential cost savings brought about by better plant performance.

Cost Reductions from Better Plant Performance

Prior research has demonstrated that first-of-a-kind process facilities suffer more performance problems during the first 12 months then plants that do not incorporate high levels of commercially unproven technology[2]. The findings suggest that the greatest potential for exposing workers to toxic process streams will occur during the commercialization phase of the industry. Consequently, the costs of preventive maintenance and other technologies for reducing worker exposure should be high during this period.

Later plants can benefit from the operating experience gained by first-of-a-kind facilities. As technologies mature and develop, these plants will slowly evolve into the standard facilities of the industry. Basic materials research, in combination with practical operating experience, should result in significant performance improvements over time. This can reduce the potential for prolonged worker exposure while lowering required preventive maintenance levels and other worker protection costs.[3]

Cost Increase to Meet New Regulatory Standards

The commercialization phase of the synfuels industry, and the time extending for several years into the future, represents a period during which research will be under way to determine the severity of

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[2]E. Merrow, K. Phillips, and C. Myers, Understanding Cost Growth and Performance Shortfalls in Pioneer Process Plants, R-2569-DOE (Santa Monica, California: The Rand Corporation, September 1981).

[3]Cost reductions from performance improvements are different from learning curve-cost reductions. In the latter case, cost savings are argued to derive from capital cost reductions that correspond to the amount of total industry processing capacity put in place. Learning-curve cost savings are generally viewed as a log-linear curve, with the percentage cost reduction expressed as a function of processing capacity. For discussion of the learning curve effects on synfuels facilites see W. F. Hederman, Jr., Prospects for the Commercialization of High-BTU Coal Gasification, R-2294-DOE (Santa Monica, California: The Rand Corporation, April 1978); and E. W. Merrow, Constraints on the Commercialization of Oil Shale, R-2293-DOE (Santa Monica: The Rand Corporation, September 1978).

health effects from environmental pollutants and toxic products in synfuels process streams. The future stream of results from toxicological and epidemiological studies can affect synfuels production costs in two ways. First, results could suggest that currently unregulated substances should be controlled by establishing new ambient standards. Second, the findings could suggest that currently existing standards should be strengthened. Even if no greater restrictions are applied to known levels of regulated pollutants, eventual saturation points could be reached that will require new entrants into the market to offset existing pollution levels with far more costly control technology. Innovative aspects of the new control technology may reintroduce poor performance problems and high worker exposure rates for a short time.

In either case, a relatively flat cost curve for health and safety compliance could swing sharply upward sometime during the post-commercialization phase of the synfuels industry.

Figure 1 shows the cost curves that result from better plant performance and from new or stricter regulatory requirements. The horizontal axis traces the life cycle of a synfuels industry, moving from the early stages of commercialization through full deployment.[4] The envelope curve represents a simple algebraic sum of the two separate cost curves illustrating their possible combined effects on product costs. The clear implication is that over the life cycle of the industry, costs will first decrease, reach a minimum point sometime during the deployment phase, and then rise continually as firms begin to address increasingly severe requirements to offset pollution. Clearly, the point at which costs are likely to reach a minimum depends on the combination of (1) how quickly performance problems can be corrected in first-generation plants, and (2) how much delay occurs before stricter regulations and pollution offset requirements drive costs back up. The time-related changes in the cost of health and safety compliance derive from regulations that evolve through the formulation of federal, state, and local policy. The research needs for developing cost analysis methodologies must be sensitive to this issue.

RESEARCH NEEDS TO DEVELOP COST ANALYSIS METHODOLOGY

A comprehensive program of research, encompassing three topical areas, would be required to develop the methodology for tracing health- and safety-related costs through the life-cycle of a synthetic fuels industry. The key areas include:

[4]Plant decommissioning is acknowledged. However, it is assumed that permanent facility shutdowns would be staggered and that the decommissioning costs and the associated health and safety problems would not face the entire industry in the same time period.

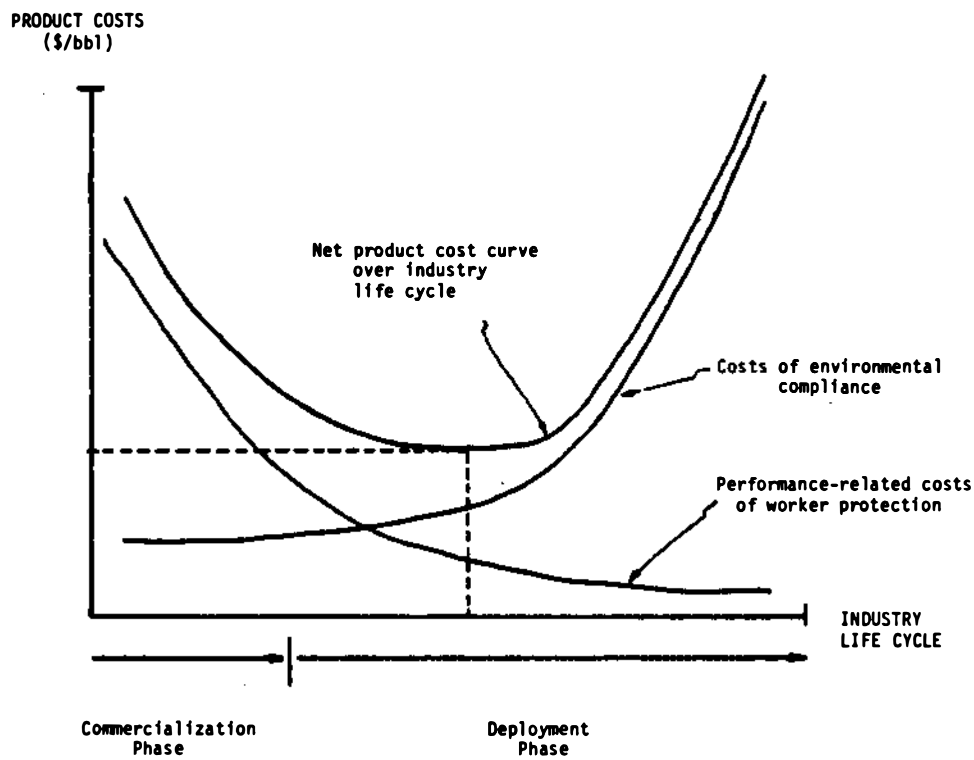

Figure 1 Change in product costs over the life cycle of the synfuels industry.

- Health effects research--epidemiological and toxicological studies to develop relationships between health effects and exposure levels to toxic materials.
- Research on plant performance and toxic exposure--the development of relationships to link technical measures, plant performance, and the time for worker exposure to toxic process streams during plant repairs.
- Research on cost and performance tradeoffs--the development of relationships linking product costs to improvements in plant performance.

Health Effects Research

Research requirements in the areas of epidemiology and toxicology have been addressed partly through the Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, and are the subject of more detailed consideration by other members of the Committee on Synthetic Fuels Facilities Safety.[5] Health effects research, mentioned later, is one element required for examining cost-benefit trade-offs. However, this discussion limits its focus to the last two areas of research need.

Research on Plant Performance and Toxic Exposure

Studying the effects of plant performance on toxic exposure levels implies a need for two related programs of research. This requirement results because the technical characteristics of a process could affect both plant performance and the toxic exposure levels that correlate with the repair time needed to correct the performance problems.

The first program of research concerns developing relationships between plant performance problems and the technical characteristics of the process. The second program would focus on developing relationships between plant performance and exposure time to toxic intermediate process streams. By implication, performance becomes the common denominator that relates technological characteristics directly to worker exposure levels.

In connection with this research, one might easily embark on a data collection strategy that would address only technological

[5] Federal Interagency Committee on the Health and Environmental Effects of Energy Technologies, op. cit. See also companion report Health and Environmental Effects of Oil Shale Technology, op. cit.; and Health and Environmental Effects of Synthetic Fuel Technologies: Research Priorities, op. cit.

characteristics and worker exposure, linking them directly through an appropriate statistical methodology. That approach is unacceptable. Linking technology and exposure rates through plant performance is necessary because performance adjustments represent one of industry's tools for complying with regulatory policy.

Prior research examined the link between technology and performance in first-of-a-kind process plants. Major findings showed that average plant performance during the first year could be predicted using measures of: the level of commercially unproven technology in the plant, knowledge about the heat and material balances, solid vs. liquid feedstock handling, and design problems for waste-stream handling.[6] These results demonstrate the feasibility of trying to predict a system's performance using technical characteristics. However, considerable need remains for developing predictive variables that relate more closely to engineering measures and process operating parameters.

Research on technology evaluation in related energy areas suggests that this can be accomplished. For example, the results from studies in ocean thermal energy conversion (OTEC) and magnetohydrodynamic power generation demonstrated that methodologies for linking system performance and engineering measures show considerable promise.[7] In addition, the literature on innovative weapons systems development offers an independent body of evidence suggesting further that engineering measures and process operating parameters can help predict cost and performance outcomes.[8]

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[6]Merrow, Phillips, and Myers, op. cit.

[7]See the following reports published by The Rand Corporation, Santa Monica, California: E. C. Gritton et al., A Quantitative Evaluation of Closed Cycle Ocean Thermal Energy Conversion Technology in Central Station Applications, R-2595-DOE (May 1980); R. Y. Pei and R. W. Hess, The Liquid-Metal Closed-Cycle System of Magnetohydrodynamic Power Generation, R-2343-DOE (December 1978); and R. Y. Pei and R. W. Hess, The Noble Gas Closed Cycle System of Magnetohydrodynamic Power Generation, R-2128-ERDA (August 1977).

[8]See, for example, Fisher's discussion for a mathematical treatment of aircraft characteristics in, G. H. Fisher, Cost Considerations in Systems Analysis (New York: The Rand Corporation/American Elsevier Publishing Company,1971). Also see the following reports published by The Rand Corporation, Santa Monica, California: A. J. Alexander and J. R. Nelson, Measuring Technological Change: Aircraft Turbine Engines, R-1017-ARPA/PR (June 1972); J.R. Nelson and F. S. Timson, Relating Technology to Acquisition Costs: Aircraft Turbine Engines, R-1288-PR, (March 1974); and J. P. Large, H. G. Campbell, and D. Cates, Parametric Equations for Estimating Aircraft Airframe Costs, R-1693-1-PA&E (February 1976).

Figure 2 shows the linkage between technical characteristics and exposure rate. The top graph corresponds to the research program for understanding the relationship between technological characteristics and plant performance. Normally, as a dependent variable, performance would locate on the vertical axis. The graph was changed to help visualize performance as the common denominator. The hypothesized relationship remains the same. The bottom chart addresses research to develop relationships between exposure levels and plant performance.

As shown by Figure 2, technical characteristics can imply different performance and worker exposure levels. Using variables from the research on first-of-a-kind process plants as an example, the vertical axis of the top graph could easily represent the number of commercially unproven process units in the plant.[9] The top curve (process 1) might represent a project with severe waste-handling design problems while the lower curve could apply to a process with no unusual problems in waste handling. Even for the same number of process steps, the plants could perform at different levels. In the case shown, process 1 performs at a higher rate than process 2.

The bottom graph shows that the differences can translate even further into different exposure levels. In the hypothetical case shown the different curves in the lower graph could well apply to variations in the complexity of each process. Process 1 represents a plant with few process units. Process 2 could have many continuously linked process steps. As a result, even when overall performance is high for both plants, if a failure does occur, the complexity of process 2 could require longer worker exposure to toxic process streams during equipment repairs.

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[9]The vertical axis could also represent process operating parameters. See D. Deutsch, and P. Kohn, "Materials, Equipment for Conversion of Coal," Chemical Engineering, (June 2,1980); L. W. Daily, "Maximizing On-Stream Time for Large Plants," Chemical Engineering Progress, Vol. 66, No. 12, (December 1980); V. S. Morello, "Improving Onstream Time in Process Plants," Chemical Engineering Progress, Vol. 66, No. 3, (March 1972); and W. Tucker and W. E. Cline, "Large Plant Reliability," Chemical Engineering Progress, Vol. 67, No.1, (January 1971). See also T. R. Shives and W. A. Willard (eds.), "Prevention of Failures in Coal Conversion Systems," Proceedings of the 24th Meeting of the Mechanical Failures Prevention Group, NBS Special Publication 468 (Washington, D.C.: National Bureau of Standards, April 1977).

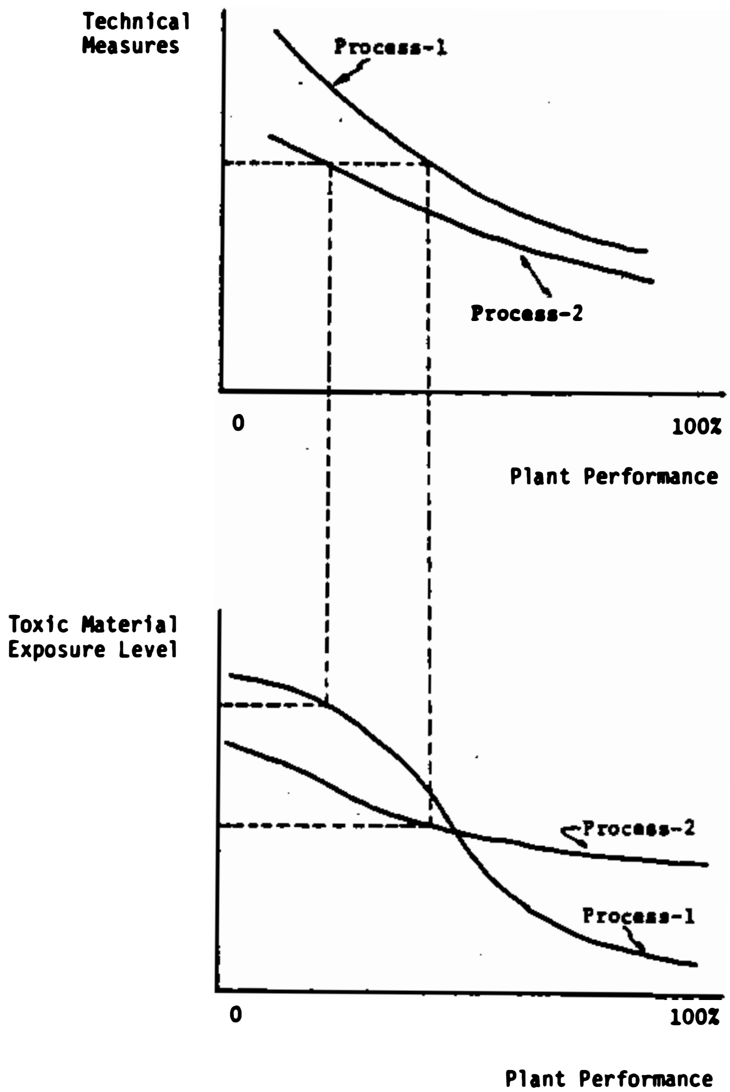

Figure 2 Plant performance as a common denominator linking technical characteristics to toxic exposure levels.

By implication, the literature on plant failures supports this argument.[10]

Research on Cost and Performance Trade-offs

Figure 3 shows hypothetical curves relating plant performance to production costs. As suggested, plant performance acts as a common denominator for technical measures, toxic exposure levels, and product costs. Performance is located along the horizontal axis to facilitate the discussion in the next section.

As noted in the discussions for Table 1 and the last section, performance represents an industry tool for bringing exposure levels into compliance with regulatory policy. The graph shows product costs because different cost forms can apply simultaneously to performance modification. See Table 1.

Integrating Research--Costs, Benefits, and Regulation

Figure 4 demonstrates the importance of integrating research on health and safety issues in synthetic fuels production. Each graph shows a form for displaying results from research in one of the three required areas. The graph in the upper left hypothesizes results from health effects research. The horizontal axis shows increasingly severe health effects as time and exposure increase. The vertical axis measures levels of exposure to toxic material; the exposure levels increase moving away from the origin. The graph in the upper right shows results from research on plant performance and toxic exposure. The graph in the lower right shows results from research on cost and performance trade-offs. (Both were explained in their respective sections earlier.) The intermediate graph relating technical measures to plant performance (top graph from Figure 2) is not included.

The health effects graph (upper left) contains the information for simulating a regulatory policy and assessing its social benefits. The policy change can be implemented along the vertical axis. The social benefits can be assessed along the horizontal

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[10]See, for example, N. D. Cox, "An Application of Reliability Theory to Process Design," Annals of Reliability and Maintainability, Ninth Reliability and Maintainability Conference, July 1970; K. M. Lewis and A. Kelly, "Maintenance Strategy, Now and In the Future," Production Developments: Papers from Production Congress '78' (Birmingham, Alabama: University of Aston in Birmingham, April 1978).

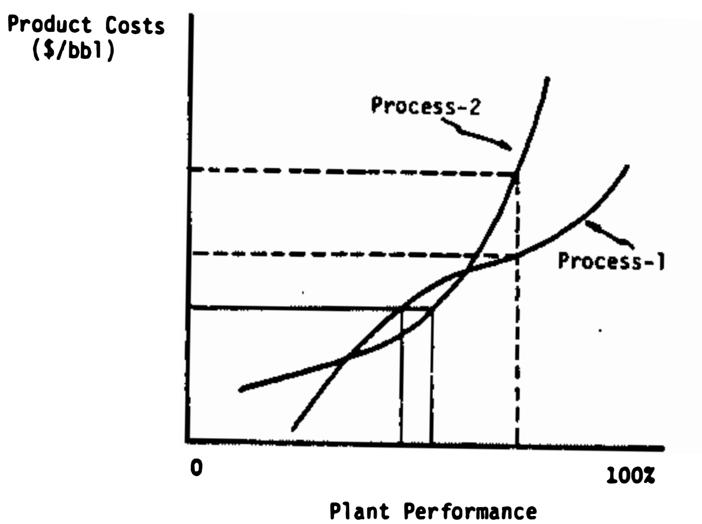

Figure 3 Research to develop relationships between cost and plant performance.

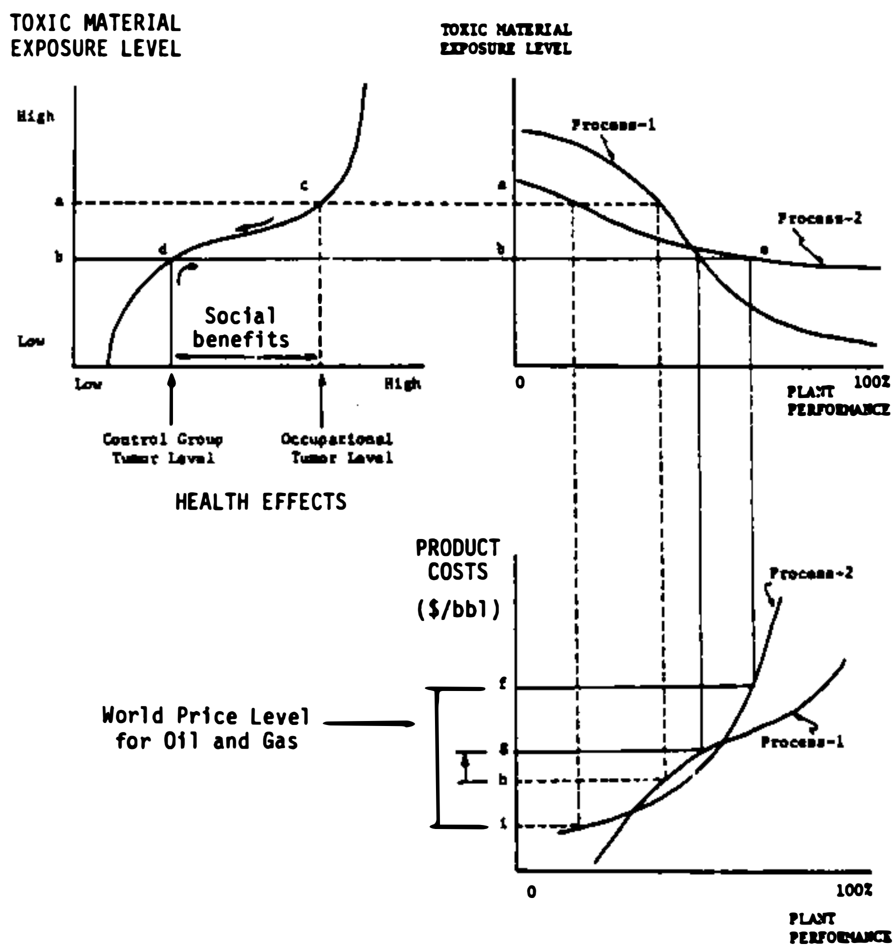

Figure 4 Integration of research on health and safety issues in synthetic fuels production (tracing the cost effects and social benefits of a regulatory policy shift).

axis. The performance-cost trade-off graph (lower right) contains the information for assessing the costs of regulatory changes. The entire figure can be read clockwise to trace the cost-effects associated with a simulated regulatory policy. The figure permits comparison among different synfuels processes.

An Example--Simulating a Regulatory Policy

Consider a hypothetical example. Begin with the horizontal axis on the health effects graph (upper left) and, for the moment, ignore all the dashed lines in the figure. Suppose that health effects investigators conclude that the level of tumor formation[11] for occupations in synfuels processing is significantly higher than for a control group of workers from all other industries. Perhaps in response to congressional hearings on these findings, legislators could enact policies to lower the maximum allowable exposure level to some particular toxic material.[12] The policy is simulated by a move from a to b along the vertical axis. It corresponds to movement from point c to d along the curve relating health effects to exposure levels. Social benefits are indicated by the net tumor difference between the occupational and control groups.

The performance-exposure graph (upper right) shows how the technical parameters of different synfuels processes can translate regulatory mandates into very different implied levels of plant performance. In this particular example, for the same level of toxic exposure, process 2 must perform better than process 1.[13]

The performance-cost trade-off graph shows how the individual cost profile for a particular process can translate the performance

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[11]Tumor formation was chosen completely arbitrarily for use with this example.

[12]An equally realistic policy would result for a first-time application of controls to currently unregulated materials.

[13]The curves in this graph, although not thought to be unreasonable, are obviously conceptual. The crossover point for the curves signals the toxic exposure level below which process 2 must perform better than process 1. At less restrictive exposure levels process 1 is required to perform better than process 2. This has interesting implications for the engineering and design of synfuels processes.

requirements into different implied product costs.[14] To comply with the simulated regulatory policy regarding toxic exposure, process 2 (at the point f) incurs far more cost impact than process 1, shown at point g.[15] The dashed lines in Figure 4 are included only to help visualize the amount of change in product costs associated with different regulatory policies. As the figure shows, for the particular case selected, a change in toxic exposure level from a to b causes the product costs for process 2 to start from a level lower than process 1 and rise to a level higher than process 1.[16]

This example demonstrates the utility of integrating research in the three areas. Although the actual investigations must, of necessity, take place within disciplinary boundaries, dialogue should be encouraged between researchers engaged in health effects studies and those investigating engineering and economic issues.

REQUIREMENTS AND CONSTRAINTS FOR IMPLEMENTING COST RESEARCH

Key logistical requirements for implementing the research agenda sketched in the previous section include model specifications, data collection, and statistical estimation of model parameters. Comments apply only to the programs of research on plant performance and exposure rates and on plant performance and product costs.

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[14]As noted in section 2, several methods and cost forms can accomplish plant performance adjustments to meet exposure level requirements (Table 1). Therefore, product cost changes may depend on changes in capial costs, maintenance costs, operating costs, and even revenue losses--depending on whether long- or short-term investment options are adopted.

[15]Product costs, as noted during the discussion for Table 1, derive from several different forms of cost (some fixed and others variable) that move in different directions depending on the method used to reduce toxic exposure. Performance is only one such method. Pollution reduction could just as well be substituted on the horizontal axes of the two charts on the right side of Figure 4. Obviously, the two methods are not exclusive. Representing both simultaneously, however, would require unnecessary complication using charts with three axes.

[16]Empirical calibration of structural relationships like those shown in Figure 4 would actually describe plant performance in probabilistic form. Therefore, the regulatory compliance costs would show up as expected values and a continuous distribution function would attach probabilities to the cost range = (g - h) for process 1 and the cost range = (f - i) for process 2.

Model Specification

Research to specify structural models for the two programs of research could proceed immediately. Available literature on equipment failures can help identify candidate variables to predict performance levels. Previous studies of plant maintenance levels can help suggest variables for measuring toxic exposure potential during repair and servicing. Discussion with industry process and plant engineers would be required to gain the proper feel for operating, maintenance and repair problems.

Data Requirements

Although the available literature can suggest candidate predictor variables, developing methods to assess the costs of health and safety compliance requires all data on a project-specific basis. A high level of industry cooperation would be required--mostly from firms in the oil and chemicals industries. Individual plant maintenance, cost, and performance histories must be surveyed and linked through the structural models. Technical characteristics for each plant would be required to match data on cost and performance. Much of the information may be proprietary.

Experience suggests that data collection and synthesis could proceed at an average rate of 5.0 plants per man year.[17] This includes time required to return to firms and discuss the information provided to assure that data are interpreted accurately and time for computerizing the data base.

Excluded is the front-end time needed to develop an appropriate data collection instrument and plant selection guidelines. Also excluded is time for meeting with industry representatives to decide which plants can yield enough data and the time for executing nondisclosure agreements.

Statistical Estimation of Parameters

Approximately six months would be required to generate preliminary findings using different statistical analysis methodologies. Data

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[17]Based on time and resources to collect data for the 44 commercial process plants underlying the statistical analyses in the Rand Corporation's research on cost and performance in pioneer plants. Companies can however require as much as six months to assemble all the information for tracing the various aspects of a plant's operating and cost history.

collection could overlap the analysis. How much, depends upon the complexity of the models and the required degrees of freedom needed for statistical purposes. Final parameter estimates for a continually growing data base could stabilize about one year after statistical analysis begins.

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POSITION PAPER N

MINING PROBLEMS UNIQUE TO OIL SHALE

Peter A. Rutledge
U.S. Geological Survey

The mining of oil shale is not analogous to any other mining. Some mines use large-opening, high-extraction-rate methods, and some mines operate under gassy conditions, but with the possible exception of salt dome mines, no mines operating under gassy conditions use large-opening, high-rate-of-extraction methods such as required for oil shale mining. This may present safety hazards as yet unknown to mining.

An Oil Shale Safety Committee was organized with members from companies with interest in the development of oil shale to collaborate on these problems. Research and regulatory changes will be required for the resolution of problems confronting this unique industry.

The five initial areas of concern which require extensive research are:

1. The ignitability of oil shale dust clouds--minimum electrical ignition energy and its thermal dependence.
2. Fire hazard of oil shale dust layers on a hot surface.
3. Development of effective face ventilation systems for large openings.
4. Investigation of the flammability and spontaneous combustion potential of coarse oil shale and determination of the most effective means of extinguishment.
5. Development of large permissible diesel-powered mining equipment.

The Bureau of Mines has the best established research center available for work in these areas. The Mine Safety and Health Adminstration is the agency responsible for approval and certification of large diesel-powered equipment which will be operated under the gassy conditions of the oil shale mines.

The size of diesel-powered equipment used in the oil shale mines will be several times larger than any available approved equipment. The temperature controls, flame arrestors, and emission controls cannot be simply scaled up from the smaller units. Safe limits and innovative devices must be developed to produce equipment of the required sizes that can be operated safely in the gassy mines.

At present, the Bureau of Mines does not have equipment large enough to test such large horsepower equipment. Through research the Bureau of Mines could develop safe limits for operation, and equipment design necessary to maintain these limits. Methods could also be developed for testing and approving the equipment to be used.

Once safe limits are established and equipment is designed to meet these limits, the Bureau of Mines could then work with the regulatory agency to write regulations governing the operations.

POSITION PAPER O

OIL SHALE FACILITIES SITING

GEOLOGIC AND ENVIRONMENTAL CONSIDERATIONS

Peter A. Rutledge
U. S. Geological Survey

RESOURCE BASE

One principal factor in determining location of surface facilities is the resource base, especially when mining by open-pit methods. It is generally accepted that areas having a stripping ratio of less than 1:1 (tons of overburden/tons of ore) are amenable to open-pit mining. The shaded area on Figure 1 indicates those areas of the Piceance Creek Basin where there are at least 100 billion barrels of shale oil in place that could be recovered from open-pit mining. There are additional areas along the southern edge of the basin at the Chevron property and at the Naval Oil Snale Reserve that could be developed by open-pit mining. The major factor in plant siting for all of these areas will be the trade-off between locations of the open pit and materials handling distances.

The area of the basin south of the Roan Plateau to the south rim and much of the Uinta basin in Utah are suitable only for mining methods such as underground room-and-pillar mining. Major siting factors will include materials handling distances and the necessity of plant protection pillars.

The area north of the Roan Plateau, but south of the open pit area, calls for some form of high column mining such as modified *in situ* retorting. Plant protection pillars and the effects of subsidence and vibration may be the significant plant siting factors.

MATERIAL HANDLING

In all cases, surface facilities must be located to minimize transportation of ore and product. Existing transportation corridors, tract configuration, and tract geology will be major considerations.

Figure 1 Map of oil shale resource area in Colorado, Wyoming, and Utah.

ENVIRONMENTAL CONSIDERATIONS

Geologic Hazards

Earthquakes

The oil shale region is in a zone-1 classification area. Therefore, the potential for earthquakes is very low. No reports of tremors have been received from the tracts since monitoring operations began in 1974, although one small earthquake occurred in Grand Junction in 1975.

Subsidence

In general, any underground mining will result in some surface subsidence. Plans developed to date produce very low (<10 ft) surface effect. Two important considerations are pillar design to promote even subsidence and eliminate sharp breaks along the property boundary, and the necessity and extent of plant protective pillars.

Alluvial Slumping

Minor alluvial slumping and associated fracturing have been observed in alluvial valleys on and near Tract C-a. No cause for this slumping has yet been identified. Slumping is characterized by opening of surface fractures ranging from a few inches to a few feet in width and up to more than 1000 ft in length.

Knowledge of likely slump locations is essential to plant siting.

ATMOSPHERIC CONSIDERATIONS

Atmospheric phenomena that must be considered follow with their applicability to the area:

- Hurricanes--no possibility. Hurricanes spawn and grow over water. Their strength weakens quickly as they come onto land and soon become low pressure storms. A hurricane could not occur over Colorado or Utah because they are too far from any coastal area.
- Tornadoes--very slight possibility. Western Colorado and eastern Utah are considered areas of very low tornado probability. Funnel clouds (tornadoes not reaching the ground) have been sighted but are rare. Should a tornado occur in this area its life would be short and it would soon revert to a funnel cloud due to the rough terrain.

- Thunderstorms--Heavy rains causing flash flooding, along with strong winds and lightning, are a real potential in these areas. Wind gusts of 50 to 60 mph have been recorded on the Colorado Lease Tracts. The winds and lightning could cause power outages and make driving conditions hazardous.
- Severe blizzards (high winds and snow)--High winds and heavy snowfalls during the winter months could cause power outages and isolation in the oil shale area.
- Winds--Except in infrequent instances, wind velocity is not considered a significant problem in the oil shale areas. During the period from 1975 to 1980, the highest record average wind velocity on Prototype Oil Shale Tract C-a was only 39 mph and the mean average hourly wind speed was 7 to 9 mph.
- Temperature extremes--Wide temperature extremes occur in the oil shale area. Yearly temperatures ranging from $-51^{o}F$ ($-46^{o}C$) to $98^{o}F$ ($37^{o}C$) have been recorded. The mean annual temperatures average between 43^{o} and $45^{o}F$ (6^{o} and $7^{o}C$). The coldest temperatures occur in the valleys as cold, dense air drains to lower elevations. Extremely high and low temperatures could affect the operation of equipment and construction schedules.
- Temperature inversions (increase in temperature with height compared with normal decrease in temperature with height)--The inversions occur frequently in the oil shale area. These inversions develop in early evening and break up or dissipate by early to mid-morning. Table 1 shows the quarterly average inversion height, onset time, breakup time, and duration at Tract C-b.

TABLE 1 Inversion Heights and Durations at Tract C-b (Quarterly Averages)

Month/Year	Average Height (miles)	Onset Time	Breakup Time	Duration (hours)
Sep 78 - Nov 78	303	1720	0820	15.7
Dec 78 - Feb 79	310	1720	0940	16.7
Mar 79 - May 79	323	1800	0740	13.7
Jun 79 - Aug 79	272	1900	0720	12.3
Sep 79 - Nov 79	266	1730	0840	15.2
Dec 79 - Feb 80	273	1600	1220	20.3
Mar 80 - May 80	283	1800	0740	13.7
Jun 80 - Aug 80	314	1820	0720	13.0
Sep 80 - Nov 80	355	1700	0920	16.3

Temperature inversions in the valleys are more critical and would cause much more of a pollution problem from stack emissions. Therefore, oil shale processing facilities must be located on the ridges or plateaus rather than in the valleys in order to meet the air quality standards. Strong, prolonged inversions have been measured in the Piceance Creek Valley, Parachute Creek Valley, and the Grand Valley area including Grand Junction. In Grand Junction, winter inversions have, on occasion, lasted up to two weeks but more commonly may last from four to six days.

HYDROLOGICAL CONSIDERATIONS

Snowmelt in this area only rarely produces high rates of runoff. The melting typically occurs at these altitudes in February and March. Normal precautions in dealing with stream-flow hazards would adequately cover this hazard, except for the highly unusual combination of a heavy snowpack and a warm rain. Such a combination has produced disastrously high runoffs as it did in the Salt Lake City flood in 1952.

Destructive thunderstorms and resultant flash floods typically occur during July through September in oil shale country. In the Piceance Basin, an almost yearly occurrence is the temporary closing of reaches of Piceance Creek Road due to alluvial cones of debris from such events. Surficial deposits at several places in the basin attest to the frequentness of such storms. The most thoroughly documented such event occurred on September 7, 1978, when 1.5 inches of rain was recorded in a two-hour period at a gage in the lower reaches of Yellow Creek. This produced a peak flow of about 6,800 cubic feet per second (cfs) in Yellow Creek and resculptured the stream channel there; normal flow at the gage is 1 to 2 cfs. Studies in this area indicate that runoff peaks of as much as 500 cfs per square mile can be expected in small drainages.

For design purposes, the prototype leases and other guidelines generally refer to considerations of "100-year storms" or "100-year floods." It must be kept in mind that a 100-year storm can produce much greater or much less runoff than that of the 100-year flood. Antecedent conditions, such as rain on a snow pack, largely govern the runoff. Also, recurrence intervals of unusual events which tend to cause great damage are imprecisely known. For example, a 100-year flood on Yellow Creek, using two methods of estimation, ranges from about 2,000 to 3,000 cfs. There is no conventional method of estimating recurrence of a flood like 1978's (6,800 cfs).

Implications of these hydrologic hazards are that:

- They should be recognized as being very likely to occur sometime during the long project life at an oil shale plant.
- They are distinctly seasonal; planning of site conditions subject to damage should take this into account. The snow-melt runoff conditions are readily anticipated, but thunderstorms are much less so.
- Physical site planning for an oil shale plant should include very conservative design features when construction is necessary in a drainageway. Earth-moving, retorting shale pile construction, and early phases of revegetation are particularly vulnerable to damage by thunderstorms.

POSITION PAPER P

POTENTIAL USES OF A SYNTHETIC FUELS WORKER REGISTRY

David A. Savitz
University of Colorado School of Medicine

In order for the committee to consider research recommendations involving worker registries, some background information on what registries can and cannot do is essential. Too often, the idea of a registry is blindly supported or opposed with inadequate considerations of its true merits. The central themes were derived primarily from Dr. John Berg through discussions and from his statements at the conference on Medical Aspects of Oil Shale Development in Glenwood Springs with supplementary ideas from the open literature.[1] The author's experience derives mostly from work in the oil shale industry as a member of the risk analysis team, though most of the comments are equally applicable to other synfuels.

The three general principles presented below may seem obvious but are rarely discussed:

1. Plans for a registry should emanate from explicitly stated needs and goals.
2. Because of the tremendous expense and cumbersomeness of a registry, it should be turned to only as a last resort for answering those questions. In the same sense, only data essential to addressing the specific needs ought to be collected.
3. The analyses to answer the questions must be built into the registry system. It is insufficient to have a general intention to do some analysis at a later date.

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[1]J.W. Berg, "Comments on Worker Registry," Conference on Medical Aspects of Oil Shale Development, Glenwood Springs, Colorado, October 28-30, 1981.

Brooke published a World Health Organization monograph discussing in general terms the use of registries in studies of health.[2] She provided a rather comprehensive list of purposes which registries can serve; the facets applicable to worker registries in synfuels merit some comment:

- Identification of individuals--A simple roster or tally of workers involved in different facets of the industry would serve to characterize in broad terms occupational exposures and provide a sampling frame for cross-sectional studies and serve as a cohort list for future historical prospective investigations.

- Immediate protection of the individual--In most discussions of worker registries, little attention is given to the time course of the health outcomes of interest. Rapid identification of such fatal diseases as lung cancer offers little solace to the sentinel individuals. For these purposes, a focus on clinical disease precursors such as abnormal cytology or decrements in lung function would offer more hope of effective early intervention. Of course, even when the victims who identify the problem cannot be helped, future workers often can be. Hazardous exposures can be quickly and accurately identified through registries, and presumably the rapid identification of unforeseen problems allows for the rapid eradication of the problem. Area statistics on mortality and cancer patterns by county, for example, can be useful,[3] especially in regions where the occupational group of interest predominates. Utilization of existing general population registries would certainly be one worthwhile consideration in the case of oil shale, which is being developed in a very sparsely populated region.

- Surveillance--A registry provides the opportunity to keep track of workers over long periods of time. Substantial work force mobility would diminish the utility of regional health statistics in identifying occupational hazards. In addition, long-latency diseases such as cancer would not necessarily be observable in the active work force. Long-term follow-up with explicit considerations of comparably long-term confounders (smoking history, prior occupational exposures) is necessary for the precise identification of occupationally induced risks. The

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[2]E.M. Brooke, The Current and Future Use of Registers in Health Information Systems (Geneva, Switzerland: World Health Organization, 1974).

[3]J.R. Goldsmith, "Geographical Pathology as a Method for Detecting Occupational Cancer," Journal of Occupational Medicine, Vol. 19 (1977), pp. 533-539.

expense and difficulty in such prospective studies must be balanced with the potential gains in deciding whether a registry ought to be employed for this purpose.

- Descriptive epidemiology--The cause-specific mortality pattern in different segments of the industry would serve the time-honored role of descriptive epidemiology--the generation of suggestions for more detailed analytical studies. Some industry-wide approach to defining exposure groups would need to be implemented to generate meaningful rates.
- Research--Part of the interest of epidemiologists and other scientists transcends the immediate concerns for worker health and tends toward more basic research questions. The question of where the line is drawn between industry's obligation to occupational health and the support of scientists' exploratory endeavors is often unclear.

Given these principles, a summary in the form of specific comments on just what registries can and cannot accomplish is called for. First, a registry is extremely beneficial to the accurate identification of occupationally induced diseases with a long latency period, such as cancer. A registry allows for detailed considerations of exposure as well as confounders in relation to a temporally distant health outcome. The possibility of a single, extremely high dose causing disease cannot be dismissed, but the emphasis here is on long-term low-dose exposures. The argument for a registry on this criterion in discussion of catastrophic events is not supportable.

Second, even a minimal registry would provide the data source for cross-sectional and case-control studies. The opportunity for active surveillance would exist if, for example, an important teratogen or skin carcinogen were discovered. A roster of this sort would be indispensable in the follow-up of acute, catastrophic exposures with delayed health effects. Without a clear identification of exposed workers, health studies would be nearly impossible.

Finally, a registry allows for the rapid identification of unexpected problems. An ongoing but unrecognized catastrophic exposure (at least as catastrophic to health as asbestos was) would be recognized in this way. Even automated monitoring can be employed to identify clusters of health outcomes requiring immediate attention. Access to detailed exposure histories would allow for a quick identification of "real" (that is, exposure-caused) epidemics versus spurious (random) clustering. Again, the goal of protecting worker's health is central and some form of a registry would be extremely useful in these apparent emergencies.

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POSITION PAPER Q

SURVEY OF WORKER EXPOSURES AT A FLUIDIZED BED COAL GASIFICATION FACILITY

J. Singh, D. Lazarevic
Clayton Environmental Consultants, Inc.
and
E. F. Vandergrift
Westinghouse Electric Corporation

The energy crisis which the United States faces today points to the drastic need for increasing the nation's use of coal over the next decade. Oil, oil shales, and natural gas have historically been the major components of U. S. energy supply even though coal reserves are far more abundant.

It is therefore important to pursue the production of synthetic fuels from coal. The U. S. Department of Energy has estimated that by the year 2000, the coal gasification industry may employ up to 140,000 workers.[1] However, currently no commercial-scale coal conversion facilities are operating in the United States, although several second-generation coal gasification processes are under development and a few demonstration pilot plants are already in operation.

It is difficult under these conditions to effectively predict how workers in the coal gasification industry will be affected, as the scale of future operations may result in different exposures than those encountered during the demonstration of a pilot plant. The potential health hazards from each process may also differ in nature and magnitude. Potential health hazards from coal conversion processes could result from silica, metals, benzene, phenolics, polynuclear aromatic hydrocarbons, heterocyclic compounds, aromatic amines, and sulfur compounds. Although the presence of these compounds in the process stream has been fully documented, little available data concerns actual worker exposures at these facilities.

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[1]U. S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, Criteria for a Recommended Standard...Occupational Exposures in Coal Gasification Plants, Publication No. 78-191 (Washington, D. C.: U. S. Government Printing Office, 1978).

The data presented in this paper are representative of worker exposures to the various contaminants during the coal gasification process.

THE WESTINGHOUSE COAL GASIFICATION FACILITY

During the early 1970's, Westinghouse Electric Corporation made its first commitment to develop an effective coal gasification process for electric power generation. The decision to pursue the development of coal gasification technology was predicated on the need to provide an acceptable alternate fuel source.

The Synthetic Fuels Division, located at the Waltz Mill Site, Madison, Pennsylvania approximately 30 miles southeast of Pittsburgh, is responsible for developing and testing an optimized coal gasification process and integrating the fuel source with combined cycle or other compatible end-uses. These other uses include fuel cells, cogeneration, and industrial applications. In addition to the Waltz Mill facility, the Westinghouse program is also supported by the Research and Development Center in Churchill Borough, Pittsburgh, Pennsylvania and the Combustion Turbine Systems Division department facilities in Concordville, Pennsylvania.

The Westinghouse process is based on fluidized bed technology similar to the fluidized beds used for over 30 years by the petrochemical industry. The process development work has been verified by operation of the 15 ton per day (TPD) process development at the Waltz Mill facility. During the gasification process, three basic mechanisms occur: devolatilization, gasification, and combustion and ash agglomeration. The technical feasibility and flexibility of the process is currently being established. The most promising characteristics of the Westinghouse process are: the ability to process all ranks of coal regardless of sulfur content or caking tendency and the compatibility with environmental considerations.

CONTAMINANT POTENTIAL

Coal gasification is certainly a viable candidate for commercialization because of the need to reduce U. S. dependence on petroleum and natural gas and the apparent advantages of the coal gasification combined cycle. This technology appears to be an attractive energy source for the electric utility industry.

Prior to acceptance in the marketplace, the environmental effects of this technology must be established. Toward that end, the data in this paper, with acknowledged limitations, are presented. The results indicate that personal contaminant exposure levels can be maintained within an acceptable level.

Major sources of personnel exposure occur from these sources:

- o Coal storage and handling,
- o Uncontained emissions from the gasification process,
- o Uncontained emissions from the cleanup system, and
- o Waste disposal.

Coal Storage and Handling

Coal feedstock for gasification purposes must be dry and of a fine-mesh size. As a result, dust is a serious problem. An ideal solution is to have an enclosed drying and crushing unit on the inlet side of the process so that the feedstock can be handled in a more favorable condition. This equipment will undoubtedly be an intrinsic part of all commercial plants. A 5 ton-per-hour unit is currently being installed on the Westinghouse Process Development Unit (PDU).

Uncontained Emissions

Each commencement of a coal gasification operation includes a pressure test of the entire system as a means of determining and repairing, if needed, any leaks. Ideally, the emissions are limited to either end of the process system, where they are isolated and can be dealt with. In practice, small leaks in the gasification and cleanup system are unavoidable due to the many reactor and pipeline connections, sample ports, and instrumentation installations.

Frequent sample taking in a development unit is essential if the process variables are to be adequately characterized. In a commercial plant, the need will be reduced with only verification of process conditions required. Personnel exposure to process vapors and solids must also be considered during disassembly or maintenance operations.

Waste Disposal

The waste disposal aspect also requires attention. In the process described in this paper, all product and vent gases are burned in a thermal oxidizer. The used cooling water is collected in a pit where the more dense settled portion or sludge is withdrawn by means of an Eden separator, a device which conveys this material to a portable bin. The water remaining in the pit is recirculated into the process, while the bin is hauled to a landfill where the contents are deposited.

The ash residue from the process is collected in two lock hoppers from which deposits are alternately removed for weighing and chemical analysis. This operation provides significant exposure to dust; however, the dust at this stage of the process consists of considerably reduced carbon content.

SAMPLING AND ANALYTICAL PROCEDURES

Three industrial hygiene surveys were conducted at the Westinghouse fluidized bed coal gasification PDU between May 1978 and August 1979. The surveys included measurements of exposure to benzene, phenolics, arsenic, lead, total and respirable dust, crystalline silica, naphthalene, and particulate polycyclic aromatic hydrocarbons (PPAH).

Sampling was conducted during five consecutive shifts for Survey 1 and during six consecutive shifts for Surveys 2 and 3. Four process technicians were monitored in all cases, and were selected on the basis of having the greatest potential for exposure from coal gas operations.

Three of the four technicians spent the entire eight-hour shift, excluding work breaks, on or around the coal gasification structure. Their assignments included taking samples in various locations and maintaining operations of the system in response to directions from the control room. Although job functions were monitored for each, there was no significant distinction in results. The results on one of the four technicians, assigned the responsibility for control and maintenance of utilities, and as a result spent less time near the structure, did show less exposure in some cases.

All samples were collected and subsequently analyzed using currently accepted methods and equipment.[2]

RESULTS AND DISCUSSION

Survey 1

Sampling results for benzene, total dust and PPAH are presented in Table 1. Benzene concentrations ranged from 0.04 to 0.5 parts benzene per million parts of air (ppm). Samples taken were within the proposed eight-hour time-weighted average (TWA) standard of 1 ppm by the Occupational Safety and Health Administration (OSHA). One sample (Process Technician [PT] 8, May 25, 1978) indicated a benzene level of 0.5 ppm, which OSHA defines as the "action level" for benzene.

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[2]U. S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, NIOSH Manual of Analytical Methods, Vols. 1 through 3, 2nd ed., Publication No. 017-033-00267-3 (Washington, D. C.: U. S. Government Printing Office, 1977).

TABLE 1 Survey 1

Workshift Process technician	Benzene (ppm)	Total Dust (mg/m^3)	PPAH (mg/m^3)
DAY		May 24, 1978	
PT - 1	0.09	2.8	0.2
PT - 2	0.1	2.9	0.03
PT - 3	0.2	3.1	void
PT - 4	0.3	1.2	0.06
		May 25, 1978	
PT - 1	0.04	1.2	<0.06
PT - 2	0.1	4.4	0.2
PT - 3	0.2	136.0	0.3
PT - 4	0.1	0.5	0.8
AFTERNOON		May 24, 1978	
PT - 5	0.1	4.0	0.2
PT - 6	0.2	0.3	<0.06
PT - 7	0.07	1.0	0.2
PT - 8	0.2	0.3	0.06
		May 25, 1978	
PT - 5	0.1	2.7	0.09
PT - 6	0.3	0.5	0.2
PT - 7	0.1	0.2	<0.06
PT - 8	0.5	0.5	<0.06
MIDNIGHT		May 24, 1978	
PT - 9	0.2	4.4	0.1
PT - 10	0.2	14.0	0.2
PT - 11	void	0.3	<0.07
PT - 12	void	1.5	0.2

Total dust results ranged from 0.2 to 136 mg/m^3. One total dust concentration of 136 mg/m^3 (PT-3, May 25, 1978) exceeded both the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) and the OSHA standard of 15 mg/m^3. Another total dust concentration of 14 mg/m^3 (PT-10, May 24, 1978) exceeded the ACGIH TLV of 10 mg/m^3.

Sampling results for PPAH, as the benzene-soluble fraction of total particulate matter, ranged from less than 0.06 to 0.8 mg/m^3. PPAH levels for PT's 3 and 4, (May 25,1978) were 0.3 and 0.8 mg/m^3, respectively, both of which are in excess of the ACGIH TLV and OSHA standard of 0.2 mg/m^3.

Sampling for phenol was conducted as follows. Area samples were collected using the conventional impinger method and silica gel tubes. Pumps were strategically placed to obtain a representative sample of the work environment. Personal samples were not collected because the possibility of an impinger breaking or the absorbing solution spilling. This parallel sampling was conducted in hope of determining a more practical method of sampling. Since results for all area samples for both sampling methods were less than the detectable limit of the sampling and analytical methods used, no comparisons could be made.

Survey 2

Table 2 presents the sampling results for benzene, total dust, PPAH, arsenic, respirable dust, and crystalline silica. Measured concentrations for benzene ranged from less than 0.02 to 0.1 ppm. Results of breathing zone sampling for benzene provided no evidence of exposures in excess of the current OSHA limit.

Concentration of total dust ranged from less than 0.2 to 97 mg/m^3. The TWA concentration of 97 mg/g^3 total dust determined for PT-3, October 25, 1978, exceeded the OSHA limit and ACGIH TLV for total "inert or nuisance dust." Due to visibly heavy loading of particulate matter on the initial filter, a new sample was started approximately six hours into the work shift. The TWA concentration reported in Table 2 is the result of time-weighting both sampling results. One of the tasks performed by this individual was hourly sampling of the ash streams. Subjectively, the observed ash sampling procedure appeared to be quite dusty; however, it is unlikely that the duration of the activity (as observed) was sufficient to account for the indicated concentrations. Except for the possibility of inadvertent contamination of this sample, no explanation of the result in terms of the activities observed is apparent.

The PPAH results ranged from less than 0.03 to 0.56 mg/m^3. Two samples, for PT-6 (October 25,1978) and PT-8 (October 24,1978), indicated concentrations of 0.56 and 0.32 mg/m^3, respectively; both concentrations are in excess of the OSHA and ACGIH limits. The remaining samples indicated concentrations below the current limit.

TABLE 2 Survey 2

Workshift / Process Technician	Benzene (ppm)	Total Dust (mg/m³)	PPAH (mg/m³)	As (mg/m³)	R.D. (mg/m³)	SiO_2 (%)	OSHA Limit (mg/m³)
DAY				October 25, 1978			
PT - 1	0.02	--	--	<0.0005	0.4	7.9	1.0
PT - 2	0.05	--	--	<0.0005	0.5	2.1	2.4
PT - 3	0.03	97.0	0.10<PPAH<0.14	<0.0005	--	--	--
PT - 4	0.03	1.1	0.13	<0.0005	--	--	--
				October 26, 1978			
PT - 1	0.04	0.72<TD<0.96	<0.14	<0.001	--	--	--
PT - 2	0.1	1.9	0.04	<0.0005	--	--	--
PT - 3	0.1	--	--	<0.0005	0.2	4.5	2.4
PT - 4	<0.02	--	--	<0.0005	0.1<RD<0.3	5<S<20	0.4<L<1.4
AFTERNOON				October 24, 1978			
PT - 5	0.06	--	--	<0.0004	0.5	8.3	1.0
PT - 6	0.06	--	--	<0.0004	0.2	21.4	0.4
PT - 7	<0.02	0.4	0.06	<0.0003	--	--	--
PT - 8	0.03	0.8	0.32	<0.0004	--	--	--
				October 25, 1978			
PT - 5	0.04	0.6	0.07	<0.0005	--	--	--
PT - 6	0.02	0.4	0.56	<0.0007	--	--	--
PT - 7	0.06	--	--	<0.0004	0.3	3.8	2.4
PT - 8	0.03	--	--	<0.0004	<0.1	>20.0	<0.5
MIDNIGHT				October 25, 1978			
PT - 9	0.04	--	--	<0.0005	0.4	3.6	2.4
PT - 10	<0.05	--	--	<0.001	0.5	20.0	0.5
PT - 11	<0.02	0.4	0.07	<0.0006	--	--	--
PT - 12	0.03	0.8	<0.06	<0.0005	--	--	--
				October 25, 1978			
PT - 9	0.05	4.0	0.04	<0.0007	--	--	--
PT - 10	0.02	0.09<TD<0.2	<0.03	<0.0005	--	--	--
PT - 11	0.02	--	--	<0.0005	0.3	<3.7	2.4
PT - 12	0.06	--	--	<0.0005	0.4	<3.6	2.4

The benzene-extracted residues of the above two samples were subjected to gas chromatographic-mass spectrometric (GC/MS) analyses for the determination of polynuclear aromatic (PNA) content. The GC/MS analyses did not indicate the presence of any polynuclear aromatic compounds, such as benzo(a)pyrene (BAP), suggesting that the benzene soluble materials may not be polynuclear in nature. Comparison of these values against the OSHA standards for PPAH may not be strictly valid since the intent of the standard is to protect workers against polynuclear aromatic compounds.

The reason for a higher than expected value for PPAH compared with the total dust content for PT-8 (October 25, 1978) is not clear, even though there are fairly large random errors associated with the determination of benzene soluble matter.

At first glance, the PPAH concentration (of greater than 0.10 but less than 0.14 mg/m^3) indicated for PT-3 (October 25, 1978) may appear inconsistent with the concentration of total dust (97 mg/m^3). However, the bulk of dust collected on the samples was probably generated during repeated sampling of C-117A and B ash; because the ash should contain little, if any, benzene soluble matter, the two results are not inconsistent.

Concentrations of respirable dust ranged from less than 0.1 to 0.5 mg/m^3. The samples for PT-10 (October 25, 1978) indicated a TWA concentration (0.5 mg/m^3) essentially equal to the calculated OSHA limit for "coal dust" containing 20.0 percent quartz.

All samples indicated TWA concentrations of arsenic less than 0.0001 mg/m^3, well below the 0.01 mg/m^3 OSHA standard for inorganic arsenic.

Survey 3

Sampling results for Survey 3 are presented in Table 3. All samples indicated TWA concentration of naphthalene to be less than 0.04 ppm, well below the 10 ppm OSHA standard.

Concentrations of total dust ranged from less than 0.1 to 770 mg/m^3.With two exceptions, concentrations were below the OSHA limit for a daily TWA exposure to total "inert or nuisance dust."

The sample collected on PT-2 (July 31, 1978) indicated a TWA concentration of 770 mg/m^3 of total dust. Due to a visibly heavy loading of the initial filter, a new sample was started approximately 2 1/2 hours into the shift. The concentration reported in Table 3 is a TWA of the individual samples.

One task performed by this individual prior to the filter change was cleaning the T-121 belt weigher. During damp weather conditions (rain and/or high humidity), the coal char tends to become wet and clogs the grating which separates the gravel and char. The cleaning of the T-121 belt weigher by the technician was not observed during the survey. Therefore, the nature of the activity (whether or not it was a dusty enough operation to account for such a high

TABLE 3 Survey 3

Workshift / Process Technician	Naphthalene (ppm)	Total Dust (mg/m^3)	Lead (mg/m^3)	Respirable Dust (mg/m^3)	Crystalline Silica (%)	OSHA Limit (mg/m^3)
Day			July 31, 1979			
PT - 1	<0.03	<0.4	<0.003	<0.1	--	--
PT - 2	<0.03	770.0	0.04	0.1	20.0	0.45
PT - 3	<0.01	6.8	<0.002	0.1	<10.0	>0.83
PT - 4	<0.04	0.5	<0.003	<0.1	--	--
			August 1, 1979			
PT - 1	<0.03	0.4	<0.002	<0.1	--	--
PT - 2	<0.02	0.9	<0.003	0.2	<5.0	>1.4
PT - 3	<0.03	0.3	<0.003	<0.1	<10.0	>0.84
PT - 4	<0.04	0.3	<0.002	<0.1	--	--
Afternoon			July 31, 1979			
PT - 5	<0.03	6.1	<0.003	0.4	10.0	0.83
PT - 6	<0.03	0.8	<0.003	0.1	<10.0	>0.83
PT - 7	Void	0.8	<0.003	0.3	5.0	1.4
PT - 8	<0.03	1.3	<0.002	<0.1	--	--
			August 1, 1979			
PT - 5	<0.03	1.6	<0.002	1.3	<1.0	>3.3
PT - 6	<0.03	3.9	<0.003	0.1	20.0	0.45
PT - 7	<0.03	1.0	<0.003	0.3	<5.0	>1.4
PT - 8	<0.03	1.2	<0.003	<0.1	--	--
Midnight			July 31, 1979			
PT - 9	<0.01	0.6	<0.003	0.1	--	--
PT - 10	<0.01	0.5	<0.002	0.1	--	--
PT - 11	<0.01	0.6	<0.002	0.3	<5.0	>1.4
PT - 12	<0.01	0.9	<0.003	0.3	<5.0	>1.4
			August 1, 1979			
PT - 9	<0.01	11.0	<0.003	1.2	4.0	1.7
PT - 10	<0.01	5.9	<0.003	1.1	5.0	1.4
PT - 11	<0.01	<0.1	<0.003	<0.2	--	--
PT - 12	<0.01	35.5	0.006	1.5	4.0	1.7

concentration) and its duration could not be determined. Except for the possibility of inadvertent contamination, no explanation for this excessive exposure is apparent.

A second excessive exposure, indicating a concentration of 35.5 mg/m^3, was determined for PT-12 (August 1, 1978).

The sampling results for airborne concentrations of lead ranged from less than 0.003 to 0.04 mg/m^3. With one exception, concentrations were well below the 0.05 mg/m^3 (50 g/m^3) OSHA limit. The sample for PT-2 (July 31, 1978) indicated a concentration of 0.04 mg/m^3. (The concentration was calculated using the same procedure discussed in the previous section on total dust). The 0.04 mg/m^3 concentration is below the permissible exposure limit, but in excess of the "action level" of 0.03.

Concentrations of respirable dust ranged from less than 0.1 to 1.5 mg/m^3. None of the respirable dust samples exceeded the OSHA limit for silica-containing respirable dust. However, crystalline silica was detected in the majority of the samples with three of these samples indicating concentrations approaching the OSHA limit for silica-containing dust. The exposures all occurred during the midnight shift.

The OSHA limit had been calculated using both the crystalline silica standard and the coal dust standard. Since exposures were below both standards, it was decided that the more stringent standard (crystalline silica) would be reported.

In view of the low levels of PPAH's found in the previous surveys and the relatively large analytical errors associated with the measurement of small quantities of these materials, it was decided to evaluate PPAH concentrations using high-volume area sampling. These results are presented in Table 4. A review of the PPAH data indicates that PPAH concentrations were low, ranging from 0.001 to 0.008 mg/m^3.

Five high-volume samples, representing the highest detected concentrations of PPAH residue at each of the five stations, were submitted to gas chromatographic-mass spectrometric (GC/MS) analyses for the determination of polynuclear aromatic (PNA) content. The selected ion monitoring technique was incorporated. Trace amounts of several PNA's (namely, fluoranthene, pyrene, benz(a)anthracene, benzo(e)pyrene, and benzo(a)pyrene) were detected.

TABLE 4 High Volume Monitoring Data

Work Shift	Date 1979	SITES									
		1		2		3		4		5	
		TSP mg/m^3	PPAH mg/m^3	TSP mg/m^3	PPAH mg/m^3	TSP mg/m^3	PPAH mg/m^3	TSP mg/m^3	PPAH mg/m^3	TSP mg/m^3	PPAH mg/m^3
Midnight	7/30-7/31	0.071	0.002	0.070	0.005	0.075	0.004	0.28	0.004	0.21	0.003
	7/31-8/1	0.060	0.001	0.045	0.002	0.057	0.003	0.061	0.001	0.12	0.004
Day	7/31	0.11	0.003	0.12	0.004	0.24	0.005	0.67	0.008	0.40	0.002
	8/1	0.088	0.002	0.058	0.002	0.089	0.003	0.13	0.002	0.17	0.004
Afternoon	7/31	0.092	0.002	0.076	0.002	0.11	0.002	0.14	0.003	0.19	0.002
	8/1	0.17	0.003	0.070	0.001	0.088	0.003	0.088	0.002	0.10	0.008
Geometric Mean		0.093	0.002	0.070	0.002	0.096	0.003	0.16	0.003	0.18	0.003

Site 1 - North side of coal feed shed (ground level)
Site 2 - Northwest of tower structure, north of oxider (ground level)
Site 3 - West of tower structure (ground level)
Site 4 - East of tower structure, between tower and coal feed shed (ground level)
Site 5 - North of water pit separator (ground level)

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POSITION PAPER R

RISKS OF SHALE OIL RECOVERY

R. J. Stegemeier
Union Oil Company of California

ISSUE

What are the risks to the public or the environment from shale oil recovery operations that may be associated with: natural disasters, sabotage, plant reliability, facility sites, and process technology?

POSITION

Based on the assumption that shale oil recovery will be concentrated in western Colorado and will involve mining of oil shale, retorting of oil shale to produce raw shale oil, and upgrading of raw shale oil to produce high-quality syncrude, risk considerations can be generalized as follows:

- o The infrequency of seismic and severe weather events in western Colorado, as compared with other areas of the nation, reduce the risks of such natural disasters to shale oil facilities to levels lower than similar risks normally experienced by similar petroleum-producing facilities elsewhere in the United States.
- o Security precautions at new shale facilities can be expected to be at least as effective as security precautions currently in place at older, petroleum-related facilities elsewhere in the United States. There is no reason for security to be of unique concern at shale facilities.
- o Plant reliability of new shale facilities can be expected to be at least as effective as for similar petroleum-related facilities. Reliability factors related to human and environmental risks accordingly should be of no special concern.
- o Sites for mining, retorting, and upgrading facilities are similar to sites that have been used for other industrial operations, particularly mining facilities, in comparably rugged terrain. Any risks posed by land slippage, river contamination, or localized air pollution can be expected to be minimal or nonexistent as a result of current engineering practices and environmental requirements.

- Process technology risks can be expected to relate primarily to questions of process operability, on-stream efficiency, and economics, with the minimization of such risks being directly related to the extent of prior research and bench-, pilot-, and demonstration-scale development. Risks to humans and the environment from shale processes can be expected to be compared with risks commonly presented by mining and petroleum operations, both of which--along with shale operations--are covered by an extensive array of environmental and safety regulations.

By placing shale operations into the context of comparable industrial operations for which risks and precautions are well known and accepted, and by assuring that shale operators comply with both the letter and spirit of existing environmental and safety laws and regulations, risks that might be posed to employees, neighbors, consumers, and the environment can be expected to be no greater than those posed by any other modern mining or petroleum operation of a comparable scale.

RATIONALE

Natural Disasters

Western Colorado, where most shale development is anticipated, is seismically stable in contrast to other areas, particularly the Far West, where similar petroleum operations have been conducted for nearly a century. No credible reason can be seen for concern over unique risks due to seismic events, given the engineering practices commonly employed to accommodate potential seismic loads.

Western Colorado weather, although occasionally harsh, is essentially free from the severe weather events that are normally experienced in other areas, particularly the Gulf Coast, the Southwest, and the Mid-West, where petroleum operations are commonplace. Again, no credible reason can be found for concern over unique risks due to severe weather events, given the engineering practices commonly employed for weather factors and the environmental regulations that cover spill prevention.

No other natural disasters can be envisioned as presenting any risks worthy of unique consideration. In comparison with petroleum operations in some frontier areas, shale operations in western Colorado present much lower levels of natural disaster risks as well as more ready access to major population centers with good communications and medical facilities.

Security

Security risks for shale operations can be considered comparable to security risks for any similar mining or petroleum-related operation. All require a moderately high level of security, and no risks requiring unusual precautions for shale operations can be envisioned.

Plant Reliability

Plant reliability and operability could be of economic concern to some shale operators, particularly those that may not have done extensive research, development, and scale up work on retorting facilities. Less concern can be expected over reliability and operability of the mining and upgrading facilities because of the similarity of these facilities to conventional mining and petroleum operations.

Assuming that only well developed processes will be commercialized because of the major financial requirements, no severe operating conditions or materials environments are likely to be encountered with shale operations that have not been encountered and controlled in other petroleum or petrochemical operations that routinely use high temperatures and pressures.

Actual risks to humans and the environment--which might result primarily from upset conditions--can be expected to be well controlled and minimal given the required compliance with fugitive emission regulations, New Source Performance Standards (NSPS), National Pollution Discharge Elimination System (NPDES) provisions, Spill Prevention Control and Countermeasure (SPCC) requirements, and OSHA and Toxic Substances Control Act (TSCA) provisions.

Facility Sites

Shale facilities can be expected to be sited on high plateaus, on benches along canyon walls, and on bottom lands in steep-walled canyons. Site-specific risks could be related to land slippage, river or stream contamination, or localized air pollution.

Land slippage appears to be an inconsequential risk because of engineering and mining standards and practices commonly in use.

River or stream contamination appears to be a well controlled risk due primarily to provisions of the Clean Water Act (CWA), the Resource Conservation and Recovery Act (RCRA), and the Colorado Mined Land Reclamation Act. The risk of perhaps greatest concern--release of raw shale oil into ground or surface waters--will be controlled and minimal as a result of compliance with Safe Water Drinking Act, and RCRA and SPCC requirements that call for precautions such as impermeable barriers under tankage, vulnerable pipeways, and transfer areas and for quick-response cleanup capabiltiy to capture and dispose of any spilled oil.

Localized air pollution similarly would be a well controlled risk due to the provisions of the Clean Air Act that call for NSPS and Best Available Control Technology (BACT) design for air emissions, and for compliance with National Ambient Air Quality Standards as well as with Prevention of Significant Deterioration increments. Concerns over potential emissions of a broad range of "unregulated pollutants" have no credible basis in fact as a result of NSPS, BACT, and fugitive emission requirements. The only obvious way such "unregulated pollutants" could become of concern would be if raw shale oil were to be used as fuel in some sort of inefficient and unregulated fired unit. Such use is not anticipated.

Safety concerns over remoteness, loss of power, unavailability of skilled workers, or unreliable water supplies similarly have no credible basis in fact because western Colorado is hardly remote, the climate is relatively benign, and any shale processes commercialized in the area will have assured supplies of power, manpower, and water as key conditions for the major financial commitments.

Process Technology

Process technology and plant reliability can be considered together because concerns will focus on risks related to operability, on-stream efficiency, and economics. Human and environmental risks, which could occur as a result of process upsets, uncontrolled emissions, or inordinate exposure of maintenance personnel to biologically active materials, are well controlled through standard petroleum safety practices and through requirements of the Clean Air Act, OSHA, and TSCA.

Toxicological comparisons of petroleum products and shale products have yet to show any unanticipated biological risks that would set shale operations uniquely apart from petroleum operations. In the event that future comparisons would show special toxicological problems for shale, OSHA and TSCA provisions, as well as current safety, industrial hygiene, and medical surveillance plans, are designed to detect and mitigate such problems at an early and correctable stage.

Given the financial requirements for shale operations there appears to be little probability that inadequately researched and developed processes will be commercialized. Starting and operating facilities that ultimately are commercialized should be relatively straightforward, with any potential risks to humans or the environment being well controlled.

SUMMARY

When proposed shale operations are viewed in the context of comparable mining and petroleum operations, and when shale products are compared with analogous petroleum products, it is difficult to find any area where an unusual and credible environmental or health risk may remain after compliance with the current array of environmental, safety, and health laws.

POSITION PAPER S

THE TOXICOLOGY DATA BASE AND RESEARCH PROGRAM PLANS FOR DIRECT COAL LIQUEFACTION

G. K. Vick
Exxon Research and Engineering Company

This paper will address the issue of the adequacy of the present toxicology data base and toxicology research program to minimize the probability of future unpleasant surprises from a direct coal liquefaction industry. First the present direct coal liquefaction toxicology data base and research program are reviewed. Then the criteria a toxicology data base should meet to ensure a surprise-free future, are considered, along with additional research which could be useful.

CURRENT DATA BASE ON HUMAN HEALTH EFFECTS

Acute Toxicity

Based upon animal tests and medical surveillance programs in pilot plants, the acute toxicity of coal-derived materials appears to be low except for low-boiling streams with high concentrations of phenolics. Acute oral LD 50's for H-Coal and SRC-I and II materials range from about 0.6 g/kg to over 15 g/kg.[1] The most toxic

[1]See the following two reports published by Battelle Pacific Northwest Laboratory, Biomedical Studies on Solvent Refined Coal (SRC-II) Liquefaction Materials: A Status Report, PNL-3189, (Appendix December 1979) (Richland, Washington: Battelle Pacific Northwest Laboratory, December 1979); The Pittsburgh and Midway Coal Mining Company, "Solvent Refined Coal (SRC) Process: Health Programs," FE/496-T19 (Pittsburgh, Pennsylvania: The Pittsburgh and Midway Coal Mining Company, April 1979); P. D. Mahlum, Chemical, Biomedical and Ecological Studies of SRC-I Materials from the Fort Lewis Pilot Plant: A Status Report, PNL-3474 (Richland, Washington: Battelle Pacific Northwest Laboratory, January 1981); D.K. Schmalzer, "The Solvent Refined Coal Pilot Plant: Health Programs and Observations," Proceedings of Advisory Workshop on Carcinogenic

material in acute inhalation tests was a low-boiling stream from SRC-I, wash solvent, with an LC_{50} of 16.7 mg/l when administered as an aerosal.[2] It has been reported that 27 percent of this material is an acidic fraction consisting mainly of a variety of phenolic compounds,[3] and this probably accounts for the stream's acute toxicity. Acute dermal toxicities for H-Coal distillates are reported to be low, $LD_{50} > 2$ g/kg.[4]

Acute eye irritation by the Draize technique for SRC-I materials is reported to be minimal to moderate except for the low-boiling light oil and wash solvent which showed irreversible corneal opacity. These fractions have significant concentration of phenols which are thought to be responsible.[5] Some reversible superficial abrasions were reported in eye irritation tests on H-coal distillates.[6]

The acute toxicity reported in the literature for the low boiling streams shows a wide range of results. Those investigators measuring high levels of toxicity suggest that phenol content is probably responsible. The data indicate that phenol contents have probably varied widely. Surprisingly, however, little information on phenol content has been reported in the toxicity studies.

The experience at the SRC pilot plant in Fort Lewis, Washington has revealed only cases of mild eye irritation, mild transient dermatitis (erythema), and foliculitis (mechanic's acne) from exposure to coal-derived materials.[7] All have responded well to temporary suspension of exposure.

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[1] (cont.) Effects of Coal Conversion, EPRI WS-78-110 (Palo Alto, California: Electric Power Research Institute, September 1979); and Oak Ridge National Laboratory, Health Effects Research in Direct Coal Liquefaction. Studies of H-Coal Distillates: Phase I. PDU Samples--The Effect of Hydrotreatment, ORNL-TM-8071 (Oak Ridge, Tennessee: Oak Ridge National Laboratory, November 1981).

[2] The Pittsburgh and Midway Coal Mining Company, op. cit.; and Schmalzer, op. cit.

[3] Mahlum, op. cit.

[4] Oak Ridge National Laboratory, op. cit.

[5] The Pittsburgh and Midway Coal Mining Company, op. cit.; and Schmalzer, op. cit.

[6] Oak Ridge National Laboratory, op. cit.

[7] Schmalzer, op. cit.; and The Pittsburgh and Midway Coal Mining Company, "Solvent Refined Coal (SRC) Process: Health Programs," FE/496-T15 (Pittsburgh, Pennsylvania: The Pittsburgh and Midway Coal Mining Company, January 1978).

Subchronic Toxicity

Some evidence of cumulative toxic effects have been noted for the SRC-I and SRC-II liquids boiling above 400°F in tests in which a daily oral dose was repeated for five consecutive days.[8]

Carcinogenicity

Liquids from the direct liquefaction of coal have been found to be fairly potent mouse skin carcinogens.[9] Several investigators have reported that carcinogenicity is greatest in the high boiling fractions (500 to 1000°F)[10] and is absent from low-boiling liquids (boiling below 500°F).[11]

Hydrotreating has been reported to decrease the carcinogenicity of H-Coal distillates dramatically.[12] In this same skin painting study, however, there was evidence from body weight, kidney weight, and increased water uptake that the material produced at the highest hydrotreatment level may be producing some chronic systemic toxicity.

A number of cancerous and precancerous skin lesions among workers at the coal hydrogenation facility in Institute, West Virginia have

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[8]Battelle Pacific Northwest Laboratory, op. cit.; and Mahlum, op. cit.

[9]Battelle Pacific Northwest Laboratory, op. cit.; Oak Ridge National Laboratory, op. cit.; W. C. Hueper, "Experimental Studies on Cancerigenesis of Synthetic Liquid Fuels and Petroleum Substitutes," Archives of Industrial Hygiene and Occupational Medicine, Vol. 8 (1953), pp. 307-327; C. S. Weil and N. I. Chondra, "The Hazards to Health in the Hydrogenation of Coal: 2. Carcinogenic Effects of Materials on the Skin of Mice," Archives of Environmental Health, Vol. 1 (1960), pp. 187-193; L. M. Holland et al., "Skin Carcinogenicity of Synthetic and Natural Petroleums," Journal of Occupational Medicine, Vol 21 (1979), p. 614-618; and W. H. Calkins et al., Synthetic Crude Oils Carcinogenicity Screening Tests, COO-4758-4 (Wilmington, Delaware: E. I. du Pont de Nemours and Company, Inc., August 1980).

[10]Battelle Pacific Northwest Laboratory, op. cit.; Oak Ridge National Laboratory, op. cit.; Hueper, op. cit.; and Weil and Chondra, op. cit.

[11]Oak Ridge National Laboratory, op. cit.; Weil and Chondra, op. cit.; and Holland et al., op. cit.

[12]Oak Ridge National Laboratory, op. cit.

been reported.[13] However, because of the paucity of data on the background incidence of such skin lesions, the significance of the data is unclear. A follow-up study showed no evidence that those people with verified or suspected cancerous skin lesions experienced higher cancer mortality rates.[14]

Other Chronic Effects

In mouse skin-painting tests on H-Coal distillates, one material produced a neurotoxic reaction in some of the mice on test.[15] Not all the mice showed the effect and not always the same mice each time. The syndrome involved prostration, then tonic-clonic convulsions transitioning into hyperactivity, followed by exhaustion and collapse, and eventually recovery and a return to normal activity. The significance of the observation is not clear.

Developmental Toxicity

Fetal growth and survival have been reported to be decreased by both SRC-I and SRC-II liquids. Only the high-boiling liquids increased the incidence of fetal malformations (mainly cleft palate, immature lung, and herniated diaphragms). In most cases, prenatal toxicity was seen only at doses producing indications of maternal toxicity.[16]

Pilot dermal and inhalation teratogenesis trials on SRC-I materials were reported to show some evidence of decreased viability of offspring and reduced fetal weight in rabbits.[17]

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[13] R. J. Sexton, "The Hazards to Health in the Hydrogenation of Coal IV, The Control Program and Clinical Effects," Archives of Environmental Health, Vol. 1 (1960), pp. 208-231.

[14] A. Palmer, "Mortality Experience of Fifty Workers with Occupational Exposures to the Products of Coal Hydrogenation Processes," Journal of Occupational Medicine, Vol. 21 (1979), pp. 41-44.

[15] Oak Ridge National Laboratory, op. cit.

[16] Battelle Pacific Northwest Laboratory, op. cit.; and Mahlum, op. cit.

[17] The Pittsburgh and Midway Coal Mining Company, Solvent Refined Coal (SRC) Process: Health Programs, FE/496-T19, op. cit.

Mutagenicity Tests

A great deal of the recent toxicology literature on direct coal liquefaction materials involves in vitro tests for mutagenicity.[18] These tests involve exposing a particular cell line (bacterial or mammalian) in the laboratory to a material and then measuring certain changes in succeeding generations of the cells. The word mutagenicity has been applied to the results from a variety of different techniques using different kinds of cells and different end points. About the only thing the various results have in common is that positive results indicate that some change in the cell's genetic apparatus has been induced by the material.

It is a very big jump from such tests to the human "genesis" risks: carcinogenesis (cancer), teratogenesis (birth defects), and mutagenesis (mutations), and the proper use and interpretation of in vitro mutagenicity test results is a subject of considerable controversy. The most popular justification for the tests is as a preliminary screen for human carcinogens, based on correlations reported in the literature. However, the value of the tests for identifying toxic hazards to humans in synthetic fuels has been questioned on the basis that the degree of correlation has been overstated, and that the degree of correlation is not high enough to

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[18]Battelle Pacific Northwest Laboratory, op. cit.; Mahlum, op. cit.; Oak Ridge National Laboratory, op. cit.; Calkins et al., op. cit.; R. F. Kimball and N. B. Munro, A Critical Review of the Mutagenic and Other Genotoxic Effects of Direct Coal Liquefaction, ORNL-5721 (Oak Ridge, Tennessee: Oak Ridge National Laboratory, July 1981); R. A. Pelroy and B. W. Wilson, Fractional Distillation as a Strategy for Reducing Genotoxic Potential of SRC-II Coal Liquids: A Status Report, PNL-3787 (Richland, Washington: Battelle Pacific Northwest Laboratory, September 1981); Oak Ridge National Laboratory, Life Sciences Synthetic Fuels Semiannual Progress Report for the Period Ending June 30, 1981, ORNL/TM-7926 (Oak Ridge, Tennessee: Oak Ridge National Laboratory, October 1981); Battelle Pacific Northwest Laboratory, Initial Chemical and Biological Characterization of Hydrotreated Solvent Refined Coal (SRC-II) Liquids: A Status Report, PNL-3464 (Richland, Washington: Battelle Pacific Northwest Laboratory, July 1980); J. L. Epler, et. al., "Analytical and Biological Analyses of Test Materials from the Synthetic Fuel Technologies," Mutation Research, Vol. 57 (1978) pp. 265-276; R. A. Pelroy, The Mutagenic and Chemical Properties of SRC-I Materials: A Status Report, PNL-3604 (Richland, Washington: Battelle Pacific Northwest Laboratory, January 1981); and M. R. Guerin et al., "Polycyclic Aromatic Primary Amines as Determinant Chemical Mutagens in Petroleum Substitutes," Environmental Research, Vol. 23 (1980).

make tests useful for identifying the human carcinogens.[19] Perhaps the best indication of the present utility of the tests for identifying hazards and managing risk with synthetic fuels come from those who use the tests. Mutagenicity investigators regard a positive test to indicate the need for further testing, usually in animal skin tests. However, negative results have been followed by animal skin testing also, because the tests are known to produce false negative results. Since either positive or negative results lead to the same action, the results, in practice, appear to be contributing little to the problem of identifying hazards for synthetic fuels.

This is not to say that mutagenicity tests have no value in other applications. They are apparently considered to be of value in the drug industry for screening a large number of potential drugs for genotoxicity. Similarily, they can probably be of value as a preliminary screening device in studies to find ways to alter the carcinogenicity of a particular synthetic fuel and some mutagenicity studies have been directed toward this goal.[20] The tests seem also likely to be useful in the attempt to gain a more fundamental understanding of the mechanism of chemically induced genotoxic effects.

CURRENT DATA BASE ON ECOLOGICAL EFFECTS

Relatively little data has been reported on the results of toxicity tests aimed at the evaluation of toxic hazards to ecological systems. Most of the data reported concern aquatic systems. In

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[19] M. S. Legator, "Genetic Toxicology--Relevant Studies with Animal and Human Subjects," Proceedings of Advisory Workshop on Carcinogenic Effects of Coal Conversion, EPRI WS-78-110, (Palo Alto, California: Electric Power Research Institute, September 1979); and R. A. Scala, "How Valid are Short-Term Tests in Assessing Human Carcinogenicity?", Presented at the Anglo-American Conference on Human Health and Environmental Toxicants, London, England, May 15, 1979.

[20] Oak Ridge National Laboratory, Health Effects Research in Direct Coal Liquefaction Studies of H-Coal Distillates: Phase I, op. cit.; R. A. Pelroy and B. W. Wilson, op. cit.; Oak Ridge National Laboratory, Life Sciences Synthetic Fuels Semiannual Progress Report for the Period Ending June 30, 1981, op. cit.; Battelle Pacific Northwest Laboratory, Initial Chemical and Biological Characterization of Hydrotreated Solvent Refined Coal (SRC-II) Liquids: A Status Report, op. cit.; R. A. Pelroy, op. cit., and Guerin et al., op. cit.

general, the results confirm expectations. Raw process waters with high concentrations of sulfur and ammonia were toxic to amphibian embryos.[21] Treated waste waters were not toxic to fresh water algae, nor to midge larvae but 50 percent of Daphnia magna were killed or immobilized by 1.1 percent of treated waste water in a 24-hour test.[22]

Aqueous extracts of product and process streams have been tested to examine the potential for toxic hazards resulting from spills into aquatic environments. In general, the major determinant of aquatic toxicity identified thus far are water-soluble phenols.[23] Testing of process waters and aqueous extracts is complicated by the fact that the aqueous solutions are unstable. Phenols tend to be biodegraded fairly rapidly by microorganisms. Toxicity of these aqueous solutions is strongly affected by pH and pH also tends to change with time which complicates the toxicity tests.[24] Hydrotreatment of low boiling fractions (which tends to destroy phenols) has been shown to decrease the toxicity of aqueous extracts.[25]

Even less work has been done on the terrestrial systems. One study showed no effect on germination, growth, or yield of barley for solid SRC-I product mixed 50/50 with soil.[26]

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[21]Oak Ridge National Laboratory, Life Sciences Synthetic Fuels Semiannual Progress Report for the Period Ending June 30, 1981, op. cit.

[22]Ibid.

[23]J. A. Strand, III and B. E. Vaugh (eds.), Ecological Fate and Effects of Solvent Refined Coal (SRC Materials: A Status Report), PNL-3819 (Richland, Washington: Battelle Pacific Northwest Laboratory, October 1981); and J. M. Giddings and J. N. Washington, "Coal Liquefaction Products, Shale Oil and Petroleum Acute Toxicity to Freshwater Algae," Environmental Science and Technology, Vol. 15 (1981), pp. 106-108.

[24]Oak Ridge National Laboratory, Life Science Synthetic Fuels Semiannual Progress Report for the Period Enging June 30, 1981, op. cit.; and Strand and Vaugh, op. cit.

[25]Oak Ridge National Laboratory, Health Effects Research in Direct Coal Liquefaction. Studies of H-Coal Distillates: Phase I. PDU Samples--The Effect of Hydrotreatment, op. cit.

[26]Mahlum, op. cit.

PLANNED RESEARCH PROGRAMS

Toxicology research program plans for the H-Coal, SRC-II, and EDS processes have been reported.[27] These programs are summarized in Tables 1, 2, and 3. These programs appear to cover essentially all the current state-of-the-art testing technology and in some cases, go beyond that into experimental procedures.

RESEARCH NEEDS

Management of toxic risks involves three steps. First, a toxic hazard associated with a particular material must be identified. Second, some estimate of the magnitude of the risk must be made. Third, if the magnitude of the risk is judged unacceptable, controls must be applied to reduce the risk to an acceptable level. In this discussion the word hazard means a material or condition capable of inflicting injury or damage, and the word risk means the probability of a particular injury or damage occurring as a result of exposure to a hazard.

A conceptual framework for managing risk before an industry is built is shown in Figure 1. Some kind of model of the industry (or the part of concern, such as the plant or the transportation system) is used to estimate a level of emissions. Those emissions are fed into a dispersion model along with information on the location and activities of people to generate an exposure estimate, that is an estimate of the levels and duration of exposure and the number of people exposed. Based on the exposure, a dose must be estimated which can be fed into a dose/response model to provide an estimate of the risk. That estimate can then be used to decide whether and how controls must be changed to bring risks to an acceptable level. Controls can be used to intervene at any number of points. Releases can be decreased, exposed individuals can be protected from the exposure, or the basic toxic potency of the material may be altered. Thus the need for data must be judged against the ability of that data to fit somehow into a framework for risk management, and to contribute significantly to a decision maker's ability to judge the magnitude of the risk and options for controlling risk.

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[27]Battelle Pacific Northwest Laboratory, Solvent Refined Coal-II (SRC-II) Detailed Environmental Plan, PNL-3517 (Richland, Washington: Battelle Pacific Northwest Laboratory, October 1980); K. E. Cowser (ed.), Environmental and Health Program for H-Coal Pilot Plant (Oak Ridge, Tennessee: Oak Ridge National Laboratory, November 1980); and W. R. Epperly, EDS Coal Liquefaction Process Development, Phase V, EDS Environmental Program, FE-2893-79 (Florham Park, New Jersey: Exxon Research and Engineering Company, November 1981).

TABLE 1 Summary of Toxicology Program on SRC-II

Phase I
Biomedical Studies
Submammalian and Mammalian Cell *In Vitro* Assays for Genotoxicants
Acute Oral Toxicity
Acute Dermal Toxicity
Eye Irritation
Dermal Sensitization
Aspiration Hazard
Teratogenicity
Ecological Screening Assays
Acute toxicity to:
Algae (*Selenastrum capricornutum*)
Zooplankter (*Daphnia magna*)
Sediment dwelling detritivores (*Chironomus tentans* and *Tanytarus dissimilis*)
Fathead minnow (*Pimephales promelas*)
Rainbow trout (*Salmo gairdneri*)
Attraction/avoidance with fish
Plant growth and rooting (barley)
Phase II
Biomedical Studies
Dermal Carcinogenicity (Mouse Skin Painting)
Inhalation Toxicity (3 week, 13 week, and lifetime)
Dominant Lethal Test
Transplancental Carcinogenesis
Developmental Toxicology
Neurobehavioral Toxicology
Conditioned Taste Aversion
Conditioned Avoidance Behavior
Learning and Memory
Open Field Activity
Physical Endurance
Ecological Studies
Biological Fate in the Aquatic Environment
Biological Fate in the Terrestrial Environment
Multispecies Testing in Aquatic Systems
Lab Studies on Revegetation of Solid Wastes
Chemical and Microbiological Fate in Sediment and Soil Systems

TABLE 1 Summary of Toxicology Program on SRC-II - Continued

Phase III
Biomedical, ecological, and chemical analyses of materials which may be produced by demonstration and commercial facilities under different conditions than those established as baseline in Phase II and materials processed through various control technology options or subjected to upgrading.
Materials:
Liquid process streams and products Solid process streams and effluents Process waters

SOURCE: Battelle Pacific Northwest Laboratory, Solvent Refined Coal-II (SRC-II) Detailed Environmental Plan, PNL-3517 (Richland, Washington: Battelle Pacific Northwest Laboratory, October 1980).

TABLE 2 Summary of Toxicology Program on H-Coal

Occupational Toxicology

Cellular Bioassays (Mutagenesis and Cytotoxicity)

Mammalian Toxicity Tests

- Acute Oral LD_{50}
- Acute Intraperitioneal LD_{50}
- Acute Dermal LD_{50}
- Primary Eye Irritation and Skin Corrosion
- Dermal Sensitization

Subacute (90 day) tests for systemic toxicity

Chronic Studies

- Lung Adenoma Bioassay
- Mouse Skin Painting Tests
- Extended Inhalation Tests

Environmental Fate and Effects

Chemical and Physical Characterization

Toxicity Screening Tests

- Algal Photosynthetic Inhibition
- Acute Toxicity to:
  - Planktonic Crustacean (*Daphnia magna*)
  - Midge Larvae (*Chironomus tentans*)
  - Fathead Minnow (*Pimephales promelas*)

Chronic Toxicity Tests

- 28 day reproduction (*Daphnia magna*)

48 hour Fish Embryo-Larval Tests

- Reproductive effects of terrestrial insects
- Laboratory studies of the fate and effect of soil spills
- Studies of attenuation of contaminants in solid waste leachates during movement through soils
- Studies of transport and fate of products spilled in aquatic environments

TABLE 2 Summary of Toxicology Program on H-Coal - Continued

Materials:

These tests and studies will be carried out on selected liquid and solid product and process streams, waste water streams and solid waste.

SOURCE: K. E. Cowser (ed.), Environmental and Health Program for H-Coal Pilot Plant (Oak Ridge, Tennessee: Oak Ridge National Laboratory, November 1980).

TABLE 3 Summary of Toxicology Program on EDS

HUMAN HEALTH EFFECTS		
Acute	**Subchronic**	**Chronic**
Oral Dermal Inhalation Repeat Dermal Eye Irritation Invitro Mutagenicity	Toxicity Teratology Reproductive Effects	2 yr Mouse Skin Painting
Environmental Effects		
2 hr Algal Photosynthesis 48 & 36 hr Algal Growth	Embryo-Larval, 30 day post hatch, fat head minnows	21 day Daphnia
48 hr Daphnia-static 96 hr Invertebrate-dynamic 96 hr Vertebrate-dynamic	Embryo-Larval, 60 day post hatch, salmonid	

Analytical Tests	
Density Boiling Point or Range Flash Point Viscosity Refractive Index Explosive Limit Mean Molecular Weight	Elemental Composition Detailed characterization of organics using GC and chemical separations, low and high resolution MS, MS, and NMR. 33 Trace Elements by ICPES

MATERIALS:

These tests will be carried out on three boiling range fractions, naphtha (150-350 F), recycle solvent (400-800 F) and a blend of vacuum gas oil in recycle solvent (400-1,000 F). This represents the full boiling range of materials which might constitute liquid products from a commercial plant.

SOURCE: W. R. Epperly, EDS Coal Liquefaction Process Development, Phase V, EDS Environmental Program, FE-2893-79 (Florham Park, New Jersey: Exxon Research and Engineering Company, November, 1981).

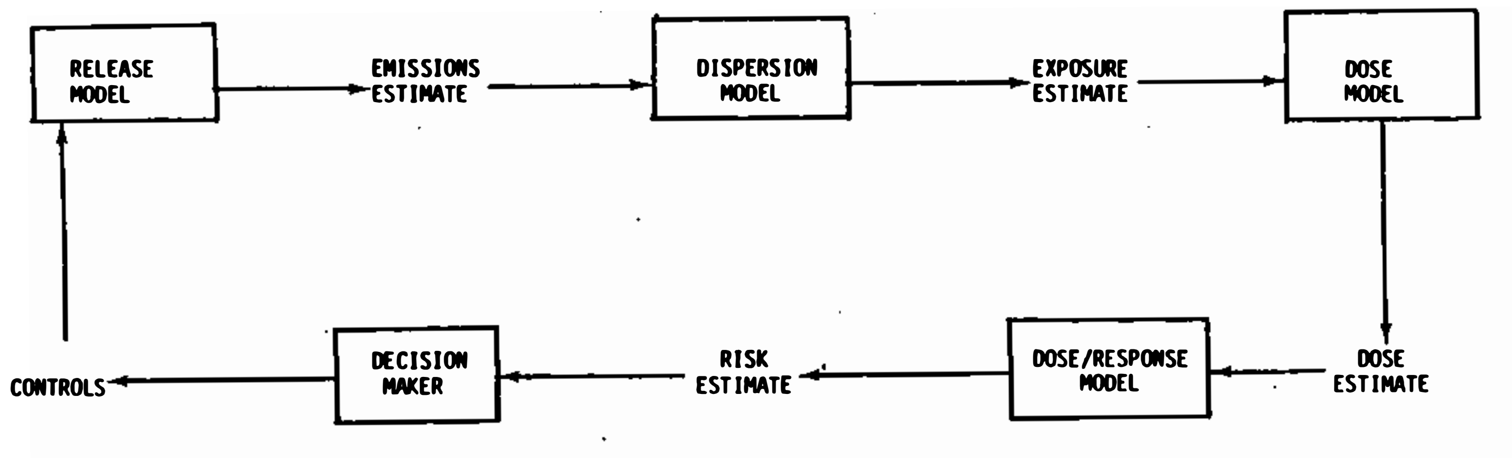

Figure 1 Framework for risk management.

Viewed against this framework, the present toxicology data base and research program appear sufficient to generate an adequate data base on acute toxicity. However, some effort should be devoted to determining the relationship between acute toxic potency and phenol concentration.

Clearly, chronic toxicity is an area of concern. Effects which are expressed only after a substantial delay or which can be caused by low levels of exposure are the hardest to test for. Carcinogenicity of the high-boiling fractions has been identified as a toxic hazard to be reckoned with. Cancer of the skin, lung, or other organ systems is a possibility, given sufficient exposure. The date base, however, is inadequate to permit a quantitative estimation of the risk of the various possible cancers which could be produced by skin contact or aerosol inhalation. A reasonable first step would be to quantify the potency of direct coal liquefaction materials relative to materials on which there is some measure of human dose/response (cigarette smoke and coke oven emissions), using existing skin carcinogenicity tests. Admittedly, this would be crude, but it would be better than nothing until such time as validated animal tests are available for lung cancer and other systemic cancers.

There is already some evidence for teratogenic effects. In this area also the need is for quantitative dose response information which will permit estimation of human risk. Tests for reproductive effects are planned.

Many materials involved in direct coal liquefaction have been identified as potential toxic hazards. Such a list, adapted from the Environmental Impact Statement for the SRC-II demonstration project is shown in Table 4.[28] Most of these materials are already widely encountered in commerce and industry, and their toxic properties are adequately understood. The materials for which an adequate data base does not exist are those unique to coal liquefaction. Clearly, the materials which differ most from conventional ones are the liquid and solid hydrocarbon product and intermediate streams. As the products are upgraded to make suitable replacements for petroleum products, they become more and more like petroleum products. At some point in the upgrading process it is likely that the differences will disappear. It would be useful to determine how much upgrading is required to bring the raw liquefaction products to the point at which they are biologically equivalent to conventional petroleum products. This would assure that, in situations where that extent of upgrading is realized, the coal-derived materials would present no greater toxic hazards than existing petroleum products. It is not clear that current studies on the effect of upgrading will achieve this goal.

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[28]U.S. Department of Energy, Final Environmental Impact Statement, Solvent Refined Coal-II Demonstration Project, DOE/EIS-0069/02 (Washington, D.C.: U.S. Department of Energy, January 1981).

TABLE 4 Hazardous Materials in Direct Coal Liquefaction Processes

Material	Assumed Hazardous Property
Coal Dust	Explosive, flammable, toxic
Slag	Pyrophoric, possibly carcinogenic
Hydrogen	Flammable, explosive, asphyxiant
Methane	Flammable, expolsive, asphyxiant
Carbon Monoxide	Flammable, toxic
Carbon Dioxide	Asphyxiant
Carbonyl Sulfide	Flammable, toxic
Oxygen	Reactive, increased fire hazard
Nitrogen	Asphyxiant
Argon	Asphyxiant
Hydrogen Sulfide	Flammable, toxic
Liquid Products	Flammable, toxic, explosive, carcinogenic
Vacuum Bottoms	Toxic, flammable, carcinogenic
Ammonia	Flammable, toxic
Sulfur	Flammable, toxic combustion products
Sulfur Dioxide	Flammable, toxic
Hydrogen Chloride	Toxic
DEA/MEA	Flammable, toxic
Selexol solvent	Flammable, toxic
Phenolics	Toxic
Hydrogen Cyanide	Toxic, flammable
Liquefied Petroleum Gas	Flammable, explosive

SOURCE: U.S. Department of Energy, Final Environmental Impact Statement, Solvent Refined Coal-II Demonstration Project, DOE/EIS-0079/U2 (Washington, D.C.: U.S. Department of Energy, January 1981).

Other potentially different materials are waste waters and solid waste. The present research program appears adequate to define the toxic properties of these materials.

The toxic risks of combustion products from coal liquefaction materials that have not been upgraded is an area not adequately covered in the present program. However, the toxicology of the products of combustion of current fuels is not well defined. The major needs are to further understanding of the toxic hazards associated with the combustion of current fuels and to determine if, chemically, the combustion products from raw coal liquids are different from those from current fuels. If they are, then some further toxicology research is probably called for.

An area of uncertainty in the present program is the extent to which the materials that have been or will be tested are representative of commercial production. The SRC-I and SRC-II samples are produced in a 30 T/D pilot plant, the H-Coal samples in a 200 T/D pilot plant, and the EDS samples in a 250 T/D pilot plant. The larger pilot plants have been designed to duplicate commercial operations well enough to permit the design of a commercial size plant, and therefore this uncertainty should be small. In addition, some indication of the magnitude of this uncertainty will be obtained when all the data are available. If the results show that the toxicity of similar boiling fractions does not vary much from process to process, it would suggest that the biological properties are not very sensitive to process changes. This would, in turn, suggest that commercial materials are not likely to behave differently from those tested. Conversely, wide variations would suggest that the relationship of pilot plant to commercial materials should be checked further.

The major uncertainty inherent in the present toxicology program is that introduced by the difference between human and animal response to toxic materials. Animals often respond differently to toxicants than do humans. It usually takes a fair amount of research to develop an animal test model which duplicates a human toxic response, and in some cases, conventional animal models do not accurately predict human response. Rodents, for example, are much less sensitive than humans to methanol, are apparently refractory to lung cancer due to cigarette smoke, and could not have identified thalidomide as a human teratogen. Conversely, rodent models may be more sensitive than humans to other materials. Aspirin, for example, is teratogenic to rodents but is not known to present toxic hazards to humans at normal dosages. When properly validated, animal tests are useful for predicting toxic hazards to humans. The battery of animal and in vitro tests being applied to direct coal liquids can be expected to detect the toxic hazards for which the tests were developed. However, because animals and humans sometimes respond differently to toxicants, the possibility exists that current animal tests may fail to detect a health effect which has never been seen before and for which no test has been developed and validated.

In the final analysis, there can be no guarantees. The problem is very much like the problem of proving a scientific theory true. At best, one can only try diligently to prove a theory false and, having failed, assume it is true. In a similar manner, researchers can only try diligently to find the unacceptable toxic risks.

Two strategies come to mind to try to deal with the uncertainty left by existing *in vivo* and *in vitro* toxicity tests. One possible strategy would be to carry out some very exploratory research attempting to expose a variety of species to conditions similar to what people are likely to experience for very long periods of time but at higher dosages to compensate for the shorter lifetimes of animals. The goal would be to determine if there are possible health effects which somehow have not been identified in current tests. Such a program would not use validated tests, and therefore positive results could only trigger further research. It would be very expensive and would probably have to be limited to just one or two materials. It would take a long time. It would probably produce a number of false positive results and raise more questions than it answered, but then that would be the purpose--an exploration of unknown territory to see what is there.

A second strategy is further epidemiological studies in the coke oven/coal tar and petroleum industries. Liquids from direct coal liquefaction are different from both coal tar and petroleum. However, as coal tar is hydrogenated, it can be made to look first like direct coal liquids and then like petroleum. It seems a reasonable assumption that raw, direct coal liquids will produce effects somewhere between those of coal tar and those of petroleum and the greater the degree of refining and upgrading, the more like petroleum they will become. There is always the possibility that in direct coal liquefaction, some molecules will be produced which are not present in either coal tar or petroleum. This is just another facet of the fact that no guarantees are possible and is not a persuasive argument for disregarding this as another strategy in the search for the toxic hazards of direct coal liquefaction. The only reason for not pursuing such a strategy would be if current data resources have already been fully exploited. That is an issue for experts in the field of epidemiology to settle.

SUMMARY

In summary, there seems to be no way to guarantee a surprise-free future, with respect to toxic risks. At best a diligent search using the best methods currently available can be conducted. The following research efforts should be considered as additions to the current program to meet the test of diligence:

- Quantify the relationship between acute toxicity and phenol content.
- Quantify the carcinogenic potency of high boiling fractions.
- Define developmental and reproductive effects and quantify as necessary.
- Define the level of upgrading at which products become biologically equivalent to current products.
- Determine if combustion products from raw coal liquids differ from those from current fuels and if so, how.
- Explore chronic exposures in a broader range of species, under conditions as representative as possible of human exposures (except for dose levels which may have to be proportionately higher to compensate for the shorter life spans of the test animals).
- Ensure that the present coke oven/coal tar and petroleum experience has been adequately examined for clues to potential effects.

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