IWG-FR-082-01
November 13, 1981

IWG-FR--082-01

DE90 004321

HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT FOR OIL SHALE--1981

by

IWG Corp.
975 Hornblend Street
Suite C
San Diego, California 92109

and

Center for Environmental Sciences
University of Colorado at Denver
Box 136
Denver, Colorado 80202

prepared for

Health and Environmental Risk Analysis Program
Human Health and Assessment Division
Office of Health and Environmental Research
Office of Energy Research
U.S. Department of Energy
Washington, D.C. 20545

Lawrence B. Gratt, Project Leader, IWG Corp.

Willard R. Chappell, Program Manager, University of Colorado

Bruce W. Perry, IWG Corp.

Jeffrey L. Feerer, IWG Corp.

Kenneth J. Berger, IWG Corp.
John A. Lanning, University of Colorado
Rafael A. Molano, IWG Corp.
Frank X. Siroky, IWG Corp.

with assistance from Patricia A. Forster-Day,
Karren R. Hakanson, Timothy M. Riley, and
Mark Underwood of IWG Corp. and
William Marine of the University of
Colorado, School of Medicine

Acknowledgement

The Oil Shale Risk Analysis project team appreciates the direction, support, and encouragement of Paul Cho and Nat Barr of the Health and Environmental Risk Analysis Program of the Department of Energy. The analysis was performed under Department of Energy Contract EV 10706. The risk analysis process included a workshop and reviews as an integral part of the methodology. The contribution of the following individuals is both noted and appreciated: Lynn Anspaugh (Lawrence Livermore National Laboratory (LLNL)), Joseph S. Broz (Energy Development Consultants, Inc. (EDC)), Ray Cooper (University of Maryland), Edward J. Faeder (University of California at Los Angeles (UCLA) and Southern California Edison), J. Phyllis Fox (Consultant), Tee Lamont Guidotti (San Diego State University), Jeffrey L. Hahn (Consultant), Kenneth Hargis (Los Alamos National Laboratory (LANL)), Marty Holland (LANL), Burton Kallman (Consultant), Donald V. Lassiter (Consultant), Edwin Piper (EDC), Peter Rutledge (US Geological Survey/Area Oil Shale Office), Gary H. Spivey (UCLA), Lee Stevens (US Geological Survey/Area Oil Shale Office), Walter Stevens (University of Utah), Marvin L. Tillery (LANL), Hector Timourian (LLNL), Jim Westhoff (Laramie Energy Technology Center), Chris G. Whipple (Electric Power Research Institute), Raymond Wildung (Battelle - Pacific Northwest Laboratories), McDonald E. Wrenn (University of Utah), members of The Oil Shale Task Force and Advisory Group and the American Petroleum Institute.

ABSTRACT

The initial effort of a continuing project to analyze the potential human health and environmental risks of a hypothetical one-million-barrels-per-day oil shale industry has been completed as an aid in the formulation and management of a program of environmental research. Readily available knowledge has been compiled and uncertainties regarding the risks have been established with appropriate research recommendations to reduce uncertainties in critical areas.

HEALTH AND ENVIRONMENTAL EFFECTS DOCUMENT

OIL SHALE - 1981

EXECUTIVE SUMMARY

This report documents the initial portion of a continuing effort to quantify the health and environmental risks from a hypothetical one-million-barrels-per-day United States oil shale industry for the purpose of identifying research needs. The quantification procedure is based upon assumptions and on both research and engineering data. The 1981 Oil Shale Risk Analysis (OSRA) has established a set of assumptions and structure for use of data to predict the potential human health and environmental risks. The assumptions and data can be reviewed, modified and updated based on ability to reduce major uncertainties affecting the significant risks. The information provided by the current analysis is intended as an aid in formulating and managing a program of environmental research focused on providing information required to reduce uncertainties in critical areas.

The use of the risk analysis results presented requires a proper understanding of the assumptions, estimates, uncertainties, and further research needs. Other extrapolations of the risks to assist the decision-making program process should be limited and made only with

proper understanding of the key assumptions and sensitivities of the analysis. The assumptions used in arriving at the current risk estimates and associated uncertainties are summarized in Table E-1. These assumptions will be reviewed as new information becomes available in the continuing and iterative nature of the risk analysis process.

The human populations working in and/or living near the oil shale industry may be exposed to a wide variety of pollutants: sulfur oxides, nitrogen oxides, particulates, ozone, carbon monoxide, dozens of trace elements, and a myriad of hydrocarbons including polycyclic aromatic hydrocarbons and nitrogen-containing aza-arenes. Many of these pollutants have been associated with adverse health effects, either through toxicologic investigations (in vitro and in vivo studies) or through epidemiologic studies in the occupational or public setting.

The estimated public risks and uncertainty bands in the 18,000-square-mile oil shale region resulting from airborne and waterborne exposure to industry pollutants are summarized in Table E-2. The baseline scenario is the current projection of a one-million-barrels-per-day oil shale industry consisting of 15 sites in the Piceance Creek and Uinta Basins, including a mix of the currently feasible processing technologies. Analysis variations based on an entire industry using open-pit mining and surface processing (OPT) and using all modified-in-situ processing (MIS) have been included as sensitivity measures.

Analysis of other potential health effects from airborne pollutants indicates exposures are below the chosen analysis threshold levels except for hydrogen sulfide, sulfur oxides, and particulates. The number of persons exposed above the conservative thresholds (i.e.,

Table E-1. Summary of Oil Shale Risk Analysis Assumptions

SOURCE TERMS

A non-existent oil shale industry can be characterized by the baseline scenario for one-million-barrels-per-day consisting of fifteen production sites and is a reasonable prediction for a large-scale U.S. oil shale industry.

The baseline scenario will transport the majority of the upgraded shale oil through Rifle, Colorado for refining outside of the oil shale region.

The occupational and public risks unique to oil shale are represented by the extraction through upgrading portions of the oil shale fuel cycle. The remaining portions of the fuel cycle will be considered in future efforts.

The use of available source characterization data is sufficient to represent industry pollutant source terms (Lurgi is replaced by TOSCO data, BX Pure/Steam and LOFRECO by TIS data, etc.).

The simplified OPT and MIS variations can be used for generation of analytic sensitivities.

Air pollutants can be controlled at a 95% level.

Water effluents controlled at 90 to 99% level.

EXPOSURE

Simplified Gaussian model results for flat terrain and a single wind rose with gravitational settling are adequate to represent the dispersion of airborne pollutants.

Simplified water analyses result in appropriate extreme exposures. This included complete mixing, negligible pollutant transformation, continual discharge of treated effluents, isotropic aquifier media, and non-attenuated leachate transport.

The uptake of heavy metals and trace elements in vegetation is at low enough levels that terrestrial food chain contamination is minor compared to the potential aquatic food chain contamination under extreme conditions.

Ecosystem risk can be meaningfully measured by community diversity and designator species.

Downstream fish tissue concentrations can be estimated by summing the metal element contributions from effluents (product water discharges and leachates) and multiplying an assigned bioaccumulation factor.

POPULATION

The occupational workforce can be estimated based on extrapolated oil company worker estimates.

The future population can be estimated using demographic study data and multipliers for industrial workers' families and for industry-influenced public sector growth.

HEALTH EFFECTS

Pollutant interactions can be ignored.

The chemical forms and their toxicities identified for oil shale research are representative of the potential industry.

Possible beneficial effects of pollutants are ignored.

Health effects, except carcinogenesis, and the SO_x surrogate for the mortality analysis, are assumed to have thresholds.

Carcinogenic effects are considered to have no threshold, based on the lack of data to the contrary.

Teratogenic effects were not considered in the initial effort

Exposures below chosen thresholds for adverse effects result in zero risk with negligible uncertainty.

TLV's (ACGIH) divided by a factor of three are appropriate to define thresholds for adverse effects for general public exposures.

ICRP's standard man of 20 m3/day respiratory rate and 2 liters/day water intake is an adequate representation of an average person in the oil shale region.

Health thresholds chosen to protect susceptible groups (particularly children and people with pre-existing lung disease) are, on the average, adequate for health effect estimation for large populations.

The health effects screening methodology adequately identifies the significant pollutants.

The airborne and waterborne pollutant health effects threshold levels derived from the literature are valid.

BaP can be used as the carcinogenesis indicator for the polycyclic aromatic hydrocarbons emitted in the vapor phase and associated with particulates in human inhalation.

Vapor-phase polycyclic aromatic hydrocarbons do not reach the general public while those absorbed onto particulates do.

Arsenic, cadmium, chromium, nickel, and BaP have valid dose-response relationships for the estimation of the non-threshold excess cancer risks.

Inhalation of sulfur oxides can be used as a surrogate for total pollution premature deaths although sulfur oxides are not necessarily the causative agent of increased mortality.

Ingestion of arsenic in water can cause skin cancers in the U.S. population.

RISK

Inhalation risks can be estimated for non-threshold effects by summing the product of the exposure in a sub-region (as calculated using a simplified Gaussian model) times the population in the region times the dose-response over all sub-regions of the oil shale region on a pollutant-by-pollutant basis.

Overall increases in mortality alone can be estimated and meaningfully interpreted using sulfur oxides as a surrogate for total pollution within the oil shale region.

The risk from exposure to water effluents and contaminated aquatic systems upstream of feeder streams is negligible.

The health effect risks from ingestion of drinking water assumes the water is untreated.

The occupational workforce accident rates can be predicted using historical occurrences from analogous industries.

The method of mining, and not the substance mined, is paramount in predicting oil shale mining accident rates.

Accidents in underground oil shale mines can be estimated from accident statistics for other underground mining.

Accidents in surface oil shale mines can be estimated from accident statistics for other surface mining.

The size of the oil shale mine will have no effect on safety.

Oil and gas extraction accident statistics are applicable to TIS drilling operations.

Retort operators in MIS mine have the same injury and accident rates as surface retort operators.

The underground oil shale miner produces an average 34.0 metric tons (37.5 short tons) of shale per workshift.

The open-pit (surface) oil shale miner produces an average of 136 metric tons (150 short tons) of shale per workshift.

Solid waste land disturbance can be estimated using piles 30 meters high, 50% backfill into mines, and compaction densities of 1.360 kg/m3.

Mule deer population decline is directly proportional to the 1,700 square kilometers (425,000 acres) of habitat disturbed supporting a herd size of 28,000.

Trout population declines with effluent/leachate releases can be predicted based on LC_{50} data for ammonia.

Threatened and endangered fish species will exhibit twice the response of trout for similar exposures.

UNCERTAINTIES & SENSITIVITIES

Non-threshold risks are the product of parameters which are log-normally distributed and independent.

Risk estimates of zero have negligible uncertainty for populations exposed below conservative thresholds.

The uncertainty in the extrapolation of linear, non-threshold dose-response relationships to low levels of exposure can be neglected in the uncertainty analysis and the minimum of the uncertainty range can be assumed zero.

Meaningful judgemental estimates can be made for uncertainties of model parameters.

Oil shale mining accident estimates have a $\pm$10% uncertainty range.

MIS mining accident estimates have a +40% upper uncertainty range.

Retorting accident statistics based on petroleum refining accidents have a $\pm$20% uncertainty range.

Oil shale construction accident statistics have a $\pm$5% uncertainty range.

MIS employment estimates are +10% more uncertain than other employment estimates.

State agencies will almost certainly monitor heavy metals in fish and prevent consumption if potential health hazards are present.

Leachate from one abandoned MIS retort flowing unattenuated into the Piceance Creek represents attenuated leachate from the entire industry and is directly scaled with the number of contributing sites for the estimation of uncertainties.

Variations in exposures estimates based on data assumed relevant (pilot facilities and laboratory experiments) are included by the sensitivity and uncertainty analyses.

Higher oil shale miner productivities than the 37.5 short tons underground/150 short tons surface/workshift can be achieved resulting in significantly reduced yearly expected occupational fatalities.

Table E-2. Oil Shale Risk Analysis Annual Non-Threshold Public Health Risks in the Oil Shale Region

Health Effect Risk Analysis	Controlled Emission or Effluent	Type of Yearly Health Effect	Estimated Public Health Risk (Uncertainty Range)		
			Baseline Scenario	MIS Variation	OPT Variation
Non-Threshold Airborne Pollutants	Arsenic	Excess Respiratory Cancer	4.5×10^{-3} (0 to 1.4×10^{-2})	2.8×10^{-3} (0 to 8.7×10^{-3})	1.7×10^{-3} (0 to 5.4×10^{-3})
	Benzo(a) Pyrene	Excess Respiratory Cancer	5.5×10^{-3} (0 to 7.0×10^{-2})	3.3×10^{-3} (0 to 4.3×10^{-2})	5.3×10^{-3} (0 to 6.7×10^{-2})
	Cadmium	Excess Lung Cancer	4.3×10^{-5} (0 to 1.6×10^{-4})	2.9×10^{-5} (0 to 1.0×10^{-4}	4.3×10^{-5} (0 to 1.6×10^{-4})
	Chromium	Excess Lung Cancer	1.6×10^{-4} (0 to 6.4×10^{-4})	8.6×10^{-5} (0 to 3.6×10^{-4})	1.6×10^{-4} (0 to 3.0×10^{-4})
	Nickel	Excess Lung & Nasal Cancer	7.1×10^{-5} (0 to 3.0×10^{-4})	8.6×10^{-5} (0 to 3.6×10^{-4})	7.1×10^{-5} (0 to 3.0×10^{-4})
Total Airborne Pollution Based on Sulfur Oxides Surrogate[a.]	Sulfur Oxides	Premature Death	73 (0 to 330)	250 (0 to 970)	220 (0 to 850)
Non-Threshold Waterborne Pollutants[b.]	Arsenic	Excess Skin Cancer	9.4×10^{-3} (0 to 3.8×10^{-2})	1.0×10^{-1} (0 to 4.0×10^{-1})	2.2×10^{-1} (0 to 8.8×10^{-1})
TOTAL POPULATION AT RISK			685,000	552,000	470,000

a. Controversial model
b. Based on an extreme analysis to create exposure conditions

chosen to account for the most sensitive members of the population) are quite small. About 2,000 persons (of the 685,000 in the region) may smell hydrogen sulfide. The expected number of exposures to the sulfur oxides and particulates are estimated to be much smaller than hydrogen sulfide, although this could range from zero to 17,000 and zero to 2,000, respectively, based on scenario variations. The health effects exhibited in these sub-populations may be increased respiratory illness, such as an increase in the prevalence of chronic bronchitis. The analysis performed for extreme discharge of effluents and leachates reaching public water supplies using many conservative assumptions indicates the potential for health effects from sodium, fluoride, mercury, and possibly selenium. Further research is needed to estimate realistic exposures to oil shale industry effluents and leachates.

The estimated occupational risks are incomplete. The exposure of the oil shale worker and the resulting health effects are a key issue of the OSRA and will be the focus of the second year's effort. Proper quantification of worker exposures is an area of further research needs, as is the examination of the toxicologic relationships related to these exposures.

Incidence rates due to accidents are predicted for the oil shale workforce through utilization of historical incidence rates from comparable industries. Mining of oil shale will most likely account for the greatest fraction of the total oil shale industry accidents and illnesses. Current mining incidence rates are used to predict the number of accidents from oil shale mining. Petroleum refining incidence rates are used for the surface processes, and construction industry rates are indicative of the construction workforce. Table E-3 presents

the OSRA estimate of the expected worker accidents and associated uncertainty ranges. To reduce the occupational accident uncertainties, further research is needed into the relative safety and production levels of oil shale mining techniques, and into theoretical determinations of accident rates for modified-in-situ and large-scale surface retorting.

Table E-3. Oil Shale Risk Analysis Estimate of Expected Worker Accidents Based on Historical Incidence Rates

Scenario	Workforce	Risks from Accidents (Uncertainty Range)		
		Yearly Fatalities	Yearly Non-Fatal Occurrences with Days Lost	Yearly Accidents with No Days Lost
Baseline	58,700	40 (37-45)	4,700 (4,300-5,200)	2,500 (2,300-2,800)
MIS Variation	39,200	24 (22-36)	2,800 (2,800-4,200)	1,700 (1,700-2,300)
OPT Variation	27,300	8 (8-10)	860 (810-970)	920 (880-1,050)

The ecosystem risks will be quantified on the basis of further work exploring changes in community diversity. The risks to designator species, mule deer for terrestrial communities and trout for aquatic communities, were estimated to illustrate the use of quantitative techniques. These species were chosen due to the high public interest

associated with them and due to data availability. The large uncertainties for the population changes of the designator species are indicative of the uncertainty in both the exposure and response of these species, as well as large natural population variations that are inadequately understood. The primary environmental research areas needed to reduce the ecosystem risk uncertainties include revegetation and habitat studies as well as additional fate and effects data on the oil shale pollutants for prevalent members of the aquatic and terrestrial communities.

Research recommendations based on the need both to narrow the critical uncertainty bands and to fill major data deficiencies are summarized in Table E-4. The OSRA has revealed that a large-scale oil shale industry will have to address energy, transportation, water, and solid waste disposal problems for the time scale of a century using an overall systems approach to minimize health, ecosystem and economic risks. The magnitude and value of the resource merit proper planning and analysis to ensure the developers do not overlook potential problems and risks. The initial candidate study areas are the water use and disposal in the Colorado River System and the transport of shale oil to refineries.

The OSRA source terms were derived from available data during the initial phases of the project. Some significant sources of additional data, such as the Lurgi spent shale, are now available for a better characterization of the proposed processes. The ongoing research in all phases of the characterization studies should continue and will be used to update the source terms. Characterization of the hydrocarbons from actual processes will be important both to help

Table E-4. Summary of Oil Shale Risk Analysis Research Needs

EXPOSURE	HEALTH EFFECTS	RISK ESTIMATES
Particulate/dust releases at site.	Dose-effect and dose-response relationships for polycyclic aromatic hydrocarbons and aza-azarines generated from the oil shale industry.	Fluoride, mercury, selenium and sodium measurements in effluents and leachates. Attenuation mechanisms during water transport.
Sulfur oxides generated, controlled, and emitted at each site.	Dose-effect and dose-reponse relationships for ingestion of oil shale effluents.	Effect of water treatment and transport facilities on oil shale effluent waters and the fate and effect of the pollutants in the environment.
Characterization of hydrocarbons released at sites into the environment.	Health effects of sulfur oxides exposure.	Data on the oil shale region's agricultural products and their potential uptake and bioaccumulation of oil shale pollutants.
Trace elements (especially the heavy metals) and their chemical reactions/-transformations in the processes, transportation, and disposal to establish their ultimate fate in the environment. Initial efforts can consider the trace element input to surface streams from snow melt.	Health effects due to cutaneous exposure to oil shale pollutants	Revegetation means and measures for prediction of time-dependent factors of ecosystem response in view of large-scale disturbances.
Water treatment, recycle, and release.	Information on the potential for an oil shale silicosis ("Mahogany Lung")	Oil shale region terrestrial species response to large-scale terrain modifications (roadways, pipelines, etc.)
Solid waste disposal plans and measurements.	Quantification of occupational safety in oil shale mines, including the factors affecting the incident rates for fatalities.	Oil shale region aquatic system effects from oil shale effluents with emphasis on edible components presenting possible bioaccumulation of toxic substances.
The interaction of complex hydrocarbons and/or trace elements in the process streams.	Toxicologic data for exposures to oil shale, oil shale dusts (raw and retorted), and oil shale products and effluents.	Fault and event tree quantification of oil shale-specific accidents, with emphasis on MIS and surface retorting.
Changes in leachate composition during movement through the ground and aquifiers.	Epidemiologic data concerning past (e.g., Scottish and Estonian experience) and present (e.g., a registry for U.S. oil shale workers) exposures to oil shale.	The effect of management safety practices in the solid handling and mining industries.
Chemical interactions of accidentally released effluents in existing stream/-sedimentation conditions.		Models for water discharge into the Colorado River drainage system from the oil shale region.
Altitude and terrain effects on the chemistry and transport of air pollutants.		
Occupational exposures during shale mining, retorting, and spent shale disposal.		

understand how the process variables can be modified to minimize human health and ecosystem risks, and to provide appropriate control strategies. Research is also needed to ensure appropriate control technology will be available.

The uncertainties concerning the health effect analysis are of two types: those related to the generic pollutant exposures which are not specific to the oil shale industry (sulfur oxides, trace elements, etc.) and those related to oil shale-specific exposures. The OSRA considers uncertainties of the latter kind to be research needs that should be addressed by oil shale research as summarized in Table E-4. Fugitive releases from process streams and the fate and effect of pollutants released need further chemical and toxicological characterization to resolve uncertainties in the risk. One additional, longer term need is the requirement for a computer-based depository and retrival system for all oil shale environmental data.

The research recommendations presented are preliminary and may not include some existing projects that will have data applicable to the future iterations of the OSRA. The recommendations for research remain to be prioritized and coupled with the Department of Energy's oil shale environmental research and development plan. This year's effort has concentrated on the public health effects related to a steady-state, one-million-barrels-per-day industry using only readily available data and selected portions of the oil shale fuel cycle. The next year's effort will concentrate on the occupational risks and will use better data and improved assumptions. After the risks for the complete oil shale fuel cycle for the installing, steady operations, and decommissioning phases of the industry are analyzed, further efforts will be required to establish and prioritize the research needs.

TABLE OF CONTENTS

List of Tables

List of Figures

HEALTH AND ENVIRONMENTAL EFFECTS
DOCUMENT FOR OIL SHALE-1981

1. INTRODUCTION

1.1 OVERVIEW OF THE OIL SHALE RISK ANALYSIS

This report presents the results of the first year of the Oil Shale Risk Analysis (OSRA) conducted by the Center for Environmental Sciences, University of Colorado at Denver and IWG Corp. of San Diego. This effort is part of the Department of Energy's Oil Shale Research, Development, and Demonstration Program performed under contract for the Health and Environmental Risk Analysis Program, Human Health and Assessment Division, Office of Health and Environmental Research.

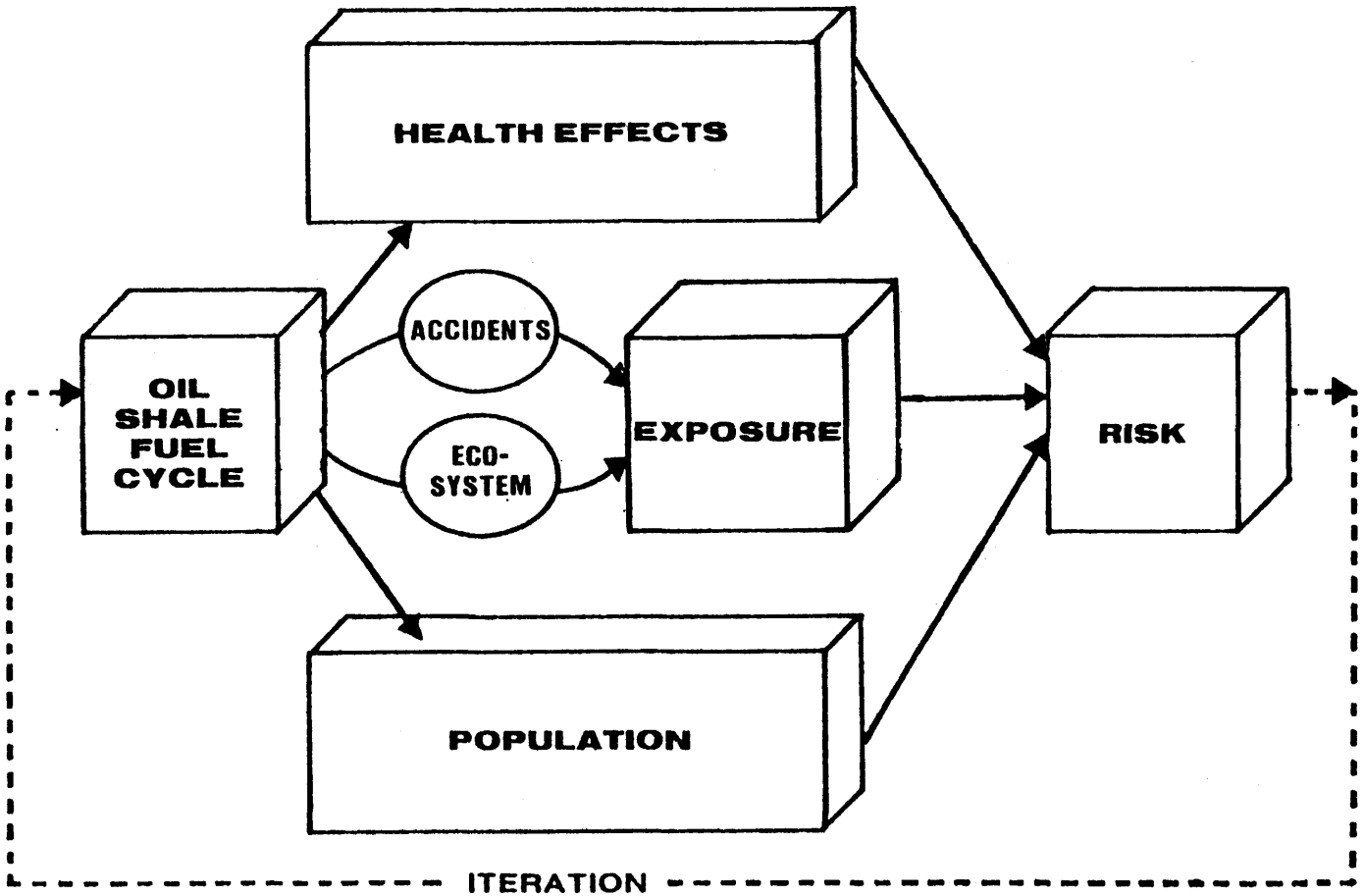
The objective of this project is to perform an analysis of potential risks to human health and the environmental effects associated with an oil shale industry capable of supplying a significant fraction of the United States' energy demand. The results are reported and disseminated in a Health and Environmental Effects Document (HEED). The HEED is a quantitative description of knowledge and uncertainty regarding potential health and ecosystem risks of an oil shale industry. The HEED is developed for providing information to aid in formulating and managing a program of environmental research focused on providing information required to reduce uncertainties in critical areas. The purpose of this document, "Health and Environmental Effects Document for Oil Shale-1981," is to present the findings of the first year's effort.

The overall process of the OSRA is shown in Figure 1-1. The nature of the risk analysis process is iterative due to the mutual interdependence among its key elements and the need to refine the results. The first year's effort is a "broadbrush" approach to the entire analysis. The risks are based on readily available data, resulting in a mechanism to establish data requirements and use applicable data as it becomes available. In addition, the following concerns were also examined:

- Determination of the significant pathways for human exposure
- Evaluation of the risk to ecosystems
- Establishment of the critical uncertainties in the risk analysis.

The estimate of risks associated with an oil shale industry is the result of the interactive process of exposure to source terms (defined as pollutants, fugitive emissions, and accidents), the health effects of those exposures, and the population at risk. Exposure to source terms is established on the basis of probability of exposure and analogous industry data for the oil shale fuel cycle. The health

Figure 1-1. Risk Analysis Process

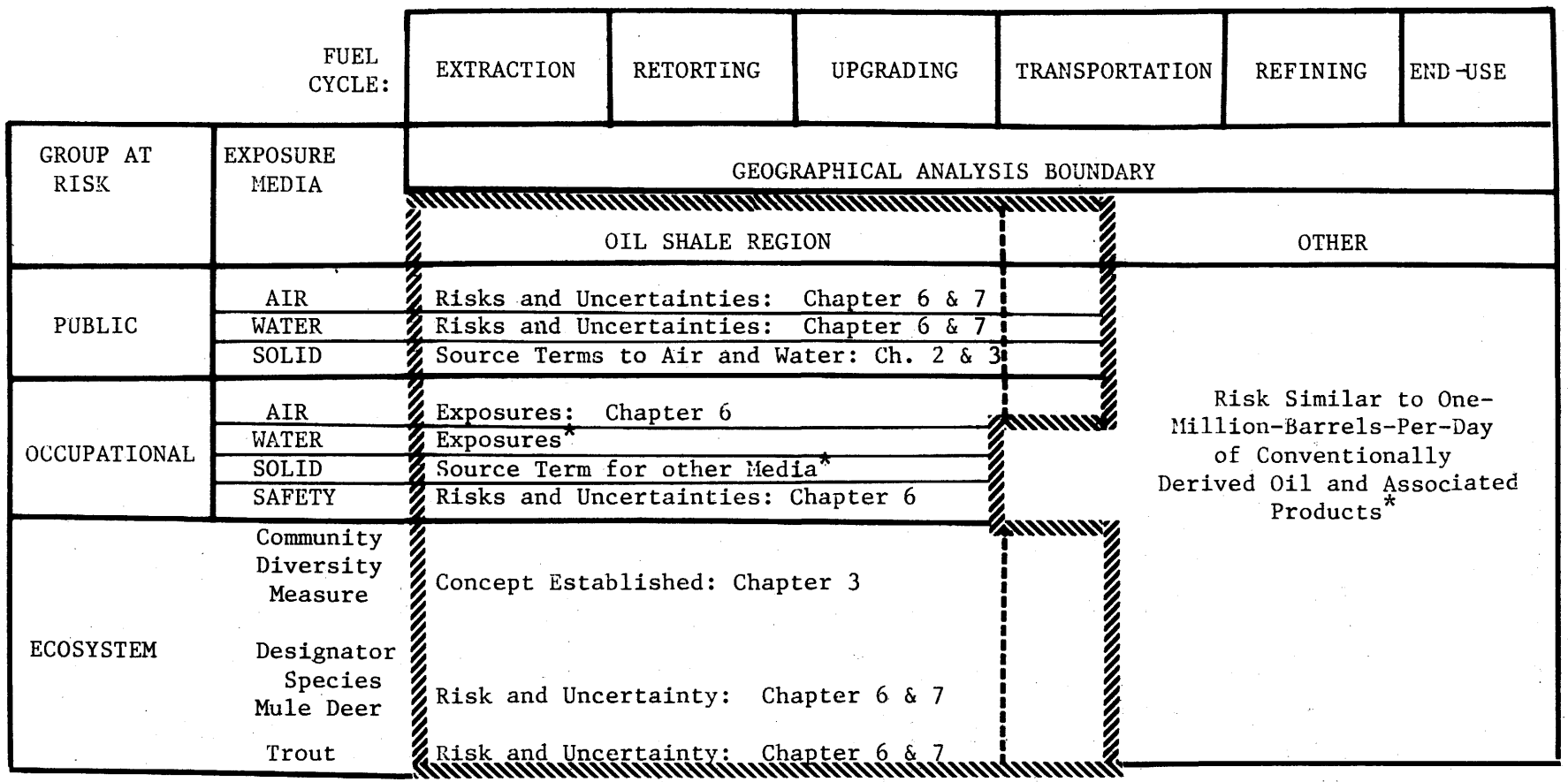


effects are characterized by the conditional probability of effect given the exposure; the risk is the expectation of population health effects under the exposures considered.

The oil shale reference industry considers the fuel cycle for oil shale, from in-place resource extraction to the end use of the products, and a scenario for producing one-million-barrels-per-day of shale oil (159 million liters-per-day). The oil shale reference industry is based on a six-step fuel cycle for oil shale, from resource extraction to product end use. These six steps, representing a simplified accumulation of various processes and procedures, are summarized in Figure 1-2 along with the geographical boundaries and populations-at-risk used in the analysis. The 18,000 square mile (46,620-square-km) oil shale region containing the prime resource of the Piceance Creek and Uinta Basins of Colorado and Utah, respectively, represents a geographical area of prime concern for health and environmental risks. This region, referred to as the "oil shale region" represents the primary exposure region for the occupational workforce and public of the region for the extraction, retorting, and upgrading portions of the fuel cycle. At this point in the fuel cycle, the shale oil product is transported out of the oil shale region. Pollutant source terms for the transportation sector are both within and outside the oil shale region. The refining and end use are all assumed to be outside the oil shale region. The first-year HEED addresses only the risks associated with the oil shale region. Based on currently available data, the upgraded shale oil within a pipeline presents similar risks to the public and occupational workforce as conventional petroleum. To derive initial estimates of complete fuel cycle risks, it is necessary to (1) add the occupational risks derived from one-million-barrels-per-day petroleum in a pipeline (transported), refined to products, and distributed for end use, (2) add the public risks from petroleum transportation wastes outside the oil shale region, refining pollutants, and product end use wastes, and (3) add ecosystem effects as in step (2).

Figure 1-2 also serves as a roadmap for the HEED by summarizing the extent of the analysis and indicating the appropriate chapters of the report for exposure and risk results. An introduction to oil shale is presented in the appendix for the reader unfamiliar with the topic. The oil shale risk analysis scenario is used to establish the pollutant source terms representing a hazard to man and the environment. Chapter 2 presents the scenario and pollutant source terms, including variations for the sensitivity of the type of mining: underground or surface. The source terms are transported and transformed in the biosphere resulting in the exposure of the ecosystem and man. Chapter 3 describes this process and the environmental effect methodology for the oil shale reference industry. Chapter 4 presents the population at risk for the occupational workforce and public within the 18,000-square-mile oil shale region. The human health effects from the pollutants of the oil shale industry are summarized in Chapter 5. The merging of the exposure, population, and health effects to predict the health and environmental risks is presented in Chapter 6. Research needs and a perspective on the risk estimates, including uncertainties, sensitivities, and recommendations, are presented in Chapter 7, followed by the conclusions in Chapter 8.

Figure 1-2. Oil Shale Fuel Cycle, Analysis Boundaries and Road Map



* To be considered in further efforts.

▨ = 1981 OSRA analysis efforts.

1.2 ASSUMPTIONS

The OSRA has used a large number of assumptions to complete the initial analysis. The major assumptions have been compiled and are listed below:

Source Terms (Chapter 2)

- A non-existent oil shale industry can be characterized by the baseline scenario for one million barrels per day, consisting of fifteen production sites and is a reasonable prediction for a large-scale U.S. oil shale industry.
- The baseline scenario will transport the majority of the upgraded shale oil through Rifle, Colorado for refining outside of the oil shale region. (Future analysis will avoid this questionable assumption by using operator plans).
- The occupational and public risks unique to oil shale are represented by the extraction through upgrading portions of the oil shale fuel cycle. The remaining portions of the fuel cycle will be considered in future efforts.
- The use of available source characterization data is sufficient to represent industry pollutant source terms (Lurgi is replaced by TOSCO data, BX Pure/Steam and LOFRECO by TIS data, etc.).
- The simplified OPT and MIS variations can be used for generation of analytic sensitivities.
- Air pollutants can be controlled at a 95% level.
- Water effluents can be controlled at a 90 to 99% level.

Exposure (Chapter 3)

- Simplified Gaussian model results for flat terrain and a single wind rose with gravitational settling are adequate to represent the dispersion of airborne pollutants.
- Simplified water analyses result in appropriate extreme exposures. This included complete mixing, negligible pollutant transformation, continual discharge of treated effluents, isotropic aquifier media, and non-attenuated leachate transport.
- The uptake of heavy metals and trace elements in vegetation is at low enough levels that terrestrial food chain contamination is minor compared to the potential aquatic food chain contamination under extreme conditions.
- Ecosystem risk can be meaningfully measured by community diversity and techniques illustrated through designator species.

- Downstream fish tissue concentrations can be estimated by summing the metal element contributions from effluents (product water discharges and leachates) and multiplying an assigned bioaccumulation factor.

Population (Chapter 4)

- The occupational workforce can be estimated based on extrapolated oil company worker estimates.

- The future population can be estimated using demographic study data and multipliers for industrial workers' families and for industry-influenced public sector growth.

Health Effects (Chapter 5)

- Pollutant interactions can be ignored.

- The chemical forms and their toxicities identified for oil shale research are representative of the potential industry.

- Possible beneficial effects of pollutants are ignored.

- Health effects, except carcinogenesis and the SO_x surrogate for the mortality analysis, are assumed to have thresholds.

- Carcinogenic effects are considered to have no threshold, based on the lack of data to the contrary.

- Teratogenic effects were not considered in the initial effort

- Exposures below chosen thresholds for adverse effects result in zero risk with negligible uncertainty.

- TLV's (ACGIH) divided by a factor of three are appropriate to define thresholds for adverse effects for general public exposures. (The authors offer apologies to the ACGIH for the stated missuse of their data. The breadth of effort in the first year's analysis did not allow for an in-depth study into the wide spectrum of pollutants, necessitating a use of available data to focus efforts for ensuing years.)

- ICRP's standard man of 20 m^3/day respiratory rate and 2 liters/day water intake is an adequate representation of an average person in the oil shale region.

- Health thresholds chosen to protect susceptible groups (particularly children and people with pre-existing lung disease) are, on the average, adequate for health effect estimation for large populations.

- The health effects screening methodology adequately identifies the significant pollutants.

- The airborne and waterborne pollutant health effects threshold levels are valid.

- BaP can be used as the carcinogenesis indicator for the polycyclic aromatic hydrocarbons emitted in the vapor phase and associated with particulates in human inhalation.

- Vapor-phase polycyclic aromatic hydrocarbons do not reach the general public; those absorbed onto particulates do reach the public.

- Arsenic, cadmium, chromium, nickel, and BaP have valid dose-response relationships for estimation of the non-threshold excess cancer risks.

- Inhalation of sulfur oxides can be used as a surrogate for total pollution premature deaths although sulfur oxides are not necessarily the causative agent of increased mortality.

- Ingestion of arsenic in water can cause skin cancers in the U.S. population.

Risk (Chapter 6)

- Inhalation risks can be estimated for non-threshold effects by summing the product of the exposure in a sub-region (as calculated using a simplified Gaussian model) times the population in the region times the dose-response over all sub-regions of the oil shale region on a pollutant-by-pollutant basis.

- Overall increases in mortality alone can be estimated and meaningfully interpreted using sulfur oxides as a surrogate for total pollution within the oil shale region.

- The risk from exposure to water effluents and contaminated aquatic systems upstream of feeder streams is negligible.

- The health effect risks from ingestion of drinking water assumes the water is untreated.

- The occupational workforce accident rates can be predicted using historical occurrences from analogous industries.

- The method of mining, and not the substance mined, is paramount in predicting oil shale mining accident rates.

- Accidents in underground oil shale mines can be estimated from accident statistics for other underground mining.

- Accidents in surface oil shale mines can be estimated from accident statistics for other surface mining.

- The size of the oil shale mine will have no effect on safety.

- Oil and gas extraction accident statistics are applicable to TIS drilling operations.

- Retort operators in MIS mine have the same injury and accident rates as surface retort operators.

- The underground oil shale miner produces an average 34.0 metric tons (37.5 short tons) of shale per workshift.

- The open-pit (surface) oil shale miner produces an average of 136 metric tons (150 short tons) of shale per workshift.

- Solid waste land disturbance can be estimated using piles 30 meters high, 50% backfill into mines, and compaction densities of 1,360 kg/m^3.

- Mule deer population decline is directly proportional to the 1,700 square kilometers (425,000 acres) of habitat disturbed supporting a herd size of 28,000.

- Trout population declines with effluent/leachate releases can be predicted based on LC_{50} data for ammonia.

- Threatened and endangered fish species will exhibit twice the response of trout for similar exposures.

Uncertainties and Sensitivities (Chapter 7)

- Non-threshold risks are the product of parameters which are log-normally distributed and independent.

- Risk estimates of zero have negligible uncertainty for populations exposed below conservative thresholds.

- The uncertainty in the extrapolation of linear, non-threshold dose-response relationships to low levels of exposure can be neglected in the uncertainty analysis and the minimum of the uncertainty range can be assumed zero.

- Meaningful judgemental estimates can be made for uncertainties of model parameters.

- Oil shale mining accident estimates have a $\pm$10% uncertainty range.

- MIS mining accident estimates have a +40% upper uncertainty range.

- Retorting accident statistics based on petroleum refining accidents have a $\pm$20% uncertainty range.

- Oil shale construction accident statistics have a ±5% uncertainty range.

- MIS employment estimates are +10% more uncertain than other employment estimates.

- State agencies will almost certainly monitor heavy metals in fish and prevent consumption if potential health hazards are present.

- Leachate from one abandoned MIS retort flowing unattenuated into the Piceance Creek represents attenuated leachate from the entire industry and is directly scaled with the number of contributing sites for the estimation of uncertainties.

- Variations in exposures estimates based on data assumed relevant (pilot facilities and laboratory experiments) are included by the sensitivity and uncertainty analyses.

- Higher oil shale miner productivities than the 37.5 short tons underground/150 short tons surface/workshift can be achieved resulting in significantly reduced yearly expected occupational fatalities.

2. OIL SHALE REFERENCE INDUSTRY AND SOURCE TERMS

The purpose of this chapter is to establish the oil shale industry scenario and pollutant source term data for exposure of man and the ecosystem. Seven different oil shale production processes and fifteen development sites are used to develop site specific source terms for a million-barrels-per-day industry scenario. Significant data deficiencies necessitated using assumptions to perform initial risk estimates. The assumptions of the analysis and the data base are under annual review in the risk analysis process. This data base is set up to be easily updated when additional information becomes available.

2.1 OIL SHALE FUEL CYCLE

The oil shale fuel cycle for the risk analysis is considered to have six steps: 1) extraction, 2) retorting, 3) upgrading, 4) transportation, 5) refining and conversion, and 6) end uses. These steps of the fuel cycle may then be further categorized and subdivided into process stages. Figure 2-1 presents a flowchart of a generalized oil shale fuel cycle from extraction to end uses. No one retorting process involves all parts of the flowchart, but specific sites may use more than one process. Extraction and retorting are significant portions of the oil shale fuel cycle when estimating the types and quantities of pollutants that are being released on-site. Upgrading may occur on-site or off-site, and produce additional pollutants of concern. The shale oil is expected to be transported from the oil shale region for refining. The end use of shale-oil-derived products is expected to occur off-site.

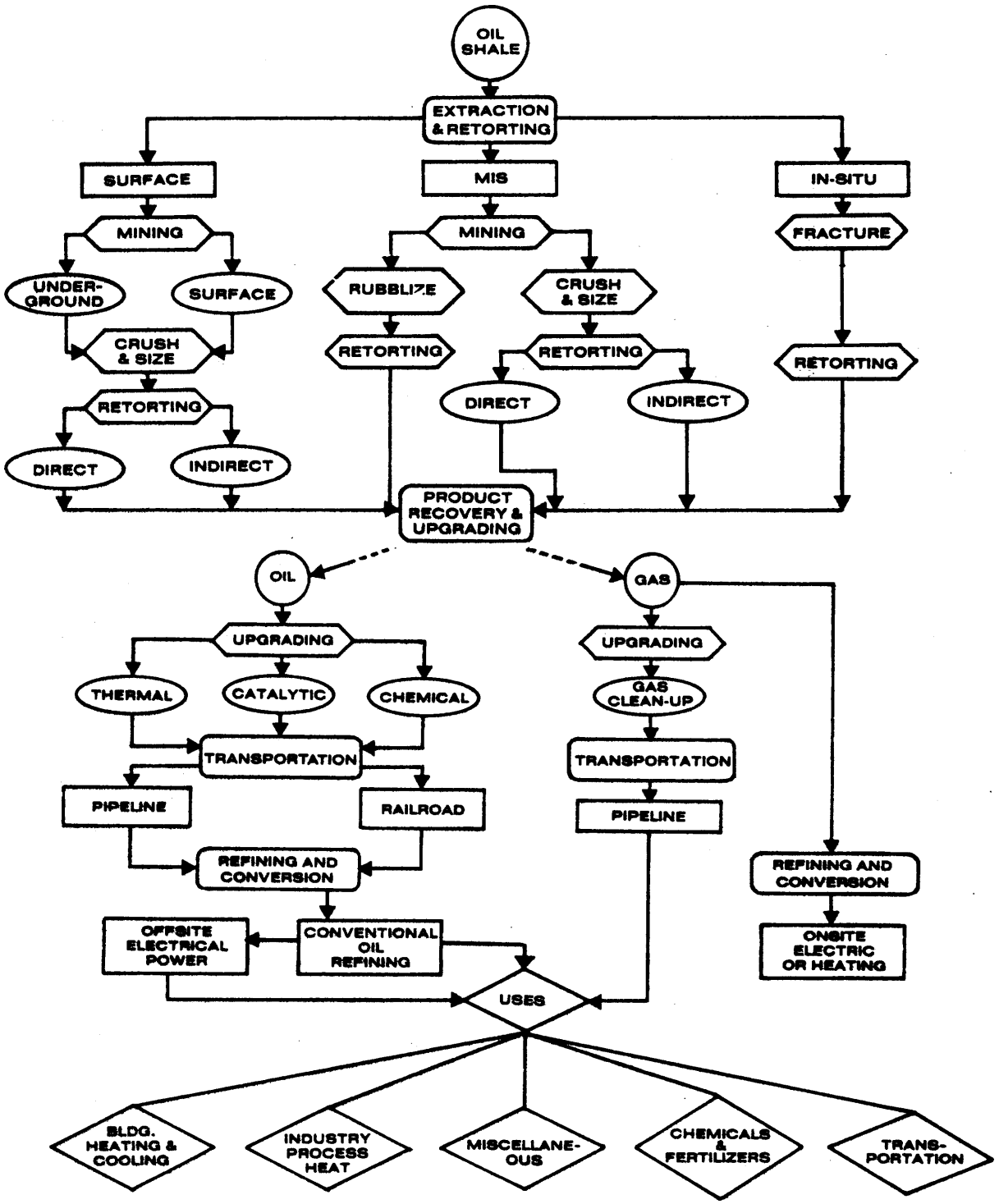
The pollutants released during the fuel cycle are a function of the assumed control technologies. The primary concern from a health effects standpoint for the public and workforce in the oil shale region is the amount and type of waste generated during the extraction, retorting, and upgrading portions of the fuel cycle. The generated wastes vary with the type of extraction and retorting process, the operational parameters within the process, and the pollution control technology applied.

The extraction and retorting steps are site and process specific. The retorting processes are grouped into one of three general categories: above ground or surface, modified-in-situ (MIS), and true-in-situ (TIS). In addition, the above ground category is further divided into direct and indirect, according to the shale heating method.

Upgrading can be performed either on-site or off-site. The off-site upgrading pollutant source terms represent significant additions of sulfur dioxide and hydrocarbons to the total source pollutant releases.

The transportation source terms are derived from air emissions

Figure 2-1. Oil Shale Fuel Cycle Analysis Flow Chart



resulting from pipeline pump stations and normal operations by rail. It was assumed that the oil will be pumped through Rifle, Colorado.

The refining wastes are important; refining operations for one million barrels of oil daily yield wastes of significant magnitude. But, this would also occur for conventional oil (non-shale derived). The risks from these pollutants were not considered in the current analysis. The addition of oil shale region refining capability to the scenario would change the risks for the population in the region.

The preliminary production distribution for the million-barrels-per-day scenario is depicted in Table 2-1. The fifteen development sites represent current information and have been verified with specific operators. They represent a consensus of their maximum capability to respond to the production requirement. In the defined production distribution, approximately 85 percent is from surface operations. Considerations regarding the type of surface retorts anticipated to be in operation, and key assumptions in deriving this scenario, are given in the footnotes in Table 2-1.

The scenario in Table 2-1 has limitations which must be addressed before establishing the pollutant source terms for the risk analysis. The major problem is the lack of sufficient data for a number of the currently listed processes. The data used has been taken from the following references: Cameron Engineers, 1978; Chappell, 1979; U.S. Department of Energy, 1980; U.S. Department of Interior, 1979; Energy Research and Development Administration, 1977; Environmental Protection Agency, 1980; Environmental Protection Agency, Region 8, 1977; Fox et al., 1979; Fruchter et al., 1979; Fruchter and Wilkerson, 1980; Nowacki, 1980; Office of Technology Assessment, 1980; Sandell et al., n.d.; Schmidt-Colerus, 1980. Both Lurgi and TOSCO processes are capable of treating shale fines, but data is currently lacking for Lurgi pollutants. For purposes of the initial analysis, the Lurgi process has been replaced by the TOSCO process throughout the scenario, under the assumption that the pollutants will be similar for similar production levels. Also, for the Equity and Geokinetics tracts, generalized true-in-situ process data have been assumed to represent the BX Pure/Steam and the LOFRECO In-Situ processes. The Union B process has been used for the Long Ridge and U-a, U-b tracts. The IIS (Integrated) process has been replaced by the Superior Circular Grate process, with mineral co-product production for similar reasons of data deficiency. Similar assumptions are made regarding the Chevron, Mobil and Getty tracts, which have unspecified processes. It is assumed that the Chevron tract will use the Paraho process, while the Mobil and Getty tracts will use the TOSCO process. Current plans indicate on-site upgrading at only three surface processing plants. It has also been assumed that both the Equity and Geokinetic tracts will have upgrading on-site, since the available data for TIS processes combine upgrading with retorting. The five plants with on-site upgrading represent 30% of the production.

Table 2-2 presents the modified scenario for a one-million-barrels-per-day shale oil production. This scenario is referred to as the Baseline Scenario for the 1981 OSRA. Figure 2-2 shows a map of the

Table 2-1. Preliminary Baseline Scenario for Hypothetical Future One-Million-Barrels-Per-Day Shale Oil Production

Site No.	Tract/ Operating Group	Process	Scenario
	ABOVEGROUND		
1	Long Ridge/Union Oil Co.	Union B/Union SGR[1]	150,000
2	Superior	Superior Circular Grate[2]	46,000
3	Colony	TOSCO II[1]	47,000
4	Sandwash/TOSCO	TOSCO II	50,000
5	Ua + Ub/White River	Paraho (Indirect)/Union B	100,000
6	Paraho	Paraho (Indirect)	30,000
7	Parachute/Chevron	Unknown	100,000
8	E. Parachute/Mobil	Unknown	100,000
9	Parachute/Getty	Unknown	50,000
10	NOSR	Unknown (Paraho?)[1]	100,000
11	Multi-Minerals	IIS (Integrated)[2]	50,000
12	C-a/Rio Blanco	Lurgi[3]	100,000
	MODIFIED-IN-SITU		
13	C-b/Oxy	OXY (MIS)/Lurgi	100,000
	TRUE-IN-SITU		
14	Geokinetics	LOFRECO In-situ	10,000
15	Equity	BX Pure/Steam	10,000

1. Potential Upgrading/Refining Facilities On-Site.
2. Mineral Co-product Production (Soda-Ash, Alumina, Nahcolite).
3. Surface mining is assumed.

Scenario Considerations and Assumptions

Production - For consistent terminology all barrels are in whole raw shale oil without pre-refining, with the notable exception of the Colony project (Exxon, TOSCO). For projects proposing to pre-refine their output, the barrels so indicated should be reduced by a factor of ~.90.

Land Exchanges - Several projects require land exchanges with the Bureau of Land Management in order to form efficient mining "blocks" of shale reserves, or to eliminate inefficient "windows" within resource units. This analysis assumes that fair and equitable exchanges will be effected between the operators and the federal government.

Technological Competence - The viability of surface processing to respond to a production scenario has been relatively proven with both field and pilot plant operations. All in-situ processes have yet to be fully demonstrated under critical technological, environmental, and economic criteria. Tract C-a operations are assumed to be of a surface processing variety in conjunction with open pit mining for resource extraction (Footnote 3). It is assumed that an indirect operation mode will be selected for most of the convective heat transfer type surface retorts. This assumption is based on the economic (unit cost) considerations of retort off-gas clean-up and the enhanced value of higher gas calorific values.

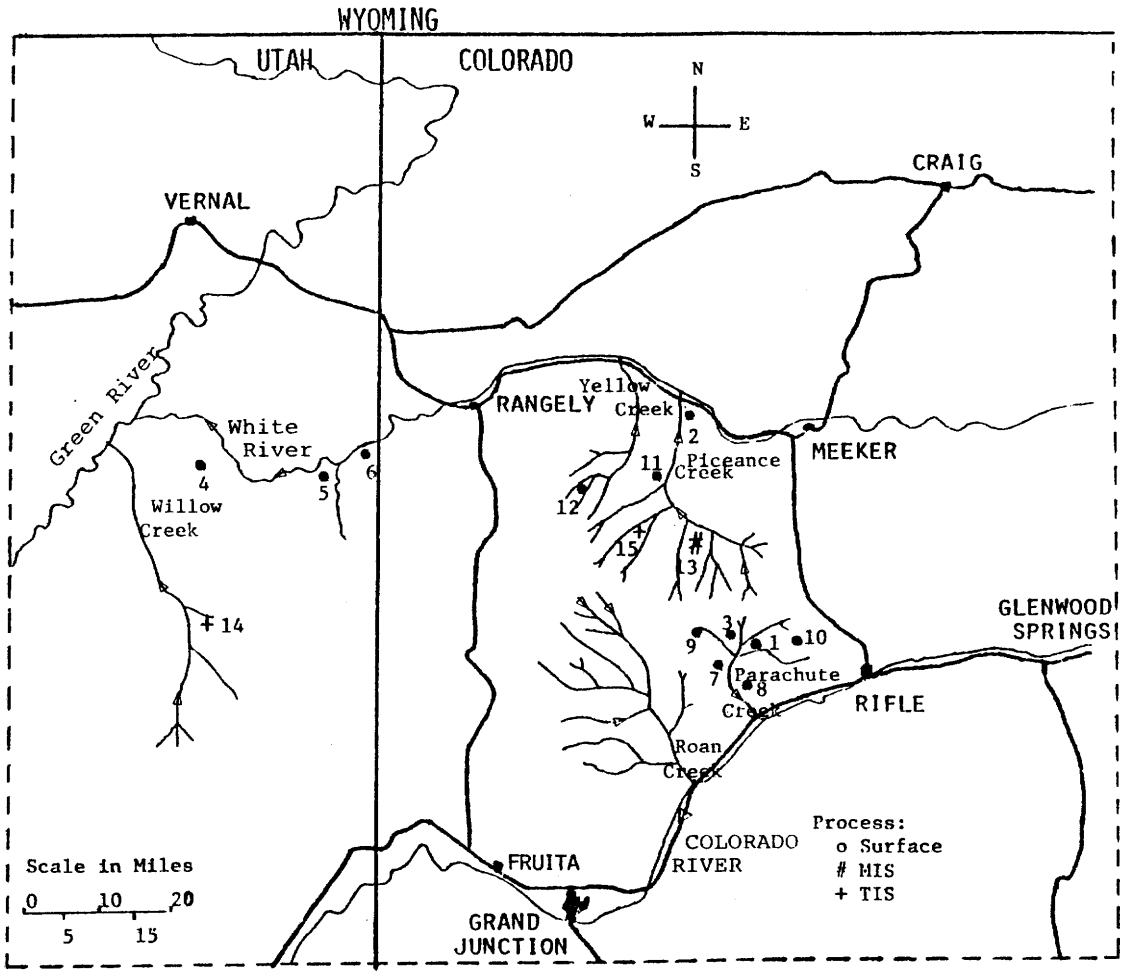
Unknown Technologies - Approximately 35% of the total production in the scenario is derived from announced operations or development plans were no specific process technology has been declared. Surface processes are assumed for these developments and best estimates have been used to define the anticipated technology.

Project Locations - The locations of the anticipated shale oil projects are exclusive to the three state Rocky Mountain area of Western Colorado, Eastern Utah, and Southwestern Wyoming. Predominately Colorado based, there are four projects in Utah and none are projected for the State of Wyoming. The majority of the locations (80%) represent known site selections such that, if the scenario is remotely correct, the sites predicted have a high assurance level of being correctly placed. The remaining locations, although unknown as to their precise location, are known with the extent of several large tract boundaries and represent probabilities for general areas of development in an expanded development scenario.

Table 2-2. Baseline Scenario for Oil Shale Risk Analysis

Site No.	Tract/ Operating Group	Production (bbl/d)	Process	On-Site Upgrading (Yes/No)	Mining	Elevation (ft)	Comments
	ABOVEGROUND						
1	Long Ridge/Union Oil Co.	150,000	Union B	Yes	Room & Pillar	7,200	
2	Superior	46,000	Superior	No	Room & Pillar	5,700	Mineral Co-Product Production
3	Colony	47,000	TOSCO	Yes	Room & Pillar	8,120	
4	Sandwash/TOSCO	50,000	TOSCO	No	Room & Pillar	5,100	
5	Ua+Ub/White River	100,000	Union B	No	Room & Pillar	5,360	
6	Paraho	30,000	Paraho	No	Room & Pillar	6,000	Uinta Co., Utah
7	Parachute/Chevron	100,000	Paraho	No	Room & Pillar	8,200	Parachute Creek
8	E. Parachute/Mobil	100,000	TOSCO	No	Room & Pillar	6,600	East Parachute Creek
9	Parachute/Getty	50,000	TOSCO	No	Room & Pillar	8,200	Parachute Creek
10	NOSR	100,000	Paraho	Yes	Room & Pillar	8,300	NOSR-1 + NOSR-3 Combined
11	Multi-Minerals	50,000	Superior	No	Room & Pillar	6,700	Mineral Co-Product Production
12	C-a/Rio Blanco	100,000	TOSCO	No	Open Pit	7,200	
	MODIFIED-IN-SITU						
13	C-b/Oxy	100,000	MIS/TOSCO	No	Underground	6,580	60% Oxy MIS, 40% TOSCO
	TRUE-IN-SITU						
14	Geokinetics	10,000	TIS	Yes	Minimal	6,500	Generalized TIS
15	Equity	10,000	TIS	Yes	Minimal	6,800	Generalized TIS
	Total	1,043,000					

Figure 2-2. Oil Shale Risk Analysis Region and Development Scenario Sites*



*Area of 46,620 sq. km. (18,000 sq. mi.) referred to as the oil shale region for the Oil Shale Risk Analysis

oil shale region with the location of the various plants.

Two variations in the development scenario also were examined. One variation, referred to as the "OPT" scenario variation, assumes that all sites use open-pit extraction, TOSCO retorting, and on-site upgrading. The other variation, referred to as the "MIS" scenario variation, assumes that all sites use a ratio of 60/40 modified in situ and TOSCO retorting, and that all upgrading is on-site. These scenario variations are extreme cases not expected to occur but can be used to compare technology options. Because the baseline scenario has a mix of technologies, the scenario variations provide a convenient means to separate the other two major oil shale development technologies for a sensitivity analysis.

2.2 OIL SHALE POLLUTANTS

The pollutants for these processes are examined as three phases: air, liquid, and solid. These are characterized in as much detail as available. The data have been normalized to a yield of 25 gallons/ton to enable the generation of pollutants for various production (product shale oil) levels. The air emissions and solid waste data are given in units of kilograms per day (kg/d) for scenario-site emissions. The wastewater treatment data are calculated in units of gallons per barrel of oil produced and later converted to kg/d at certain river locations.

Control technology will be employed to reduce the wastes entering the environment. The efficiencies and reliability of the specific control processes are beyond the scope of the current effort. Nevertheless, an important goal of this project is to define possible control technology requirements to mitigate health and ecosystem effects. Assumptions in the potential reduction due to the utilization of control devices are necessary. The scenario assumes that various control devices are available, which will allow the air emissions to be reduced by 95 percent, i.e., the devices have a 95 percent efficiency for a 100 percent duty cycle. These controlled air emissions for the baseline scenario are presented in Table 2-3. The particulates are the major air emission, followed by hydrogen sulfide, and sulfur dioxide. The largest trace element emissions are vanadium followed by arsenic, lead, and nickel. Under certain conditions, the emissions of selenium, mercury, chromium, beryllium, and cadmium also become significant.

The uncertainties associated with the source terms are dependent on the key assumptions regarding (1) the ability to characterize a non-existent industry, and (2) the level of control efficiency of future processes. The magnitudes of the uncertainties in the source terms are not as great as those in the exposure and dose-effect probabilities. However, because the source terms uncertainties can be compounded throughout the analysis, they cannot be ignored. In general, the values presented, and the associated ranges, represent high confidence estimates within a factor of 2 to 10.

The emissions in Table 2-3 are generated solely in the oil shale region. Off-site upgrading, refining, and shale oil end use will

Table 2-3. Controlled Air Emissions for Baseline Scenario for Oil Shale Risk Analysis

Site	Pollutant (kg/d)															
	Particulates	SO_2	NO_x	HC	CO	H_2S	CO_2	As	Be	Cd	Cr	Hg	Ni	Pb	Se	V
1. Long Ridge	660	780	1,100	1,700	810	9,800	770,000	0.40	.001	.0007	0.018	0.20	0.013	0.0020	0.0013	0.090
2. Superior	120	730	320	62	43	3,000	230,000	0.12	.0002	.0001	0.0033	0.060	0.0024	0.0036	0.0002	0.017
3. Colony	15,000	17,000	990	360	260	3,100	110,000	1.0	.026	.016	0.43	0.060	0.31	0.46	0.031	2.1
4. Sandwash	16,000	97	1,000	360	280	3,300	120,000	1.1	.028	.017	0.45	0.065	0.33	0.49	0.033	2.3
5. U-a + U-b	420	490	520	340	530	6,500	610,000	0.27	.0007	.00042	0.012	0.13	0.0085	0.013	0.00085	0.060
6. Paraho	2,900	59	610	17	73	1,700	190,000	0.18	.00048	.0029	0.080	0.039	0.055	0.085	0.0055	0.40
7. Chevron	9,600	200	2,000	54	240	5,500	630,000	0.60	.016	.0095	0.27	0.13	0.19	0.28	0.019	1.3
8. Mobil	33,000	200	2,000	730	560	6,500	230,000	2.2	.055	.033	0.90	0.13	0.65	0.95	0.065	4.5
9. Getty	16,000	96	1,000	360	280	3,300	120,000	1.1	.027	.017	0.45	0.065	0.33	0.49	0.033	2.3
10. NOSR	9,600	340	2,200	800	260	5,500	630,000	0.60	.016	.0095	0.27	0.13	0.19	0.28	0.019	1.3
11. Multi-Minerals	130	780	350	67	47	3,300	260,000	0.13	.0002	.00013	0.0036	0.065	0.0027	0.0039	0.00026	0.018
12. C-a	35,000	510	6,600	1,100	2,200	6,500	230,000	2.3	.060	.036	1.0	0.13	0.75	1.1	0.07	5.0
13. C-b	5,500	20	3,700	250	220	8,500	1,100,000	1.1	.028	.016	0.45	0.13	0.33	0.48	0.033	2.3
14. Geokinetics	180	2,900	410	67	17	650	500,000	0.034	.0003	.00017	0.0055	0.013	0.0041	0.0065	0.00005	.026
15. Equity	180	2,900	410	67	17	650	500,000	0.034	.0003	.00017	0.0055	0.013	0.0041	0.0065	0.00005	.026
Total	140,000	27,000	23,000	6,300	5,800	68,000	5,300,000	11.	.26	.16	4.3	1.4	3.2	4.7	0.31	22.

Assumed control level of 95% for all sources; To obtain uncontrolled sources multiply by 20.
Trace elements based on total particulates and measured raw shale.

produce emissions in different geographic areas. End use emissions will also vary with the constituents of the shale oil.

As with petroleum oils, the characteristics of raw shale oils vary depending on the source and the retorting method used. Except possibly for somewhat higher concentrations of certain elements (nitrogen and arsenic), which can be reduced substantially by appropriate upgrading/refining techniques (hydrotreating), shale oil composition falls within the composition range for petroleum crudes.

Table 2-4 presents the total controlled site emissions for the baseline scenario and the OPT and MIS scenario variations. The baseline scenario includes emissions for offsite upgrading (70% of production). The baseline scenario and variations also include the emissions of pumping stations and rail transportation within the oil shale region of Figure 2-2. None of the values in Table 2-4 include refining and oil shale end use, because these emissions are outside the oil shale region and are identical for the baseline scenario and its variations. Source terms for end use of shale oil products have not been considered.

Liquid phase pollutants discharged as effluent are identified as one of the following: suspended solid, trace organic, trace metal, dissolved organic, dissolved inorganic, dissolved gas, or oil and grease. After each constituent is identified, the appropriate control, with its respective efficiency, is assumed and the controlled amounts are calculated. Table 2-5 shows the total controlled liquid effluent constituents for the OSRA Baseline Scenario and the two variations. These effluents include various process streams, such as mine drainage or retort condensate, and are based on different control technologies and efficiencies. The two mineral co-product production sites result in large amounts of constituents, which are caused by the special processes to separate the many minerals from the shale. Figure 2-2 indicates the surface stream flow directions of the region. These stream flows have been used to estimate the effluent characteristics at four locations in the Colorado River drainage. The effluent loads are transformed to concentrations, using dilution effects, when considering the potential exposure to man and aquatic ecosystems.

The oil shale industry will be an immense solids-handling industry. At a million barrels per day, the shale industry will be mining about 1.9 million metric tons of shale per day. This can be compared to the coal industry. In 1980, the United States' coal production was approximately 712 million metric tons (785 million short tons), which is a daily mining rate of about 1.9 million metric tons of coal. Thus, a one-million-barrels-per-day oil shale industry will have mining requirements similar to the total U.S. 1980 coal mining.

The shale oil industry will also have an immense disposal problem with about 1.7 million metric tons per day of spent shale. Upon processing the resulting spent shale, which is the bulk of the solid waste, it expands to roughly 20% more volume than the original shale. The volume of spent shale to be handled will be about 1.25 million cubic meters per day.

Table 2-4. Total Controlled Oil Shale Region Airborne Emissions for the Risk Analysis Baseline Scenario and Two Scenario Variations

Scenario	Description	Controlled (Assumed 95% Level) Air Emissions (kg/d)														
		Particulates	SO_2	NO_x	HC	CO	H_2S	CO_2	As	Be	Cd	Cr	Hg	Ni	Pb	Se	V
Baseline (15 sites + Upgrading)	Primarily Room and Pillar Mining, Aboveground Processing. Technology Mixed.	140,000	200,000	23,000	8,000	5,800	68,000	5,300,000	11	.24	.16	4.3	1.4	3.2	4.7	.31	22
OPT (15 sites)	All Open Pit Mining, TOSCO Aboveground Processing.	370,000	370,000	69,000	12,000	21,000	68,000	2,400,000	24	.63	.038	1.1	1.4	7.9	12.	7.4	52
MIS (15 sites)	All Underground Mining, 60% MIS and 40% TOSCO processing.	56,000	270,000	39,000	2,600	2,300	89,000	11,000,000	13	2.9	.019	5.2	1.4	4.0	5.8	.40	27

Emissions include upgrading and transportation within the oil shale region.

Table 2-5. Risk Analysis Scenario Controlled Site Water Effluent Constituents

Scenario	Description	Metal Effluent Constituents* (kg/Day)														
		Al	As	B	Co	Fe	Hg	Li	Mn	Mo	Rb	Sb	Se	Sn	Ti	V
Baseline (15 sites)	Primarily Room and Pillar Mining, Aboveground Processing and 70% Off-Site Upgrading; Technology Mixed	82	3.8	9.3	0.0042	4000	0.029	2.9	9.0	5.0	0.053	0.67	1.7	0.020	0.77	0.15
OPT (15 sites)	All Open Pit Mining, TOSCO Aboveground Processing and On-Site Upgrading	---	70	31	0.16	100	---	0.42	---	0.42	3.2	---	---	0.81	15	0.16
MIS (15 sites)	All Underground Mining, 60% MIS and 40% TOSCO Processing, and On-Site Upgrading	---	30	3400	40	540	---	---	---	540	21	---	---	10	26	120

Scenario	Description	Non-Metal Effluent Constituents TOTAL (kg/day) Assumed Control Efficiency (%)													
		Cations					Anions					Other			
		Ca	Mg	Na	Si	K	HCO_3^{-2}	S^{-2}	Cl	F	PO_4^{-3}	NH_3	S	BOD	CO_2
Baseline (15 sites)	Primarily Room and Pillar Mining, Aboveground Processing and 70% Off-Site Upgrading; Technology Mixed	4.8×10^{3}	1.4×10^{3}	4.1×10^{3}	1.9×10^{4}	6.3×10^{2}	5.1×10^{3}	1.9×10^{4}	1.4×10^{3}	3.2×10^{3}	4.6×10^{2}	1.1×10^{5}	4.1×10^{3}	5.8×10^{4}	8.2×10^{4}
		99	99	99	95	99	99	95	99	95	99	95	99	90	95
OPT (15 sites)	All Open Pit Mining, TOSCO Aboveground Processing and On-Site Upgrading	5.3×10^{4}	1.1×10^{4}	9.9×10^{4}	8.4×10^{1}	5.2×10^{2}	4.6×10^{3}	1.2×10^{6}	1.5×10^{6}	2.1×10^{1}	---	3.3×10^{6}	4.3×10^{5}	7.5×10^{5}	3.7×10^{5}
		99	99	99	95	99	99	95	99	95	99	95	99	90	95
MIS (15 sites)	All Underground Mining, 60% MIS and 40% TOSCO Processing, and On-Site Upgrading	2.4×10^{4}	3.4×10^{5}	3.4×10^{5}	9.5×10^{3}	6.3×10^{3}	5.5×10^{6}	1.1×10^{6}	4.7×10^{4}	1.7×10^{4}	---	6.2×10^{6}	4.6×10^{5}	4.5×10^{5}	7.5×10^{6}
		99	99	99	95	99	99	95	99	95	99	95	99	90	95

(---) No data available
* All control efficiencies to be 99 percent.

The solid wastes represent sources of air emissions and water effluents. The primary effect of the solid waste will be the disturbed surface area used for storage and disposal. A rough estimate of land needed to store spent shale after 30 years of operation is presented in Table 2-6 for the oil shale scenarios. By far, the major solid waste concern is the spent shale, because only about 50% can be disposed of by backfilling the mines. The remaining will either be stored in piles, or used to fill in canyons, followed by revegetation.

Table 2-6. Solid Waste Land Disturbance for the Oil Shale Risk Analysis Scenarios

Site	Land Disturbance (square kilometers/30 yrs) Baseline Scenario	OPT Scenario	MIS Scenario
1. Long Ridge/Union Oil Co.	36.0	36.	14.7
2. Superior	7.8	11.1	4.5
3. Colony/Dow	12.	12.	4.8
4. Sandwash/TOSCO	12.	12.	4.8
5. Ua + Ub/White River	24.3	24.3	9.6
6. Paraho	7.5	7.5	3.0
7. Parachute/Chevron	24.3	24.3	9.6
8. E. Parachute/Mobil	24.3	24.3	9.6
9. Parachute/Getty	12.	12.	4.8
10. NOSR	24.3	24.3	9.6
11. Multi-Minerals	8.4	12.	4.8
12. C-a/Rio Blanco	24.3	24.3	9.6
13. C-b/Oxy	9.6	24.3	9.6
14. Geokinetics	0	2.4	0.96
15. Equity	0	2.4	0.96
TOTAL	227	253	101

Estimates based on spent shale piles 30 meters high, 50% backfill into mines, and 1360 kg/m^3 (85 lb/ft^3) compaction of spent shale. Estimates will vary greatly from specific site values of operators; values are to be used as an estimate of overall average land disturbed for simplified ecosystem analysis. Accurate values reflecting operator's plans can be obtained if the additional accuracy is needed for the ecosystem risk in future efforts.

3. ENVIRONMENTAL EXPOSURE

3.1 TRANSPORT AND TRANSFORMATION OF POLLUTANTS

This chapter presents the initial environmental transport and transformation analysis of pollutants to estimate the potential human and ecosystem exposures for a one-million-barrels-per-day oil shale industry scenario in the 1981 Risk Analysis. Exposure pathways include inhalation of air pollutants and ingestion of water and food chain pollutants. Human exposures to oil shale industry pollutants are estimated in this analysis based on key assumptions regarding transport phenomena in the Piceance Creek and Uinta Basins. These assumptions and data uncertainties form the basis of an estimation of uncertainty in exposure results and a sensitivity analysis. Areas with high degrees of uncertainty and large variation are recommended as potential research areas in Section 7.2.

The transport and transformation analysis examines the major transport and transformation processes that may result in human exposure to pollutants. Major transport phenomena associated with oil shale industry pollutants include dispersion and deposition of air pollutants, dispersion of groundwater pollutants through porous aquifer media, mass flow of surface water pollutants in water courses, and eventual uptake of pollutants by aquatic and terrestrial food chain biota. Pollutants from the baseline scenario, and variations to this scenario designated "OPT" and "MIS", interact with the environment through these transport processes. Environmental transformation of pollutants resulting in enhancement or attenuation of pollutant concentrations is quantitatively considered only when sufficient data is available.

A predictive methodology for assessing ecosystem risk based on community diversity is also developed. Estimates of changes in community diversity required significant data not readily available. Based on available data and public interest, designator species are chosen as illustrative examples. Mule deer are selected as the terrestrial ecosystem designator species, and trout are considered a designator species for aquatic ecosystems.

Air

Air pollutant transport and transformation in the Piceance Creek and Uinta Basins is composed of three classes of processes: dispersion, chemical transformation, and deposition. The present section describes estimates of atmospheric dispersion, chemical transformation, and deposition to ascertain occupational and public exposure as a component of human risk from a commercial oil shale industry.

Atmospheric dispersion of pollutants occurs because air is in

constant motion. The components of atmospheric dispersion are vertical turbulent diffusion, horizontal turbulent diffusion, prevailing winds, and atmospheric stability. The dispersion power of the atmosphere is usually categorized into seven classes, labeled stability categories, in accordance with a method proposed by Pasquil (1962) and modified by Gifford (1961) and Yansky et al. (1966). These concepts are straightforward for level to semi-level terrain, but become difficult to predict in complex mountainous terrain, typical of the oil shale region.

All of the organic air pollutants, nitric oxides, and sulfur compounds can undergo chemical transformation in the atmosphere. The details of these complex processes and precise reaction rates are, in general, unknown. In order to simplify the analysis of these processes, three classes of reactions are considered: ozone formation by reactions of nitrous oxides and oxygenated hydrocarbons, sulfate formation, and nitrate formation.

Suspended dust and aerosols evolve and are eliminated from the atmosphere by the following physical processes:

- Growth or change by chemical reactions of gases on the surface of particles.
- Change by attachment and adsorption of gases and vapors to aerosols.
- Collision between particles undergoing Brownian motion or differential gravitational settling.
- Change between particles due to atmospheric turbulence.
- Loss by gravitational settling.
- Impaction on obstacles.
- Rainout in clouds.
- Washout under clouds.

The importance of each mechanism is dependent on particle size, particle shape, particle density, and local atmospheric conditions. The high number of variables involved in predicting atmospheric transport and transformation has prompted the use of computer simulations (models).

To calculate the expected air concentrations of pollutants emitted from the oil shale industry, available Gaussian dispersion model results were used (Huang and Sandusky, 1979). Air pollutants from the 15 sites in the baseline scenario (plus five off-site upgrading sources) and each variation were assumed to emit simultaneously at full production. Deposition of aerosols and dry particulates by gravitational settling was incorporated into the Gaussian model by the equation $E=V_y S \div V_x H$, where E is the fraction of particles of diameter D settling out in a distance, S, from the source; V_y is the particle settling

velocity; V_x is the wind velocity carrying the particle; H is the particle release height. V_y is calculated using Stoke's Law if particle size distributions are known, otherwise it is assumed to be 5 cm/sec. The behavior of this algorithm is consistent with many field measurements (Pedco, 1978). However, use of a Gaussian model for the overall analysis excludes the effects of complex terrain, which may significantly alter ground level concentrations. In general, airborne particulate exposure to vegetation and soils is much higher near the source and exposure to smaller respirable particulates of respiratory concern occurs even at sizable distances from the source.

The air exposure results are in the form of isopleth maps of ground level concentrations summarized in Table 3-1 for the baseline scenario under controlled (95%) emissions.

Review of reaction rate constants for ozone, nitrate, and sulfate formation allowed first order estimates of concentrations (NAS, 1977c; Calvert et al., 1978; Stephens, 1969; Eggleton and Cox, 1978; Tsang, 1973; Demerjian et al., 1974). Based on a 10-hour irradiation with sunlight, it was estimated that sulfate concentrations will be 50 percent of sulfur dioxide concentrations, nitrate will be 79 percent of nitrous oxide concentrations, and ozone will be 2.1 percent of the ratio of nitrous oxide concentration to nitric oxide concentration.

Water

Transport of pollutants generated from the proposed oil shale industry by surface and groundwater is a critical pathway to man. The pollution potential of water effluents is significant due to large quantities and control difficulties. The water problem has an associated time dependence making the analysis very difficult. If the anticipated water pollutants are readily released by the industry, existing laws would be violated and significant human health risks would result. On the other hand, if the waters are contained within the basin and continually reused, the contaminants will concentrate with the potential for a large acute release. Water pollutants may take centuries to reach residential and agricultural water supplies, allowing for potential initial complacency among operators, regulatory agencies, and the public. Exposure to water-borne pollutants from the oil shale industry will eventually result if surface streams or groundwater quality is degraded by leaching, spillage, erosion of solid wastes, consumptive use of water, or disturbance of local drainage patterns. The initial analysis of the water media-related risks was to investigate extreme cases for further study.

Leaching of solid wastes from oil shale development is a major transport pathway to water supplies because of the huge volume of leachable solid wastes that will be produced. If the solid wastes are disposed of in surface piles, leaching may occur from rainfall and snow melt, resulting in the eventual transport of leachates to water courses and aquifers. If processed shale and other solid wastes are backfilled into mines, or if it remains underground in abandoned in-situ retorts,

Table 3-1. Ground-Level Air Concentrations for Controlled Air Emissions for the Oil Shale Risk Analysis Baseline Scenario at Five Selected Oil Shale Population Centers

Pollutant	Annual Average Air Concentration* ($\mu g/m^3$)				
	Rio Blanco	Rifle	Meeker	Rangely	Grand Junction
Sulfur Oxides	8.0	8.5	20.0	0.30	0.065
Particulates	6.0	4.3	2.5	0.76	0.13
Nitrogen Oxides & Ozone	2.1	1.2	1.1	0.37	0.037
Hydrocarbons	0.080	0.55	0.45	0.079	0.018
BaP	1.5×10^{-8}	1.6×10^{-7}	9.2×10^{-8}	2.8×10^{-8}	4.6×10^{-9}
Carbon Monoxide	0.45	0.30	0.27	0.12	0.012
Hydrogen Sulfide	6.6	4.0	3.4	1.4	0.15
Arsenic	3.0×10^{-4}	2.1×10^{-4}	1.2×10^{-4}	9.4×10^{-5}	1.2×10^{-5}
Beryllium	6.7×10^{-6}	4.7×10^{-6}	2.8×10^{-6}	8.4×10^{-7}	1.4×10^{-7}
Cadmium	3.6×10^{-6}	2.5×10^{-6}	1.5×10^{-6}	4.4×10^{-7}	7.5×10^{-8}
Chromium	2.3×10^{-4}	1.7×10^{-4}	9.8×10^{-5}	2.8×10^{-5}	5.2×10^{-6}
Fluoride	3.6×10^{-3}	2.6×10^{-3}	1.5×10^{-3}	4.5×10^{-4}	7.7×10^{-5}
Mercury	1.4×10^{-4}	8.5×10^{-5}	6.8×10^{-5}	3.0×10^{-5}	3.2×10^{-6}
Nickel	1.6×10^{-4}	1.1×10^{-4}	7.1×10^{-5}	1.9×10^{-5}	3.1×10^{-6}
Lead	1.4×10^{-4}	9.4×10^{-5}	6.4×10^{-5}	1.7×10^{-5}	2.7×10^{-6}
Selenium	1.6×10^{-5}	1.1×10^{-5}	7.4×10^{-6}	2.0×10^{-6}	3.0×10^{-7}
Vanadium	5.3×10^{-4}	3.6×10^{-4}	2.4×10^{-4}	6.3×10^{-5}	1.0×10^{-5}

*Does not include background levels.

leaching may occur by direct contact with groundwater. The leachate may be then withdrawn in wells or discharged as base flow to nearby streams. Clearly, groundwater disruption is a key concern because it tends to be irreversible and have long-term consequences.

The water quality of surface streams can also be affected by oil shale development. Water is used at an oil shale facility for mining operations, dust control, steam and power, compaction of processed shale, irrigation, and other uses. The retorting process generates an effluent referred to as "retort water" or "product water" which is produced with the oil. Retort water is separated from the oil on the surface by heat treatment and decantation. Large quantities of gas condensate also will be produced. In-situ operations in areas of significant ground water flow will displace large quantities of mine water, which is groundwater that is pumped out of the retort before and during mining. All of these effluents will have to be collected, treated, and disposed of on-site. Although operators claim zero-discharge facilities under normal operation, the huge quantities of water that must be handled indicate a potential for accidental spillage.

Declining water availability may affect exposure to effluents. Some oil shale facilities, especially surface retorting operations, will divert and consume higher quality surface water, reducing downstream flows and decreasing the volume available to dilute the load of dissolved salts. Furthermore, surface facilities, solid waste piles, and surrounding community development may disrupt drainage patterns, resulting in channeling and erosion of sediment. Higher sediment loads will be added to surface streams of possibly decreased flow volumes. The net effect will be a downstream increase in salinity and other dissolved constituents. The growing salinity of the Colorado River is already of national concern; further increases of dissolved constituents in the Colorado River will result in pollutant exposures to a wide portion of the southwestern U.S., including some major population centers of southern California.

Estimation of human exposure to water-borne pollutants from the oil shale industry is based on three exposure pathways. First, exposure from accidental discharges of untreated effluents is calculated based on simplifying assumptions of complete mixing in a flowing surface stream and negligible transformation of pollutants. Second, exposure from assumed continual discharge of treated effluents is calculated using the same assumptions. Finally, exposure resulting from transport of leachates by groundwater is considered assuming isotropic properties of the aquifer media. The analysis will separately consider surface and groundwater pathways because the human exposure from each will be on vastly different time scales. Although transformation processes will be important in determining downstream exposures, the available data is insufficient to make reasonable initial estimates of chemical and physical transformation in either groundwater or surface water. Exposure to water pollutants for these extreme cases results in significant human risk establishing the need to examine water transformation in more detail in subsequent exposure estimates.

Accidental spillage may occur regardless of any control measures due to the large amounts of liquid effluent that will be handled. Production of retort water and gas condensate alone will range from four million to one billion gallons per day for a one-million-barrels-per-day industry, depending on the mix of technologies and the geographical location of the sites (Farrier, et al., 1978). Surface processes produce less than one-quarter of the amount of process water than in-situ technologies. Additionally, rupture of holding ponds or capture basins could occur due to containment failure or overflow from high-intensity storms.

Acute exposures to contaminated water in Piceance Creek after rupture of one 62,000-cubic-meters (500-acre-foot) impoundment of in-situ retort water are found to be low, although brief periods of high concentrations in fish may occur. These temporary water quality changes are shown in Table 3-2 for various constituents at four locations in the Colorado River drainage. Concentrations of ammonia and carbonate may temporarily increase up to three orders of magnitude in Piceance Creek after the postulated spill. Vanadium, arsenic, and iron concentrations in Piceance Creek may temporarily increase to as high as 90 mg/ℓ and then rapidly decline due to the flushing action of the stream, binding in bottom sediments, and uptake by aquatic vegetation. Changes in far downstream concentrations of some constituents will probably not be detectable with current analytical tools.

Chronic exposures from discharge of leachate to groundwater supplies may begin as long as one century after discharge due to slow transport of pollutants to surface streams. Well contamination may occur much sooner. The estimated water quality changes of the Colorado River drainage due to discharge of leachate is shown in Table 3-3. Almost all water quality constituents, including most metals, will increase in Piceance Creek one to two orders of magnitude due to leachate discharge. In particular, carbonate, boron, iron and the salinity may show significant increases downstream in the Colorado River. For example, at Lee's Ferry, Arizona, the salinity of the Colorado River may increase 1 to 55 mg/ℓ. The combination of high salinity and increased boron uptake by agricultural crops using Colorado River water for irrigation may result in significant effects on downstream agriculture.

Discharge of treated waters may also affect the water quality of the Colorado River system. The estimated water quality changes of the Colorado River drainage due to discharge of treated process waters is shown in Table 3-4. Comparisons of the baseline oil shale risk analysis scenario and the two variations indicate that on-site upgrading results in increased surface water concentrations of most constituents by several orders of magnitude. The Superior process also results in increased surface water concentrations of most constituents by one to two orders of magnitude over other processes. Discharge of treated effluents may result in increases of most non-metal constituents from one to four orders of magnitude near the site. Dilution effects result

Table 3-2. Estimated Water Quality Changes Downstream of 500 acre-feet Discharge of Untreated In-Situ Retort Waste (mg/ℓ)

Constituent	Maximum present concentration in Piceance Creek	Post-Discharge Change in Concentration Piceance Creek	White River at Rangely	Green River at Willow Creek	Colorado River at Lee's Ferry
Cations					
Calcium	104	44	1.2	0.14	0.05
Magnesium	123	167	4.6	0.55	0.2
Sodium	292	773	21	2.5	0.9
Potasium	10	61	1.7	0.20	0.07
Anions					
Carbonate	48	7120	194	23	8
Bicarbonate	805	53000	1440	170	61
Sulfate	575	1045	28	3.4	1
Sulfide	---	73	2.0	0.24	0.08
Chloride	30	894	24	2.9	1
Ammonia	0.9	6970	190	23	8
Metals					
Arsenic	---	4.8	0.13	0.015	0.006
Cobalt	---	0.30	0.008	0.001	3.5×10^{-4}
Boron	---	0.06	0.002	2×10^{-4}	7×10^{-5}
Vanadium	---	88	2.4	0.30	0.10
Titanium	---	0.83	0.02	0.003	0.001
Iron	35	36	1.0	0.12	0.042
Molybdenum	---	0.58	0.016	0.002	7×10^{-4}
Tin	---	0.05*	0.001	2×10^{-4}	6×10^{-5}
Rubidium	---	0.20*	0.005	6×10^{-4}	2×10^{-4}

--- = Data not available.
* = Data not available for in-situ retort water; values are data for surface retort water.

Table 3-3. Estimated Average Water Quality of the Colorado River Due to Discharge of Leachate (mg/ℓ)

Constituent	Present Average Concentration of Constituent in Upper Aquifer+	Present Concentration in Piceance Creek+	Piceance Creek	White River at Rangely	Green River at Willow Creek	Colorado River at Lee's Ferry
Cations						
Calcium	35	20-104	27,3600	0.7-98	0.09-12	0.03-4
Magnesium	52	19-123	18-180	0.5-5	0.06-0.6	0.02-0.2
Sodium	212	75-292	300-4300	8-120	1-14	0.4-5
Potassium	2.2	2-10	6-300	0.2-8	0.02-1	0.007-0.4
Silicon	160	12-61	140-1500	4-41	0.5-5	0.2-2
Anions						
Carbonate	0.9	0-48	170-3700	5-100	0.5-12	0.2-4
Bicarbonate	482	323-805	550-1400	15-38	2-5	0.6-2
Sulfate	325	83-575	450-2500	12-68	2-8	0.5-3
Chloride	12	1-30	45-120	1-3	0.1-0.4	0.05-0.1
Nitrate	0.9	0.1-6	2-45	0.05-1	0.006-0.1	0.002-0.05
Fluoride	0.4	*	7-81	0.2-2.2	0.02-0.3	0.008-0.09
Other						
Dissolved Solids	905	600-1524	800-49000	22-1300	3-160	1-56
Organic Carbon	8.5	*	13-225	0.4-6	0.04-0.7	0.01-0.3
Phenols	0.003	*	0.1-0.7	0.002-0.02	$3x10^{-4}$-$2x10^{-3}$	$1x10^{-4}$-$8x10^{-4}$
Metals						
Aluminum	0.014	*	0.6-45	0.02-1	0.002-0.1	$7x10^{-4}$-$5x10^{-2}$
Boron	0.033	0.06-2.8	0.9-2.7	0.02-0.07	0.003-0.008	0.001-0.003
Chromium	0.01	*	0.02-32	0.0005-32	$6x10^{-5}$-$1x10^{-1}$	$2x10^{-5}$-$4x10^{-2}$
Iron	5.0	0.3-35	0.9-5.4	0.02-0.1	0.003-0.02	0.001-0.006
Lithium	0.13	*	0.3-7	0.008-0.2	0.001-0.002	$4x10^{-4}$-$8x10^{-3}$
Lead	0.17	*	0.3-0.5	0.008-0.01	0.001-0.002	$4x10^{-4}$-$6x10^{-4}$
Zinc	0.26	*	0.3-0.6	0.008-0.02	0.001-0.002	$4x10^{-4}$-$7x10^{-4}$

*Data not available.

+Occidental Oil Shale (1976); Rio Blanco Oil Shale Project (1977); Fox(1979).

Table 3-4. Estimated Water Quality Changes (+) in the Colorado River Drainage for the Oil Shale Risk Analysis Baseline Scenario and Two Scenario Variations*

Constituent	Parachute Creek	Piceance Creek	White River at Rangely	Green River at Willow Creek	Colorado River at Lee's Ferry
Cations					
Calcium	0(2,2)	2(2,2)	0(1,0)	1(0,-1)	-1(0,-1)
Magnesium	-1(1,3)	1(1,3)	-1(0,1)	-1(0,1)	-2(-1,0)
Sodium	0(2,3)	1(2,3)	0(1,1)	-1(0,1)	-1(0,0)
Silicon	-2(-1,1)	2(-1,1)	1(-2,0)	0(-3,1)	-1(-3,-1)
Potassium	-2(0,1)	1(0,1)	-1(-1,0)	-2(-2,-1)	-2(-2,-1)
Anions					
Carbonate	1(3,4)	1(3,4)	-1(1,3)	-1(1,2)	-1(1,2)
Sulfide	2(3,3)	2(3,3)	1(2,2)	0(1,1)	0(1,1)
Chloride	1(3,2)	0(3,2)	-1(1,0)	-2(0,0)	-2(0,0)
Fluoride	-2(-2,2)	1(-1,2)	0(-3,0)	-1(-4,1)	-2(-4,-1)
Phosphate**	--(-,-)	1(-,-)	-1(-,-)	-2(-,-)	-2(-,-)
Other					
Ammonia	3(4,4)	3(4,4)	1(2,3)	0(2,2)	0(1,2)
Sulfur	1(3,3)	1(3,3)	0(1,1)	-1(1,1)	-1(1,1)
BOD	2(3,3)	2(3,3)	1(3,1)	0(1,1)	0(1,1)
Carbon Dioxide	2(3,4)	2(3,4)	1(1,3)	9(1,2)	0(1,2)
Metals					
Aluminum**	--(-,-)	0(-,-)	-2(-,-)	-3(-,-)	-3(-,-)
Arsenic	-3(-1,1)	-2(-1,-1)	-3(-2,-3)	-4(-3,-3)	-4(-3,-4)
Boron	-3(-1,)	-1(-1,1)	-3(-3,-1)	-4(-3,-1)	-4(-4,-2)
Cobalt	-5(-3,-1)	-4(-3,-1)	-5(-5,-3)	-6(-6,-3)	-6(-6,-3)
Iron	-2(-1,0)	-1(-1,0)	0(-2,-1)	-1(-3,-2)	-1(-3,-2)
Mercury**	--(-,-)	-4(-,-)	-5(-,-)	-6(-,-)	-7(-,-)
Lithium	-5(-3,-)	-2(-3,-)	-3(-5,-)	-3(-5,-)	-5(-5,-)
Magnesium**	--(-,-)	-1(-,-)	-3(-,-)	-4(-,-)	-4(-,-)
Molybdenum	-5(-3,0)	-1(-3,0)	-3(-5,-1)	-4(-5,-2)	-4(-5,-2)
Rubidium	-4(-2,-1)	-4(-2,-1)	-5(-4,-3)	-6(-4,-4)	-6(-5,-5)
Antimony**	--(-,-)	-2(-,-)	-4(-,-)	-5(-,-)	-4(-,-)
Selenium**	--(-,-)	-2(-,-)	-3(-,-)	-4(-,-)	-5(-,-)
Tin	-5(-3,-2)	-4(-3,-2)	-6(-4,-3)	-6(-5,-4)	-7(-5,-4)
Titanium	-3(-1,-1)	-2(-1,-1)	-4(-3,-3)	-5(-4,-4)	-5(-4,-4)
Vanadium	-5(-3,01)	-3(-2,-1)	-5(-4,-2)	-5(-6,-3)	-6(-6,-3)

+Values are given as order of magnitude estimates of water quality changes in mg/l, e.g., -4 = 10^{-4} mg/l. Water quality values can be converted to daily exposure (mg/day) by multiplying by 2l/day consumption.

*Each set of three values for a constituent corresponds to estimates from the baseline scenario and two scenario variations. Baseline scenario values are given first, followed by the "OPT" and "MIS" variations in parenthesis, e.g., baseline (OPT, MIS).

**Constituents reported for two sites assumed using the Superior process in the baseline scenarios.

in lowered concentrations farther downstream. However, even small increases in some metal concentrations may result in uptake by agricultural crops and bioaccumulation by aquatic organisms such as game fish.

Land

Solid waste generated by the oil shale industry will promote increased air and water pollution as well as increased risks to the surrounding ecosystem. Air pollutants from solid waste piles will be primarily fugitive dust. Water pollutants will partially consist of leachates percolated from surface disposal piles, eventually resulting in bioconcentration of certain elements in aquatic food chains. Additional ecosystem risks will result from the loss of habitat associated with the enormous amount of solid waste generated by a commercial oil shale industry. Because exposures from solid waste are derived from the other media, air and water, transporting the particles, the related solid waste issues have been discussed in appropriate air and water transport sections.

Food Chain

Contamination of the ecosystem may be a significant human risk pathway from the oil shale industry. Clearly, ingestion of contaminated agricultural products or game species will result in human exposure to pollutants. This contamination can result from transport of environmentally mobile pollutants in the air, water, and soil to plants and animals.

Certain pollutants are of more concern in the environment than others. The key properties of importance are potential bioconcentration and mobility. Pollutants which bioconcentrate are usually hydrophobic chemicals which can be partitioned into fat and lipid tissues as well as certain organs.

Human exposure resulting from ingestion of pollutants originating with the oil shale industry are estimated in this section. Terrestrial and aquatic food chains are considered separately, although linked through the utilization of water resources and soil/sediment water interactions on both a chemical and a physical level.

Soil constituents are the source of most terrestrial food chain contamination. The fate of soil pollutants is determined by the persistence and mobility of the pollutant as well as soil properties such as pH. Several ongoing research efforts are examining the consequences of revegetation of spent shale piles (Kilkelly and Lindsay, 1979; Schwab et al., 1980). The vegetation used in these studies are candidates for the eventual revegetation effort. Herbivores browsing on revegetated shale piles may ingest significant quantities of some heavy metals. However, the current results indicate that most elements are present in the vegetation at extremely low levels.

The rates of uptake and bioaccumulation of elements released into the aquatic environment are a function of concentration, chemical form, inorganic and organic water chemistry, physical water properties, and food web dynamics. However, studies have shown significant aquatic species bioaccumulation only for metals and some organic species (Braunstein et al., 1977).

Bioaccumulation of elements can be compared between aquatic species by the use of a ratio defined as the aquatic bioaccumulation factor. The aquatic bioaccumulation factor is the ratio of the concentration of an element in an organism to the concentration in the surrounding water. Bioaccumulation factors vary widely between species, and may by highly dependent on the chemical form of the substance, the route of uptake (ingestion or absorption), and even the season of the year. The bioaccumulation factors range from less than one for boron to 8,500 for zinc (Braunstein et al., 1977).

Human exposure from food chain contamination by the oil shale industry will primarily result from ingestion of mule deer, game fish, and agricultural products in the Uinta and Piceance Creek Basins. The magnitude of the potential bioaccumulation factors for plants and aquatic organisms indicate that terrestrial food chain contamination from the oil shale industry will be minor in comparison to aquatic food chain contamination. Until further data is available, only human exposure from aquatic food chain contamination is considered.

Downstream fish tissue concentrations were calculated by summing the metal element contribution from product water discharges with leachate discharges and multiplying by a suitable bioaccumulation factor. The results of these calculations are shown summarized in Table 3-5 for the OSRA baseline scenario and variations. Fish tissue concentration results for Piceance Creek and Parachute Creek watersheds are expected to be high due to the sites of the facilities. Under the stated analysis assumptions, toxic amounts of several elements are predicted for the fishes of Parachute and Piceance Creeks. Many values, such as Al, Cr, Mg, Rb, Sn, and Ti, are unrealistically high. Under these conditions fish die-offs will occur. Human exposure could be minimal if the affected area is placed off-limits to fishing. Fishing restrictions may not be easily imposed further downstream. Dilution effects lower some of the downstream concentrations, but additional sources located downstream result in extremely high values for Cr, Mg, and Zn. These elements, along with Al, B, Fe, and Pb, are almost entirely contributed by leachate sources.

Summary of Potential Human Exposure

The air dispersion analysis indicates that sulfur dioxide, particulates, nitrous oxides, and hydrogen sulfide are the major pollutants emitted from a one-million-barrels-per-day oil shale industry. The "MIS" scenario variation resulted in decreased particulates and hydrocarbons, while the "OPT" scenario variation resulted in increases of all major pollutants compared to the baseline

Table 3-5. Estimated Changes(+) in Tissue Concentration of Metals in the Fishes of the Colorado River Drainage for the 1981 Oil Shale Risk Analysis Baseline Scenario and Two Scenario Variations*

Metal	Parachute Creek	Piceance Creek	White River at Rangely	Green River at Willow Creek	Colorado River at Lees' Ferry
Aluminum	-(-,-)	2(2,2)	0(0,0)	-1(-1,-1)	-1(-1,-1)
Arsenic	0(2,1)	1(2,1)	-1(0,0)	-2(-1,-1)	-2(-1,-1)
Boron	-4(-2,0)	-1(-1,0)	-2(-2,-1)	-3(-3,-2)	-4(-3,-2)
Cobalt	-3(-1,1)	-1(-1,1)	-3(-3,0)	-3(-3,-1)	-4(-3,-1)
Chromium	-(-,-)	4(4,4)	3(3,3)	2(2,2)	1(1,1)
Iron	0(1,2)	2(2,2)	1(1,1)	1(0,0)	1(-1,0)
Mercury	-(-,-)	-1(-,-)	-2(-,-)	-3(-,-)	-4(-,-)
Magnesium	1(3,5)	3(3,5)	2(2,3)	2(2,2)	0(1,2)
Mangenese	-(-,-)	2(-,-)	0(-,-)	-1(-,-)	-1(-,-)
Molybdenum	-4(-2,1)	0(-2,1)	-2(-4,0)	-3(-4,-1)	-3(-4,-1)
Lead	-(-,-)	2(2,2)	0(0,0)	-1(-1,-1)	-1(-1,-1)
Rubidium	-1(1,2)	0(1,2)	-2(0,0)	-3(-1,0)	-3(-1,0)
Antimony	-(-,-)	-2(-,-)	-4(-,-)	-5(-,-)	-5(-,-)
Selenium	-(-,-)	0(-,-)	-1(-,-)	-2(-,-)	-3(-,-)
Tin	-1(1,2)	-1(1,2)	-2(-1,0)	-3(-2,0)	-3(-2,-1)
Titanium	0(2,2)	1(2,2)	-1(0,0)	-2(-1,-1)	-2(-1,-1)
Vanadium	-4(-2,0)	-2(-1,0)	-4(-3,-1)	-4(-5,-2)	-5(-5,-2)
Zinc	-(-,-)	3(3,3)	2(2,2)	1(1,1)	0(0,0)

+ Values are given as order of magnitude estimates of concentration in fish tissue in mg/ℓ, e.g., $-4 = 10^{-4}$ mg/ℓ. Fish tissue concentrations can be converted to daily esposure (mg/day) by multiplying by 2ℓ/day consumption.

* Each set of three values for a constituent correspond to estimates from the baseline scenario and two scenario variations. Baseline scenario values are given first, followed by the OPT and MIS variations, e.g., baseline (OPT, MIS)

scenario.

Concentrations of ammonia and carbonate may temporarily increase up to three orders of magnitude after a large retort-water spill. Vanadium, arsenic, and iron may also temporarily increase, although all spill constituent concentrations will decline due to the flushing action of the stream, binding in bottom sediments, and uptake by aquatic vegetation.

Chronic exposures from discharge of leachate to groundwater supplies may begin as long as one century after discharge due to slow transport of pollutants to surface streams. Well contamination may occur much sooner. Almost all water quality constituents, including most metals, will increase in Piceance Creek one to two orders of magnitude due to leachate discharge. Discharge of treated waters may also affect the water quality constituent concentrations of the Colorado River system by as much as four orders of magnitude. Upgrading of the retort oil results increased surface water concentrations of most constituents by two to three orders of magnitude.

Under the extreme conditions of this analysis, aquatic food chain contamination is far more significant than terrestrial food chain contamination. Fishing restrictions may be placed near oil shale facilities to minimize human ingestion of contaminated game fish.

3.2 ECOSYSTEM RISK

Environmental Setting

The environmental setting of the oil shale region is a factor in determining the ecosystem risk from industrial development. Three types of background information are used to evaluate ecosystem risk: the geography of the region, geology of the region, and the biotic environment.

The geography of the region is characterized by mountainous terrain and paucity of surface water. A diverse range of features are encountered within the 18,000 square mile oil shale region. The Piceance Creek and the Uinta Basins dominate the topography of the region. The topography in both basins is typified by rolling plateaus, cliffs, and canyons. The basins are surrounded by several mountain ranges, and the region is drained by the Colorado River system (U.S. Department of Interior, 1973).

The geology of the basins is dominated by the lacustrine sediments which formed the oil shale deposits. These sediments were deposited in the varying stages of Lake Uinta. The basins are composed of the Green River Formation, which was laid down during the Eocene Epoch in four layers. The layers make up the Parachute Creek, Garden Gulch, and Douglas Creek members, and the Uinta Formation on the surface of the basin. The richest oil shale layer, called the Mahogany Zone, is located in the Parachute Creek Member (Desborough, 1978; Eugster and

Surdam, 1973; Donnell, 1961).

The climate of the region is characterized by hot summer days, cool nights, and cold winters. Precipitation ranges from 18 cm (7 inches) per year, in the lower elevations of the Uinta Basin, to 64 cm (24 inches) per year in the southwestern section of the Piceance Creek Basin. In general, the Uinta Basin is dryer than the Piceance Creek Basin. However, in both basins, about half the precipitation is in the form of snow between December and April (Iorns et al., 1965).

The biotic environment of the region is characterized by a rich abundance of wildlife. At least 300 species of birds, mammals, reptiles, and amphibians reside in the two basins. The most widely known member of the wildlife community is the mule deer. A large migratory mule deer herd, with an estimated population of 15,000 to 35,000 deer, winters in the Piceance Creek Basin. During autumn, hunters harvest 5,000 to 6,000 deer in the basin, providing much of the income to the surrounding community. Other big mammals in the region include black bear, buffalo, elk, mountain lion, and wild horses. Small game mammals in the region include cottontail rabbit, pine squirrel, and snowshoe hare (Lechleitner, 1969). Beaver, mink, and bobcat are also found occasionally.

Bird species also are abundant in the region. In particular, falcons and other raptors enjoy the steep excarpments as nesting habitat. Golden eagles are sighted occasionally. Wild turkeys, doves, and chuckar partridge are the dominant game species (Baily and Neidrach, 1967).

The Colorado River system contains over 40 native and introduced fish species. Sport fishes include the rainbow, brown, and brook trouts. Six native species are classified as threatened or endangered: Colorado Squawfish, Humpback Chub, Bonytail Chub, Razorback Sucker, Colorado Cutthroat Trout, and the Kendall Warm Spring Dace (Colorado Department of Natural Resources, 1971).

The flora of the region vary according to the elevation, topography, and local precipitation. Much of the area can be classified biologically as the upper Sonoran Life Zone, and is in the eastern portion of the Great Basin cold desert. There are eight major plant species or associations in the two basins. Pinyon-Juniper occupies about 35 percent of the Piceance Creek Basin and about 10 percent of the Uinta Basin. Sagebrush is about as common as Pinyon-Juniper in both basins. Saltbrush and other salt desert shrubs are mostly found in the Uinta Basin, where it occupies about 15 percent of the area. Higher elevation woody shrub species dominate about 20 percent of the Piceance Creek Basin but is uncommon in the Uinta Basin. Conifers, aspen, and greasewood comprise the remaining groundcover in the basins (U.S. Department of Interior, 1973).

Ecosystem Risk Methodology

The evaluation of ecosystem risk resulting from an environmental perturbation involves predicting the ecosystem response. Ecosystem risk should be related to desirable ecosystem community traits such as stability, resilience, and productivity. Additionally, ecosystem risk analysis should spotlight areas needing ecological research. Species diversity has attractive properties for use as a measure of ecosystem risk. Species and the number of individuals in each species can be counted. Species diversity is relatively unaffected by sample size and is related to desirable community traits. Species diversity can be used as a predictive tool because it provides a measure of post-disturbance community composition and structure.

Species diversity has been chosen as an initial measure of ecosystem risk. Ecosystem risk approaches the concept of ecosystem resilience, or the ability of ecosystems to recover from a given disturbance. A high species diversity is usually the result of high overall productivity, high energy flow between trophic levels, and good nutrient cycling. These conditions are reflected in a high ecosytem resilience (Rickless, 1973).

However, much more data is needed before a comprehensive, community diversity approach can be used to estimate ecosystem risk related to the oil shale scenario. The initial efforts in this approach are based on estimating risk to selected species of the Colorado River drainage from obvious major disturbances caused by development of the oil shale resource. As more data becomes available, the analysis will be expanded to include other taxocenes. Other, less obvious risk components, such as trace element input to surface streams from snow melt, will be added to the analysis.

4. POPULATION AT RISK

The oil shale risk analysis has considered two general classes of population at risk: (1) the occupational workforce, and (2) the general public. The number of workers needed by the industry is a major factor in the estimation of the public population. Populations at risk change in different portions of the oil shale fuel cycle. The present analysis is concerned with the population at risk in the oil shale region.

The demographic impact in the oil shale region has been studied (Stinson and O'Hara, 1977; Center for Demographic Studies, 1980; McDowell-Smith, 1975; Quality Development Associates, 1979; Denver Research Institute, 1979; and Pacific Northwest Laboratory, 1980). Wide descrepancies exist among these studies, not only in the results obtained, but in the methodologies used. The most significant discrepancy has been the inconsistent treatment of government policy and industry's commitment on the level of development.

In the OSRA the population at risk was estimated using a simple methodology based on the workforce estimates developed by the oil shale companies. This workforce has an impact on basic and non-basic employment simulated by using a multiplier. Family members are also estimated using a multiplier. Once the total population is estimated, the geographical allocation was made following historical population patterns, distance, and physical constraints.

4.1 WORKFORCE AT OIL SHALE SITES

The oil shale risk analysis scenario is based on a production level of a million barrels per day using various estimated levels of production for 15 separate production sites. The workforce for the sites was estimated using available projections shown in Table 4-1.

The operational workforce consists of miners and above-ground personnel. The type of mining determines the miner productivity, which in turn will determine the total number of miners required for each site. The above-ground mining is estimated to have a daily net production of 150 tons/miner. This level includes the removal of the overburden, which may amount to a range of between 150 to 250 tons/day, in addition to the oil shale. Hence, the total amount of material handled by each surface miner will be about 300 to 400 tons per day.

The underground mining for oil shale operations is more labor intensive and productivity is lower. The historical experience for oil shale underground mining is limited. It is expected that most underground mining will use the standard room-and-pillar method. The underground miner productivity level was assumed to be 37.5 tons/workshift.

The above-ground personnel consists of surface (retort) and construction personnel. The surface personnel estimates are based on

Table 4-1. Industry Projected Oil Shale Workforce Data Used to Derive Oil Shale Risk Analysis Projections

Sites	Production (10^3 barrels per day)	Mining (man-years)	Surface (man-years)	Total Operation (man-years)
Surface Induced:[a]				
White River	40.0	300	600	900
White River	100.0	1060	990	2050
TOSCO/Sandwash	43.0	560	700	1260
Paraho (Utah)	10.0	120	400	520
Long Ridge/Union Oil	30.0	N/A	N/A	700
Paraho (Colorado)	10.7	N/A	N/A	550
Superior	24.0	N/A	N/A	1200
Dow/Colony	50.0	N/A	N/A	1040
Rio Blanco[b]	47.25	N/A	N/A	1500
MIS:				
Oxy-Tenneco	30.0	N/A	N/A	1500
TIS:				
Geokinetics	20.0	120	900	1020

Notes: N/A = Not Available
a = Room and Pillar Mining except as noted
b = Open Pit Mining

References: Utah Energy Office, 1980
U.S. Department of Interior, 1975
Colorado Department of Natural Resources, 1979

available project projections. The permanent construction workforce is assumed to be 10 percent of the workforce (miners plus retorters). The total workforce estimate of 58,700 for the one-million-barrels-per-day OSRA Baseline Scenario is presented in Table 4-2.

The variations to the baseline scenario present different workforces, as shown in Table 4-2 which indicate the major assumptions for these estimates. The total workforce for the MIS variation is estimated at 39,200, while the workforce for the OPT variation is estimated at 27,300.

4.2 PUBLIC ASSOCIATED WITH THE OIL SHALE REGION

The development of an oil shale industry will bring about a significant increase in the overall population of the region. Three factors will affect the population: associated energy development, indirect employment, and worker families. These three factors accumulate and have a multiplicative effect on the original oil shale workforce.

The associated energy developments that will take place in the area are difficult to predict. Many energy resources are expected to be developed. Among the most important ones are coal, power generation, oil and natural gas exploration, and water projects. For purposes of this analysis a multiplier of 1.3 is assumed, meaning that a workforce equivalent to 30% of the oil shale workforce will be involved in other energy development.

The second factor is the indirect employment that will be generated as a result of the oil shale workforce and other energy development. For purposes of this analysis, a multiplier of 2.1 was chosen (Denver Research Institute, 1979).

The third factor is the family members of each worker. Assuming the average worker family household size is 2.5 persons, a multiplier of 2.5 was used. The three factors have the cumulative effect depicted in Table 4-3.

Table 4-3. Workplace Multiplication Factor for Prediction of Public Populations

	Workplace	Energy Developments	Indirect Employment	Worker Family	Total
Factor	1	1.3	2.1	2.5	6.83

The base population of the region will increase continually as a function of normal economic activity. The base population is a function of the chosen year. Because the million-barrels-per-day scenario is for a steady-state industry, the year 2000 was chosen as a representative year. The aggregate population rate of increase was estimated at 3.2 percent annually for the region (Colorado Western Area

Table 4-2. Workforce Estimates for Oil Shale Risk Analysis Scenario and Variations

SITE	MINING			SURFACE	CONSTRUCTION**			TOTALS***		
	Baseline Scenario*	MIS Option	OPT Option	(All Scenarios)	Baseline Scenarios	MIS Option	OPT Option	Baseline Scenarios	MIS Option	OPT Option
1 Long Ridge/Union Oil	6,720	3,237	1,680	1,085	781	432	277	8,586	4,754	3,042
2 Superior	2,060	992	515	826	289	182	134	3,175	2,000	1,475
3 Colony	2,104	1,014	526	833	294	185	136	3,231	2,032	1,495
4 Sandwash/TOSCO	2,240	1,079	560	852	309	193	141	3,401	2,124	1,553
5 U-a + U-b/White River	4,480	2,157	1,120	1,037	552	319	216	6,069	3,513	2,373
6 Paraho	1,344	647	336	697	204	134	103	2,245	1,478	1,136
7 Chevron	4,480	2,157	1,120	1,037	552	319	216	6,069	3,513	2,373
8 Mobil	4,480	2,157	1,120	1,037	552	319	216	6,069	3,513	2,373
9 Getty	2,240	1,079	560	852	309	193	141	3,401	2,124	1,553
10 NOSR	4,480	2,157	1,120	1,037	552	319	216	6,069	3,513	2,373
11 Multi-Minerals	2,240	1,079	560	852	309	193	141	3,401	2,124	1,553
12 C-a/Rio Blanco	1,120	2,157	1,120	1,037	216	319	216	2,373	3,513	2,373
13 C-b/Oxy	2,157	2,157	1,120	1,037	319	319	216	3,513	3,513	2,376
14 Geokinetics	61	216	112	449	51	66	56	561	731	617
15 Equity	61	216	112	449	51	66	56	561	731	617
Total	40,267	22,501	11,681	13,117	5340	3558	2481	58,700	39,200	27,300

Notes:

* Assumes 37.5 tons/day per miner for room and pillar mines. Site 12 is open pit: assume 150 tons/day per miner. Site 13 is MIS: 40% mined to surface, rest done by drilling and blasting. Sites 14 and 15 are TIS: no mining just drilling operations.

** Assumes 10% of the operation workforce.

*** Final sums rounded off to three significant figures.

Council of Government, 1979). The general public population is 685,000 for the baseline scenario, 552,000 for the MIS variation and 470,000 for the OPT variation.

The distribution of the projected population throughout the region was allocated based partly on historical patterns and studies on the commuting habits of the oil shale workers, (Pacific Northwest Laboratory, 1980). Most of the population will continue to be concentrated along the Colorado River corridor. The city of Rifle, in particular, is projected to be the focal point of considerable future development. The allocation assumed one new town, Battlement Mesa. The lowest population densities were obtained in the southern part of the Uinta Basin.

5. HUMAN HEALTH EFFECTS

5.1 METHODOLOGY

The major goal of the Oil Shale Risk Analysis (OSRA) is to identify and quantify the risks of adverse health effects that may be associated with development of an oil shale industry and the inherent uncertainties of these estimates. Scenarios for the oil shale industry were used to estimate the fuel cycle source terms for the oil shale region and the resultant public exposure. These results are used together with toxicology data derived from in-vitro assays, animal experiments, and epidemiological studies in humans to perform the risk analysis.

The human populations working in and/or living near the oil shale industry may be exposed to a wide variety of pollutants: sulfur oxides, nitrogen oxides, particulates, ozone, carbon monoxide, dozens of trace elements, and a myriad of hydrocarbons including polycyclic aromatic hydrocarbons and nitrogen-containing aza-arenes. Many of these pollutants have been associated with adverse health effects, either through toxicological investigations (in vitro and in vivo animal studies) or through epidemiological studies in the occupational or public setting.

Due to the complexity of the exposure, the methodology for the OSRA was to initially analyze the health risk on a pollutant-by-pollutant basis. In this way, each pollutant was considered independently. Health effects data were analyzed, the dose-response relationship estimated, and the risk of the associated health effect determined for the population at risk.

Assumptions concerning the pollutant-by-pollutant approach were:

- Interactions were not considered in this first effort of the OSRA due to the difficulty in quantifying such relationships. In the future, important interactions will be investigated to determine possible changes in risk estimates.

- The route of exposure was considered in the pollutant-by-pollutant analysis. For the most part, air is the main route of direct exposure. However, if ingestion is a major route for a specific effect and oil shale-related water pollution contributes significantly to background intakes, ingestion was considered. Contact exposure to oil shale effluents and products were considered an occupational exposure and thus an occupational risk.

- Speciation is an important factor in determining the toxicity of pollutants. The health risk analysis made

assumptions concerning the chemical form of many oil shale pollutants. Lack of species-specific source term data limited attempts of actual quantification.

Unless otherwise specified, the term "health effect" will imply an adverse effect in the health of an individual. Beneficial effects, if any, were not considered.

Health effects can be divided into acute and chronic effects. Acute effects are defined as sudden onset, rapid progression, and a short course. Chronic effects are slowly accumulating symptoms after a long, continuous exposure. Environmental pollution usually exposes a population over a long period of time, but can result in both acute and chronic effects. In the initial effort of the public health risk analysis, chronic exposures were considered exclusively. This is due to the difficulty in modeling pollution exposures on a monthly, weekly or daily time scale. As data becomes available, these exposures may be quantifiable.

A wide range of possible health effects are associated with the pollutants released by the oil shale industry. Some pollutants exhibit systemic toxicity; others impair the function of specific organs. Four trace elements (As, Cr, Cd, Ni) have been implicated on the basis of epidemiological investigations (Sunderman, 1978) as respiratory carcinogens. Mutagenicity and teratogenicity are also issues for some contaminants although these effects are not considered at this time.

A threshold is the exposure level below which no adverse health effect is observed. Excluding carcinogenic effects, the health effects related to the oil shale industry pollutants will be assumed to have thresholds. If it was determined that exposures will be below the chosen threshold, then it was assumed that no adverse effects will be observed and the quantifiable risk will be zero. Thresholds were chosen to protect the most sensitive subgroups of the population. If exposures are below this threshold, the probability of effects occurring in the general population is extremely low. Thresholds for this analysis were chosen from published toxicological and epidemiological literature. Where thresholds are very difficult to define, occupational threshold limit values or TLVs (American Conference of Governmental Industrial Hygienists, 1980) are used with a safety factor of 3. This factor should allow for a twenty-four-hour exposure and yield conservative thresholds. It is important not to confuse "health effects" with normal homeostasis and physiologic response to exposure. While this homeostasis does vary within the population, a threshold can be fairly well established within a certain range.

Carcinogenic effects were considered to have no threshold. This assumption reflects the absence of data to the contrary as well as the need to be conservative with this effect. While there may be different thresholds for subgroups of the population (Rall, 1978), "examination of published dose response data for chemical carcinogenesis in laboratory animals provides no clear indication of a threshold for any carcinogen" (Lepkowski, 1978). Dose-response relationships are

often assumed to be linear at low doses which approximates the shape of the curves derived from toxicologic investigations of chemical carcinogens.

In the general case, the incidence of a particular cancer in a population exposed to a carcinogen due to the exposure is known as the Attributable Incidence Rate (AI). The Attributable Incidence for a particular exposure (AI_E) to dose D_E can be expressed as follows:

$$AI_E = I_E - I_O \ , \tag{1}$$

where I_E = observed incidence in a population exposed to a carcinogen at dose D_E and I_O = observed baseline incidence in a population not exposed to the carcinogen.

But, $I_E = RRI_O$ where RR = relative risk of a population exposed to the carcinogen dose D_E. Substituting in (1),

$$AI_E = RRI_O - I_O = I_O \ (RR - 1) \tag{2}$$

However, an approximation of the RR is the Standardized Mortality Ratio (SMR). Thus, substituting SMR for RR in (2),

$$AI_E = I_O \ (SMR - 1). \tag{3}$$

Again, this attributable incidence AI_E is specific to a particular dose D_E of the carcinogen. The risk analysis requires estimates for the attributable incidence in a population exposed to doses other than D_E. Therefore, to estimate the Attributable Incidence (AI) for other doses (D), a linear, non-threshold dose-response curve is assumed. The relationship can be described by a straight line through the origin and a point defined by AI_E and D_E. The formula for this line is:

$$AI = bD \tag{4}$$

where the slope of the line,

$$b = AI_E/D_E \tag{5}$$

Substituting (3) into (5), the slope becomes:

$$b = \frac{I_O \ (SMR - 1)}{D_E} \tag{6}$$

Finally, an equation for the attributable incidence given <u>any</u> exposure D to the carcinogen is found by substituting (6) into (4) as follows:

$$AI = \left[\frac{I_O \ (SMR - 1)}{D_E}\right] x \ D \tag{7}$$

Data derived from epidemiologic investigations can be used to obtain the SMR and D_E. Where more than one SMR is available, the geometric mean

is taken. National incidence rates can be used for I_0.

To estimate dose-response relationships and effects thresholds for the general population, it was necessary to have a set of standard measurements for the average person. The OSRA used the data of the International Commission on Radiological Protection (ICRP) reference man (ICRP, 1975). This is an extensive collection of average values of anatomical, physiological, and metabolic parameters. From this data, key values for the calculations were derived. An average respiratory rate for the entire population (men, women, and children combined) is 20 m^3/day. The average intake of water is 2 liters of water/day. Various organ-specific data also were based on the reference man.

There are many characteristics of individuals in the general population which can alter an individual's risk of disease given a certain exposure. Calabrese (1978) has discussed in detail the biological basis for these susceptibilities. Developmental factors, such as susceptibilities of the fetus and the aged due to immunodeficiency, are exhibited by specific age groups. Where possible, the OSRA could address the sensitivity of these groups by weighing the increased risk by the proportion of the population within the age group of interest. Genetic disorders which increase susceptibility are numerous although the incidence of these disorders is very low. The OSRA need only deal with these characteristics if there is evidence of an alteration of oil shale-associated risks due to these disorders. Dietary deficiencies are also a modifier of disease susceptibility. Quantifying the prevalence of these diseases would be difficult although necessary if an exposure related to oil shale development is altered by a dietary deficiency. Diseases and behavioral factors are of particular interest of the OSRA because 1) the air pollutants to be emitted from the oil shale industry are known to affect persons with pre-existing lung diseases, and 2) cigarette smoking and air pollution exposures can interact detrimentally in a variety of ways.

This initial effort of the OSRA recognized the presence of these susceptible groups in the population; health thresholds were chosen to protect susceptible groups, particularily children and persons with pre-existing lung disease. The results of the analysis will therefore be conservative to allow for the wide margin of uncertainty regarding these groups. If population data were available, it might be practical to include age distribution, smoking habits, alcohol use, and reproductive status in the risk analysis. As estimates of the proportion of the population having these traits become available, these estimates of risk can be calculated.

5.2 POLLUTANT SCREENING RESULTS

Oil shale pollutants include nitrogen oxides, sulfur oxides, carbon monoxide, ozone, ammonia, hydrogen sulfide, hydrocarbons (including polycyclic aromatic hydrocarbons and aza-arenes), particulates, and many trace elements. To reduce this list to a practical size, health effects were quickly reviewed. For those pollutants known to cause adverse health effects, a comparison was made between occupational TLVs and crude estimates of exposure. If the TLV

and the crude estimate came within four orders of magnitude, the pollutant was given a detailed analysis. The results of this screening as well as the original list of potential pollutants are presented in Table 5-1.

5.3 HEALTH EFFECTS DATA FOR THE POLLUTANT-BY-POLLUTANT ANALYSIS

This chapter individually addresses each of the oil shale pollutants selected for detailed analysis. Health effects are summarized, the basis for dose-response relationship or threshold is given, and the data for the risk analysis is derived.

Sulfur Oxides And Particulates

Sulfur oxides and particulates are criteria pollutants which are often considered together; sulfur oxides can only reach the deep lung by being absorbed on particulates. As both are major effluents of burning fossil fuels, most urban areas have elevated levels.

Sulfur oxides have been associated with acute and chronic respiratory disease. Studies have shown increased mortality is associated with increased concentrations of sulfur oxides and total suspended particulates. The critical organ is the respiratory tract. Chronic effects associated with SO_x and TSP are increased respiratory tract infection, increased bronchitis, and decreased lung function.

Recent reviews of the effects of these pollutants are given by Holland (1979), NAS (1978), and WHO (1979). Based on these reviews, a general range of agreement was found for a threshold effect. No effects have been measured at annual average total suspended particulate concentrations of less than 180 $\mu g/m^3$ and sulfur oxides at less than 120 $\mu g/m^3$. These values were used in the risk analysis.

Nitrogen Oxides And Ozone

As NO and NO_2 are released, their environmental concentrations increase near the release site. The formation of ozone by photochemical reactions follows and, as a result, its concentration increases. The ozone concentrations are highest far downwind from the highest NO_x levels.

Predicting ozone concentrations from NO_x releases is dependent upon the time of release, release rates, wind speeds, topography, concentrations of other pollutants, temperature, and sunlight. At this time, such a prediction is beyond the scope of the risk analysis. However, based on measurements from other cities (NAS, 1977d) and on smog chamber experiments (Niki, 1972), ozone levels do not exceed NO levels although they can be as high as NO_x levels.

Nitric oxide (NO) has not been found to be toxic although nitrogen dioxide (NO_2), the highly reactive oxidant, is toxic. Effects of acute exposure are pulmonary, the critical organ being the respiratory tract. At low levels (1-10 mg/m^3), increased airway resistance is noted. Bronchitis, bronchopneumonia, and fatal pulmonary edema occur at

Table 5-1. Oil Shale Pollutants Considered for the Health Risk Analysis

* Sulfur Oxides	Germanium
* Particulates	Hafnium
* Nitrogen Oxides	Iron
* Ozone	Lanthanum
Ammonia	* Lead
* Carbon Monoxide	Lithium
* Hydrogen Sulfide	Magnesium
Aluminum	Manganese
Antimony	* Mercury
* Arsenic	Molybdenum
Barium	* Nickel
* Beryllium	Potassium
Boron	Rubidium
Bromine	* Selenium
Calcium	* Sodium
* Cadmium	Strontium
Cerium	Titanium
* Chromium	* Vanadium
Copper	Zinc
* Fluorine	* Polycyclic Aromatic Hydrocarbons and Aza-arenes
Gallium	

* - selected for detailed analysis

large doses (+ 40 mg/m^3) (Wilson, 1980). Chronic exposures have also been found to be related to changes in pulmonary function, although the threshold is in doubt. One epidemiologic study has found changes at concentrations of 0.15 to 0.28 mg/m^3 (Shy, 1970). This study, known as the Chattanooga study, is not well supported due to inconsistencies of the methods throughout the study period (NAS, 1977c). Two other studies (Speizer 1973, Cohen 1972) found no effects at this level. Therefore, 0.3 mg/m^3 will be used as a threshold for effects. Health effects related to ozone exposure are difficult to study due to the presence of other pollutants. Many studies that attempted to find an association between ozone and increased mortality, increased acute respiratory infection, and aggravation of pre-existing disease, particularly asthma. Some effects have been seen in healthy populations as well (NAS, 1977c).

In terms of dose-effect, the most sensitive ozone-related adverse effect was found by Wayne, Wehrle, and Carroll (1967). They found that hourly oxidant concentrations above 200 $\mu g/m^3$ affected high school cross-country runner performance. Effects on chronic respiratory disease patients occurs near 500 $\mu g/m^3$ (Hammer, Hasselblad, and Portnoy, 1974; Schoettlin and Landau, 1961). Eye irritation, also an early sign of ozone exposure is apparent at 200 $\mu g/m^3$ (Hammer, Hasselblad, and Portnoy, 1974).

This analysis considers 0.1 mg/m^3 as a conservative threshold for effects related to ozone. The environmental fate of the released NO_x from the oil shale industry is not predictable at this time. Depending on meteorologic conditions, the population may be exposed to: 1) large NO_x concentrations that have only slight oxidation to ozone, 2) very low NO_x concentrations and very high ozone concentrations, or 3) any combination between these extremes.

To establish exposure concentrations of nitrogen oxides and ozone, the risk analysis treated NO_x emissions as a non-attenuating gas in a Gaussian dispersion model. This procedure assumes that the concentration derived from the model will approximate the sum of the actual NO_x concentration and the photochemically created ozone. It was decided that if the model-derived exposure approached the thresholds of 0.1 mg/m^3 (ozone) and 0.3 mg/m^3 (NO_x), these pollutants would be considered a potential health hazard.

Carbon Monoxide

Chronic exposure to carbon monoxide in humans has not been determined to have detrimental effects although animal studies have linked these exposures to cardiovascular effects. Whether there is a threshold concentration of carboxyhemoglobin for adverse effects is still unknown. There is evidence of behavioral effects at carboxyhemoglobin levels of 3 to 5% (NAS, 1977a) saturation and other effects at higher levels. The present EPA standards of 10 mg/m^3 for an eight-hour exposure and 40 mg/m^3 for a one-hour exposure are designed to prevent carboxyhemoglobin over about 2.5% saturation (NAS, 1977a).

A threshold of 3.3 mg/m^3 was used to allow for a safety factor. It should be noted that this level assumes that there will be

some fluctuation of carbon monoxide levels allowing time for clearance and that there is a "safety factor" inherent in the standard.

Hydrogen Sulfide

Hydrogen sulfide is a colorless gas which acts as an asphyxiating systemic poison at high concentrations (700 to 1400 mg/m^3). Exposure to these concentrations results in unconsciousness and death through respiratory paralysis (Milby, 1962). The danger of this concentration is compounded by the immediate paralysis of the olfactory nerve, making the usual "rotten egg" odor imperceptible. At lower concentrations, 70 to 700 mg/m^3, hydrogen sulfide is primarily a respiratory irritant with pulmonary edema and bronchial pneumonia as possible effects. Other effects at these exposures include conjunctivitis, eye irritation, nervousness, cough, nausea, headache, and insomnia (Poda, 1966). Eye irritation is considered the most sensitive adverse effect and has been observed at concentrations around 28 mg/m^3. ACGIH (1980) has set a TLV at 14 mg/m^3 (10 ppm) to protect workers from hydrogen sulfide effects.

Public exposures to hydrogen sulfide will be well below this TLV and therefore severe adverse effects are unlikely. However, the offensive odor which occurs at concentrations below the TLV could be considered at "nuisance factor" if not an adverse effect. The odor perception threshold varies between 1 and 45 $\mu g/m^3$ (Waldbott, 1973).

Assuming the odor will be a nuisance above 50 $\mu g/m^3$, this concentration is an acceptable threshold for this effect. Adverse health effects were treated with a threshold of 5 mg/m^3, a factor of 3 below the TLV.

Arsenic

Arsenic has long been recognized as a powerful toxin capable of poisoning with both acute and chronic exposure. Classic chronic arsenic poisoning is characterized by progressive symptoms and signs of nausea, vomiting, anxiety, and jaundice. Gastrointestinal involvement, skin changes, peripheral neuropathy, and liver damage have been associated with arsenic poisoning (Dickerson, 1980). The risk analysis will address these threshold effects as well as arsenic-related carcinogenic effects.

Carcinogenic potential of arsenic has been reported for over ninety years. Several reports of respiratory cancers associated with occupational exposures to arsenic have been reported. Those recent epidemiologic studies (Lee and Fraumeni, 1969; Pinto, 1977; Ott, 1974) have been used by the Carcinogen Assessment Group (EPA, 1978b) to derive a dose-response function for respiratory exposure to arsenic. The dose-response relationship is 2.8 respiratory cancers per year per 100,000 persons exposed per $\mu g/m^3$.

Ingestion of arsenic compounds has been associated with increased risk of skin cancer. Tseng (1968, 1977) has studied a limited

area in southwestern Taiwan where artesian well-water had extremely high concentrations of arsenic. Skin cancer prevalence for the area was 10.6 per 1000. The EPA has established skin cancer risks given arsenic concentrations in drinking water from Tseng's data. A skin cancer risk of 1 per 100,000 is related to water arsenic concentrations of 0.02 μg/liter (Sittig, 1980). These risk levels were calculated by applying a modified "one-hit" extrapolation model to the human epidemiologic data. Because the extrapolation model is linear at low doses, the additional lifetime risk is directly proportional to the water concentration. The resulting skin cancer risk is 5.9×10^{-4} cancers per year per 100,000 per μg arsenic.

Tseng's study (Tseng, 1968) has been reanalyzed for the EPA since it formed the basis for their draft water quality criteria document arsenic standard. It was calculated that, in the U.S., there should be observed 18.69 to 94.5 million lifetime arsenic-involved skin cancers. The best estimate for arsenic-induced skin cancers in the U.S. is very small. Therefore, the EPA risk equation should be considered an extremely conservative upper bound.

The non-carcinogenic effects of arsenic can be considered threshold effects. The TLV for arsenic which is intended to protect workers from these effects and reduce the cancer risk is 0.2 mg/m^3 (ACGIH, 1980). NIOSH recommendations are on the order of micrograms. Outside of the occupational setting, no recommendations have been made in this country. The U.S.S.R. and Czechoslovakia have twenty-four-hour maximum atmospheric concentration recommendations of 3 $\mu g/m^3$. Applying a safety factor of 3 to the ACGIH TLV, the OSRA will use 60 $\mu g/m^3$ as a threshold for non-carcinogenic effects for public arsenic exposure.

Beryllium

Beryllium is related to an acute poisoning (found in occupational settings), a chronic disease (found in occupational settings and neighborhoods surrounding beryllium industries), and carcinogenesis in animal experiments. Of interest to the OSRA is the chronic, non-occupational disease and the potential carcinogenicity.

Beryllium is poorly absorbed from the gastrointestinal tract. Water concentrations are kept low by industry effluent standards primarily to protect the environment. Therefore, the major route of beryllium exposure is through the air; the water route can be disregarded for now.

Chronic beryllium disease, berylliosis, is a systemic intoxication characterized by effects of the respiratory system. Common symptoms include dyspnea and a chronic cough. Other symptoms include fatigue, anorexia, weakness, and weight loss (Stokinger, 1981a). Hall et al. (1950) found the solubility of the compound determined toxicity. The form of beryllium from coal burning is thought to be oxides of relatively little biological activity. In fact, there is no evidence of disease in man nor animals exposed to beryl, bertiandite or effluents to the atmosphere from power plants (Tepper, 1980).

The occupational TLV for beryllium is 2 μg Be/m^3. A ceiling limit of 25 μg/m^3 also has been established. For community air, the recommended threshold for protection against chronic beryllium disease is 0.01 μg Be/m^3 (Tepper, 1980). If oil shale dust beryllium is in the form of soluble oxides as in coal, it is reasonable to use 0.01 μg Be/m^3 as a threshold in the risk analysis. This is a more conservative threshold than would be found by applying a safety factor to the TLV. However, since neighborhood exposures have been considered, it is best to use those results.

Beryllium is a suspected carcinogen in man although the evidence is not strong enough to definitely implicate this metal (Sunderman, 1978). In animal studies, beryllium has been found to be carcinogenic in many species (Stokinger, 1981a). Epidemiologic studies (Mancuso, 1970; Hasan and Kazemi, 1974; Wagoner, et al., 1980) have found greater than expected incidence of lung cancer but small numbers limit statistical interpretation. Whether or not beryllium is carcinogenic in man continues to be debated. The risk analysis will not attempt to calculate lung cancer risk due to beryllium exposure.

Cadmium

Man's primary exposure to cadmium is in food (U.S. average daily intake of 50 μg), although smokers inhale 0.15 μg Cd per cigarette and absorb approximately 40% of this amount. Also some workers get substantial exposures on the job (Schroeder, 1961). The average daily intake from water is 2 μg (NAS, 1977b).

Major health concerns are almost exclusively chronic exposures, and acute poisoning is rare. The two major health effects are decreased lung function due to inhaled cadmium and renal damage due to total cadmium uptake. The effect of greatest sensitivity is proteinuria as a consequence of kidney damage.

Friberg (1974) has determined the threshold for proteinuria to be 200 μg/g kidney cortex. Assuming that the concentration of cadmium in the cortex is 1.5 times the average kidney concentration, that one-third of the total body burden is in the kidney, and that the average kidney weighs 300 grams, then the total body burden threshold can be calculated to be 120 mg cadmium. Assuming no excretion and a 50 year exposure, the daily cadmium retention needed to exceed this threshold is 6.6 μg/d.

Because cadmium gastrointestinal absorption is only 5 percent, daily assimilation of cadmium from food and water equals (50 μg x .05) + (2 μg x .05) = 2.6 μg. Using a respiratory tract absorption of 50% and a daily air intake of 20 m^3, the ambient air concentrations needed to exceed the threshold of 6.6 μg/day is (4.0 μg x (1/0.5)) / 20 m^3 = 0.4 μg/m^3. This quantity, although very conservative, was used for the threshold for cadmium-related health effects.

If cadmium exposures are in the μg/m^3 range, it may be important to consider the sensitive sub-population of cigarette smokers. The ambient air concentration necessary to reach the threshold in a

two-pack-a-day smoker is 0.1 $\mu g/m^3$.

Cadmium is one of four metals that has been implicated as a human carcinogen on the basis of epidemiological investigations (Sunderman, 1978). Occupational cadmium exposure has been associated with increased incidence of cancer of the lung, prostate, and other organs. Lemen (1976) found an SMR of 2.4 for pulmonary cancers in a cadmium refinery.

Based on this study and others, the EPA Carcinogen Assessment Group (1978a) calculated a dose-response relationship of 2.9 lung cancers per year per 100,000/μg cadmium per m^3.

Chromium

Chromium is fairly abundant in the earth's crust and is an essential element in man's diet. In fact, "with chromium, the major concern with respect to human health is deficiency rather than excess" (NAS, 1974b).

Two oxidation states are commonly found in nature, Cr^{+3} and Cr^{+6}. The trivalent state is the more stable and therefore the most abundant. Hexavalent chromium in air can react with dust particles and other pollutants to form trivalent chromium. Cr^{+6} is also very unstable in the presence of organic material.

In occupational settings, exposures to chromium dusts have caused skin ulcers, dermatitis, nasal irritation, allergic responses and the classic chromium-related symptom, perforation of the nasal septum. ACGIH has determined that a TLV of 0.5 mg/m^3 of chromium metal, Cr^{+2}, or Cr^{+3} will protect workers from these effects. The TLV for Cr^{+6} compounds is 0.05 mg/m^3 (ACGIH, 1980).

Public exposure to oil shale chromium will be airborne, and possibly via food and water. The latter routes will not be considered important in terms of public health. Because hexavalent chromium is only a small part of natural chromium, a threshold for non-carcinogenic effects was set for this analysis at 0.1 mg/m^3.

Hexavalent chromium exposure has been associated with increased respiratory cancer in several epidemiologic investigations. Standard Mortality Ratios (SMR) have been reported in the range of 5 to 40 (Langard and Norseth, 1979). Mancuso and Hueper (1951) found an SMR of 15 while Langard and Norseth (1975) determined an SMR of 38 in a cohort study of bronchial carcinomas. Unfortunately, the actual exposures to chromium have not been measured. Researchers estimate, however, exposures are between 1.5 mg/m^3 and 0.5 mg/m^3.

Dose-effect curves cannot be determined at this time (NAS, 1974a; Langard and Norseth, 1979; Towill, 1978). However, because epidemiological investigations have demonstrated an association, it is necessary to estimate a dose-response relationship on the basis of the data available.

Assumptions are as follow:

- Hexavalent chromium is 10% of oil shale chromium. This is a very conservative estimate. This speciation factor will be included during the calculation of risk.

- $(SMR - 1)/D_E = 28$. This is based on the Mancuso and Hueper (1951) SMR of 15 which is in the center of the range indicated by Langard and Norseth (1979). The exposure (D_E) is assumed to be 0.5 mg hexavalent chromium / m^3. SMR-1 divided by the exposure equals a risk factor of 28 per mg hexavalent chromium / m^3.

- $I_O = 0.0323$, the lifetime risk of respiratory cancer, both sexes and all races combined (Cutler, 1975).

The resulting slope is 1.3×10^{-1} cancers per year per 100,000 exposed per μg Cr/ m^3.

To properly interpret results derived from this dose-response function, it must be remembered that the relationship is based on high-dose, occupational exposures. Increased incidence of lung cancer due to environmental exposures to chromium has not been demonstrated. Axelsson and Rylander (1980) found no increase lung cancer deaths in populations exposed to air pollutants from ferro-alloy industries.

Fluoride

Flouride, a ubiquitous element in nature, reaches man through food, water, and air. At elevated levels of exposure, three adverse health effects are seen in man: acute flouride poisoning, dental fluorosis, and crippling skeletal fluorosis. Other effects, observed in animal studies only, include kidney injury, anemia, interference with reproduction, changes in thyroid structure and function, and body weight loss.

In addition to adverse effects, fluoride has one major beneficial effect: protection against dental caries (NAS, 1971). For more than 30 years, fluoride has been added to drinking waters in the United States to reduce the incidence of dental caries. The recommended dose for this treatment is 1 mg/liter. Many parts of the country, Colorado included, have natural water fluoride concentrations of greater than 0.7 mg/liter (NAS, 1977b). Some communities have concentrations greater than 2 mg/ℓ. Additional fluoride is not needed in these cases.

Mottled enamel is the most sensitive adverse effect. Epidemiologic studies have found higher incidences of mottled enamel when water concentration exceed 2 to 8 mg/ℓ. The lower end of this range will be used to calculate a threshold for this effect. Assuming 2 liter/day, daily intake from water equals 4 mg. At 1 mg/ℓ, daily intake from water would equal 2 mg. Fluoride from food is estimated to be 0.2 mg. Therefore, the range of possible fluoride exposures from food and water is 2.2 to 4.2 mg with unacceptable mottling possibly occurring at the top of the range.

Fluoride concentrations in rural areas are usually less than 0.16 $\mu g/m^3$. The contribution to daily intake is negligible at this level (Hodge and Smith, 1970). However, if industrial pollution increases ambient concentrations, the resultant load could cause mottling.

For this analysis, 200 µg will be considered the maximum negligible airborne contribution of fluoride in the daily intake. This corresponds to a airborne concentration of 10 $\mu g/m^3$ assuming a respiratory rate of 20 m^3/day and 100% absorption. Above this level, it is possible that an increased mottling could occur in high water fluoride areas. Natural waters in the oil shale area will be assumed to contain 0.7 mg/ℓ fluoride. Increased dental mottling will be possible with additional fluoride in the range of 1.3 to 7.3 mg/ℓ. If the threshold for crippling fluorosis is between 20 to 80 mg, the corresponding water concentrations needed (with an exposure of 10 to 20 years) is 10 to 40 mg/ℓ. Crippling fluorosis although highly likely, could occur in the oil shale area after many years of public exposure to water having an extreme level of 9.3 to 39.3 mg/liter oil shale contributed fluoride. Regulatory constraints would preclude this level of exposure.

Lead

Chronic lead toxicity has been with man since antiquity. Although acute lead poisoning is rare, chronic lead toxicity is severe and can occur with relative low intake of lead. A large data base has been collected on lead in recent years. Dose-effect and dose-response relationships have been fairly well worked out. At low levels, enzyme changes and shortening of red blood cell life have been noted. Other effects, occurring at higher levels, are anemia, impairment of renal function, and encephalopathy.

Fifty µg Pb/100 g blood is generally considered a conservative threshold for adverse health effects although children and the fetus may be more sensitive (WHO, 1977). Average daily intake of lead in food and water is 100 to 600 µg (Mahaffey, 1977; Moore et al., 1979). Assuming an absorption of 10%, a maximum of 60 µg Pb/d is assimilated from food and water.

NAS (1972a) calculated a dose-effect curve relating µg Pb assimilated per day with µg Pb/100 g blood from data of the California Department of Health (1967). The assumptions used by NAS to calculate this relationship were 30 µg/day assimilated from food and water, 37% lung retention of inhaled lead, and 23 m^3 respired per day. The relationship is

$$\mu g \text{ Pb assimilated} = \text{Exp } 10\ (((\mu g \text{ Pb}/100 g \text{ blood}) + 69.9312)/54.2467)$$

From this curve, 162 µg Pb total assimilation is necessary to reach a blood level of 50 µg/100 g blood.

$$162\ \mu g\ (total) - 30\ \mu g\ (food\ and\ water) = 132\ \mu g\ (air)$$

The corresponding air concentration is

$$(132\ \mu g/d\ /\ 23\ m^3/d)/.37 = 15.5\ \mu g/m^3$$

By this relationship, exposure to 15 $\mu g/m^3$ may result in health effects in the population. To protect sensitive subgroups of the population, children, and the unborn, a safety factor of 3 must be applied to this concentration. A concentration of 5 $\mu g/m^3$ was used as the threshold for effects.

Mercury

As occupational mercuralism has become rare in modern times, chronic exposure to mercury compounds in the environment has been recognized as a potential health hazard. The tragic epidemic of methyl mercury poisoning at Minimata Bay in Japan demonstrated the bioaccumulation of methyl mercury in fish in polluted waters (Kazantzis, 1980).

Classic mercuralism, caused by inhalation of mercury vapors, is characterized by a variety of neurologic disorders including tremor, lung irritation, and possibly proteinuria as a result of renal damage. Ingestion of mercury salts does not result in neurological effects because they cannot cross the blood brain barrier. The kidney is the critical organ for mercuric salt ingestion. Methyl mercury, when ingested, does cross the blood brain barrier and neurologic symptoms result with involvement of the central nervous system. Symptoms are paraesthesia, disturbance of gait, persistent headache, sensory difficulties and rash. Methyl mercury is concentrated in the fetus, thereby making neurologic developmental disorders one of the most sensitive effects of chronic mercury exposure (Friberg, 1972).

Mercury is released in the gaseous emissions and the water effluents of the oil shale industry. Environmental changes of the mercury species are impossible to accurately predict. Because health effects depend on the species of the mercury involved in public exposure, a different method of analysis is necessary.

A joint FAO/WHO Expert Committee on Food Additives (WHO, 1972) set a tolerable daily intake of mercury from all sources to be 40 $\mu g/d$ with less than 25 μg methyl mercury. Assuming 20 $\mu g/d$ methyl mercury in food intake (Berglund et al., 1971) and 2 $\mu g/d$ from water (WHO, 1971), a person may have a maximum mercury intake from air of 18 $\mu g/d$, 3 to 5 μg (17 to 28%) of which may be methyl mercury. Assuming 20 m^3 respirated per day and 90% absorption, the maximum allowable air concentration without effects is:

$$(18\ \mu g/d)\ /\ (20\ m^3/d \times 0.9) = 1\ \mu g/m^3$$

This threshold assumes the following:

- FAO/WHO total daily intake adequately protects individuals (including the fetus) from mercury-related health effects.

- No more than one-quarter of airborne mercury is methyl mercury.

- Conservative estimates have been made for daily intake from water and food. Daily intake from food is below 20 μg/d and primarily in the form of methyl mercury. This estimate indicates an upper value in an intake range.

- Worst-case assumption that all mercury in water will be methyl mercury.

Nickel

Health effects associated with nickel exposure have been observed in occupational settings. Nickel carbonyl, a toxic, volatile liquid, causes a systemic poisoning with acute exposures. Pulmonary effects predominate the clinical course of this poisoning although parenchymal degeneration is observed in liver, kidneys, and other organs. Nickel dermatitis, caused by contact exposure with nickel salts, is infrequently seen today in occupational settings. There are no epidemiologic studies which confirm the systemic toxicity of nickel and its compounds, excluding nickel carbonyl. Animal studies have shown a variety of effects at high doses including myocardial damage, liver damage, and neurologic effects (NAS, 1975).

The oil shale related public health exposures are expected to be far below levels necessary to cause systemic effects. To consider these effects in the initial risk analysis, a threshold was set at 0.03 mg/m^3, one-third the TLV of 0.1 mg/m^3 (ACGIH, 1980).

Nickel is considered one of the four trace elements that has been well demonstrated as a carcinogen in man (Sunderman, 1978). There is some doubt as to the actual nickel compound (or compounds) that are principal carcinogens. In 1975, NAS reported that suspicion of carcinogenicity had been focused on respirable particles of nickel, nickel subsulfide, and nickel oxide and on nickel carbonyl vapor (NAS, 1975). Although nickel carbonyl is carcinogenic in animals, no epidemiological evidence has demonstrated this gas to be the main carcinogen in man. Recently, the slightly soluble nickel salts, nickel oxide, and nickel subsulfide, have gained evidence as the most probable active agents in nickel carcinogenesis (Norseth, 1980).

Two respiratory cancers have been related to nickel exposures: nasal sinus cancer and lung cancer. Doll et al. (1970) and Pedersen et al. (1973) have studied these cancers in industrial settings. Using the U.S. incidence for these cancers from the third national cancer survey (Cutler, 1975), the individual lifetime cancer risks were found.

The dose-response relationships used in the analysis are:

6.6×10^{-2} cancers / year per 100,000 / $\mu g/m^3$ for lung cancer and
3.9×10^{-2} cancers / year per 100,000 / $\mu g/m^3$ for nasal sinus cancer.

A major difficulty for the OSRA was estimating the proportion of carcinogenic nickel compounds within the total nickel exposure. Assuming that the slightly soluble compounds, nickel subsulfide, and nickel oxide are the active carcinogens, an estimate of the proportion of these species in the particulates can be made. MacFarland (1974) speculated that nickel emissions from the burning of coal and fuel oil are predominantly nickel oxides while studies of nickel refineries have found high concentrations of nickel subsulfide (~50%) and little nickel oxide. It is apparent that a major part of nickel effluents are suspected carcinogenic forms of nickel (Schmidt and Andren, 1980).

The OSRA made the assumption that all nickel in oil shale industry air effluents is carcinogenic. This is a conservative assumption based on the inconclusive nature of available data on nickel speciation.

Selenium

Selenium is probably an essential trace element in man. While man can be exposed through air and by direct contact, the major source of selenium is in food (NAS, 1976).

Health effects are different for acute and chronic exposures. Acute effects, seen mainly in occupational settings, include dermal irritation and dermatitis, upper respiratory tract effects, and possible allergic responses. Acute distress is characterized by pallor, lassitude, irritability, vague complaints of indigestion, and giddiness. These are accompanied by a garlic-like odor. Chronic effects are damage to the liver and kidney (Wilber, 1980). Reports of selenium as a carcinogen, an anti-carcinogen, and a teratogen have not been demonstrated in man. The acute effects have been found to have a threshold above 0.2 mg/m^3 (Glover, 1970) which has been set as the occupational TLV (ACGIH, 1980). Concerning a threshold for chronic effects, Sakurai and Tsuchiya (1975) estimated a range of average daily selenium intake in the diet, 50 to 150 μg, and the range of the safety factor between these intakes and the intake necessary for adverse effects is 10 to 200 on the basis of human and animal toxicological studies. Using the lower of these ranges, a tentative and conservative recommended maximum daily intake of 500 μg/day was calculated. The difference between this level and the maximum average intake (500 μg/d - 150 μg/d = 350 μg/d) was used as an acceptable maximum intake from air. Assuming 100 percent absorption, a conservative threshold was derived, (350 μg/d)/(20 m^3/d) = 17.5 $\mu g/m^3$.

Sodium

Drinking water sodium has recently been shown to be a contributor to hypertension in healthy populations (Tuthill and Calabrese, 1979a,b). Persons on sodium-restricted diets (3% of population) have been shown to have adverse health effects with high sodium drinking water (Elliot and Alexander, 1961). To minimize the effect on public health from drinking water, NAS (1977b) has recommended sodium levels be kept below 100 mg/ℓ. Because more precise

dose-response information is not possible, OSRA will use this as a threshold for "possible increased cardiovascular effects due to sodium intake."

Vanadium

Man is exposed to vanadium in food, water, and air in high concentrations in occupational settings. Food, the main source of vanadium for the general population, contains between 0.02 and 2.0 mg/day (ICRP, 1975). Air concentrations have been measured at 0.25 to 75 $\mu g/m^3$ in rural areas (Vouk, 1979). While water concentrations range widely with geographic location, U.S. drinking water averages about 1 μg V/liter. In Colorado River water, vanadium has been measured as high as 300 $\mu g/\ell$ with an average of 105 $\mu g/\ell$ (Stokinger, 1981b). Because absorption from the gastrointestinal tract is very small (2%), fluctuation in water and food concentrations are negligible.

Health effects related to vanadium are mostly respiratory effects observed in occupational settings. In man, acute distress is characterized by sneezing, cough rhinitis, and sore throat. Chronic effects include chronic bronchitis, chronic rhinitis, and pharyngitis. Absorption from the lungs is approximately 25%. In animals, liver, kidney, hematological, cardiovascular, metabolic, and neurological effects have been seen. There is no evidence for carcinogenicity, teratogenicity, or mutagenicity. In man, the systemic effects are vague. In terms of general exposures, a weak epidemiologic association with heart disease and ambient air pollution vanadium is known (Hickey, 1967).

Because occupational exposures and volunteer studies are the only human studies to show effects, the results were used to quantify a safe threshold level. The TLV for vanadium pentoxide, 0.05 mg/m^3, is based primarily on the study of Zenz and Berg (1967) where five human volunteers had severe upper respiratory tract irritation in the form of persistant cough at concentrations of 0.2 mg/m^3 with an eight-hour exposure (ACGIH, 1980). The vanadium pentoxide threshold of 0.05 mg/m^3 corresponds to approximately 30 $\mu g/m^3$ vanadium. Using a safety factor of 3 to protect sensitive populations, the OSRA threshold for adverse effects of vanadium is 10 $\mu g/m^3$.

Polycyclic Aromatic Hydrocarbons and Aza-Arenes

Polycyclic aromatic hydrocarbons (PAH's) and aza-arenes are classes of polycyclic organic matter (POM) of which several members are carcinogenic. Animal studies have established relative carcinogenicities of many compounds (NAS, 1972b). Epidemiologic studies have associated increased lung cancer and skin cancer risk with exposures to polycyclic organic matter. Man's exposures to PAHs and other POMs is occupational, through cigarette smoking, and in ambient air. The first two exposures are much greater than the latter and have been studied to a much greater extent.

Ambient air exposure to PAHs is dependent on particulate concentrations. Vapor phase organics emitted into the atmosphere from

industry and fuel-burning sources are rapidly degraded (Cupitt, 1980). It is the organic matter absorbed on particulates that can reach man without major breakdown.

Establishing dose-effect/dose-response relationship is difficult because the class of compounds is very large, the actual important carcinogenic compounds in the class are not known, and very few PAHs are measured in ambient air. One compound, benzo(a)pyrene (or BaP), is used as an indicator of PAH carcinogenicity. This is done because BaP is a major carcinogen in the group and because it is the most common PAH measured in the environment. Expense has made measurement of all important PAH's prohibitive. Use of BaP as an indicator of PAH carcinogenesis assumes that BaP concentrations are always proportional to the actual carcinogen in the class. Because this is not always the case, analysis using BaP as indicator must be considered broad-based and subject to large uncertainty.

Cuddihy et al. (1980) developed a dose-response curve for polycyclic organics, PAH, and aza-arenes, using BaP as the indicator. It is based on BaP exposures and associated lung cancer rates for non-smokers (rural and urban), smokers, and coke oven workers. For use in the OSRA, an annual risk factor of 5000 respiratory cancers per 100,000 exposed per μg BaP per m^3 was used.

Using this risk factor assumes that oil shale particulate PAHs have similar carcinogenicity as the particulates used in the model. There is no data ready available at this time to assess the relative carcinogenicity of oil shale dusts as compared with other particulates. However, studies are now underway at Los Alamos National Laboratory that can be used in the future years of the OSRA.

BaP source terms were unavailable and had to be estimated. It was assumed that volatile BaP will not reach the general population due to rapid degradation by environmental factors. Therefore, only the BaP per milligram of particulates is estimated to be 3.7×10^{-8} mg BaP/ mg particulate matter (based on data supplied by Los Alamos National Laboratory). A BaP source term was then derived from the particulate source term.

Polycyclic aromatic hydrocarbons and aza-arenes are present in retort water. A number of processes act on these compounds in surface waters changing their forms and reducing their quantity (Herbes et al., 1979). The public exposures are therefore difficult to predict.

Benzo(a)pyrene is very persistent in water and has been detected in treated water. Health effects related to waterborne BaP are difficult to assess. In animal studies, cancer of the stomach has been observed in mice with oral administrations and skin tumors have been induced in mice, rats, and hamsters. Evidence of similiar effects in man have not been shown (NAS, 1977b).

5.4 TOTAL AIR POLLUTANTS AND MORTALITY

Numerous epidemiological studies have failed to show acute or

chronic health effects below thresholds for sulfur oxides (120 $\mu g/m^3$) and particulates (180 $\mu g/m^3$). In fact, at a recent conference ("The Proposed SO_x and Particulate Standard," Atlanta, Georgia, September 16-18, 1980) there appeared to be a consensus that these threshold levels should be raised. However, there is reason to question the sensitivity of the rather gross detection methods. Support for potential long-term effects of air pollution levels below the threshold has, until recently, come from clinical epidemiological studies which have repeatedly shown an increased incidence of diseases such as bronchitis and lung cancer suspected of being caused by air pollution in urban areas as contrasted to rural areas. The several studies which show an even greater urban/rural ratio of lung cancer among the non-smoking population are most persuasive that cleaner air may be of more than esthetic value.

Beginning in 1970 and culminating in 1977 with the publication of their book, Lave and Seskin (1977) took a broad approach to this problem and used regression analysis to examine the differential mortality rates in 117 SMSAs in the United States. They used five socioeconomic variables and six air pollution variables, initially, that together explained over 80% of the variance in mortality. While the socioeconomic variable relating age of the population was always the most important component in the regression, over 25% of the variance was still accounted for when age-sex-race standardized mortality rates were used thus effectively removing the age and race as socioeconomic variables. Since the levels taken in the 117 SMSAs were overwhelmingly below the threshold and the most significant sulfate measure was the minimum level and the most significant measure for particulate was the average levels, the authors argue that this suggests a subthreshold health effect of air pollution. Furthermore, statistical analyses were unable to reject the hypothesis that the relationship between sulfate or particulate levels with mortality is linear. Lave and Seskin conclude their study by examining their air pollution - mortality association using the nine epidemiological criteria of causation advanced by Hill (1965). If a causal relationship is assumed, 8% of the United States mortality in urban areas (approximately 53,000 deaths annually) can be explained by air pollution. Wilson (1980) reviews other studies of air pollution and mortality and finds Lave and Seskin's conclusion in general agreement with them. Wilson, using a subjective averaging approach, arrived at the following relationship for quantifying risk: 3.5 premature deaths/year/100,000/μg SO_x/m^3. Morgan et al. (1978) used a similar approach and estimated an overall 11.8 person-years lost per premature death considering all age groups. Applying this figure to Wilson's 3.5 premature deaths yields an estimate of mortality in person-years: 41.3 person-years lost/100,000/μg SO_x/m^3.

Recent data suggests that particulates (TSP) may be more important than sulfates (Mazumdar, Schimmel, and Higgens, 1980; Lipfert, 1980; Morris, 1981). However, Lipfert still concludes that the net effect of all pollutants on mortality is seen to be about 4%. Thus, at this time, estimates of premature death from air pollution produced by the oil shale industry will be presented on the basis of Lave and Seskin's work as adopted by Wilson and Morgan using SO_x as a surrogate. This function is linear with no threshold which implies that any

addition to the ambient air SO_x concentration results in premature deaths.

5.5 HEALTH EFFECT DATA SUMMARY

The health effects data used in the calculation of risk due to exposure to oil shale pollutants is presented in Tables 5-2 through 5-6. The background data is the best available estimate of average rural pollutant concentrations. As oil shale region-specific data becomes available, these values will be reviewed and updated.

Table 5-2. Air Exposure-Related Health Effects Data for the Oil Shale Risk Analysis-- Threshold Effects

Pollutant	Threshold $\mu g/m^3$ *	Background $\mu g/m^3$	Ref
Sulfur Oxides	120	25.0	(1)
Particulates	180	50.0	(1)
Nitrogen Oxides	300	-	
Ozone	100	-	
Carbon Monoxide	3300	100.0	(2)
Hydrogen Sulfide	50	-	
Arsenic	60	<0.01	(3)
Beryllium	0.01	0.0001	(4)
Cadmium	0.4	0.002	(3)
Chromium	160	0.01	(5)
Fluoride	10	<<0.05	(6)
Lead	5	0.8	(3)
Mercury	1	0.02	(3)
Nickel	30	<0.01	(3)
Selenium	17	<0.01	(7)
Vanadium	10	<0.02	(3)

1) EPA Air Quality Criteria, 1980.
2) NAS (1977a), Carbon monoxide.
3) Waldron, (1980).
4) Reeve, (1979).
5) NAS (1974a), Chromium.
6) NAS (1971), Fluoride.
7) NAS (1976), Selenium.

- = negligible
* = annual averages

Table 5-3. Dose-Response Relationships for Air Exposure-Related Health Effects for the Oil Shale Risk Analysis-- Carcinogenic Effects

Pollutant	Site	Lifetime cancers/year/100,000/$\mu g/m^3$
Arsenic	Respiratory	2.8
Cadmium	Lung	2.9
Chromium	Lung	1.3×10^{-1}
Nickel	Nasal Cavity	3.9×10^{-2}
	Lung	6.6×10^{-2}
PAHs (BaP)	Respiratory	5.0×10^{3}

Table 5-4. Dose-Response Relationships for Air Exposure-Related Health Effects for the Oil Shale Risk Analysis-- SO_x as Surrogate for Total Pollutants.

Pollutant	Premature Deaths/year/100,000/$\mu g/m^3$
Surrogate SO_x	3.5

Table 5-5. Waterborne Pollutant Related Health Effects- Threshold Effects

Pollutant	Effect	Route	Threshold μg/d	Background μg/d	
				Food	Water
Fluoride	Mottling	Water	4,000		2,000
	Fluorosis	Water	20,000		2,000
Mercury	Neuropathy	Food + water	40	20	2
Selenium	Selenosis	Food + water	400	100	6
Sodium	Hypertension	Water	200,000		150,000

Table 5-6. Waterborne Pollutant Related Health Effects- Carcinogenic Effects

Pollutant	Effect	Lifetime cancers/year/100,000/μg As
Arsenic	Skin cancer	5.9×10^{-4}

6. HUMAN HEALTH AND ECOSYSTEM RISK

This chapter of the HEED estimates the human health and ecosystem risks from the one-million-barrels-per-day OSRA scenario. Two human populations are considered: the general public and the occupational workforce. Public risks result from exposure to pollutants discharged as the result of normal and abnormal facility operation. Occupational risks include risk from accidents and pollutant exposures. Ecosystem risks are quantified in terms of two indicator species, mule deer as a member of the terrestrial ecosystem and trout as a member of the aquatic ecosystem.

6.1 PUBLIC HEALTH RISK

The general population of the oil shale region will be exposed to a variety of pollutants in the air, food, and water. Many of these pollutants can cause adverse health effects as discussed in Chapter 5. Using the dose-response and threshold data derived from the literature, the population at risk estimates, and the estimated exposure contours, public health risk is estimated as follows:

- Estimate the number of persons exposed to varying concentrations of pollutants based on demographic and geographically dependent exposure results.
- If a pollutant has a no-effect threshold, estimate the number of persons exposed to concentrations above the threshold. Background exposures are added to oil shale-related exposures to derive the final pollutant exposure.
- The dose-response function (Chapter 5) is multiplied by the geographically varying population estimate and the exposure estimate to obtain risk. For non-threshold effects, the risk is calculated for the exposed population. For threshold effects, risk is estimated for the population with exposures above the threshold; for populations with exposure below the threshold, risk is assumed to be zero.

Risk results are discussed separately for inhalation (air exposures) and ingestion (food and water exposures).

Inhalation Risks

The availability of air dispersion models, the resulting air pollution exposures, and the estimates of the population distribution allowed the calculation of the health risks using a computer algorithm. The oil shale region used in this analysis was divided into twenty-five square mile areas. For each pollutant considered in the pollutant-by-pollutant analysis, the risk was calculated for each five

mile by five mile area and then summed across the entire region to obtain the total risk.

Table 6-1 presents the results of the air pollutant, threshold effect risk analysis. This table presents only health effects which are considered to have no-effect thresholds. Of the sixteen pollutants analyzed, three pollutants were found to have exposures above the threshold for a portion of the population for at least one of the three scenario variations. They are sulfur oxides, hydrogen sulfide, and (for the OPT variation only) particulates.

For the baseline scenario, eleven persons (0.001%) are exposed to sulfur oxide concentrations above the threshold for increased prevalence of lung diseases and decreased lung function. The MIS and OPT variations had 3% of the population exposed above the threshold. To interpret these findings, it is necessary to consider the studies on which the threshold is based. The "effects" measured in many these studies were increased prevalence of chronic lung disease and decreased lung function. An increase in bronchitis prevalence might be from 2% to 6% of the study population based on a dose-response relationship developed in Japan (Tsunetoshi et al., 1971). Applying this to the eleven persons over the threshold for the baseline scenario results in a risk too small to realistically interpret. However, a 4% increased prevalence of chronic bronchitis in 17,000 (MIS variation) or 12,600 persons (OPT variation) is a significant population health effect. The particulate concentration for the OPT variation is also over the threshold for 940 persons. This additional burden could increase the response in this group.

Hydrogen sulfide concentrations are above the odor threshold for 0.3% of the population associated with the baseline scenario and 0.2% for the MIS and OPT variations. One to two thousand persons will be able to smell this pungent gas in the ambient air. However, no part of the general public is exposured to H_2S concentrations that cause eye irritation or other severe adverse effects.

The OSRA found no health effect potential related to air exposure of nitrogen oxides, ozone, carbon monoxide, fluoride, mercury, lead, selenium or vanadium. Also, with the exception of carcinogenic risk, no health effect potential was related to air exposures of arsenic, cadmium, chromium, and nickel.

The carcinogenic risk has been calculated for four trace metals (arsenic, cadmium, chromium, and nickel) and the polycyclic aromatic hydrocarbons (PAHs) as indicated by benzo(a)pyrene. The risks are presented in Table 6-2. All cancer risks for the three scenario variations are less than one hundredth of a cancer per year. In terms of lifetime risk, the best estimates are less than one lifetime cancer in the oil shale region for each pollutant considered. For comparison, the PAH risk estimate is 3.5×10^{-8} of the overall annual U.S. lung cancer rate of about 3.5 (Cutler, 1975).

In addition to the pollutant-by-pollutant analysis, the increased overall mortality associated with total pollution exposure was

Table 6-1. Inhalation Threshold Effect Results for Public Populations in the Oil Shale Region

Pollutant	Persons exposed to pollutant concentrations above the threshold for health effects or "nuisance" (H_2S)		
	Scenario variation		
	Baseline	MIS	OPT
Sulfur oxides	11 (0.001%)	17,000 (3%)	12,600 (3%)
particulates	0	0	940 (0.2%)
NO_x and Ozone	0	0	0
Carbon Monoxide	0 (B)	0 (B)	0 (B)
Hydrogen Sulfide	2,000 (0.3%)	1,300 (0.2%)	940 (0.2%)
Arsenic	0 (B)	0 (B)	0 (B)
Beryllium	0	0	0
Cadmium	0 (B)	0 (B)	0 (B)
Chromium	0 (B)	0 (B)	0 (B)
Fluoride	0	0	0
Mercury	0 (B)	0 (B)	0 (B)
Nickel	0 (B)	0 (B)	0 (B)
Lead	0 (B)	0 (B)	0 (B)
Selenium	0 (B)	0 (B)	0 (B)
Vanadium	0	0	0
Population	685,000	552,000	470,000

B = oil shale related concentrations insignificant when compared to background concentration

Table 6-2. Inhalation Non-threshold Effect (Cancer) Risk Results for Public Populations in the Oil Shale Region

Pollutant	Site	Excess Cancers per year Scenario variation		
		Baseline	MIS	OPT
arsenic	respiratory	4.5×10^{-3}	2.8×10^{-3}	1.7×10^{-3}
cadmium	lung	4.3×10^{-5}	2.9×10^{-5}	4.3×10^{-5}
chromium	lung	1.6×10^{-4}	8.6×10^{-5}	1.6×10^{-4}
nickel	respiratory	7.1×10^{-5}	8.6×10^{-5}	7.1×10^{-5}
PAH (BaP)	respiratory	5.5×10^{-3}	3.3×10^{-3}	5.3×10^{-3}

estimated using sulfur oxides as a surrogate for all pollutants combined. As discussed in Chapter 5, this approach is a crude measure of mortality effects based on correlational epidemiologic studies. Differences in air pollution makeup, population diversity and other factors make careful interpretion of the results in Table 6-3 mandatory. For the baseline scenario, 73 premature deaths per year are expected while the MIS and OPT scenarios yield higher numbers. To put this result in some perspective, it is useful to consider the expected mortality of the general population. Assuming an average lifespan of 70 years, one out of seventy, or 1.4%, of the population dies annually. This is 9590 persons out of the estimated general population of 685,000. According to the SO_x surrogate risk calculation, 73 will die earlier than expected.

The number of person-years lost per premature death can be estimated from U.S. age-specific life expectancy tables (U.S. Department of Health, Education, and Welfare, 1975). Morgan et al. (1978) found 11.8 person years lost per excess death to be the best estimate. Therefore, the 73 premature deaths per year predicted for the baseline scenario accounts for 861 person-years lost per year.

To aid in interpreting these mortality estimates, it is useful to apply the same model to other conditions. The results can be used as a measure for comparison with OSRA results. The National Ambient Air Quality primary standard for sulfur dioxide is 80 $\mu g/m^3$. This level is not associated with measurable health effects. However, the SO_x surrogate model predicts 1300, 8400, and 20,000 premature deaths per year for Denver, Chicago, and New York, respectively at this level (1980 census data used for population estimate, U.S. Census Bureau, 1980).

Ingestion Risks

Public exposure to oil shale pollutants by water and food is difficult to estimate due to the complexity of the transport mechanisms involved. However, investigation of the health risks related to extreme cases of water and food exposure yielded a limited number of potential concerns from this analytical approach. Fluoride, mercury, selenium and sodium were analyzed for the effect of their related threshold effects. Arsenic was analyzed for its non-threshold skin cancer effect.

The population exposed to various water sources and to game fish was estimated using the closest water source to each population center. If a town is upstream from the oil shale effluent route, the additional risk to that population can be assumed to be zero. For populations drinking water or taking fish from water that are contaminated by oil shale industry effluents, the concentrations of pollutants at the site of extraction were estimated, the extreme daily dose calculated, and the health risk estimated. Background exposures were added to oil shale-related exposures to assess threshold effect risks.

The results for the threshold effects are presented in Table 6-4. To properly interpret these results, it is essential to remember that sub-populations with exposures above the threshold are expected to

Table 6-3. Premature Mortality Related to Total Air Pollutants Using Sulfur Oxides as a Surrogate

Pollutant	Premature deaths per year Scenario variation		
	Baseline	MIS	OPT
SO_x surrogate	73	253	222
Population	685,000	552,000	470,000

Table 6-4. Ingestion Threshold Effect Results for Public Populations in the Oil Shale Region

Pollutant	Effect	Persons exposed to pollutant concentrations above the threshold increased incidence of health effects Scenario variation		
		Baseline	MIS	OPT
flouride	dental mottling	0	180,000	0
	fluorosis	0	21,000	0
mercury	neuropathy	500	---	---
selenium	selenosis	---	---	---
sodium	hypertension	21,000	194,000	140,000
Population		685,000	552,000	470,000

--- no data

have an increased incidence of the effect. For example, given the baseline scenario, 500 persons have an increased risk of developing neuropathy due to the concentration of mercury in their water supply. Sodium-induced hypertension risk is increased for 21,000 persons, according to the baseline scenario, and even greater numbers for the MIS and OPT variations. Fluoride is above the threshold for a sub-population given the MIS scenario only. Based on incomplete data, selenium concentrations were found to be close to the health effect threshold. Therefore, selenium may or may not be a health concern.

Further quantification of these increased risks is inappropriate considering the assumptions made concerning release and transport of oil shale effluents resulting in extreme exposures. No treatment of drinking water was assumed although some towns of the oil shale region are expected to have some forms of water treatment. As the water and food concentrations estimates are refined, better quantification of health effects will be possible.

The results of the arsenic-related skin cancer analysis are shown in Table 6-5. For the baseline case, the annual expected skin cancers caused by oil shale industry arsenic is 9.4×10^{-3}. The MIS and OPT risks are higher but also less than one cancer per year. This result can be put in perspective by considering the estimated excess skin cancers are less than 0.001% of the U.S. incidence of skin cancer. The increased risk of this disease is dwarfed by the background rate. Furthermore, the validity of the dose-response relationship is extremely dubious as discussed in Chapter 5, and most likely is an upper bound.

Table 6-5. Ingestion Non-threshold Effect (Cancer) Risk Results for Public Populations in the Oil Shale Region

Pollutant	Site	Excess cancers per year		
		Scenario variation		
		Baseline	MIS	OPT
arsenic	skin	9.4×10^{-3}	1.0×10^{-1}	2.2×10^{-1}

6.2 OCCUPATIONAL HEALTH AND SAFETY

The most significant risk in terms of exposure to hazardous materials and situations is present at the occupational level of the oil shale industry. The occupational hazards include the inhalation of toxic dusts, gases, and vapors, skin contact with product oil and other processed effluents, exposure to physical stress such as heat and noise, and occupational traumatic injury and accidents. The health and safety of the oil shale worker will be a paramount issue for generations because oil shale in Colorado and Utah is a resource that will take at least a hundred years to exploit fully.

Occupational Risk Approach and Concerns

The oil shale workforce will be exposed to risk of occupational accidents. Additionally, the polluted environment is of major concern for health effects resulting from chronic exposure. The workers can be exposed through the media of air, liquid, and solid wastes in the workplace. The air emissions are considered for two worker groups on the basis of their respective working environments. Underground miners are exposed to one set of conditions, while surface workers (including miners in a surface mine) are exposed to another. Exposure to liquid and solid products is evaluated on the basis of their potential for creating adverse health effects.

Incidence rates for accidents are predicted for the oil shale workforce through utilization of historical occurrence rates from comparable industries. Mining incidence rates are used to predict the number of accidents from oil shale mining; petroleum refining is used to predict the incidence rates for the surface processes; and construction industry rates are used for the construction workforce. Eleven accident scenarios are presented to illustrate the special hazards and dangers associated with oil shale processing.

Worker Illnesses

Two of the primary concerns for occupational illness from chronic exposures involve pulmonary and dermatological exposures. Pulmonary exposure involves the inhalation of dusts, vapors, and gases. Diseases caused by the inhalation of inorganic dust particles generally are referred to as pneumoconiosis. The results of exposure are dependent upon particle size, chemical nature, severity or duration of exposure, and host factors (e.g., immunocompetency, predisposing illnesses, smoking history).

Silicosis is a collagenous pneumoconiosis caused by the inhalation of free silica (Ziskind et al., 1976). The oil shale industry, based on a one million barrels per day, has the capacity to produce 2,900 metric tons/day of particulate matter as uncontrolled air emissions. In addition, this level of oil shale industrial production will yield the following estimated quantities of solid wastes: 46,000 metric tons/day of raw shale dust, 3,600 metric tons/day spent shale dust and 640 metric tons/day of retort feed dust. Green River oil shale contains a high percentage of silicon dioxide (averaging 12%). Silicosis is a progressive disease that differs in its severity depending upon the amount of exposure, dust concentrations and other factors. Acute silicosis involves the buildup of scar tissue in the lungs (fibrosis) and may develop over a period of weeks following massive but short-term exposure to quartz. It may be fatal within a year. The inhalation of silica dust with inert dusts can cause mixed-dust fibrosis which is a progressive form of silicosis occurring over a period of years. Since the severity of the disease is graded depending on several other factors besides exposure, one cannot effectively and conclusively devise a dose-response curve for silicosis.

Some of the symptoms of silicosis, such as difficulty in

breathing, may take 20 to 30 years to develop. It is not uncommon to have concomitant tuberculosis, mycobacterial infection, bronchitis, or emphysema with silicosis during any stage of its development. Uncomplicated silicosis is not fatal nearly as often as silico-tuberculosis (combined silicosis and tuberculosis). In advanced complicated silicosis (progressive massive fibrosis) respiratory failure and death are the usual results. Other factors, such as smoking tobacco or the inhalation of other dusts and gases may have a synergistic effect with the inhalation of silica dust causing a higher incidence or more severe form of silicosis.

Silicosis and other forms of pneumoconiosis due to the exposure to silica will be of concern in the oil shale mines. The Threshold Level Value (TLV) of silica-bearing dust is given by a formula which is 10 milligrams of respirable dust per cubic meter of gas sample divided by the sum of the percent silica in the sample plus 2. That is,

$$TLV = \frac{10\ mg/m^3}{\%qtz + 2}$$

For 3% quartz present in the dust, the TLV is 2 mg/m^3. Many other types of pneumoconioses are known, and can be caused by different agents including aluminum, silicates, beryllium, and barium. It is possible that silica, acting in a synergistic fashion with some other agent present in oil shale, may cause respiratory ailments distinct to the oil shale industry, creating a "mahogany lung" problem similar to that of black lung in the coal mining industry.

Occupational exposures in the developing oil shale industry may sometimes be above established TLV's for dust particulates. The risk of exposure to silica particles depends on the efficiency of safety methods concerned with creating a minimal exposure of individuals to the oil shale dust.

Exposure to hydrogen sulfide, nitrogen oxides, sulfur dioxide, ammonia, polycyclic aromatic hydrocarbons (PAH), carbon monoxide, and hydrocarbons presents a hazard of particular importance to the oil shale worker. Threshold Limit Values (TLV's) and calculated air exposures for oil shale workers are given in Table 6-6. The effects of exposure are variable, ranging from mild side effects to lung cancer. Hydrogen sulfide, in addition to its noxious odor at low concentrations, can cause bronchitis, pneumonia at medium concentrations, and coma or death with acute exposure (Simon and Simpson, 1971). A habituation-response to hydrogen sulfide caused by olfactory fatigue may occur at moderate concentrations, thus inhibiting the ability of the worker to respond to higher concentrations of the gas (Sittig, 1979).

Nitrogen oxides may cause eye and mucous membrane irritation at low concentrations with severe pulmonary irritation at higher concentrations. Acute exposure may cause collapse and death; chronic exposure results in pulmonary dysfunction, suggestive of emphysema.

Sulfur dioxide irritates the upper respiratory tract and mucous membranes with coughing, dyspnia, fatigue, altered sense of smell

and rhinitis resulting from chronic exposure. Suffocation and death may result from acute over-exposure. It has been suggested that there is a synergistic effect between particulate and sulfur dioxide exposure in the development of silicosis and pulmonary disease.

Polycyclic aromatic hydrocarbons have been demonstrated as being carcinogenic in test animals. Of particular importance is benzo(a)pyrene (BaP) which has been indicated as a carcinogen. The BaP concentrations were found to be less than the TLV for coal tar pitch volatiles, although their concentrations varied depending on the source of exposure (Coomes, 1978).

Exposures for toxic gases and vapors tend to be within the TLV for the particular chemicals as shown in Table 6-6. Some of the major concerns include hydrogen sulfide and sulfur dioxide exposures on a chronic basis. The synergistic effects of diesel fumes, toxic gases, silica dusts, and oil product vapors have yet to be determined.

Table 6-6. TLV's and Calculated Air Exposures for Toxic Gases and Vapors.

Source Term	Air Exposure (mg/m^3) Controlled	Uncontrolled	Threshold Limit Values (mg/m^3) (ACGIH, 1980)
Hydrogen Sulfide	0.09	1.8	15
PAH	0.0001	0.002	0.2
Sulfur Oxide	0.008	0.16	13
Hydrocarbons	0.016	0.32	0.2
Arsenic (gas)	3.5×10^{-6}	7.0×10^{-5}	---
Nitrogen Oxide	0.09	1.8	1.8
Carbon Monoxide	0.031	0.62	55

Oil shale workers will be directly exposed to shale product oils and other processed effluents. The carcinogenicity of oil shale has been demonstrated in man (Scott, 1922), and in laboratory animals (Holland and Wilson, 1981). Shale oil has been determined to be less carcinogenic than most coals, tars, and pitches, but more carcinogenic than petroleum products. Apparently, this is somewhat related to the PAH content of the oil, although no strict correlation has been found (Bogovski and Vinkmann, 1979). Shale oil has also been found to cause epidermal degeneration in mice along with tumors (Wilson et al., 1981).

Some studies support the carcinogenic activity of shale oil while others fail to offer any evidence of these effects. Cancer patterns in the oil shale area of the Estonia S.S.R. demonstrated an excess of skin cancer in females who worked for 10 to 20 years in the oil shale industry (Purde and Rahu, 1979). The study also indicated an

increase of 1.6 to 2.5 times in the cases of stomach and lung cancer of oil shale workers over the normal community. A 10 percent incidence has been reported in the number of mice with tumors after applying 40 mg per week of shale oil for 15 to 20 weeks while 35 percent of the mice had epidermal degeneration with the same treatment (Wilson et al., 1981).

In studies of Colorado oil shale workers, no relationship has been found between the development of any skin lesion and the degree of exposure to shale oil (Birmingham, 1954; Rudnick and Voelz, 1980). However, the small sample size and short latency period preclude interpretation of this result. Oil shale industrial waste-water contains large amounts of BaP (0.002 to 0.17%). The health effects of BaP in shale oil effluents were not determined.

Physical hazards include exposure to noise, heat, explosions, and traumatic injury (accidents). The occupational exposure to heat and noise are expected to parallel other mining industries. Permissible exposure limits for noise levels are 90 decibels for 8 hours based on protecting the worker from permanent hearing loss. Calculated occupational exposures are 25 decibels above the exposure limit in some coal mining operations. The exposure limit for heat stress is 27-degrees C wet-bulb globe temperature for continuous work. This number increases or decreases depending upon the actual work-rest regime. Processes with the oil shale industry are specific (e.g., retorting operations) and the related risks can be evaluated when the specific exposures are determined. One of the significant effects of chronic or low-level physical factors is that of decreasing worker performances or productivity through physical stress. Physiologic stress is apparent with increased levels of physical stimuli, and acute exposure may produce damaging effects. Risks for some physical factors (such as noise) can be eliminated with proper use of protective devices developed in other mining industries.

Occupational Exposure

Underground oil shale mine environments were sampled for the following compounds: carbon dioxide, nitrogen dioxide, arsine, formaldehyde, xylene, carbonyl sulfide, benzene, toluene, and phenol. If present at all, concentrations of most of these compounds were below their detectable limit. One sample of hydrogen sulfide (out of 14) was found at its Threshold Limit Value (TLV) of 15 mg/m^3. TLV refers to an airborne concentration of a substance and represents a condition under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. Sulfur dioxide and amines were detected, but not at levels near their respective TLVs. Polycyclic aromatic hydrocarbons (PAH) were found to vary from less than 0.01 $\mu g/m^3$ up to 2.64 $\mu g/m^3$. Dust concentrations ranged from less than 0.0076 mg/m^3 to 8.5 mg/m^3. Dust and PAH concentrations are of concern because the measured concentrations were near or above their TLVs, 5 mg/m^3 and 0.2 mg/m^3, respectively (Oil Shale Task Force, 1981).

Air concentrations associated with surface operations are dependent upon the emissions from the mines, crushing units, retort

vessels, storage tanks, and (where applicable) upgrading units. A production-related (per barrel) set of exposure terms was calculated for the different processing technologies. To estimate site-specific occupational exposures, these terms were scaled by the site's shale oil production.

An example of the air concentration of pollutants at a 100,000-bbl/day open-pit mining/TOSCO retorting site is given in Table 6-7. This table represents what can be considered average air concentrations for the entire oil shale site. Naturally, particulate concentrations will be higher near mining and crushing areas, while hydrocarbons will be higher near retorting and storage units. Based upon measurements taken at specific areas of the oil shale workplace, pollutants of major concern are: particulates; sulfur dioxide; hydrocarbons; hydrogen sulfide; and trace elements such as arsenic, cadmium, and chromium. Particulates are by far the most important pollutant of concern, not only in mass, but also because hydrocarbons, sulfur dioxide, and the trace elements are absorbed by (or are already a part of) the dust particle.

Although the health effects from exposure to source terms from the oil shale industry are understood in general terms, much work needs to be done. In particular, worker exposure needs to be quantified in terms of duration and quantity of the exposure, and in the number of workers who will be exposed. Also, further research is needed to develop dose-effect and dose-response relationships for the exposures associated with the oil shale industry. While the current toxicological research on oil shale and its products will provide some useful data for risk analysis, epidemiologic investigations of oil shale worker experience will prove to be invaluable in ten to forty years.

Occupational Accidents

Oil shale processing creates and uses many materials which can be hazardous if not controlled or used properly. Table 6-8 lists the derived hazards and the associated hazards of the oil shale industry (Crookston, 1978). The derived hazards unique to oil shale are of primary interest, in that their effects are unknown. The associated hazards are common to other industries besides oil shale, and as such, present no new and unknown factors to the industry. For example, the effects of methane in underground mines is fairly well known, and procedures have been developed to handle this particular problem. However, the problems presented by raw shale dust are an unknown factor.

Three of the derived hazards (raw shale dust, spent shale dust, and retort gases) acting alone or in a synergistic fashion with another hazard, are considered the most dangerous of the derived hazards due to their explosive nature. Raw shale dust has been studied at the Bureau of Mines (Richmond and Miller, 1977), and was found to have an explosive potential that is a function of nominal dust concentration, added rock dust, and oil assay. Explosions were not possible with shale quality less then 104 liters/metric ton (25 gallons per ton). The nominal explosive concentration varied between 0.2 and 0.6 grams/liter (0.2 and 0.6 oz/ft^3) for 208 and 104 liters/metric ton (50 and 25 GPT),

Table 6-7. Controlled Air Concentrations for 100,000 bbl/d Oil Shale Operation with Open-Pit Mining and Tosco Processing.

Pollutant	mg/m^3	Pollutant	mg/m^3	Pollutant	mg/m^3
SO_x	8.0×10^{-3}	Particulate	0.48	NO_x	9.0×10^{-2}
HC	1.6×10^{-2}	CO	3.1×10^{-2}	H_2S	9.0×10^{-2}
As(gas)	3.5×10^{-6}	As	2.3×10^{-5}	Be	5.5×10^{-7}
Cd	2.9×10^{-7}	Cr	2.0×10^{-5}	F	2.9×10^{-4}
Hg	1.9×10^{-6}	Ni	1.2×10^{-5}	Pb	1.1×10^{-5}
Se	1.2×10^{-6}	V	4.1×10^{-5}		

Table 6-8. Oil Shale Derived and Associated Hazards
Source: Crookston, 1978.

Derived Hazards

- Raw Shale in Place
- Crushed Raw Shale
- Spent Shale
- Raw and Processed Shale Oil
- Raw Shale Broken by Blasting
- Raw Shale Dust
- Spent Shale Dust
- Retort Vapors, Gases, and Mists

Associated Hazards

- Machinery and Equipment
- Conveying Equipment
- Methane
- Dynamite and Other Explosives
- Fuel, Oil, and Grease
- Hydraulic Fluid
- Oxygen and Acetylene
- Mine Electrical Equipment
- Static Electricity
- Welding and Cutting
- Ventilation Equipment, Fans
- Doors, Conduits, etc.
- Maintenance, Supplies, Tires, Belting, etc.
- Ammonium-Nitrate Fuel Oil
- Explosive Detonators, Primacord
- Timber and Frame Structures
- Trash and Waste
- Butane, Propane, Natural Gas Space Heaters
- Natural Phenomenon
- Groundwater

respectively, while the minimum concentration of volatiles was 0.05 grams/liter for all propagating explosions. In addition, rock dust was found to be slightly more effective in preventing propagation than the inorganic matrix from oil shale. The upper limit for incombustible material was 86 percent for propagation. Thus, for a typical room in the Anvil Points mine 20 meters wide by 20 meters high, approximately 1,800 kg of pulverized dust would be required to fill the room with an explosive mixture.

The spent shale dust contains about 6 wt.% carbon; when mixed in the right concentration with air, it is explosive. The retort gases, which are retort vapors, low Btu gases and oil mist is obviously a potential explosive hazard. If this is mixed with enough oxygen, it can be explosive.

Eleven accident scenarios were developed to demonstrate how oil shale hazards may lead to an accident which could endanger lives and damage property.

1) Rubble on a floor pile soaked with hydraulic fluid is ignited by cutting and welding. The fire spreads to a muck pile and to the adjacent roof and ribs of the opening.

2) A combination of events in a mine causes an explosion of methane propagated by oil shale dust on the mine surfaces.

3) The dust in a hopper below a crusher is scattered by a repairman, the heavy concentration of dust is ignited and/or detonated by a cutting torch.

4) A layer of dust on a hot exhaust manifold is ignited at the time a mine round is fired. The burning dust detonates the airborne dust cloud raised by the blast.

5) Spontaneous combustion occurs in the "dead" portion of a large coarse ore stockpile on the surface.

6) After repairing a hot recycle gas compressor, an air leak into the rich, hot recycle gas stream is undetected and the combination reaches explosive limits. The resulting explosion starts secondary fires of raw shale, spent shale, and shale oil in the area.

7) An accident causes hot spent shale dust to be dispersed in a heavy airborne concentration which is detonated by an electric spark.

8) A mechanical malfunction in an electrostatic precipitator results in an air leak into the precipitator forming an explosive mixture of oil mist, low-BTU gas, and air. An electrical spark in the precipitator causes an explosion.

9) The sensible heat in a shut down retort is to be used to preheat a rubblized retort. The heat is transferred by flowing low-BTU gas from an operating retort through the spent retort. The recycle gas also picks up rich gas and vapors. When the combination contacts

the air in the rubblized retort, an explosion occurs which is propagated by the dust in the rubble.

10) The combustion zone burns through the rich shale section of a retort wall, the recycle gas stream drives the rich gas and vapors into an adjacent ready-to-be-fired retort resulting in explosive ignition of the new retort.

11) Methane which fills a rubblized retort is not purged before igniting the rubble. The resulting explosion is propagated by the shale dust in the rubble.

These accident scenarios give an idea of the type of accident that can occur; accident statistics can be used to quantify this risk. Any labor-intensive industry can expect significant occupational injuries.

The accident incidence rates for surface operations (retorting and construction) are given in Table 6-9.

Table 6-9 Surface Operation Accident Statistics.
(See Notes, below)

Operation	Fatalities (F)	Non-Fatal Days Lost (NFDL)	No Days Lost (NDL)	Total
Retorting*	0.02	2.32	3.83	6.17
Construction	0.02	4.18	8.59	12.79

References: American Petroleum Institute (1980) and National Safety Council (1980).

Notes: All figures are given as incidence rates for 100 workers per year or 200,000 man-hours per year. Injuries are reported in four categories, defined by the National Security Council (1980) as follows:

- Injuries (F): the number of occurrences resulting in death.
- Non-Fatal Occurrences with Days Lost (NFDL): the number of occurrences that result in days away from work or days of restricted activity.
- Occurrences With No Days Lost (NDL): the number of non-fatal occurrences resulting only in loss of consciousness or requiring medical treatment other than first aid.
- Total Occurrences: the sum of the above three categories.

*Based on Petroleum Refinery Statistics.

Mining of oil shale will most likely account for the greatest fraction of the total oil shale industry accidents and illnesses. In 1978, fatality rates were seven times higher in mining and quarrying than in manufacturing, and the disability injury rates were twice as high. The method of mining is the deciding factor for injury rates, rather than the substance being mined. An examination of Table 6-10, Underground Mining Statistics, and 6-11, Surface Mining Statistics, reveals that underground mining is two to three times more hazardous to the worker than surface mining. Underground coal mines, however, are as safe, if not safer, than the non-coal underground mines, as shown in Table 6-10. One reason coal mining has been considered more hazardous than non-coal mining is the large amount of coal mining done in the United States, and hence, the large number of accidents. For example, there were 115 fatalities due to coal mining in 1979, and only 31 in non-coal mining. Yet, they both have the same incidence rate: 0.09 accidents per 100 worker-years. Another reason is that one type of coal mining, Pennsylvania anthracite, is extremely hazardous with high individual incidence rate. However, the amount of Pennsylvania anthracite mining is relatively small compared to the mining of bituminous coal, and does not have much of an effect on the overall accident figures for coal mining activity.

Certain aspects of underground mining of oil shale are similar to that of hard rock mining. Accidents will be of a similar nature: rock and roof falls, explosions and fires, bumps, falls, electrocution, heavy mining equipment, and vehicular traffic. The mining will also be similar to coal mining in the size of the operation, the explosiveness of the dust (however, shale dust is not as explosive as coal dust), and the gassy nature of the mines. In Bureau of Mines studies, the possibility that deep oil shale mining shafts may contain methane was noted (Matta et al., 1977). The Bureau of Mines oil shale research shaft was classified "gassy" in November, 1978, and a methane ignition started a fire in December of 1978 that necessitated flooding of the shaft (Vinson et al., 1979). The experimental shafts on Tracts C-a and C-b have both been classified as gassy. The presence of methane gas could hinder MIS and TIS processes.

At the present, only one surface mine is planned for the oil shale industry, that being at Tract C-a. Surface mining statistics, given in Table 6-11, show that the surface mining of coal, on the whole, is somewhat less hazardous than that of surface mining for other minerals. Accidents in surface mining are generally due to heavy equipment operation, handling of the large amounts of materials, and slips and falls down the mine wall (MSHA, 1981).

TIS processes do not involve underground mining, only aboveground drilling, much like gas and oil extraction. The injury incidence rates for oil and gas extraction, as given in Table 6-12, are applicable to this technology.

Table 6-10. Underground Mining Statistics

Type of Accident	Year	Coal		Non-Coal	
		Number	Incidence Rate*	Number	Incidence Rate*
Fatalities	1978	74	0.07	39	0.13
	1979	115	0.09	31	0.09
	1980	100	0.08	23	0.07
Non Fatalities With Days Lost (NFDL)	1978	10,516	10.11	2,892	9.62
	1979	14,647	11.66	3,432	10.39
	1980	14,637	11.95	3,099	9.17
Occurrences With No Days Lost (NDL)	1978	2,650	2.55	1,973	6.56
	1979	2,402	1.91	1,935	5.86
	1980	2,228	1.82	1,746	5.16
Total Occurrences	1978	13,240	12.73	4,904	16.32
	1979	17,164	13.66	5,398	16.35
	1980	16,965	13.85	4,868	14.40
Average Number of Workers	1978	141,361		33,772	
	1979	147,143		35,692	
	1980	141,548		38,430	
Employee Hours Reported	1978	207,984,147		60,107,115	
	1979	251,279,656		66,037,842	
	1980	244,928,100		67,619,233	

Reference: MSHA (1978, 1979, 1980)

*Incidence Rates = 100 full time employees, 200,000 hours (50 weeks, 40 hours per week)

$$= \frac{\text{Number of Injury Occurrences}}{\text{Number of Employee Hours}} \times 200{,}000$$

= Number of accidents per 100 workers per year

Table 6-11. Surface Mining Statistics

Type of Accident	Year	Coal		Non-Coal	
		Number	Incidence Rate*	Number	Incidence Rate*
Fatalities (F)	1978	17	0.03	60	0.06
	1979	15	0.02	65	0.06
	1980	22	0.03	50	0.05
Non Fatalities With Days Lost (NFDL)	1978	2,053	3.39	3,881	3.92
	1979	2,198	3.40	4,297	4.20
	1980	2,182	3.28	3,491	3.58
Occurrences With No Days Lost (NDL)	1978	1,365	2.25	2,757	2.78
	1979	1,067	1.65	2,329	2.27
	1980	885	1.33	1,646	1.69
Total Occurrences	1978	3,435	5.67	6,698	6.76
	1979	3,280	5.08	6,691	6.53
	1980	3,089	4.65	5,187	5.32
Average Number of Workers	1978	73,686		114,694	
	1979	72,445		121,090	
	1980	70,839		116,363	
Employee Hours Reported	1978	121,216,546		198,059,179	
	1979	129,171,611		204,796,128	
	1980	132,962,314		194,880,715	

Reference: MSHA (1978, 1979, 1980)

*Incidence Rate = Number of Accidents per 100 workers per year

Table 6-12. Occupational Injury and Illnesses for TIS Oil Shale Extraction*

Total Incidence Rates (Number of Accidents per 100 Workers per Year)		
Fatalities (F)	Non-Fatal With Days Lost (NFDL)	No Day Lost (NDL)
0.03	1.9	4.27

Reference: National Security Council (1980).
*Data based on aboveground gas and oil extraction industry data.

To date, there are seven companies involved with five underground oil shale mines operating in the Piceance Creek Basin. Their employment and injury report for 1980 is given in Table 6-13 and types of accidents in Table 6-14. Overall, the total incidence rate is expected to be similar to that of underground coal, however, with a fatality in 1980, and one in 1979 (at C-b), the fatality incidence rate is quite high. A third fatality in December 1980 occurred on Colony's tract, however, it was not associated with mining.

The oil shale mining risk predictions were based on the following assumptions:

- The accident statistics for underground mining will be used for underground mines; surface accident records for surface mining.
- The size of the mine will be considered to have no effect upon safety.
- For TIS operations, the drilling operations are assumed to be similar to that of oil and gas extraction.

Table 6-15 gives the expected yearly injuries from oil shale mining based on the historical incidence rates of mining for both the 1981 OSRA baseline scenario and the scenario variations. In comparing the baseline scenario versus its OPT option, the differences in the amount of fatalities and total injuries is significant. This is due to the smaller number of miners needed to mine the same amount of coal as an underground miner (a factor of about 4) and the accident incidence

Table 6-13. Employment and Injury Report. Underground Oil Shale Mines. January 1980 - December 1980 (Source: MSHA, 1981)

Company Name/Mine Name	Employee Hours	F	NFDL	NDL	Total	Incidence Rate per 200,000 Emp. Hrs. F	NFDL	NDL	Total
Exxon Co., USA Colony Shale Oil Project	28,420	0	1		1	*	7.04	*	7.04
Occidental Oil Shale, Inc. Logan Wash Oil Shale	729,400	0	39	25	64	*	10.69	6.85	17.55
Occidental Oil Shale, Inc. Cathedral Bluffs Shale Oil	280,401	0	5	2	7	*	3.57	1.43	4.99
Union Oil Co. of California Long Ridge Experiment	44,732	0	1		1	*	4.47	*	4.47
Gilbert Corp. of Delaware C-b Tract	215,132	0	7	1	8	*	6.51	0.93	7.44
Morrison Knudson Co., Inc. Federal Oil Shale Lease	36,920	0	2		2	*	10.83	*	10.83
Mine Shaft & Tunnel Corp. Tract C-a	286,067	1	6	6	13	0.70	4.19	4.19	9.09
Total Oil Shale Underground Mining	1,621,072	1	61	34	96	0.12	7.53	4.19	11.84

Incidence Rate at 200,000 Employee Hours = 100 Full-Time Workers (50 weeks, 40 hours per week)

$$\text{Incidence Rate} = \frac{\text{Number of Injury Occurrences}}{\text{Number of Employee Hours}} \times 200{,}000$$

F: Occurrence Resulting in Death

NFDL: Non-fatal Occurrences With Days Lost (Lost Workdays)

*: Incidence Rate Less than 0.005

NDL: Occurrences With No Days Lost. That is, non-fatal injury occurrences resulting only in loss of consciousness or medical treatment other than first-aid.

Table 6-14. Types of Accidents. Underground Oil Shale Mines. January 1980 through December 1980 (Source: MSHA, 1981)

Type of Accident	No. of Accidents
Drilling	6
Electrical	1
Explosives	5
Fall of Face, Rib, or Sidewall	3
Fall of Roof	3
Handling Material	26
Haulage	4
Hoisting	3
Machinery	16
Slip or Fall	15
Trucking	1
Other	13

Total Number of Accidents = 96

Note: Only reported accidents included.

Table 6-15. Expected Yearly Injuries from Oil Shale Mining Based On Historical Incidence Rates for Mining

Scenario and Technology	Employ-ment	Fatalities (F)	Non-Fatal Days Lost (NFDL)	No Days Lost (NDL)	Total
BASELINE SCENARIO*					
Underground Mines	39,025	35	4,090	1,553	5,678
Surface Mines	1,120	1	41	22	64
TIS	122	0	2	5	7
Total	40,267	36	4,133	1,580	5,749
MIS Variation	22,501	20	2,358	896	3,274
OPT Variation	11,681	5	424	234	663
TOTAL INCIDENCE RATES (Accidents per 100 workers per year used to generate above).					
Underground Mining		0.09	10.48	3.98	14.55
Surface Mining		0.04	3.63	2.00	5.67
TIS		0.03	1.90	4.27	6.20

* Certain values have been rounded up to nearest integer to allow totals to be correct to nearest integer.

rates (a factor of about 2), giving a numerical factor of almost eight for the differences between the two for the mining component of the fatalities. The MIS options are between the baseline scenarios and the OPT options. The employment is less than that of the baseline scenario, and underground mining incidence rates were used to calculate the expected injuries.

It should be noted that although industry-wide averages were used for MIS mining, this technology may prove to be more hazardous due to the increased possibility of explosions, leaking gases, and fire from the burning of retorts underground while operations continue in another part of the mine.

Other factors which could increase the injury incidence rates of all types of mining are:

- Unknown factors which could arise concerning the health and safety of the workers.
- The time needed to work the mines and operating systems to establish the safest operating parameters.
- The industry might develop as a crash program during a national emergency.

The size of the workforce is one of the key parameters in estimating the number of accidents. Due to different (sometimes conflicting) reports on the number of miners needed, it was assumed underground miners will produce 34.0 metric tons (37.5 short tons) of shale per shift, and surface miners will produce 136 metric tons (150 short tons) per shift, which leads to the different accident and injury estimates seen in Table 6-16. The number of accidents for each case is the total for the extraction through upgrading portion of a million-barrel-per-day oil shale industry. These results do not represent any individual incidence rate in the previous tables, but a combination of several incidence rates. The number of deaths and injuries are quite high for underground mining compared with surface mining. This is due to the increased incidence and employment rates for the underground mines. MIS options show an incidence rate between the two.

Table 6-16. Estimated Yearly Accidents for the Oil Shale Risk Analysis Baseline Scenario Based on Historical Incidence Rates

Case	Employ-ment	Fatalities (F)	Non-Fatal Days Lost (NFDL)	No Days Lost (NDL)	Total
Baseline	58,724	40	4,688	2,510	7,237
MIS Variation	39,176	24	2,839	1,673	4,535
OPT Variation	27,279	8	860	918	1,785

There are many hazards unique to oil shale which can cause operating problems and increased fatalities and injuries. The MIS mines are of particular concern due to the combination of burning retorts, volatile gases, and an underground environment. Other hazards include methane, shale dust, products mixed with air, and spent and raw shale. These hazards could lead to a higher incidence rate than has been predicted for the 1981 OSRA and is reflected in a large uncertainty range for the MIS estimate.

Other oil shale workers will work aboveground, involved in various aspects of the retorting process, such as crushing, retorting, and upgrading. Because retorting is a new technology in the United States and has not been operated except at the pilot test stage, no data on accident statistics are available. The accident rate is expected to be less than that of underground mining and comparable to an industry which uses similar technology.

A significant degree of attention to safety by responsible management and labor will be necessary to maintain risk levels which will be comparable to those in analogous industries.

Summary

Occupational air exposure to pollutants of concern are the highest for underground miners, especially dust, PAH, and hydrogen sulfide. Other gases and vapors appear to be well below their TLVs. Surface exposures are significantly less; however, this assumes equal dispersion of the pollutants and does not take into account the higher concentrations that are expected to occur at the points of emission. Because a high proportion of the oil shale workers are miners, the application of existing accident statistics show a high incidence of injuries and fatalities can be expected. Surface mining is considerably safer than underground mining, as are retorting and other surface operations.

6.3 ECOSYSTEM RISK

The ecosystem risk methodology will be based on the concept of community diversity when appropriate data is available. Initial measures of risk are illustrated using first order estimates for selected species with the terrestrial and aquatic communities.

Terrestrial Community Risk

The largest effect on the terrestrial community may come from habitat destruction or alteration from surface disturbance. The magnitude of the surface disturbance will depend on the location, size, and type of mining and processing options. Most of the surface disturbance will be from solid waste disposal. Solid waste disposed on the surface was estimated based on the oil shale scenario. Assuming 50 percent of the material will be backfilled into mines and the waste piled 30 meters high, then land disturbance from solid wastes in the baseline scenario will be approximately 230 square kilometers (57,000 acres). If another 40 square kilometers (10,000 acres) were used for other surface facilities and utility rights-of-way, and another 81

square kilometers (20,000 acres) for associated urban development (U.S. Department of Interior, 1973), then the total land disturbance for the one-million-barrels-per-day baseline oil shale development scenario is 350 square kilometers (87,000 acres). Clearly, the amount of habitat disturbance from the scenario is also dependent on the success of revegetation efforts. "Success of vegetation," however, is usually determined from post-vegetation productivity estimates and does not necessarily replace pinyon-juniper and sagebrush communities in structure or nutrient array. Thus, the revegetation process and results are associated with additional ecosystem risks. Unless toxic element uptake and salinity, pH, and boron tolerance problems are solved, revegetated communities on spent shale piles will not resemble the natural communities that were replaced. Revegetation of disturbed land other than shale piles is possible, given that revegetated areas will require several years of management before stable, viable communities are established which resemble the existing, natural communities.

Oil shale operations may also cause additional ecosystem risk from the nature of the anticipated off-site land used such as roads and pipelines. These type of structures create barriers to animal movement, which is essential to the survival of migratory species such as mule deer. Surface water quality and quantity, air quality, and noise may result in additional risk to the terrestrial community.

Mule deer (Odocoileus hemionus) have been initially selected to indicate the effects of oil shale development on the terrestrial community. Mule deer are probably the terrestrial species evoking the most public interest, thus more biological data are known about its life history than any other terrestrial species in the basin. Additionally, deer hunting provides substantial economic benefit to the region. Population changes of mule deer affect community diversity, and are a component of the terrestrial community at risk.

Mule deer have the widest distribution of any subspecies of large game in North America. They range from the Sierra Nevada-Cascade mountains through the U.S. Northwest into British Columbia, west into the Canadian prairies and south to the panhandle of Texas and northern New Mexico and Arizona. Historically, mule deer population decline has been a consequence of habitat loss. Extension of rangeland in the western United States has pushed most mule deer herds into suboptimal habitat. It is estimated that in pre-Columbian times, there were over 5 million mule and blacktail deer in the western United States; in 1975, the population was estimated at 3.6 million despite intensive management of the herds.

The quality of the winter range is critical to the northwestern Colorado mule deer populations since because animals will succumb when stressed by deep snow, storms, or other inclement weather (Gilbert et al., 1970; Hansen and Dearden, 1975). The mule deer reproduction cycle in northwestern Colorado is keyed to the biannual migration, allowing fawn weaning and nursing to occupy the mild months on the summer range. Migration timing is essential to successful reproduction, with the winter range providing breeding grounds and sufficient food, water, and cover to allow return to the summer range in good physical condition.

An oil shale industry in the Piceance Creek Basin will disrupt the migration and winter habitat of mule deer by destroying vegetation, erecting migration barriers, and increasing mortality from road kills and poaching. The population decline resulting from the development is difficult to predict because intensive deer management or revegetation success could keep mule deer population declines to a minimum. Even after the oil shale industry is in place, it will be difficult to assess resulting changes in mule deer populations because natural mortality can cause severe population fluctuations which would effectively mask development-induced effects (Bartman, 1980).

Mule deer population decline resulting solely from habitat destruction of oil shale development in Piceance Creek Basin could be estimated if several assumptions are considered valid. First, it must be assumed that all winter habitat is occupied to carrying capacity by mule deer. In other words, destruction of winter range results in deer mortality; shifting to new areas is not possible due to a lack of food, water, or cover. Second, it is assumed that there is an even distribution and constant density of deer in a given habitat throughout the Piceance Creek Basin. Third, revegetated shale piles are assumed not to support a significant number of mule deer due to a lack of suitable forage and cover. Fourth, it is assumed that intensive habitat management will not successfully increase the carrying capacity of non-disturbed vegetative communities. Fifth, and finally, only habitat loss is considered to affect mule deer populations. Migration barriers, noise, air and water pollution, and road kills are assumed to not cause a significant net decrease in mule deer population when compared with the effects of habitat loss.

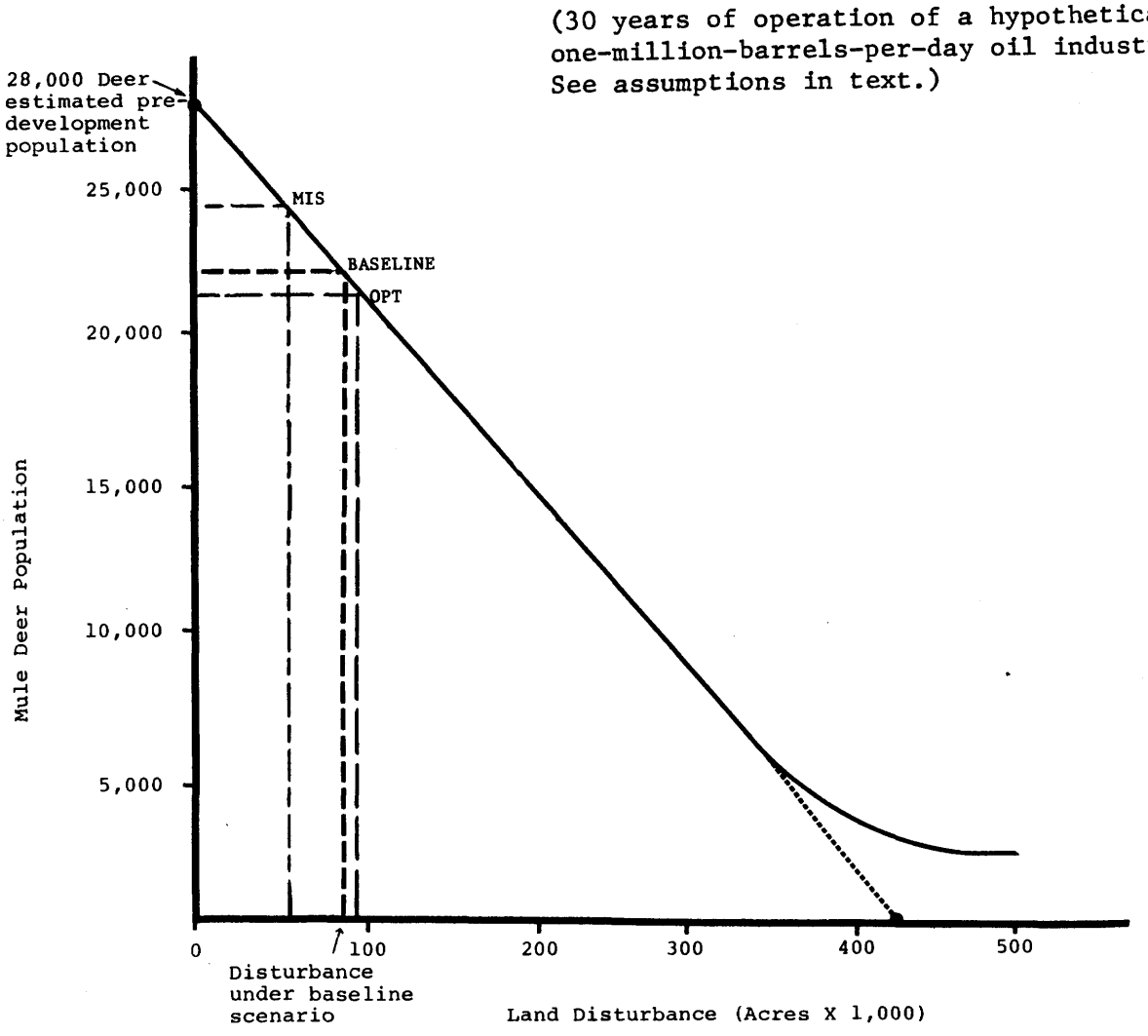
The above assumptions have limited validity, but none of the assumptions are completely true based on the presently available data. However, using the assumptions, mule deer population decline from the oil shale industry can be predicted as an indication of ecosystem risk.

The estimated relationship of mule deer population decline and land disturbance is shown in Figure 6-1. The curve is based on an estimated average winter baseline population of 28,000 deer in the Piceance Creek Basin and a total habitat size of 1,700 square kilometers (425,000 acres). Estimated utilization of different vegetation communities is currently under study at Los Alamos Laboratories and preliminary data will not be available until after the 1980-81 winter season. However, if 350 square kilometers (87,000 acres) are disturbed under the baseline scenario, then the relationship given in Figure 6-1 indicates a loss of approximately 5,700 deer (20 percent) can be expected. The OPT and MIS scenario variations may result in a 22 percent and 13 percent decline, respectively, in mule deer populations. Although natural fluctuations in the mule deer population are as high as $\pm$ 40 percent, at any given year the deer herd is predicted to have approximately 20 percent fewer individuals due to land disturbance related to oil shale development.

Aquatic Community Risk

Ecosystem risk in aquatic communities, like terrestrial communities, is a function of changes in natality and mortality of populations. However, turnover rates in aquatic communities are usually

Figure 6-1. Estimated Mule Deer Population Decline Due to Land Disturbance (modified from Bartman, 1980).



much higher than terrestrial communities, and natural fluctuations in populations can be extreme. Changes in diversity are a much more meaningful measure of ecosystem risk than absolute natality and mortality in aquatic communities, although risk to a specific species can be determined from probability of effluent discharge resulting in a population change. Aquatic community diversity is a strong function of water quality. Water quality changes can result from direct effluent discharge, leaching of solid wastes, erosion, and air pollutant deposition.

Threatened or endangered fish species would serve as excellent species of ecosystem risk if suitable life history and toxicological information were known. However, because there are so few individuals of these diminishing populations, it is difficult to obtain suitable numbers for laboratory or field study. Toxicological tests inevitably involve fish mortality, which is unacceptable when studying threatened or endangered species. Based on these considerations, trout Salmo sp. are a suitable "designator" species for aquatic ecosystem risk. The term "designator" species is used to delineate from "indicator" species since trout are not true indicator species. However, adult trout are carniverous and at the top of the aquatic ecosystem food chain. Trout also have a substantial history in the Piceance and Uinta Basins, and estimates of trout abundance can be found from 1969 to the present. The most recent study indicates that brook, brown, and rainbow trout are most common in the upper reaches of Piceance Creek and its tributaries (Goettl and Eddy, 1978). Brook and brown trout are reproducing naturally in Piceance Creek, but rainbow trout appear to be declining.

All of these introduced trout are adaptable; they can live in a variety of environments ranging from small brooks to large rivers and lakes, and they feed on a broad spectrum of organisms. All trouts are opportunistic and eclectic in their diet, which essentially reflects the availability of food organisms in their particular environment. Growth depends primarily on food availability, size of prey, the degree of intraspecific and interspecific competition, water temperatures and length of the growing season. Fecundity, in turn, depends on size. All of non-domesticated western trouts of the genus Salmo spawn in the spring; increasing water temperatures trigger reproduction. Most spawning activity begins when the water temperatures reach 5.5 to 9.0 degrees C. Elevation and latitude also influence the onset of spawning, which may occur as early as March or April in some areas and extend well into June and July in others. The necessity of gravel for nest construction and high oxygen tensions for the developing embryos makes all of the trouts under consideration obligatory stream spawners. Fry emerge from nests in early to midsummer, depending on when the spawning occurs; the length of the growing season dictates the size, which reaches 2.5 to 7.5 cm by autumn. Fish six to eight years old may attain a length of less than 25 cm in small streams with restricted habitats and dense populations, but in large rivers and lakes growth can be rapid with trout reaching about a kilogram by the fourth or fifth year. Sexual maturity typically occurs at an age of two to four years. In small stream populations mature trout may be only 15 to 20 cm in length and spawn only 100-200 eggs. A generalization on fecundity, with wide individual variations, is that females will spawn about 1000 eggs per 450 grams of body weight.

Ammonia concentrations will also cause trout mortality, depress egg hatchability, and reduce the growth of fry. The 96 hr LC_{50} value (concentration resulting in 50 percent lethality) of ammonia with Rainbow trout is 3300 mg/ℓ (Anderson et al., 1980). The ammonia concentrations in Table 3-4 with the LC_{50} value indicates that the baseline development scenario results in acute trout mortality. Linear extrapolation from the single LC_{50} value allows a first order estimate of trout mortality from discharge of ammonia. Table 6-17 shows these estimates of trout mortality, indicating complete disappearance of trout populations from Piceance and Parachute Creeks under the scenario variations. Trout population decline under the baseline scenario appear to be more moderate. However, these estimates are only for discharge ammonia, although ammonia has been indicated as the most potent fish toxicant in oil shale process waters. It should be noted, that ammonia is sensitive to the assumption of no pollutant transformation.

Although the available data is inconclusive, additional trout mortality and morbidity may also occur from heavy metal burdens. Fish tissue concentrations will be highest during periods of high water flow, which allows metals bound to bottom sediments to become resuspended and available. Fishing restrictions may have to be imposed near oil shale facilities, especially during the heavy spring runoff.

Threatened and endangered fish species are probably more sensitive to water quality than the tolerant introduced trout. If it is assumed that ammonia and metal concentrations in surface streams will have at least twice the effect on sensitive species than on trout, then percent mortality values in Table 6-17 should be at least doubled for all indigenous fish, especially the threatened and endangered species.

Table 6-17. Acute Trout Mortality From Discharge on NH_3 for Oil Shale Risk Analysis

Location	Percent Mortality		
	Baseline	MIS	OPT
Parachute Creek	20	100	100
Piceance Creek	22	100	100
White River at Rangely	2	10	18
Green River at Willow Creek	1	2	3
Colorado River at Lee's Ferry	1	1	3

7. PERSPECTIVE ON RESULTS

This chapter presents the analysis uncertainties and sensitivities, and research needs. The risk analysis procedure involves the use of available data and a series of assumptions to complete the analytical data base. The analysis procedures include the use of expert consultants to help establish reasonable approaches to risk quantification, the best estimates for missing data, and appropriate assumptions. The OSRA process included a workshop (held in January 1981 by IWG Corp.) involving health experts to address key issues which have been under review and revision during the project. The health effects area represents potential controversy and has the greatest degree of uncertainty.

The use of these OSRA initial results presented requires a proper understanding of the assumptions, estimates, uncertainties, and further research needs. The iterative nature of the risk analysis process allows the extrapolation of data to answer "what if" questions. Further extrapolations of the risks to assist the decision-making process should be made only with the proper understanding of the key assumptions and sensitivities of the analysis.

An oil shale industry providing a significant portion of our nation's energy demand does not exist. Many tradeoffs will be made to create this industry, with economic and health concerns as key issues.

The use of the risks presented herein as a guide to environmental research needs is appropriate; the use in an absolute manner to determine the future course of this industry is inappropriate.

7.1 UNCERTAINTIES AND SENSITIVITIES

Public Risk

The estimates of public health risk are sensitive to the uncertainties of the source term estimates, the transport model assumptions, and the health effect data and functions. Different techniques were used to estimate the associated uncertainties for the various approaches used in the calculation of risk for threshold and non-threshold effects.

The OSRA estimate of the uncertainties of the non-threshold effect public health risk assumes all parameters to be log-normally distributed and independent. The geometric standard deviations, σg, were estimated because analytic determinations were not possible given the paucity of necessary data. A root-mean-squares determination of the geometric standard deviation of the final risk estimate was made. The three original σgs for the source term, the exposure term, and the health function as well as the final risk σgs are presented in Table 7-1. The PAH(BaP) health function σg is considerably larger than the others due to the problems involved in using BaP as an indicator. The source term σg for the SO_x-surrogate risk is larger for the baseline scenario due to inconsistencies of published data for some processes.

The upper and lower limits to the 68% confidence interval can be found by multiplying and dividing the risk estimate by the σg. The non-threshold dose-effect relationships are based on data from high exposure levels extrapolated to low exposures. These low exposure predictions have little scientific substantiation, thus the lower confidence intervals are all zero. That is, the exposures indicated may have no measurable health effect as a lower bound-high confidence estimate. The resulting confidence intervals for the non-threshold effects are shown in Table 7-2. The ranges for premature mortality due to total air pollutants are in Table 7-3.

Threshold effect public health risk was analyzed by conservatively estimating the no-adverse-effect threshold, and then calculating public exposures which are above and below this estimate. Because the thresholds were conservative, the associated uncertainty band extends from slightly below the threshold to well above it. Consequently, the risk estimates of zero are assumed to be zero with negligible uncertainty.

For the few pollutants which were found to have sub-segments of the population exposed above the threshold, the uncertainty band extends from the best estimate down to zero risk.

In addition to the analytical uncertainties associated with the risk estimates, there is underlying uncertainty regarding the basic assumptions of the analysis. Non-threshold dose-response relationships were derived by extrapolating epidemiological study results to low levels of exposure, assuming a linear response. The actual shapes of the curves at these levels are not known. Therefore, the risks derived from these relationships are only as good as this assumption. Nonetheless, it is the most reasonable assumption that can be made at this time.

Other assumptions must be carefully considered for proper interpretation of the risk results. The arsenic-induced skin cancer dose-response is based on data collected in Taiwan and may not be applicable to the U.S. Re-analysis has found that this relationship predicts far more arsenic-induced skin cancers than are observed. The use of benzo(a)pyrene as an indicator of polycyclic aromatic hydrocarbon carcinogenicity may not be applicable to the oil shale problem. Analysis of the actual carcinogenic hydrocarbons in oil shale products and effluents will allow better methods of PAH risk estimation. Finally, the use of sulfur oxides as a surrogate for all pollutants in the mortality analysis makes gross assumptions concerning the similarity of the oil shale industry pollutants and environment with those of major U.S. cities. If sulfur oxides are the cause of increased mortality in these cities, the application of the dose-response is probably valid. However, the relationship between air pollution and mortality has not been well established and, therefore, results of dose-response relationships of this kind must be regarded with care and some skepticism.

Table 7-1. Geometric Standard Deviation Estimates for Parameters of Public Health Risk Analysis

Pollutant Analysis (Cancer Site)	Geometric Standard Deviation (σ_g)			
	Source Term	Exposure Models	Health Function	Risk Estimate
Arsenic (respiratory)	1.4	2.1	2.2	3.1
Arsenic (skin)	1.4	2.0	3.16	4.0
Cadmium (lung)	1.3	2.2	2.6	3.5
Chromium (lung)	1.3	2.2	3.16	4.1
Nickel (lung and nasal)	1.3	2.2	3.16	4.1
PAH (BaP) (respiratory)	1.9	2.4	10.00	12.7
SOx surrogate for baseline	2.0	2.0	3.16	4.5
SOx surrogate for MIS & OPT	1.1	2.0	3.16	3.8

computations based on log σ_g risk =

$$\sqrt{(\log\ \sigma_g\ \text{source})^2 + (\log\ \sigma_g\ \text{exposure})^2 + (\log\ \sigma_g\ \text{health})^2}$$

Table 7-2. Uncertainty Ranges for Non-Threshold Effect Risk Estimates

Pollutant Analysis	Excess Cancers per Year Scenario Variation		
	Baseline	MIS	OPT
Arsenic-lung	0 to 1.4×10^{-2}	0 to 8.7×10^{-3}	0 to 5.4×10^{-3}
Cadmium	0 to 1.6×10^{-4}	0 to 1.0×10^{-4}	0 to 1.6×10^{-4}
Chromium	0 to 6.4×10^{-4}	0 to 3.6×10^{-4}	0 to 6.4×10^{-4}
Nickel	0 to 3.0×10^{-4}	0 to 3.6×10^{-4}	0 to 3.0×10^{-4}
PAH (BaP)	0 to 7.0×10^{-2}	0 to 4.3×10^{-2}	0 to 6.7×10^{-2}
Arsenic-skin	0 to 3.8×10^{-2}	0 to 4.0×10^{-1}	0 to 8.8×10^{-1}

Table 7-3. Uncertainty Ranges for Premature Mortality Estimates

Analysis	Premature Deaths Per Year Scenario Variation		
	Baseline	MIS	OPT
SOx-surrogate	0 to 330	0 to 970	0 to 850

Occupational Accidents

The accident estimates for the oil shale industry are sensitive to several parameters. One of these is the incidence rate selected for the various worker tasks. It can be argued that the oil shale mines, for instance, will be very large, and that large mines statistically are safer than their smaller counterparts. However, large mines make up the bulk of mining activities and thus dominate the mining accident statistics.

The other sensitive parameter is the workforce population. For instance, the difference in fatalities for the baseline scenario between the results presented for an underground mining rate of 34.0 metric tons (37.5 short tons) / worker-shift versus 90.7 metric tons (100 tons) / worker-shift is 26 deaths. The workforce estimates also effect the public risk analysis by driving the public population estimates. Because it is one of the key parameters of the risk analysis, further investigation into the expected mining rates and occupational employment needed to produce one-million barrels per day of shale oil is warranted.

As stated earlier, the method of mining and not the substance being mined was the key factor in predicting the accident incidence rate for the industry. Accordingly, MIS mining was grouped with underground mining, although blasting, mining, retorting, and abandonment of the retort will all be going on at the same time in huge underground mines. These activities may lead to a higher probability for accidents than has been predicted for the MIS mines.

In addition, the retort operators of an MIS mine were assumed to have the same injury incidence rates as surface retort operators. If the MIS operators move underground, the accident rates increase, though probably not to the rate of an underground miner. The MIS miners and retort operators accident incidence rates can be considered the most uncertain of the incidence rates chosen.

The potential uncertainty associated with the estimates of the number of yearly accidents in a one-million-barrels-per-day oil shale industry is significant. To quantify an uncertainty range for the yearly accident estimates, several assumptions were made as follows:

- Mining statistics used to predict accidents are valid estimates within a range of $\pm$10% except for MIS mining.

- MIS mining has an assumed uncertainty range of +40%. MIS mines present an entirely new technology with new hazards, such as underground combustion, which may lead to much larger accident rates than predicted.

- Retorting accidents are assumed to be valid predictions within $\pm$20%. Retorting accidents were based on petroleum refining statistics. However, retorting uses a combustion and hot solids handling process on a large-scale, increasing the likelihood of different types of accidents.

- Construction accident statistics are valid estimates within ±5%. A small uncertainty band was chosen to allow for differences in site elevations, shale properties, and statistical variation.

- MIS employment estimates were assumed to be +10% more uncertain than other employment estimates. Present MIS employment estimates may account for underground miners; other underground workers who install bulkheads, pipelines, and ignite the retorts will represent a potential increase in the workers at risk.

The estimated uncertainty ranges for the accident estimates are given in Table 7-4. In the case of the MIS variation, the estimated number of accidents is at the lower end of the uncertainty range. This presents an area of large uncertainty that can be reduced through future research. Even with the uncertainty ranges taken into consideration, there are significant differences between the number of estimated accidents for the conventional baseline scenario and the conventional OPT variation.

Table 7-4. Estimated Yearly Accidents and Associated Uncertainties for the Oil Shale Risk Analysis Scenario.

Scenario	Fatalities (F)	Non-Fatal Occurrences With Days Lost (NFDL)	Accidents with No Days Lost Total (NDL)
Baseline	37-45	4300-5200	2300-2800
MIS	22-36	2800-4200	1700-2300
OPT	7-10	810-970	880-1100

Ecosystem Risk

Based on the extreme case water pollution, elemental metal pollutants in game fish are the most significant source of human exposure from the food chain. However, due to the limited number of people ingesting game fish, coupled with almost certain monitoring by state agencies, very few people are expected to be exposed through this pathway.

Drinking water exposures are dominated by leachate contamination. In the OSRA, it was assumed that the leachate from one abandoned MIS retort flowing without attenuation into Piceance Creek represents attenuated leachate from a one-million-barrels-per-day industry. The validity of this assumption has a direct bearing on estimated concentrations of alumiunum, boron, chromium, iron, lithium, lead, and zinc. If the actual attenuation is not significant, many abandoned MIS retorts as well as several surface disposal sites may simultaneously contribute leachates. If it were assumed that a total of 40 sites are active contributors, concentrations of these elements may increase by 40 times over calculated values in the analysis. Bioconcentration by aquatic organisms also may be critical because any increase in water concentration can be magnified through bioaccumulation.

Other water pollutant constituents are dominated by contributions from the Superior multi-mineral process (one or two orders of magnitude over other processes) and by contributions from on-site upgrading (two to three orders of magnitude over most sites using off-site upgrading). Increases in the number of facilities using this multi-mineral process or on-site upgrading may have a significant influence on all effluent constituents.

Inhalation exposures have been estimated using flat terrain. An accurate method for estimating terrain influences is needed (a method does not presently exist for the oil shale region). Terrain effects may cause localized air concentrations to be at least one order of magnitude higher than calculated by this analysis. Additionally, estimates of photochemical effects are from smog chamber studies performed at low altitude. Increased insolation due to higher altitude may result in at least doubling of estimated photochemical effects.

Food chain exposure estimates are partially dependent on the air and water transport estimates, but mainly based on the assumed bioconcentration factors. Bioconcentration factors may vary by two orders of magnitude and, in any event, have not been assessed for species present in the Uinta and Piceance Creek basins. Changes in the assumed bioconcentration factor result in similar changes to exposures from the food chain.

Finally, all exposure estimates are based on data from pilot facilities and laboratory experiments. Composition of pollutants from commercial facilities will be different than assumed in this analysis. However, the sensitivity study and large uncertainty in key assumptions result in ranges of values adequate for expected emission and effluent

compositions.

The estimate of ecosystem risk has a basic uncertainty because of the inherent variability of any biological system. Moreover, the relative lack of knowledge of biological systems compared with our understanding of physical systems increase the apparent biological variability over that which is naturally present. Thus, even the best available methods for censusing animals can be highly inaccurate. The predictions based upon even the best information can be rendered useless, for example, by changes in weather.

The relationship of mule deer decline and land disturbance has a significant uncertainty due to the yet unknown utilization of reclaimed areas and the potential carrying capacity of undisturbed lands. It is possible that the oil shale industry will have no net effect on the mule deer herd if undisturbed lands can be effectively managed for big game. Deer population numbers on the winter range are extremely sensitive to the natural elements, a sensitivity which may overshadow any effects from the oil shale industry.

The risk to the fisheries of the Piceance Creek, White River, and the Colorado River is highly dependent on the frequency of accidental leaks and discharge of effluent. Effectiveness of leachate containment over an indefinite maintenance period will also determine the long-term water quality of the drainages. The response of the native fish fauna to both acute and chronic water quality changes is as yet unknown and is a key factor of aquatic ecosystem risk.

Table 7-5 summarizes the estimated total uncertainties in key parameters and results of the environmental transport portion of the OSRA. The largest uncertainty is in the water transport results, followed by results of the ecosystem risk analysis.

Population Projections

The uncertainty level of the population projections is based on the assumptions for the estimate. The uncertainty level is not expected to be more than $\pm$50 percent. This value represents uncertainty in the population induced by other energy developments, miner productivity, and base population growth.

The most critical assumption concerns the miner productivity. This assumption will have a significant effect on the final estimated population. In the baseline case analyzed previously, the miner productivity ranged from 37.5 short tons/workshift for underground mining to 150 short tons/workshift for open-pit mining. The variation in mining technologies, if underground mining produced 150 short tons/workshift and open-pit mining 200 short tons/workshift would result in a decrease of about 50 percent of the total workforce for the baseline scenario. The effect on the scenario options would be less. The predicted fatalities for these advanced mining technologies would be 13 (baseline), 11 (MIS), and 7 (OPT); this is a considerable decrease for the baseline and MIS variation. The effect in overall population number is significant due to the cumulative multiplier of 6.83. The

magnitude of expected risks would be less, but the percentage would be similar.

Changes in the multiplier caused by smaller families, smaller indirect employment, or less employment in other energy sources can have an effect. The effect of increasing the multiplier to 8.0, from 6.83, would change the original estimate by 10.3 percent. If the multiplier is lowered from 6.83 to 5.65, the change in the original estimate is also 10.3 percent because the multiplier has been changed proportionally. The sensitivity of the multiplier effect is not as great as the variation of miner productivity.

Another area of uncertainty is the expected growth of the base population in the region. An annual growth of 3.2 percent was assumed in the scenario. However, this could be different. For purposes of a sensitivity test, two rates (2.0 and 4.4 percent) are assumed as possible. The change for the 2.0 percent case is 8.4 percent, but for the 4.4 percent case the change is 10.5 percent. In both cases, the changes are not as important as the sensitivities to the miner productivity.

Table 7-5. Estimated Uncertainty in Key Parameters of the Environmental Transport and Ecosystem Risk of the Oil Shale Risk Analysis.

Analysis Variable or Parameter	Estimated Probable Range in Value (Percentage)
Relationship of mule deer decline and land disturbance	-50,+200
Leachate constituent concentration	-50,+300
Water pollutant concentrations after incident	-50,+300
Long-term water pollutant concentrations	±100
Air pollutant concentrations (ambient average value)	±100
Fish tissue concentrations	-20,+200

7.2 RESEARCH RECOMMENDATIONS

The research recommendations are based on the need both to narrow the critical uncertainty bands and to fill major data deficiencies. The recommendations are given in three general areas: needs to better define the exposure of man and the ecosystem, needs to enhance the health effects data base, and other needs to support the risk estimates, such as population predictions.

Exposure

The OSRA has revealed that a large-scale oil shale industry will have to address energy, transportation, water, and solid waste disposal problems for the time scale of a century using an overall systems approach to minimize health, ecosystem and economic risks. The large percentage of federal ownership of the resource and the current acreage limits may inhibit the private sector from initiating such studies. The magnitude and value of the resource merit proper planning and analysis to ensure the developers do not overlook potential problems and risk. The initial candidate study areas are the water use and disposal in the Colorado River System and the transport of shale oil to refineries.

The OSRA source terms were derived from available data during the initial phases of the project. Some significant sources of additional data, such as the Lurgi spent shale, are now available for a better characterization of the proposed processes. The ongoing research in all phases of the characterization studies should continue and will be used to update the source terms. Characterization of the hydrocarbons from actual processes will be important both to help understand how the process variables can be controlled to minimize human health and ecosystem risks, and to provide appropriate control strategies. Of course, a primary concern is the pollutants released. This means that control technology capabilities must by assumed. Research is needed to ensure appropriate technology will be available. However, upsets may occur and equipment may malfunction, resulting in "fugitive" releases. The process streams and the fate and effect of pollutants released in the oil shale region will need further chemical and toxicological characterization to resolve uncertainties in the risk.

The uncertainties that can be reduced for the OSRA by data refinements include the following:

- Particulate/dust releases at site.
- Sulfur oxides generated, controlled, and emitted at each site.
- Characterization of hydrocarbons released at sites into the environment.

- Trace elements (especially the heavy metals) and their chemical reactions/transformations in the processes, transportation, and disposal to establish their ultimate fate in the environment. Initial efforts can consider the trace element input to surface streams from snow melt.

- Water treatment, recycle, and release.

- Solid waste disposal plans and measurements.

Data gaps include the following:

- The interaction of complex hydrocarbons and/or trace elements in the process streams.

- Changes in leachate composition during movement through the ground and aquifiers.

- Chemical interactions of accidentally released effluents in existing stream/sedimentation conditions.

- Altitude and terrain effects on the chemistry and transport of air pollutants.

- Occupational exposures during shale mining, retorting, and spent shale disposal.

Health Effects

The uncertainties concerning the health effect analysis are of two types: those related to the generic pollutant exposures which are not specific to the oil shale industry (sulfur oxides, trace elements, etc.) and those related to oil shale-specific exposures. The OSRA does not consider uncertainties of the first kind to be research needs that should be addressed by oil shale research. This research is being pursued outside the realm of oil shale research and, ultimately, can be found in the general literature.

The oil shale related uncertainties, however, can be reduced by addressing the following areas:

- Dose-effect and dose-response relationships for polycyclic aromatic hydrocarbons and aza-arenes generated from the oil shale industry.

- Dose-effect and dose-reponse relationships for ingestion of oil shale effluents.

- Health effects of sulfur oxides exposure.

- Health effects due to cutaneous exposure to oil shale pollutants

- Information on the potential for an oil shale silicosis ("Mahogany Lung")

- Quantification of occupational safety in oil shale mines, including the factors affecting the incident rates for fatalities.

To address these uncertainties, the following data gaps should be filled.

- Toxicologic data for exposures to oil shale, oil shale dusts (raw and retorted), and oil shale products and effluents.

- Epidemiologic data concerning past (e.g., Scottish and Estonian experience) and present (e.g., a registry for U.S. oil shale workers) exposures to oil shale.

Risk Estimates

The research recommendations for reducing the uncertainties and unknowns that have not been covered in the previous categories are addressed in three categories: ecosystem, population, and risk estimation.

Ecosystem research needs include the following:

- Fluoride, mercury, selenium and sodium measurements in effluents and leachates. Attenuation mechanisms during water transport.

- Effect of water treatment and transport facilities on oil shale effluent waters and the fate and effect of the pollutants in the environment.

- Data on the oil shale region's agricultural products and their potential uptake and bioaccumulation of oil shale pollutants.

- Revegetation means and measures for prediction of time-dependent factors of ecosystem response in view of large-scale disturbances.

- Oil shale region terrestrial species response to large-scale terrain modifications (roadways, pipelines, etc.)

- Oil shale region aquatic system effects from oil shale effluents with emphasis on edible components presenting possible bioaccumulation of toxic substances.

Population estimates were shown to be dependent on the underground mining rate. Definitive data for the rate in tons of shale mined per miner for the larger underground mines would reduce the

uncertainty on the expected occupational fatalities and improve the public population estimates.

In the area of risk estimation, the research needs include the following:

- Fault and event tree quantification of oil shale-specific accidents, with emphasis on MIS and surface retorting.
- The effect of management safety practices in the solid handling and mining industries.
- Models for water discharge into the Colorado River drainage system from the oil shale region.

One additional, longer term need is the requirement for a computer-based depository and retrival system for all oil shale environmental data.

The research recommendations presented are preliminary and may not include some existing projects that will have data applicable to the future iterations of the OSRA. The recommendations for research remain to be both prioritized and coupled with the Department of Energy's oil shale environmental research and development plan. This cannot properly be performed until the occupational risks for chronic illness and the industry installation and decommissioning risks are analyzed.

8. SUMMARY

The OSRA has demonstrated that risks from a projected oil shale industry supplying a significant portion of U.S. energy demand, namely one-million barrels of oil per day, can be quantified. The quantification procedure is based on assumptions and both research and engineering data. The 1981 OSRA has established a set of assumptions and a structure for the use of data to predict the potential human health and environmental risks. The validity of the assumptions and applicability of data can all be questioned and examined through the use of the scientific method, based on the priority scheme arising from the risk analysis. That is, the priorities may be assigned based on reduction of the major uncertainties affecting the predicted significant human health and environmental risks. The sensitivity and uncertainty analyses have identified some of the critical variables of the analysis and associated research needs from the source terms (as the initiator of the risks) through the exposure, health and ecosystem effects; populations at risk; and, in the end point of the analysis, risk estimates. The information provided by the 1981 OSRA is an aid in formulating and managing a program of environmental research focused on providing information required to reduce uncertainties in critical areas.

Public health risk estimates are: there will be less than one excess cancer per year, zero to one thousand premature deaths per year may occur (based on the use of sulfur oxides as an air pollution surrogate), and increased risk of health effects due to ingestion of fluoride, sodium, selenium and mercury is possible for segments of the population. Occupational accidents may result in 7 to 45 yearly fatalities while occupational morbidity has yet to be quantified. A methodology for estimating ecosystem risk based on community diversity was established.

Research recommendations reflected data gaps in establishing worker exposures and accident rates, pollutant releases and environmental fate, dose-response relationships for oil shale exposures, and ecosystem risks.

The limitations of the first year's OSRA should be evident. The effort to comprehensively quantify the human health and environmental effects for oil shale cannot be completed in one year. Selected portions of the oil shale fuel cycle, concentrating on the oil shale region public population, have been addressed for the steady-state industry of one-million barrels per day using only readily available data. The next year's effort will concentrate on the occupational risks and will include using better data, improved assumptions, and prioritization of research needs.

9. REFERENCES

American Conference of Governmental Industrial Hygienists, Documentation of the Threshold Limit Values, Fourth Edition. ACGIH, Cincinnati, Ohio, 1980.

American Petroleum Institute, Summary of Occupational Injuries and Illnesses in the Petroleum Industry, 1979. Washington, D.C., May 1980.

Anderson, A.D., M.E. Lebsack, G.M. DeGrave, S. Farrier and A.L. Bergman, "Toxicity of an in-situ oil shale process water to Rainbow trout and Fathead minnows." Arch. Environ. Contam. Toxicol. 9: 173, 1980.

Axelsson, G. and R. Rylander, "Environmental chromium dust and lung cancer mortality." Environ. Res. 23: 469-476, 1980.

Baily, A.M. and R.J. Neidrach, Pictorial Checklist of Colorado Birds. Denver Museum of Natural History, Denver, Colorado, 1967.

Bartman, R., Wildlife Biologist, Colorado Division of Wildlife, Fort Collins, Colorado. Personal Communication, October 1980.

Berglund, F., M. Berlin, G. Birke, R. Cederlof, U. Von Euler, L. Friberg, B. Holmstedt, E. Jonsson, J.C. Luning, C. Ramel, S. Skerfving, A. Swensson, and S. Tejning, "Methylmercury in fish. A toxicologic-epidemiologic evaluation of risk, Report of an expert group." Nord. Hyg. Tdskr, Suppl. 4: 1-364, 1971.

Birmingham, D.J., "Interim report on the shale oil study." On file in the U.S. Department of Health, Education, and Welfare, 1954.

Bogovski, P.A. and R. Vinkmann, "Carcinogenicity of oil shale tars, some of their components, and commercial products." Environmental Health Perspectives 30: 165-169, 1979.

Braunstein, H.M., E.D. Copenhaver and H.A. Pfuderer, Environmental, Health and Control Aspects of Coal Conversion. Volume 2. Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/EIS-95, 1977.

Calabrese, E.J., Pollutants and High-Risk Groups. Wiley-Interscience, New York, New York, 1978.

California Department of Public Health, Div. of Environmental Sanitation and Division of Laboratories, Lead in the Environment and Its Effects on Humans. California Dept. of Public Health, Berkeley, California, 1967.

Calvert, J.G., F. Sly, J.W. Bottenjeim and O.P. Strausz, "Mechanism of homogeneous oxidation of sulfur dioxide in the troposphere." Atmospheric Environment 12: 197-226, 1978.

Cameron Engineers, Inc., Synthetic Fuels Data Handbook. Cameron Engineers, Inc., Denver, Colorado, 1978.

Cavanaugh, E.C., G.M. Clancy, J.D. Colley, P.S. Dzierlenga, V.M. Felix, D.C. Jones and T.P. Nelson, Atmospheric Pollution Potential from Fossil Fuel Resource Extraction, On-site Processing, and Transportation. Radian Corporation, Austin, Texas, 1977.

Center for Demographic Studies, Data Base Development and Data Analysis. Social Research Staff, U.S. Bureau of the Census prepared for the Bureau of Land Management, U.S. Department of the Interior, April 1980.

Chappell, W.R., Trace Elements in Oil Shale. Progress Report, 1976-1979. University of Colorado, Boulder, Colorado, 1979.

Cohen, C.A., A.R. Hudson, J.L. Clausen and J.H. Knelson, "Respiratory symptoms, spirometry, and oxidant air pollution in nonsmoking adults." Amer. Rev. Resp. Dis. 105: 251-261, 1972.

Colley, J.D., W.A. Gathman and M.L. Owen, Emissions From Synthetic Fuel Production Facilities. Volume 2, Radian Corporation, Austin, Texas, 1977.

Colorado Department of Natural Resources, Division of Game, Fish and Parks, Wildlife Management Unit 22 (Piceance) Rio Blanco and Garfield Counties. Denver, Colorado, 1971.

Colorado Department of Natural Resources, Colorado Oil Shale: The Current Status, Office of the Executive Director, Denver, Colorado, 1979.

Colorado Western Area Council of Government, Oil Shale Trust Fund Request. Rifle, Colorado, November 1979.

Coomes, R.M., "Oil shale - the state of the industry and potential health effects." In: Rom, W.N. and J.E. Archer, eds., Health Implications of New Energy Technologies. Ann Arbor Science, Ann Arbor, Michigan, 1980.

Crookston, R.B., M.T. Atwood and R.E. William, An Evaluation of the Fire and Explosion Hazards of Oil Shale Mining and Processing. NTIS No. PB80-113228, TOSCO Corp., Los Angeles, California, 1978.

Cuddihy, R.G., F.A. Seiler, W.C. Griffith, B.R. Scott and R.O. McClellan, Potential Health and Environmental Effects of Diesel Light Duty Vehicles. Department of Energy, Washington, D.C., 1980.

Cupitt, L.T., Fate of Toxic and Hazardous Materials in the Air Environment. EPA 600/S3-80-084, 1980.

Cutler, S.J., Third National Cancer Survey: Incidence Data. National Cancer Institute Monograph 41: 1975.

Demerjian, K.L., J.A. Kerr and J.G. Calvert, "The mechanism of photochemical smog formation." Advanced Environmental Science and Technology 4: 1-262, 1974.

Denver Research Institute and Research Planning Associates, Socioeconomic Impacts of Western Energy Resource Development. Volume II: Assessment Methodologies. Denver, Colorado, June 1979.

Desborough, G.A., "A biogenic-chemical stratified lake model for the origin of the Green River Formation: an alternative to the Playa-Lake model." Geological Society of American Bulletin 89: 961-971, 1978.

Dickerson, O.B., "Arsenic." In: Waldron, H.A., ed., Metals in the Environment. Academic Press, London, England, 1980.

Doll, R., L.G. Morgan and F.E. Speizer, "Cancers of the lung and nasal sinuses in nickel workers." Brit. J. Cancer 24: 623-632, 1970.

Donnell, J.R., Tertiary Geology and Oil Shale Resources of the Piceance Creek Basin Between the Colorado and White River. Northwestern Colorado, U.S. Geological Survey, Bulletin 1082-L, 1961.

Eggleton, A.E. and R.A. Cox, "Homogeneous oxidation of sulfur compounds in the atmosphere." Atmos. Environ. 12: 227-230, 1978.

Elliot, G.B. and E.A. Alexander, "Sodium from drinking water as a suspected cause of cardiac decompensation." Circulation 23: 562-66, 1961.

Energy Research and Development Administration, Paraho Full Size Oil Shale Module Draft Environmental Impact Statement. Washington, D.C., U.S. ERDA, 1977.

Environmental Protection Agency, Region 8., Trace Elements Associated with Oil Shale and Its Processing. Denver Research Institute, Denver, Colorado, 1977.

Environmental Protection Agency, Assessment of Carcinogenic Risk from Population Exposure to Cadmium in Ambient Air. Carcinogen Assessment Group, EPA, Washington, D.C., 1978a.

Environmental Protection Agency, Carcinogen Assessment Group Report on Arsenic. EPA, Washington, D.C., 1978b.

Environmental Protection Agency, Air Quality Criteria for Particulate Matter and Sulfur Oxides, Preliminary Draft. EPA, Washington, D.C., 1980a.

Environmental Protection Agency, Environmental Perspective on the Emerging Oil Shale Industry. Final Draft Report, Volume 1. U.S. EPA, Office of Research and Development, Cincinnati, Ohio, 1980b.

Eugster, H.P. and R.C. Surdam, "Dispositional environment of the Green River Formation of Wyoming: a preliminary report." Geological Society of American Bulletin 84: 1115-1120, 1973.

Farrier, D.S., J.E. Virgona, T.E. Phillips and R.E. Poulson, "Environmental research for in-situ oil shale processing."In: Proceedings of the 11th Oil Shale Symposium. Colorado School of Mines, Golden, Colorado, 1978.

Fox, J.P., Water Quality Effects of Leachate From an In-Situ Oil Shale Industry. LBL8997, Lawrence Berkeley Laboratory, Berkeley, California, 1979.

Fox, J.P., K.K. Mason and J.J. Duvall, Partitioning of Major, Minor, and Trace Elements During Simulated In-Situ Oil Shale Retorting in a Controlled State Retort. Lawrence Berkeley Laboratory, University of California, Berkeley, California, April 1979.

Friberg, L., Mercury in the Environment. CRC Press, Cleveland, Ohio, 1972.

Friberg, L., M. Piscator, G.F. Nordberg and T. Kjellstrom, Cadmium in the Environment, 2nd Edition. CRC Press, Cleveland, Ohio, 1974.

Fruchter, J.S., C.L. Wilkerson, J.C. Evans, R.W. Sanders and K.W. Abel, Source Characterization Studies at the Paraho Semiworks Oil Shale Retort Prepared for the U.S. DOE. Battelle--Pacific Northwest Laboratory, Richland, Washington, May 1979.

Fruchter, J.S. and C.L. Wilkerson, "Characterization of oil shale retort effluents." In: Oil Shale--The Environmental Challenges. Preprints of Publications. Center of Environmental Sciences, The Oil Shale Task Force, University of Colorado, Denver, Colorado, 1980.

Gifford, F.A., Jr., "Uses of routine meteorological observations for estimating atmospheric dispersion." Nuclear Safety 2: 4, 1961.

Gilbert, P.F., O.C. Wallmo and R.B. Gill, "Effect of snow depth on mule deer in Middle Park, Colorado." Journal of Wildlife Management 34: 15-23, 1970.

Glover, J.R., "Selenium and its industrial toxicology." Ind. Med. Surg. 39: 50-54, 1970.

Goettl, J.P. and J. Eddy, Environmental Effects of Oil Shale Mining and Processing. Part 1: Fishes of Piceance Creek, Colorado Prior to Oil Shale Processing. Colorado Division of Wildlife, Fisheries Research Center, Fort Collins, Colorado, 1978.

Hall R.H. et al., "Acute toxicity of inhaled beryllium: observations correlating beryllium; observations correlating toxicity with physiochemical properties of beryllium oxide dust." Arch. Ind. Hyg. Occup. Med. 2: 25, 1950.

Hammer, D.I., V. Hasselblad and B. Portnoy, "Los Angeles student nurse study. Daily symptoms reporting and photochemical oxidants." Arch. Environ. Health 28: 255-260, 1974.

Hansen, R.M. and B.L. Dearden, "Winter foods of mule deer in Piceance basin, Colorado." Journal of Range Management 28: 298-300, 1975.

Hasan, F.M. and H. Kazemi, "Chronic beryllium disease: a continuing epidemiologic hazard." Chest 65: 289-293, 1974.

Herbes, S.E., G.R. Southworth, D.L. Shaefferm, W.H. Griest and M.P. Maskarinec, Critical Pathways of Polycyclic Aromatic Hydrocarbons in Aquatic Environments. Oak Ridge National Laboratory, Oak Ridge, Tennessee, CONF-790486-3, 1979.

Hickey, R.J., E.P. Schoff and R.C. Clelland, "Relationship between air pollution and certain chronic disease death rates." Arch. Environ. Health 15: 728-738, 1967.

Hill, A.B., "The environment and diseases: associations and causation." Proceedings of the Royal Society of Medicine Section in Occupational Medicine 58: 272, 1965.

Hodge, H.C. and F.A. Smith, "Air quality for the effects of fluorides on man." J. Air Poll. Control Assoc. 20: 226-232, 1970.

Holland, W.W., A.E. Bennett, I.R. Cameron, C. Florey, S.R. Leeder, R.S. Schilling, A.V. Swan and R.E. Waller, "Health effects of particulate pollution: Re-appraising the evidence." Am. J. Epidemiol. 110: 525-659, 1979.

Holland, L.M. and J.S. Wilson, "Long-term epidermal carcinogenicity studies." In: L.M. Holland and C.G. Stafford, eds., The Los Alamos Integrated Oil Shale Health and Environmental Program: A Status Report. Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1981.

Huang, C.H. and W.F. Sandusky, Diffusion Estimates of Air Quality Impacts from Oil Shale Developments. Battelle Pacific Northwest Laboratories, DOE Contract EY-76-C-06-1830, 1979.

International Commission on Radiological Protection, Report of the Task Group on Reference Man. Pergamon Press, Oxford, 1975.

Iorns, W.V., C.H. Hembrace and G.L. Oakland, Water Resources of the Upper Colorado River Basin - Technical Reports. U.S. Geological Survey Prof. Page 441, 1965.

Kazantzis, G., "Mercury." In: Waldron, H.A., ed., Metals in the Environment. pp. 221-261, Academic Press, London, 1980.

Kilkelly, M.K. and W.L. Lindsay, "Trace elements in plants on processed oil shale." In Trace Elements in Oil Shale, COO-4017-3, Center for Environmental Sciences, University of Colorado, Denver, Colorado, 1979.

Langard, S. and T. Norseth, "A cohort study of bronchial carcinomas in workers producing chromate pigments." Brit. J. Ind. Med. 32: 62-65, 1975.

Langard, S. and T. Norseth, "Chromium." In: Friberg, L., G. Nordberg, and V. Vouk, eds., Handbook on the Toxicity of Metals. Elsevier/North Holland, New York, New York, 1979.

Lave, L.B. and E. Seskin, Air Pollution and Human Health. Johns Hopkins University Press, Baltimore, Maryland, 1977.

Lechleitner, R.R., Wild Mammals of Colorado. Pruett Publishing Company, Boulder, Colorado, 1969.

Lee, A.M. and J.F. Fraumeni, "Arsenic and respiratory cancer in man - an occupational study." J. Nat. Cancer Inst. 42: 1045, 1969.

Lemen, R.A., J.S. Lee, J.K. Wagoner and H.P. Blejer, "Cancer mortality among cadmium production workers." Ann. N.Y. Acad. Sci. 271: 273, 1976.

Lepkowski, W., "Extrapolation of carcinogenesis data." Environ. Health Persp. 22: 173-181, 1978.

Lipfert, F.W., "Statistical studies of mortality and air pollution: multiple regression analyses stratified by age group." The Science of the Total Environment 15: 103-122, 1980.

MacFarland, A.R., Control Technology for Toxic and Hazardous Air Pollutants. PB-247-780, 1974.

Mancuso, T.F., "Relation of duration of employment and prior respiratory illness to respiratory cancer among beryllium workers." Environ. Res. 3: 251-275, 1970.

Mancuso, T.F. and W.C. Hueper, "Occupational cancer and other health hazards in a chromate plant: a medical appraisal." Ind. Med. Surg. 20: 358-363, 1951.

Mahaffey, K.R., "Quantities of lead producing health effects in humans: sources and bioavailability." J. Occup. Med. 19: 285-95, 1977.

Matta, J.E., J.C. LaScola and F.N. Kissell, "Methane absorption in oil shale and its potential mine hazard." BuMines RI 8243, 1977.

Mazumdar, S., H. Schimmel and I. Higgins, "Daily mortality, smoke and SO_2 in London, England 1959 to 1972." In: The Proposed SOx and Particulate Standard. The Air Pollution Control Association, 1980.

McDowell-Smith and Associates, Evaluation of Selected Community Needs, Rifle, Colorado, August 1975.

Milby, T.H., "Hydrogen sulfide intoxication." J. Occup. Med. 4: 431, 1962.

Mine Safety and Health Administration, "Mine injuries and worktime, quarterly." January-December 1978.

Mine Safety and Health Administration, "Mine injuries and worktime, quarterly." January-December 1979.

Mine Safety and Health Administration, "Mine injuries and worktime, quarterly." January-December 1980.

Mine Safety and Health Administration, "MNM quarterly employment and injury report, January through December 1980, mines reporting injuries." February 1981.

Moore, M.R., M.A. Hughes and D.J. Goldberg, "Lead absorption in man from dietary sources. The effect of cooking upon lead concentrations of certain foods and beverages." Int. Arch. Occup. Environ. Health 44: 81-90, 1979.

Morgan, M.G., S.C. Morris, A.K. Meir and D.L. Shenk, "A probabilistic methodology for estimating air pollution effects from coal-fired power plants." Energy Systems and Policy 2: 287-310, 1978.

Morris, S.C., "Health risks from coal energy technologies." Preliminary draft, In: Travis, C.C. and E.L. Etnier, eds., Health Risk Associated with Energy Technologies. Westview Press, 1981. (In Press)

National Academy of Sciences, Fluoride. NAS, Washington, D.C., 1971.

National Academy of Sciences, Lead. NAS, Washington, D.C., 1972a.

National Academy of Sciences, Particulate Polycyclic Organic Matter. NAS, Washington, D.C., 1972b.

National Academy of Sciences, Chromium. NAS, Washington, D.C., 1974a.

National Academy of Sciences, Geochemistry and the Environment, Vol. 1: The Relation of Selected Trace Elements to Health and Disease. NAS, Washington, D.C., 1974b.

National Academy of Sciences, Nickel. NAS, Washington, D.C., 1975.

National Academy of Sciences, Selenium. NAS, Washington, D.C., 1976.

National Academy of Sciences, Carbon Monoxide. NAS, Washington, D.C., 1977a.

National Academy of Sciences, Drinking Water and Health. NAS, Washington, D.C., 1977b.

National Academy of Sciences, Nitrogen Oxides. NAS, Washington, D.C., 1977c.

National Academy of Sciences, Ozone and Other Photochemical Oxidants. NAS, Washington, D.C., 1977d.

National Academy of Sciences, Sulfur Oxides. NAS, Washington, D.C., 1978.

National Safety Council, Accident Facts, 1980 Edition. Chicago, Illinois, 1980.

Niki, H., E.E. Daby and B. Weinstock, "Mechanisms of smog reactions." Adv. Chem. Ser. 113: 16-57, 1972.

Norseth, T., "Cancer hazards caused by nickel and chromium exposure." J. Toxic and Environ. Health 6: 299-307, 1980.

Nowacki, P. (ed.), Health Hazards and Pollution Control in Synthetic Liquid Fuel Conversion. Noyes Data Corporation, Park Ridge, New Jersy, 1980.

Occidental Oil Shale, Inc. Oil Shale Tract C-b, Environmental Baseline Program, Final Report. Vol. 4, Coal and Ecology Occidental Oil Shale, Inc., Grand Junction, Colorado, 1976.

Office of Technology Assessment, An Assessment of Oil Shale Technologies. Congress of the United States, Washington, D.C., 1980.

Oil Shale Advisory Committee, Report on Economics of Environmental Protection for a Federal Oil Shale Leasing Program. Director of Natural Resources of the State of Colorado, Denver, Colorado, 1971.

Oil Shale Task Force, Environmental and Health Research for the Retort 0 at Lease Tract C-A, University of Colorado, Denver, Colorado, September 1981.

Ott, M.G., D.B. Holder and H.L. Gordon, "Respiratory cancer - occupational exposure to arsenicals." Arch. Environ. Health 29: 250, 1974.

Pacific Northwest Laboratory, Western Oil Shale Development: A Technology Assessment, Preliminary Draft Final Report, Department of Energy, Richland, Washington, September 1980.

Pasquill, F., Atmospheric Diffusion. Van Nostrand, Inc., London, England, 1962.

Pedco Environmental, Inc., Survey of Fugitive Dust from Coal Mines. Project Number 3311. Prepared for the USEPA Region VIII. Pedco Environmental, Inc., Cincinnati, Ohio, 1978.

Pedersen, E., A.C. Hogetveit and A. Anderson, "Cancer of respiratory organs among workers at a nickel refinery in Norway." Int. J. Cancer 12: 32-41, 1973.

Pinto, S.S., P.E. Enterline, V. Henderson and M.O. Varner, "Mortality experience in relation to a measured arsenic trioxide exposure." Environ. Health Persp. 19: 127, 1977.

Poda, G.A. and S.C. Aiken, "Hydrogen sulfide may be handled safely." Arch. Env. Health 12: 795, 1966.

Purde, M. and R. Rahu, "Cancer patterns in the oil shale area of the Estonian S.S.R." Environ. Health Persp. 30: 209-210, 1979.

Rall, D.P., "Thresholds?" Environ. Health Persp. 22: 163-165, 1978.

Reeve, A.L., "Beryllium." In: Friberg, L., G. Nordberg and V. Vouk, eds., Handbook on the Toxicity of Metals. Elsevier/North Holland, New York, New York, 1979.

Richmond, J.K. and L.F. Miller, "Explosion and fire properties of oil shale." In: 10th Oil Shale Symposium. Colorado School of Mines, 1977.

Rickless, R.E., Ecology. Chiron Press, Portland, Oregon, 1973.

Rio Blanco Oil Shale Project, Final Environmental Baseline Report for Tract C and Vicinity. Rio Blanco Oil Shale Projects, Gulf Oil and Standard Oil of Indiana, 1977.

Rudnick, J. and G.L. Voelz, "An occupational health study of Paraho oil shale workers." In: W.N. Rom and V.E. Archer, eds., Health Implication of New Energy Technologies. Ann Arbor Science, Ann Arbor, Michigan, 1980.

Quality Development Associates, Inc., Development Patterns and Social Impacts: A Focus on the Oil Shale Region, Denver, Colorado, July 1979.

Sakurai, H. and K. Tsuchiya, "A tentative recommendation for the maximum daily intake of selenium." Environ. Physiol. Biochem. 5: 107-118, 1975.

Sandell, E.T., R.A. Brady and L.K. Barker, Attachment to: Mining Report for Land Exchange Application - Superior Oil Company. U.S. Geological Survey, Conservation Division - Area Oil Shale Office, Grand Junction, Colorado, (n.d.).

Schmidt, J.A. and A.W. Andren, "The atmospheric chemistry of nickel." In: J.O. Nriagu, ed., Nickel in the Environment. John Wiley and Sons, New York, New York, 1980.

Schmidt-Colerus, J.J., Characterization of Contaminants in Oil Shale Residuals and the Potential for Their Management to Met Environmental Quality Standards. Denver Research Institute, Denver, Colorado, 1980.

Schoettlin, C.E. and E. Landau, "Air pollution and asthmatic attacks in the Los Angeles area." Pub. Health Rep. 76: 545-48, 1961.

Schroeder, H.A. and J.J. Balassa, "Abnormal trace metals in man: cadmium." J. Chronic Dis. 14: 236, 1961.

Schwab, A.P., W.L. Lindsay and G.P. Marx, "Uptake of chemical elements by plants growing on spent shale." In: Trace Elements in Oil Shale, Progress Report to DOE, Coo-10298-1. Center for Environmental Sciences, University of Colorado, Denver, Colorado, 1980.

Scott, A, "On the occupational cancer of the paraffin and oil workers of the Scottish shale oil industry." Br. Med. J. 2: 1108-1110, 1922.

Shy, C.M., J.P. Creason, M.E. Pearlman, K.E. McClain, F.B. Benson and M.M. Young, "The Chattanooga school children study. Effects of community exposure to nitrogen dioxide. I. Methods, description of pollutant exposure, and results of ventilatory function testing." J. Air Poll. Control Assoc. 20: 539-545, 1970.

Simson, R.E. and G.R. Simpson, "Fatal hydrogen sulfide poisoning associated with industrial waste exposure." Med. J. Aust. 1: 331, 1971.

Sittig, M., Hazardous and Toxic Effects of Industrial Chemicals. Noyes Data Corp., Park Ridge, New Jersy, 1979.

Sittig, M., Priority Toxic Pollutants, Health Impacts and Allowable Limits. Noyes Data Corporation, Park Ridge, New Jersey, 1980.

Slawson, G.C., Jr. and T.F. Yen, eds., Compendium Reports on Oil Shale Technology. Environmental Protection Agency, Office of Research and Development, Las Vegas, Nevada, 1979.

Speizer, F.E. and B.G. Ferris, "Exposure to automobile exhaust." Arch. Environ. Health 26: 313-324, 1973.

Stephens, E.R., "The formation, reactions, and properties of peroxyacyl nitrates (PANS) in photochemical air pollution." Advanced Environmental Science 1: 119-146, 1969.

Stinson, D.S. and M. O'Hara, Predicting the Local Impacts of Energy Development: A Critical Guide to Forecasting Methods and Models, Laboratory of Architecture and Planning, Massachusetts Institute of Technology, prepared under Energy Research and Development Contract No. E(49-18)-2295, Cambridge, Massachusetts, May 1977.

Stokinger, H.E., "The Metals: Beryllium." In: Clayton, G.D. and F.E. Clayton, eds., Patty's Industrial Hygiene and Toxicology, 3rd Edition. John Wiley and Sons, New York, New York, 1981a.

Stokinger, H.E., "The Metals: Vanadium." In: Clayton, G.D. and F.E. Clayton, eds., Patty's Industrial Hygiene and Toxicology, 3rd Edition. John Wiley and Sons, New York, New York, 1981b.

Sunderman, F.W., "Carcinogenic effects of metals." Fed. Proc. 37: 40-46, 1978.

Szabo, M.F., Environmental Assessment of Coal Transportation. PEDCO Environmental Inc., Cincinnati, Ohio, 1978.

Tepper, L.B., "Beryllium." In: Waldron, H.A., ed., Metals in the Environment. Academic Press, London, England, 1980.

Towill, L.E., C.R. Shriner, J.S. Drury, A.S. Hammons and J.W. Hollerman, Review of Environmental Effects of Pollutants, III: Chromium. Oak Ridge National Laboratory, Oak Ridge, Tennessee, ORNL/EIS-80, 1978.

Tsang, W., "HO=NO2 + M HNO3 + M." In: R.F. Hampson, ed., Chemical Kenetics Data Survey. VI. Photochemical and Rate Data for Twelve Gas Phase Reactions of Interest for Atmospheric Chemistry. National Bureau of Standards Interim Report 73-207. National Bureau of Standards, Washington, D.C., 1973.

Tseng, W.P., H.M. Chu and S.W. How, "Prevalence of skin cancer in an endemic area of chronic arsenicism in Taiwan." J. Nat. Cancer Inst. 40: 453-463, 1968.

Tseng, W.P., "Effects and dose-response relationships of skin cancer and blackfoot disease with arsenic." Environ. Health Persp. 19: 109, 1977.

Tsunetoshi, Y., T. Shimizu, H. Takahashi, A. Ichinosawa, M. Ueda, N. Nakayama and Y. Yamagata, "Epidemiological study of chronic bronchitis with special reference to effect of air pollution." Int. Arch. Arbeitsmed. 29: 1-27, 1971.

Tuthill, R.W. and E.J. Calabrese, "Elevated sodium levels in the public drinking water as a contributor to elevated blood pressure levels in the community." Arch. Environ. Health 34: 197-203, 1979a.

Tuthill, R.W. and E.J. Calabrese, "Age as a function in development of sodium-related hypertension." Environ. Health Persp. 29: 35-43, 1979b.

U.S. Census Bureau, Final Census Count, Advanced Report #PHV80V. April 1, 1980 Census. 1980.

U.S. Department of Energy, Environmental Research on a Modified In-Situ Oil Shale Process: A Progress Report from the Oil Shale Task Force. DOE, Denver, Colorado, May 1980 (DOE/EV-0078).

U.S. Department of Health, Education and Welfare, United States Life Tables: 1969-71, Vol. 1, No. 1. National Center of Health Statistics, HRA 75-1150 (May), Washington, D.C., 1975.

U.S. Department of Interior, The Prototype Oil Shale Program. Volume I: Regional Impacts of Oil Shale Development. U.S. Government Printing Office, Washington, D.C., 1973.

U.S. Department of Interior, Final Environmental Impact Statement, Volume 1: Colony Development Operation in Colorado, Bureau of Reclamation, Denver, Colorado, December 1975.

U.S. Department of Interior, Proposed Superior Oil Company Land Exchange and Oil Shale Resource Development. Draft Environmental Statement. Bureau of Land Management, Denver, Colorado, 1979.

Utah Energy Office, An Assessment of Oil Shale and Tar Sands Development in Utah, Phase 1: Development Scenarios, Salt Lake City, Utah, May 1980.

Vinson, R.P., R.C. Cox and F.N. Kissell, "Methane encountered at the Bureau of Mines oil shale shaft." In: 12th Oil Shale Symposium Proc.. Colorado School of Mines, Golden, Colorado, 1979.

Vouk, V., "Vanadium." In: Friberg, L., G.F. Nordberg and V.B. Vouk, eds., Handbook on the Toxicology of Metals. Elsevier/North Holland, New York, New York, 1979.

Wagoner, J.K., P.F. Infante and D.L. Bayless, "Beryllium: an etiologic agent in the induction of lung cancer nonneoplastic respiratory disease, and heart disease among industrially exposed workers." Environ. Res. 21: 15-34, 1980.

Waldbott, G.L., Health Effects of Environmental Pollutants. Mosby, St. Louis, Missouri, 1973.

Waldron, H.A., "Lead." In: Waldron, H.A., ed., Metals in the Environment. Academic Press, London, England, 1980.

Wayne, F.W., P.F. Wehrle and F.E. Carroll, "Oxidant air pollution and athletic performance." JAMA 199: 901-904, 1967.

Wetherold, R.G. and D.D. Rosebrook. Assessment of Atmospheric Emission from Petroleum Refining. Volume 1. Technical Report. Radian Corporation, Austin, Texas, 1980.

Wilber, C.G., "Toxicology of selenium - a review." Clin. Tox. 17: 171, 1980.

Wilson, J.S., Y. Valdez and L.M. Holland, "The effect of exposure conditions on dermotoxicity." In: Holland, L.M. and C.G. Stafford, eds., The Los Alamos Integrated Oil Shale Health and Environmental Program: A Status Report. Los Alamos Scientific Laboratory, Los Alamos, New Mexico, 1981.

Wilson, R., S.D. Colome, J.D. Spengler and D.G. Wilson, Health Effects of Fossil Fuel Burning. Ballinger, Cambridge, Massachusets, 1980.

World Health Organization, International Standards for Drinking Water, 3rd Edition. WHO, Geneva, Switzerland, 1971.

World Health Organization, Evaluation of Certain Food Additives and the Contaminants Mercury, Lead and Cadmium. Technical Report Series No. 505. WHO, Geneva, Switzerland, 1972.

World Health Organization, Environmental Health Criteria: Lead. WHO, Geneva, Switzerland, 1977.

World Health Organization, Environmental Health Criteria: Sulfur Oxides and Suspended Particulate Matter. WHO, Geneva, Switzerland, 1979.

Yansky, G.R., E.H. Markee and A.P. Richter, Climatology of the National Reactor Testing Station. USAEC, Environmental Science Services Administration, 1966.

Zenz, C. and B.A. Berg, "Human responses to controlled vanadium pentoxide exposure." Arch. Environ. Health 14: 709-12, 1967.

Ziskind, M., R.N. Jones and H. Weill, "Silicosis." Am. Rev. Respir. Dis. 113: 643-665, 1976.

APPENDIX A: Background

A.1 INTRODUCTION

The purpose of this appendix is to present a succinct background on oil shale for the reader unfamiliar with the topic. Additional references at the end of this appendix should be consulted for further information. Oil shale is commonly defined as an organic-rich marlstone that can yield substantial quantities of oil when subjected to destructive distillation by low confining pressure in a closed retort system. The amount of oil produced depends upon the organic content of the shale. The lowest boundary of oil shale is considered to be a deposit which yields 42 liters/metric ton at 3.8 wt.% (10 gallons per ton) of shale. At the other extreme, some Australian shale can give up to 1,247 liters/metric ton (300 gallons per ton) of shale (GPT) (Cane, 1979).

The oil comes from the organic component of oil shale, 80 percent of this component is kerogen, the insoluble fraction, the other 20 percent is bitumen, the soluble fraction. To release the shale oil from the rock requires thermal decomposition. The kerogen undergoes pyrolysis, a complex set of reactions, which yield a myriad of hydrocarbons. The other fraction of the rock, the inorganic fraction, consists of a fine-grained, thinly layered mixture of dolomite, calcite, quartz, pyrite, and clays.

A.2 DESCRIPTION OF OIL SHALE RESOURCE REGION

Only rough estimates of world-wide oil shale deposits are known, due to the few known occurrences and lack of widespread exploration of oil shale. The principal exception to this is the Green River Formation in Utah, Colorado, and Wyoming. On a world scale of known deposits, the Green River Formaton can be considered about average in grade. However, the tremendous thicknesses and consistency of grade (104 liters/metric ton; 25 GPT) throughout large vertical sequences are what make Green River Formation oil shale the world's largest known deposit.

A.3 HISTORY OF OIL SHALE DEVELOPMENT

The history of oil shale begins with its use in Austria in 1350, however, the first commercial operation began in France in 1838. Just a short while later, in the 1850's, an oil shale industry was initiated in the eastern United States. It came to an abrupt halt with the discovery of liquid petroleum in Pennsylvania. At about the same time, a commercial industry was begun in Scotland, one that would last until the 1960's. Scottish oil shale production peaked at $3 \times 10^{+6}$ metric ton (3.3 million tons) per-year (13,400 barrels/day) in 1913 (Cook, 1981).

Interest in oil shale began to mount again in the U.S. during the 1910's because of the need of gasoline for the growing number of

automobiles. By 1920, an experimental plant had been built in Sweden, and research and development initiated in Estonia, S.S.R. In 1926, Japan began utilization of oil shale in Manchuria; this industry still exists today in the People's Republic of China. That year was a blow to U.S. oil shale interests, however, with the discovery of the large petroleum oil fields in eastern Texas.

The outbreak of World War II saw the development of interest in oil shale in many countries, and was important to the war effort in Japan, Great Britain, Australia, Spain, Sweden, and France. German and Estonian industries were damaged in the war; the Estonian industry was eventually restored to a working capacity and is still operating today. The current daily output of the Estonian facility is approximately 96,000 barrels of shale oil (Office of Technology Assessment, 1980).

In Brazil, reserves of medium quality oil shale (831/mt; 20 GPT) are known to be adequate for a large industry. Research by the Brazilian government in the 1950's and 1960's led to the development of the Petrosix process. Operation of a 2,000 mt (2,200 ton) per day demonstration plant was begun in 1973; today plans are well underway for a 50,000 barrel-per-day production plant (The Pace Company, 1979).

Meanwhile, interest in U.S. oil shale has gone through various up and down cycles since World War II. The U.S. Bureau of Mines' Anvil Point oil shale facility near Rifle, Colorado opened in 1947 and operated until 1955. Union Oil began operation of its 1,088 mt (1,200 ton) per day retort in Colorado in the late 1950's. TOSCO arrived in the early 1960's and eventually became part of Colony which first operated the TOSCO demonstration plant in 1965. Mobil Oil headed up a six-company group that reopened the Anvil Points facility from 1964 to 1967. In 1970, Colony began a second TOSCO demonstration that lasted until 1972. Meanwhile, experimental in-situ recovery operations were conducted in the 1960's by Equity, ARCO, Shell, and the Laramie Energy Technology Center. Occidental began field testing of modified-in-situ projects in 1973, and a year later the Anvil Points facility was reactivated by Paraho. A status of the current oil shale projects is summarized at the end of this chapter.

A.4 AN OVERVIEW OF OIL SHALE TECHNOLOGY

Oil Shale Mining

Oil shale mining can be accomplished either on the surface or underground. Surface mining is economically advantageous over underground mining for very thick oil shale zones which are not deeply buried, especially in the case of relatively low oil yields.

Surface Mining

Surface mining permits a high recovery rate and is based on having space for large and efficient mining equipment. A key type surface mining is open pit, where the overburden is first drilled and blasted loose. The overburden is transported by trucks or conveyors to an offsite disposal and/or storage area. The shale is drilled, blasted,

and transported to the retort. As the mining continues, the walls of the pit are angled outwards so as to prevent collapse. A ninety percent recovery rate is possible with open pit mining, but would require changes in the current regulations.

Another type of surface mining is strip mining. In this method, the overburden is removed using a dragline. After the dragline's scoop is filled, it dumps the overburden into a nearby mined-out area. This method allows for a recovery rates greater than ninety percent.

Underground Mining

Underground mining also is being used in the oil shale industry. Although there exist numerous types of underground mining, the most promising is room-and-pillar. In this type, some shale is removed to form large rooms while some is left in place as support pillars for the roof. The sizes of the rooms and pillars are determined by: 1) the physical properties of the oil shale, 2) the thickness of the overburden, and 3) the height of the mine roof. This type of mining may cause less of an environmental effect, but it only allows a thirty to fifty percent recovery in a 23 meter (75 ft) thick interval (Office of Technology Assessment, 1980). The oil shale zone can be over 200 meters (660 ft) thick in portions of the basin. In such a case, sill pillars of about 25 meters could drop the overall ore recovery to the 10 to 20 percent range.

Oil Shale Retorting

Retorting is the process of heating shale to the temperatures at which kerogen, the organic material within the ore, is decomposed into gas, condensible oil, and a solid residue. The rate of kerogen decomposition is high at retort temperatures of 480 to 540 degree centigrade, and complete decomposition occurs within minutes. Product characteristics are similar to those of products obtained from thermal cracking or coking of petroleum: a wide range of molecular weights, hydrogen deficiency, and a high reactivity with oxygen.

Although numerous types of retorting processes presently exist, they have been grouped into three general categories: aboveground, modified-in-situ (MIS), and true-in-situ (TIS).

Aboveground Retorting

For aboveground, or surface retorting, mining of the oil shale is performed using conventional underground or surface methods. The crushed shale is retorted in vessels to volatilize the hydrocarbons.

Modified-In-Situ (MIS) Retorting

The MIS retorting process first involves the mining of 20 to 40 percent of the oil shale; the mined shale is retorted by a surface process. Explosive fracturing of the in-place shale creates the needed permeability. The result is a chimney-shaped underground retort filled

with broken shale. Retorting is initiated by heating the top of the rubblized shale column with a flame formed from compressed air and an external heat source, such as propane or natural gas. After several hours, the external heat source is turned off and compressed air flow is maintained utilizing the carbonaceous material in the retorted shale as a fuel to sustain combustion. The crude shale oil and product water are collected in a sump at the bottom of the chimney and pumped to storage. The retort off-gas, another product of the oil shale industry, can be used to fuel the process, to provide power, or as a marketable product. The Occidental (Oxy) process, developed on Tract C-b, is the leader of the MIS technologies.

True-In-Situ (TIS) Retorting

The third type of retorting, true-in-situ (TIS), is better suited for beds that are thin, deeply buried, or otherwise unsuitable for processing by other methods. In this process the shale is left underground and is heated by injecting high temperature vapors.

Shale Oil Upgrading

Upgrading broadly defines the methods and processes used to improve the physical and chemical properties of shale oil and gas. The upgrading process takes the viscous, waxy, high-nitrogen, and moderate level sulfur product yielded by the oil shale retorting, and treats it to make a more desirable product for transportation or storage. This process typically involves heating, hydrogenation, and some cracking of the crude shale oil.

The upgrading process will ultimately reduce the viscosity and pour point to facilitate transportation and storage. This is because the pour point and viscosity of shale oil are significantly higher than in most crude petroleums. Different degrees of upgrading on-site may be necessary depending on the developer's transportation and marketing needs.

A second goal of the upgrading process is to remove sulfur and nitrogen from the shale oil; both of these elements tend to "poison" heavy metal. Onsite upgrading is necessary to prevent deterioration of pipelines and storage facilities. The nitrogen content of shale oil (1.8%) is significantly higher than most crude petroleums; however, the sulfur content is labeled as moderate (0.7%).

The charcteristics of synthetic crude oil from shale are superior to those of most petroleum stocks, and as a result the oil may command a premium price. A relatively uniform quality synthetic crude oil may substitute for petroleum feed to most refineries, thereby achieving a broad market.

A.5 STATUS OF U.S. OIL SHALE PROJECTS

A brief summary of the status of the current oil shale projects in the U.S. is presented below:

Long Ridge/Union Oil Co.

From 1955 through 1958, Union Oil Co. built and operated a surface retort on its Colorado properties. The facility produced approximately 800 barrels of shale oil per day. In the early 1970's, Union reactivated research and development in its retorting process. In the fall of 1980, construction began on the first phase of Union's 50,000 bbl/day oil shale facility. The first phase of the project calls for the surface retorting of raw shale excavated from a room-and-pillar mine. After the first units have operated for a sufficient amount of time to confirm the technical, economic, and environmental characteristics of the project, Union plans to open four more mines and build additional retorts.

Pacific Property

Cleveland-Cliffs Iron Co., Sohio, and Superior Oil Co. are presently involved in several land interest swaps. When completed, these companies will have joint ownership in the Pacific Property and Superior's tract. Although Superior's commercial development efforts began in 1969, they have recently been stymied by a government decision rejecting a proposed land exchange. The three companies therefore will pursue Superior's DOE cost-sharing contract, which includes the engineering of a commercial demonstration plant, detailed design of the Superior process, and environmental compliance and permits on the Pacific Property.

Colony

The Colony shale oil project was established in 1963 and is presently operated by Exxon and TOSCO. A prototype mine and plant operation proved the viability of the underground mining plan with aboveground processing using the TOSCO II retort method. It is planned to continue to develop the Colony plant and mine facilities to commercial size by late 1985. Current project work includes finalizing project design, awarding contracts for major packages involved, and constructing access roads.

Paraho

Paraho Development Corp. is currently completing the final designs for its "Paraho-Ute" oil shale facility. This facility began when DOE selected Paraho for an eighteen-month program to design and demonstrate a commercial, full-size oil shale retort or module (mine retort, and all supporting equipment). Successful completion of the module design could result in the construction and operation of a Paraho retort as early as 1984.

NOSR

The Naval Oil Shale Reserves Project, which is under the direction of the Secretary of Energy, includes three sections of oil shale lands totaling 583 square kilometers. In 1977, TRW was chosen to be the prime engineering and management contractor for the project.

Preliminary assessments indicate that one or more types of surface retorts will be utilized in conjunction with room-and-pillar mining and upgrading through hydrotreating.

Multi-Minerals

In April 1979, Multi-Mineral Corp. signed an agreement with the U.S. Bureau of Mines to operate its research site in the Piceance Creek Basin. Multi-Minerals Corp. hopes to offset much of the expense of mining oil shale by recovering nahcolite and dawsonite. They are currently in the experimental mining phase of a three part demonstration program. Large-scale process testing is also scheduled to begin in mid-1981 with commercial operation by 1987.

C-a/Rio Blanco

In 1974, Gulf Oil Corp. and Standard Oil Co. of Indiana leased tract C-a from the Department of Interior. In mid-1982 major changes were made in the development plans of this prototype oil shale leasing program. In the second burn of a MIS retort, the company decided to test the Lurgi-Ruhrgas surface retort at the pilot rather than the demonstration level before proceeding to commercialization. Current plans involve open pit mining to begin in the northwest corner of the tract.

C-b/Oxy

Occidental Oil Shale Inc. (Oxy) and Tenneco Shale Oil Co. are currently developing tract C-b. It is expected that this tract will yield almost 1.1 billion barrels of shale oil using Oxy's MIS process combined with surface retorting of the shale removed. Currently, tract operations are in the shaft-sinking stage which began in early 1979. The production, service, and ventilation/escape shafts are nearing their completed depths of approximately 600 meters. Engineering designs for various shaft accessories and surface support facilities are also well underway.

Geokinetics

Geokinetics and DOE are currently developing a true-in-situ extraction process which is intended for areas where oil shale beds are close to the surface. This process is in its sixth year of testing and, thus far, approximately 15,000 barrels of shale oil have been produced from the 24 retorts tested. Geokinetics expects to complete its testing program by the end of 1982 and then begin construction of a commercial facility.

Equity

Early in 1977, Equity Oil Co. and DOE launched a true-in-situ test program intended to extract shale oil from a leach zone. Project field tests began in June 1979 and reportedly will continue for two years. Steam injections for a sustained period began in June 1980 and the formation has shown signs of continued and steady heating. To date,

no shale oil has been recovered.

Logan Wash

The Logan Wash facility is Occidental's testing site for their MIS process. Mining began in 1972 and, to date, six retorts have been developed and burned to produce 94,500 barrels of shale oil. Two additional retorts presently under development for experimental use and are each expected to produce nearly 100,000 barrels of shale oil at completion in 1982. Based upon the construction and operation of the previous three retorts, Oxy concluded that MIS technology was confirmed.

A.6 REFERENCES

Cane, R.F., "Oil shale of Australia and their industrial history." Twelfth Oil Shale Symposium Proceedings. Colorado School of Mines Press, Golden, Colorado, 1979.

Cook, F.M., "The Scottish shale oil industry." Proceedings; Oil Shale: The Environmental Challenges. Colorado School of Mines Press, Golden, Colorado, 1981.

Environmental Protection Agency, A Preliminary Assessment of the Environmental Impacts from Oil Shale Developments. EPA-600/7-77-069, Cincinnati, Ohio, July 1977.

General Electric Company, "Compendium reports on oil shale technology" for the Environmental Protection Agency, January 1979.

Institute of Gas Technology, Symposium Papers: Synthetic Fuels from Oil Shale. Atlanta, Georgia, December 1979.

IWG Corp., Proceedings of the IWG Workshop on the Oil Shale Health and Environmental Risk Analysis. San Diego, California, January 1981.

National Research Council, "Redistribution of accessory elements in mining and mineral processing. Part I: coal and oil shale." National Academy of Sciences, Washington, D.C., 1979.

Office of Technology Assessment, An Assessment of Oil Shale Technologies. U.S. GPO, Washington, D.C., June 1980.

The Pace Company, Oil Shale: World Resources and Development History. Unpublished Manuscript, Denver, Colorado, 1979.

Ranney, M.W., Oil Shale and Tar Sands Technology: Recent Developments. Noyes Data Corp., Park Ridge, New Jersey, 1979.

TRW Energy Systems Group, Oil Shale Data Book. Naval Oil Shale Reserves, U.S. DOE, McLean, Virginia, June 1979.

Yen, T.F., ed., Science and Technology of Oil Shale. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, 1976.