OIL SHALE HEALTH AND ENVIRONMENTAL RISK ANALYSIS

Lawrence B. Gratt
IWG Corp.
975 Hornblend Street, Suite C
San Diego, CA 92109

ABSTRACT

The potential human health and environmental risks of a hypothetical one-million-barrels-per-day oil shale industry have been analyzed to serve as an aid in the formulation and management of a program of environmental research. The largest uncertainties for expected fatalities are in the public sector from air pollutants although the occupational sector is estimated to have 60% more expected fatalities than the public sector. Occupational safety and illness have been analyzed for the oil shale fuel cycle from extraction to delivery of products for end use. Pneumoconiosis from the dust environment is the worker disease resulting in the greatest number of fatalities, followed by chronic bronchitis, internal cancer, and skin cancers, respectively. Research recommendations are presented for reducing the uncertainties in the risks analyzed and to fill data gaps to estimate other risks.

INTRODUCTION

The objective of the 1982 Oil Shale Risk Analysis (OSRA) was to estimate the potential human health and environmental risks of an oil shale industry in order to establish important research needed to reduce the uncertainties in the estimated risks. The results are reported and disseminated in the Health and Environmental Effects Document (HEED) for oil shale (1). The information contained herein is not intended for and should not be used for regulatory purposes.

A commercial domestic oil shale industry does not exist, thus a hypothetical industry at a production level of one million barrels-per-day (BPD) shale oil was analyzed as representative of a size supplying a significant fraction of the United States' energy demand. The resource of western oil shale is of sufficient magnitude that such an industry may exist for several hundreds of years at this production level. To reach this level, an installation phase of up to 30 years is possible. As the resource exploitation ceases after decommissioning, a phase of hundreds of years may be necessary before potential environmental impacts occur.

This paper will consider the human health concerns for the general public and the occupational workforce for the steady-state production scenario. The risk analysis formulation is probabilistic and is presented in a simplified form. In general, the risk is the product of four factors: the source term times the exposure-dose function times a health effect or damage function times the population at risk. A risk analysis involves the construction of scenarios for industry development, production, and distribution; pollutant source terms; media exposure for populations at risk; and workforce requirements and population migrations. The derivation of research recommendations is based on both the magnitude of the risk estimate, R, and the uncertainty factors, (u_R), used to generate the uncertainty range. The risks and uncertainties generated in this analysis have been based on both objective and subjective techniques. The resulting range on the risk estimate is computed by R/u_R to $R \cdot u_R$. The research recommendations are based on reducing the magnitude of the uncertainty range.

SCENARIO

The risk analysis scenario shown in Figure 1 has fourteen production sites, projected to produce a total of one million BPD, distributed along five of the six major oil shale region creek systems feeding the Colorado River. The production level for sites 1, 5, 7, 8, 12, and 13 is 100,000 BPD. All other sites are projected to produce 50,000 BPD. The production is based on underground room-and-pillar mining with above-ground retorting (AGR) for all but one site. The remaining site (13) is a MIS

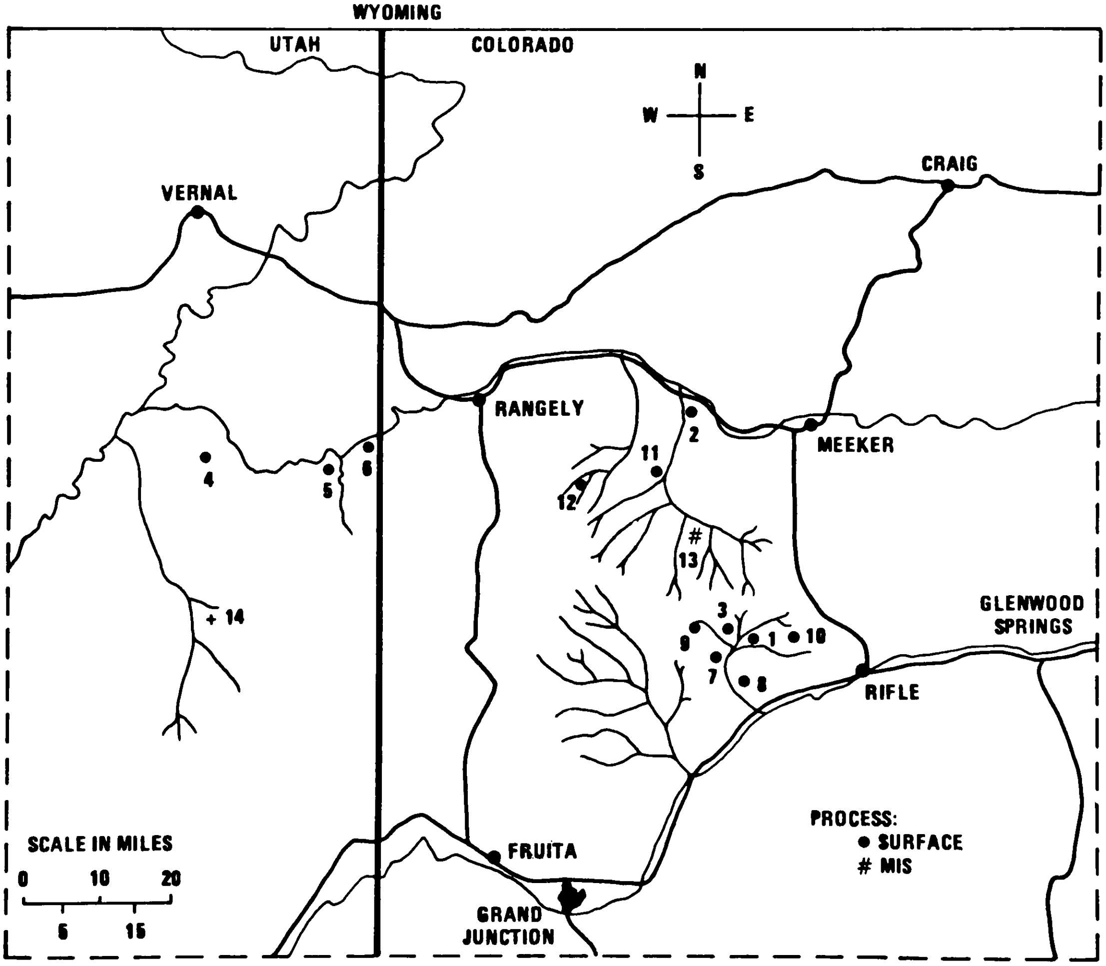

FIGURE 1. OIL SHALE REGION USED IN THE RISK ANALYSIS WITH SITE LOCATIONS

(modified-in-situ) operation with 50% of the production coming from the MIS and 50% from AGR. The year when the hypothetical scenario occurs is 2010.

OCCUPATIONAL SAFETY

The occupational workforce considers an oil shale fuel cycle ending when products are delivered to the consumers (e.g., gas stations or fuel distributors). The production site occupational workforce estimates were based on total onsite workforce necessary for the proposed technologies (2, 3, 4, 5, 6, 7) and an allocation of the workers to the different job classifications. The result was an average of 0.032 onsite workers per BPD produced. A key assumption made during this analysis was the underground mining productivity of 150 tons per man-shift (with a range of 100 to 170). The refining and transportation workforce estimates were based on statistics for 1978, 1979 and 1980 normalized to one million BPD. Table 1 summarizes the workforce estimates for the occupational safety and health analysis.

Table 1. Workforce Estimates for a One Million BPD Oil Shale Industry

LOCATION	WORKFORCE COMPONENT	ESTIMATE
On-site	Mining	14,200
	Crushing	6,200
	Construction	3,300
	Retorting-Upgrading	9,400
Off-site	Transportation	2,200
	Refining	5,600
Total		41,000

Accident and injury occurrences were estimated for each step of the oil shale fuel cycle using the incidence rates (normally specified in occurrences per 100 workers or 200,000 man-hours per year) from surrogate or actual industries. In some cases the surrogate industry was assumed to have a similar risk environment to that which would be encountered in the oil shale industry, such as refining. Three year averages (1978-1980) were used for the estimated incidence rate. Mining rates were derived from statistics of the Mine Safety and Health Administration. Crushing rates were found from statistics on coal, metal, and non-metal milling. Retorting and refining rates are from the American Petroleum Institute statistics. Transportation incidence rates are based on API statistics for pipeline transport and on National Safety Council statistics for rail transport. Construction incidence rates are also based on National Safety Council statistics. Uncertainty ranges were determined by the maximum and minimum values for the years averaged. The mining and crushing rates were also averaged across different types of mined material but restricted to underground mining. A reduction factor based on available statistics was calculated for large mines and applied to the oil shale scenario. The transportation scenario was the most complex, using different combinations of rail and pipeline utilization to produce the uncertainty range for accident and injury rates.

Table 2 is a summary of the estimated workforce accidents and injuries along with associated uncertainty ranges for each step of the oil shale fuel cycle. The estimates indicate that from 10 to 19 worker accident-related deaths will occur per year. This corresponds to an "industry" fatality incidence rate of 0.03 to 0.05 deaths per 100 workers per year based on 41,000 total workers. Similarly, the expected non-fatal accidents with days lost from work range from 1800 to 3600 (incidence rate of 4.5 to 8.8) and accidents with no days lost from 1200 to 2000 (incidence rate of 2.9 to 4.9).

Table 2. Accident and Injury Occurrences for a One Million BPD Oil Shale Industry

Fuel Cycle Component	Occurrences (Range) Fatalities	NFDL	NDL
Mining	7.1 (4.6 - 11)	1600 (1100 - 2400)	440 (290 - 660)
Crushing	2.2 (1.1 - 4.4)	310 (210 - 460)	170 (110 - 280)
Retorting & Upgrading	1.7 (.61 - 4.8)	130 (51 - 340)	300 (120 - 770)
Refining	1.00 (.67 - 1.5)	78 (74 - 82)	180 (170 - 190)
Transportation	0.5 (.10 - 2.5)	140 (18 - 1100)	81 (27 - 240)
Construction	0.77 (.54 - 1.1)	140 (100 - 190)	280 (200 - 390)
Total	13 (10 - 19)	2400 (1800 - 3600)	1500 (1200 - 2000)

NFDL is non-fatal occurrences with workdays lost.
NDL is occurrences with no workdays lost.

The sources of the greatest uncertainty in the accident and injury analysis are the incidence rates in the extraction (mining and crushing) phase. The extraction workforce is roughly half of the total workforce, and fatality incidence rates are .050 and .035 for mining and crushing, respectively. These rates are substantially higher than the fatality rates of .018 to .023 for the other components of the fuel cycle. Out of a total of 13 deaths per year, the extraction phase will account for 9. The mining fatality rate was reduced by 41 percent from the rate for all mining to adjust for large mine sizes. Without this reduction, the rate would be .085, mining fatalities would increase from 7 to 12. Research is recommended in the areas of mining and crushing accident and injury rates to make the greatest reduction in total occurrence uncertainties. Analysis of large mines safety statistics as applicable to oil shale mines is also needed.

OCCUPATIONAL HEALTH

There are a number of potential occupational health hazards involved in the extraction, retorting, upgrading, transporting, and refining of shale oil including exposure to dusts, toxic gases, heat, noise, and the oil. Human health risks are best estimated from epidemiologic data with the support of in-vivo and in-vitro test results. Estimation of the occupational health effects of a million BPD oil shale industry is constrained by the paucity of epidemiologic data from the oil shale industry itself. This analysis is based on a surrogate approach where data from industries of similar or analogous exposures and practices is extrapolated to the estimated oil shale exposure and the resulting risk is modified according to other relevant knowledge.

The carcinogenic risks were analyzed using the equation:

$$R = H \times E \times T \times P.$$

R is the estimated number of cancers in a million BPD oil shale industry workforce. H is the excess rate of a health effect in a similar "surrogate" industry. The excess (or attributable) rate is the rate of the disease above the background or baseline level. This rate is derived from (1) relative risk estimates resulting from epidemiological studies, and (2) the baseline incidence rate of the disease in the general population. The total rate for workers in the surrogate industry is found by multiplying the baseline rate by the relative risk and the excess rate is found by subtracting the baseline rate from the total. E is the ratio of the exposure in the oil shale industry to the exposure in the surrogate industry. T is a comparable ratio of toxicologic potency. P is the estimated size of the exposed worker population.

The oil refining industry was chosen as the optimal surrogate for oil shale retorting for the following reasons. First, the materials (petroleum and shale oil) are similar in the sense that both are liquid hydrocarbons. Second, both are handled with closed systems where the primary mechanism of exposure is through leaks, accidents, or in maintenance procedures. The products are both potentially toxic through inhalation or direct skin contact. Third, the involvement of essentially the same corporations in both oil refining and oil shale development suggests that industrial hygiene approaches will be similar. The primary alternative to oil refineries as the surrogate industry is coke ovens. The strength of coke oven workers as a population from which to extrapolate retorting risks is the uniquely thorough epidemiologic research on this population (8). The reason this population was not used is the absense of exposure data for retorting operations. Without scaling the risks, it would be very difficult to determine which subgroup of oven workers best represented retort workers. Thus, to select risks from a surrogate industry, oil refining was thought to be more directly applicable to shale retorting counterbalancing the admittedly inferior epidemiologic data.

Inhalation of dust as a result of mining, crushing, and retorting operations raises the possibility of adverse physiological reaction to that dust in the oil shale workforce. The ability for self-protection and repair of injury can be exceeded. Three non-neoplastic lung responses to respirable dust particles potentially occurring in the oil shale industrial environment were analyzed: pneumoconiosis, chronic bronchitis, and chronic airway obstruction. Silicosis, the pneumoconiosis caused by the inhalation of silica, was analyzed independently. Because these diseases can occur simultaneously in a given individual, the summation of the separate risk estimates will overestimate the total incidence. The estimate of pneumoconiosis was based on British coal worker data and total respirable dust exposures and silicosis risk was estimated from data on Vermont granite shed workers and Peruvian metal miners with respirable silica as the exposure measurement. The only available oil shale mine dust measurements come from studies of pilot operations and may not adequately represent exposures in a commercial operation. The current nuisance dust standard in oil shale mines of 5 mg/m^3 respirable dust was selected as the estimate for dust exposure.

The excess incidence rates, the number of workers at risk, the annual new cases, the case fatality rate, and the annual deaths for each disease are presented in Table 3. Fifteen thousand workers involved in the retorting, upgrading, and refining of shale oil are at risk of the cancers. There are 20,400 workers exposed to dusts which can cause non-neoplastic respiratory diseases; the miners and the crusher operators. The population at risk of high frequency hearing loss are the 20,400 workers in the mines and around the crushing facility. The result is the number of excess cases of each disease which could be seen annually in a million BPD industry. The case fatality rates are the estimated percentage of all cases who eventually die as a result of that disease.

Based on the magnitude of the risk estimates and the importance of the disease in terms of worker productivity and health, pneumoconiosis and chronic bronchitis stand out among the diseases considered as very important concerns for future consideration of mine dust control. It is recommended that the silicosis dose-response function be researched by reviewing original data for the purposes of a better estimate of the dose-response function. Better characterization of the hydrocarbon exposures of oil shale workers and petroleum workers is necessary to reduce the uncertainty of the internal cancer estimates. The skin cancers should remain a research priority because of the large uncertainty range. The high frequency hearing loss estimate is a direct result of the fact that the threshold limit value does not protect all workers. This risk estimate could be improved with actual noise level measurements. More industrial hygiene data is necessary to quantify dermatitis and vibration disease. Adverse reproductive outcomes as a field of research is relatively new and there is little information available concerning the role, if any, of occupation or energy technologies in the external causation of these effects. At this time there is no indication that there is a risk to adverse reproductive outcomes in the oil shale workers and their families.

PUBLIC HEALTH

Oil shale airborne emissions and waterborne leachates may increase the risk of health effects in public populations. The risk of air emissions from the steady-state industry have been analyzed. The oil shale regional population was estimated by adding a baseline population to an "oil shale worker" population. The baseline population was estimated using a growth rate of 3.2% per year (9, 10) on the estimated 1980 population of 152,000 persons. The 33,200 oil shale workers were multiplied by 6.8 to account for other developments, indirect employment, and worker families result in 226,000 persons moving in to the region. Adding the "oil shale worker" population and baseline results in an estimated 616,000 persons at risk for the public regional population. The distribution of the projected population throughout the region was allocated based partly on historical patterns and studies on the commuting patterns of the oil shale workers. Most of the population will continue to be concentrated along the Colorado River corridor.

The U.S. population was estimated to be 313 million persons in the year 2010. The 1980 population of 226 million was extrapolated 30 years at a growth rate of 11.4% per decade.

Air emission data from Prevention of Significant Deterioration Permits were used to estimate generic emission terms representing basic retorting processes (Union, TOSCO, and Paraho). The emission terms from two power plants to support the oil shale industry and the associated population growth in the region were included (Moon Lake, Utah and Grand Junction, Colorado).

The results of flat terrain Gaussian plume modeling have been adapted to estimate public exposure to air pollution within the oil shale region. A joint frequency distribution of wind speed, wind direction, and stability was obtained from data taken at Tract C-a and was used to construct a long-term average two-dimensional wind field. All of the reported results are for a non-buoyant release, which overpredicts

TABLE 3. SUMMARY OF OIL SHALE OCCUPATIONAL HEALTH: INCIDENCE, MORTALITY, AND UNCERTAINTY

Disease	Excess Incidence per 1000 per year	Uncertainty Factor* u_H	u_E	u_T	u_P	u_R	Number of Workers at Risk (1000's)	Case Fatality (%)	Cases Per Year Estimate	Cases Per Year Uncertainty Range	Deaths Per Year Estimate	Deaths Per Year Uncertainty Range
Internal Cancers												
Lung (hydrocarbons)	0.115	3.16	5	3	1.5	10.0	15.0	91	1.73	0.17 - 17.3	1.57	0.16 - 16.0
(radioactivity)	8.7×10^{-4}	2.00	3	1	1.5	3.9	20.4	91	1.77×10^{-2}	5×10^{-3} - 7×10^{-2}	1.62×10^{-2}	4.1×10^{-3} - 6.3×10^{-2}
(arsenic)	0.012	2.20	2	1	1.5	3.1	20.4	91	0.25	0.08 - 0.78	0.23	0.07 - 0.71
Stomach	0.039	3.16	5	3	1.5	10.0	15.0	88	0.59	0.06 - 5.9	0.52	0.052 - 5.2
Kidney	0.022	3.16	5	3	1.5	10.0	15.0	56	0.33	0.03 - 3.3	0.18	0.018 - 1.8
Brain	0.069	3.16	5	3	1.5	10.0	15.0	82	1.04	0.10 - 10.4	0.85	0.085 - 8.5
Skin Cancers												
Melanoma	0.029	3.16	5	3	1.5	9.96	15.0	38	0.44	0.04 - 4.4	0.17	0.017 - 1.7
Basal Cell	1.080	5	5	3	1.5	12.93	15.0	1	16.20	1.25 -210.	0.16	0.012 - 2.1
Squamous Cell	0.290	5	5	3	1.5	12.93	15.0	1	4.35	0.33 - 57.	0.04	0.003 - 0.52
Pneumoconiosis												
Method 1: Coal Dust Surrogate												
0/1+	2.9	2	2	2	1.5	3.55	20.4	7	59.2	16.70 -210.	4.03	1.1 - 14.3
2/1+	0.65	2	2	2	1.5	3.55	20.4	7	13.3	3.75 - 47	0.90	0.25 - 3.2
PMF	0.95	2	2	2	1.5	3.55	20.4	35	19.4	5.46 - 69	6.69	1.9 - 23.7
Combined (0/1+ and PMF)									78.6	22.2 -279	10.7	3.0 - 38.
Method 2: Silica	2.5	2.5	2	1	1.5	3.38	20.4	43	51.0	15.10 -172	21.90	6.5 - 74.
Chronic Bronchitis	4.5	2	2	2	1.5	3.55	20.4	4	91.8	25.9 -326	4.04	1.1 - 14.
Airway Obstruction	0.18	2	2	2	1.5	3.55	20.4	3	3.67	1.03 - 13	0.11	0.031 - 0.39
High Frequency Hearing Loss	1.4	2	2	1	1.5	2.88	20.4	-	28.6	9.9 - 82.3	-	- -

$$*\log u_R = \sqrt{(\log u_H)^2 + (\log u_E)^2 + (\log u_T)^2 + (\log u_P)^2}$$

Note: Pneumoconiosis, Chronic Bronchitis, and Airway Obstruction estimates may overlap.

concentrations closer to the source. Air exposure contours were calculated by a computer program which integrated the plumes of the fourteen oil shale sites and the two power plants.

The transport of oil shale sulfates across the United States was modeled using Fay and Rosenzweig (11) steady state two-dimensional diffusion equation for ambient air pollutant concentrations averaged over a long time period at distances greater than 100 km from the source. The model uses a constant horizontal diffusion coefficient to determine horizontal puff dispersion. Pollutants are assumed to be mixed uniformly in the vertical direction up to a constant mixing height. Precipitation rate, dry deposition rate, transformation rate, and wind speed/direction are also assumed to be fixed parameters over the geographic region of interest.

An estimate of the effects of all air pollutants was made using a sulfate surrogate model. A linear non-threshold health damage function of 3.5 premature deaths per year per 100,000 persons per ug/m^3 of sulfate was employed. This function is the result of combining several expert opinions (12) including Lave and Seskin (13) who examined the differential mortality rates of 117 SMSAs in the United States. This controversial model uses sulfates as a surrogate for all air pollution and has a range of no effect to three times the indicated damage function. It also has large uncertainties when applied to a new mix of air pollutants.

The estimates of premature deaths due to air pollution using sulfates as a surrogate are 15 premature deaths per year (with a range of 0-80 deaths) in the oil shale region population of 616,000 persons and 12 premature deaths per year (with a range of 0-220 deaths) for the U.S. population of 313 million persons in the year 2010. The total is 27 premature deaths per year with a range of 0-300.

As shale oil is produced, an equivalent amount of imported petroleum can be replaced in U.S. refineries. Under the restraints of the sulfate surrogate model, a comparison of the health damage due to oil shale development with the health benefit caused by reduction of petroleum refinery emissions in the densely populated midwest to northeast region of the United States was made. The result was a decrease of 600 premature deaths per year for the U.S. population.

The predominating uncertainty of the public health analysis is the 0-300 premature deaths per year due to air pollution as calculated using the controversial sulfate surrogate model. Reduction of the uncertainty range requires research in several areas. First, the validity of the model itself continues to need verification. There is the question of whether sulfates are the best surrogate or if some other component or combination of air pollution components may be more appropriate. The value of the linear dose-response coefficient should be researched. Research on the parameters of the air transport models have the potential for uncertainty reduction, noting that the uncertainty associated with the patterns of wet deposition introduces the largest uncertainty.

A significant omission of this analysis is the health effects of waterborne organics. A large variety of organic compounds are known to be present in retorted shales and waters. However, the uncertainty of environmental transformation and removal of these organics is too great to allow a reasonable analysis. Also, the health effect dose-response is unknown for complex organic mixtures in water. Research is necessary on both aspects of organic water pollution.

SUMMARY

The health and environmental risks and associated uncertainties have been estimated for a steady-state oil shale fuel cycle producing one million barrels-per-day. Research recommendations have been made for reducing the uncertainties in the occupational safety, occupational health, public health, and ecosystem risks. A summary of the risk analysis results and research needs are shown in Table 4. The research recommendations were based on both the relative magnitude of the risk estimate and the associated uncertainty factors. The review of the uncertainties in these estimates can aid the formulation of an environmental research program by selecting a measure of importance and investigating the sources of uncertainty in the analysis.

ACKNOWLEDGEMENTS

This analysis was performed under U.S. Department of Energy (DOE) contract DE-AC02-82ER60087 by the University of Colorado, Center for Environmental Sciences and the IWG Corp. Dr. Paul Cho of

Table 4 HUMAN HEALTH AND ENVIRONMENTAL RISKS, UNCERTAINTIES, AND ASSOCIATED RESEARCH RECOMMENDATIONS FROM A HYPOTHETICAL MILLION BPD OIL SHALE FUEL CYCLE

Health or Environmental Effect	Exposure	Risk Per Year (Uncertainty Range) Cases	Deaths	Research Recommendations
WORKERS (Population at Risk: 41,000 persons)				
Injury	Accident with days lost	2400 (1800–3600)	13 (10–19)	Mining and crushing accident incidence rates; Large mine statistics; Workforce estimates; Construction injury rates; New process (retorting) safety; Use of large equipment safety.
Injury	Accident without days lost	1500 (1200–2000)	NA	
Internal Cancers	Hydrocarbons, Radiation, As	4 (0.4–37)	3 (0.3–32)	Occupational hydrocarbon exposure characterization and organ dose; Comparative toxicology; Industrial hygiene characterization.
Skin Cancers	Hydrocarbons	21 (1.6–270)	0.4 (.03–4)	Dose-response; Exposure situation; Impact of sunlight; Carcinogenicity of shale oils, Characterization of hydrocarbon exposures.
Pneumoconiosis (Silicosis)	Dust	51 (15–170)	22 (6.5–74)	Fundamental research on pneumoconiosis; Silicosis dose-response function; Mine dust control; Characterization of exposure; Industrial hygiene.
Chronic Bronchitis	Dust	92 (26–330)	4 (1.1–14)	Mine dust control; Characterization of dust exposure; Comparative toxicology; Industrial hygiene characterization.
Airway Obstruction	Dust	4 (1.0–13)	0.1 (0.03–0.4)	Mine dust control; Characterization of dust; Comparative toxicology; Industrial hygiene characterization.
High Frequency Hearing Loss	Noise	29 (10–82)	NA	Occupational noise level measurements.
PUBLIC (Population at risk: 616,000 (Region), 313,000,000 (U.S.))				
Premature Death	Air Pollution (Sulfate Surrogate)	NA	27 (0–300)	Wet deposition and other sulfate removal terms in pollutant transport models; Sulfate surrogate dose-response model.
Internal Cancers	As, Cd, Cr, Ni, Radiation and PAH	.004 (0–.01)	.004 (0–.01)	Exposure characterization and dose to organs.
ECOSYSTEM (Area at risk: 18,000 square miles)				
Mule Deer Decline	Habitat Loss	4% to 9% (−50% to 200%)		Basic deer-habitat relationship.
Indian Rice-grass Injury	Sulfur Dioxide	<0.8%		Injury to crop-yield loss relationships.
Plant Community Decline	Solid Waste Disposal	3 communities decrease as much as 20%		Waste disposal models; Reclamation success.

NA is not applicable.

DOE's Health and Environmental Risk Analysis Program, Office of Energy Research was the project officer. Dr. W. Chappell, Mr. B. Perry, Dr. W. Marine, Dr. D. Savitz, and Mr. J. Feerer were all key contributors to this effort.

REFERENCES

1. IWG Corp., Health and Environmental Effects Document for Oil Shale - 1982. San Diego, California, December 1982.

2. U.S. Department of Interior, Proposed Development of Oil Shale Resources by the Colony Development Operation. Final Environmental Impact Statement, 1975.

3. Rotariu, G.J., Western Oil Shale Development: A Technology Assessment. Volume 1: Main Report. Pacific Northwest Laboratory, Richland, Washington, November 1981.

4. Colorado Energy Research Institute, Oil Shale 1982: A Technology and Policy Primer. CERI and Colorado School of Mines Res. Inst. November 1981.

5. Energy Development Consultants, Inc., Colorado Oil Shale: The Current Status. EDC, Inc. for U.S. DOE, 1979.

6. Nazaryk, P., Colorado Department of Health, memorandum: "Cumulative Environmental Impact Study - Production Scenarios and Workforce Projections." February 1, 1982.

7. Long, R., TOSCO, Denver, Colorado, Personal communication via telephone with L. Gratt on May 24, 1982.

8. Redmond, C.K., H.S. Wieand, H.E. Rockette, R.S. Sass, and G. Weinberg, Long-term Mortality Experience of Steelworkers. U.S. Department of Health and Human Services (NIOSH) Publ. No. 81-120. U.S DHHS, PHS, CDC, NIOSH, Cincinnati, Ohio, 1981.

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

10. Utah State Planning Coordinator, Energy: 2000 - The Impacts of Energy Development in Eastern Utah. Salt Lake City, Utah, 1980.

11. Fay, J.A. and J.J. Rosenzweig, "An analytical diffusion model for long distance transport of air pollutants." Atmos. Env. 14: 355-365, 1980.

12. Morgan, M.G., S.C. Morris, A.K. Meier 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.

13. Lave, L.B. and E.P. Seskin, Air Pollution and Human Health. John Hopkins Press, Baltimore, Ohio, 1977.