HIGH RISK GROUPS IN AN OIL SHALE WORKFORCE

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ABSTRACT

The workforce risks of a hypothetical one million barrels-per-day oil shale industry were estimated. The risks for the different workforce segments were compared and high risk groups were identified. Accidents and injuries were statistically described by rates for fatalities, for accidents with days lost from work, and for accidents with no days lost from work. Workforce diseases analyzed were cancers, silicosis, pneumoconiosis, chronic bronchitis, chronic airway obstruction, and high frequency hearing loss. A comparison of the workforce groups under different risk measures (occurrence, fatality, and life-loss expectancy) was performed. The miners represented the group with the largest fatality and the most serious accident rate, although the estimated rates were below the average industry-wide underground mining experience. Lung disease from inhalation exposure of about the nuisance dust threshold limit value presents a significant risk for future concerns. If future environmental dust exposure is at the 100 $\mu g/m^3$ alpha-quartz level, safety improvements in the mining sector are of prime importance to reduce the oil shale worker's life-loss expectancy.

INTRODUCTION

The overall health and environmental risks from a hypothetical one million barrels-per-day (BPD) oil shale industry were presented previously (1, 2). The analysis scenario was based on production sites distributed in the Piceance and Uintah Basins. The risk analysis considered an oil shale fuel cycle from oil shale extraction to delivery of refined products for consumer end use.

The analysis of health and safety risks in a future oil shale industry can be used to identify high risk concerns and reduce occupational accidents and disease. The occupational workforce size for a one million BPD industry was estimated and used to compute the occupational risks. Based on the estimated risks relative to general and analogous occupations, high risk groups were identified. Health and safety research implications of these findings were described previously (1).

WORKFORCE SIZE

Oil shale developers have treated their workforce distributions as proprietary information. It was necessary to develop a methodology for estimation of the number of workers and their distribution for a one million BPD industry. This estimate was reviewed by the potential developers and judged to be reasonable.

For the purposes of analysis, the oil shale fuel cycle was divided into the following segments:

1. Extraction (Mining and Crushing)
2. Retorting and Upgrading
3. Construction
4. Refining
5. Transportation

The segments were designed to establish work groups representing each major operation of the oil shale fuel cycle. Table 1 shows typical job classifications in each of the workforce segments. The transportation segment encompasses the transport of upgraded shale oil to the refineries and distribution of refined products to consumers. Segments 1 through 3 occur at the plant site while segments 4 and 5 are off-site operations. Estimates of the workforce size were made for both on- and off-site processes.

On-site Workforce

The on-site workforce was subdivided into four work groups: mining, crushing, retorting-upgrading and construction. Generic workforce size estimates were developed for two processes: (1) underground mining with above-ground retorting (AGR) and (2) modified-in-situ (MIS). The AGR estimate was based on the average number of workers for the three major technologies represented by Union, Paraho, and TOSCO. Estimates based on published data were made for Union

Table 1. Oil Shale Workforce Segments

Mining and Crushing	Retorting and Upgrading	Refining	Transport
Drilling	Operational	Technical	Inspection
Blasting	Maintenance	Engineering	Operational
Loading	Technical	Clerical	Maintenance
Hauling	Engineering	Operational	Engineering
Crushing	Supervisory	Maintenance	Supervisory
Ventilation		Supervisory	Drivers
Dewatering			
Operational			
Maintenance			
Engineering			
Supervisory			

and Paraho. The TOSCO process used data averaged from studies for Colony and the TOSCO process directly. The average of the three technologies was 3.2 workers/100 BPD for the AGR on-site workforce with an uncertainty range of 2.3 to 4.4 workers/100 BPD, based on the lowest and highest values.

The generic on-site workforce size estimate was then subdivided into groups for mining, crushing, construction and retorting-upgrading. The overall formula used was

$$Wsite = Wm + Wcg + Wcn + Wru \qquad (1)$$

where Wsite is the total generic on-site workforce size, Wm the mining work group, Wcg the crushing work group, Wcn the construction work group, and Wru the retorting-upgrading work group.

The mining work group size estimate was based on the productivity per miner for the appropriate technology. The underground miner productivity was set at 150 tons of oil shale per worker-day (3). Using an average grade of shale of 25 gallons per ton (GPT) and an 84% conversion efficiency into shale oil, the miner work group at a given site was calculated* to be:

$$Wm = .0133 \text{ workers/BPD} \qquad (2)$$

The crushing work group size estimate was based on the manpower needed to meet a retort feed requirement of 10,000 tons per day (4). This feed level requires 12 workers in the primary crusher, 14 workers at the secondary crusher, and seven workers in storage operations for a total of 33 worker-days per 10,000 tons**. Then,

$$Wcg = .0066 \text{ workers/BPD.} \qquad (3)$$

The construction work group size estimate was based on the assumption that 10% of the total workforce is involved in construction related activities to support the steady state operations,

$$Wcn = .10\ Wsite = .10(.032) = .0032 \text{ workers/BPD} \qquad (4)$$

The final work group was the retorting and upgrading workforce, estimated by subtracting the other work groups from the total on-site workforce. It was assumed that the workers in this group worked both at the retorting and upgrading facilities, which were co-located or near each other.

$$Wru = Wsite - (Wm + Wcg + Wcn) \qquad (5)$$

Substituting for Wm, Wcg and Wcn yielded

$$Wru = .032 - (.0133 + .0066 + .0032)$$
$$= .0089 \text{ workers/BPD} \qquad (5a)$$

The estimates for the on-site work groups from this methodology are shown in Table 2.

Table 2. Generic Workforce Size Estimates
for AGR Sites

	Workforce Size and Uncertainty Range for a Generic Above-Ground Retorting Site Production Level of 100,000 BPD	
Work Group	Workers	(Range)
Mining	1330	(1200-2000)
Crushing	660	(580-990)
Retorting-Upgrading	890	(310-970)
Construction	320	(230-440)
Total On-site	3200	(2300-4400)

The total on-site uncertainty ranges were generated using the extremes of the total site estimators (2.3 to 4.4 workers/100 BPD). The mining uncertainty range was based on a range of 100 to 170 tons of oil

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* Worker days per tons of shale x tons per assay gallon (Ga) x assay gallon per gallon (yield) x gallons per barrel = (worker-day/150 T) x T/25Ga x Ga/.84Gy x 42Gy/B = .0133 workers/BPD

** (33 worker-day/10,000 T) x T/25Ga x Ga/.84Gy x 42Gy/B = .0066 workers/BPD shale per worker-day (3, 5) for the miner productivity. The crushing uncertainty was considered to be proportional to the mining uncertainty, and the retorting-upgrading range was found from equation 5.

For the MIS technology, an analogous methodology was used to estimate the on-site workforce size to be 4.4 workers/100 BPD (with a range of 3.3 to 6 workers/100 BPD). The MIS site, producing 100,000 BPD, was assumed to have 56,000 tons of oil shale per day mined with 57,000 BPD of shale oil produced by in-situ retorting and 43,000 BPD of shale oil produced by above-ground retorting (5). The mining rate for MIS was set at 25 tons per miner-day (3) with a range from 20 to 30 tons per miner-day (5).

Off-site Workforce

The size of the refining and transportation work groups was estimated from statistics for 1978, 1979, and 1980 and normalized to one million BPD (1). It was assumed the upgraded shale oil enters the existing refining-transportation-distribution system as a substitute for imports. The off-site workforce size estimates are summarized in Table 3.

Table 3. Off-site Workforce Size Estimates for a One Million BPD Oil Shale Industry

Work Group	Workers	Range
Refining	5,600	(5,500-5,800)
Transportation	2,200	(740-3,600)

Scenario

The overall occupational workforce size estimates were based on a production scenario of 14 sites. Each site produced either 50,000 or 100,000 BPD by underground mining/AGR retorting except for a single MIS site. Table 4 summarizes the final workforce size estimates for the occupational health and safety analysis.

OCCUPATIONAL SAFETY

Accident and injury occurrences were estimated for each segment of the oil shale fuel cycle using the incidence (normally specified in occurrences per 100 workers per year or per 200,000 man-hours per year) from surrogate or actual industries. The methodology has been previously described (1). Table 5 is a summary of the estimated workforce accident and injury incidence along with associated uncertainty ranges for each segment of the oil shale fuel cycle (2).

Table 4. Workforce Size Estimates for a One Million BPD Oil Shale Industry

Location	Work Group	Estimate (Range)
On-site	Mining	14,200 (12,000-21,000)
	Crushing	6,200 (5,500- 9,300)
	Retorting and Upgrading	9,400 (3,700-11,000)
	Construction	3,300 (2,400- 4,600)
Off-site	Refining	5,600 (5,500- 5,800)
	Transportation	2,200 (740- 3,600)
Total*		41,000 (35,000-49,000)

$$\text{*upper bound} = \sqrt{\sum_{i=1}^{6}(\text{upper bound} - \text{nominal estimate})^2} + \text{nominal estimate}$$

$$\text{lower bound} = \text{nominal estimate} - \sqrt{\sum_{i=1}^{6}(\text{nominal estimate} - \text{lower bound})^2}$$

i = 1 for mining, 2 for crushing, 3 for retorting and upgrading, 4 for refining, 5 for transportation, and 6 for construction.

Larger-scale mining operations were reputed to be safer than small ones. Commercial oil shale mines are expected to be the largest mines in the United States. Mining safety statistics were analyzed to establish a mine size factor, a multiple to adjust the mining incidences for the size of the mining operation. The available mine size data were classified by the size of the workforce. The highest classification was 250 or more employees for coal, metallic mineral, and non-metallic mineral mining. The largest employment size group for stone mining was 150 to 249 employees. For example, in 1978 the fatality incidence for all underground coal mining was 0.07 deaths per 100 workers per year. The mine size factor for this incidence is 0.57 (0.04 for large mines divided by 0.07 for all mines). In this way, an adjustment which compares large-scale mining statistics to average mining operation statistics can be determined. An average mine size factor for each accident category for each material was determined using an hours-worked-weighted average of the data for the three years (1978-1980). The resulting mine size factor was 0.59 for fatalities and approximately one for the other incidences. The uncertainty factors, shown in Table 6, were used to generate uncer-

Table 5. Accident and Injury Incidence Estimates for a One Million BPD Oil Shale Industry

Work Group	Fatalities	Incidence (Range) NFDL	NDL
Mining	.050 (.040 - .060)	11.18 (10.18 - 11.82)	3.07 (2.68 - 3.63)
Crushing	.035 (.020 - .053)	4.96 (4.62 - 5.25)	2.78 (2.19 - 3.40)
Retorting and Upgrading	.018 (.012 - .023)	1.40 (1.35 - 1.46)	3.17 (3.14 - 3.20)
Construction	.023 (.020 - .027)	4.20 (4.17 - 4.24)	8.46 (7.83 - 8.96)
Refining	.018 (.012 - .023)	1.40 (1.35 - 1.46)	3.17 (3.14 - 3.20)
Transportation	.023 (.007 - .026)	6.55 (1.16 - 7.69)	3.75 (3.04 - 3.90)

Incidences for 100 workers per year or 200,000 man-hours per year.
NFDL is for non-fatal occurrences with workdays lost.
NDL is for occurrences with no workdays lost.

Table 6. Uncertainty Factors for Work Group Size, Incidence, and Occurrence Estimates for a One Million BPD Oil Shale Industry

Work Group	Work Group Size [a]	Uncertainty Factors Incidences [a] F	 NFDL	 NDL	 Occurrences [b] F	 NFDL	 NDL
Mining	1.464	1.250	1.098	1.182	1.555	1.481	1.516
Crushing	1.500	1.750	1.074	1.269	1.996	1.509	1.600
Retorting and Upgrading	2.580	1.500	1.043	1.010	2.804	2.582	2.580
Construction	1.383	1.174	1.010	1.080	1.436	1.383	1.396
Refining	1.036	1.500	1.043	1.010	1.502	1.057	1.037
Transportation	2.898	3.286	5.647	1.234	4.934	7.629	2.958

Incidences for 100 workers per year or 200,000 man-hours per year.
F is fatalities.
NFDL is non-fatal occurrences with workdays lost.
NDL is occurrences with no workdays lost.
a. Geometric standard deviation factors for work group estimates and occurrences were the highest of either Nominal Estimate/Lower Bound or Upper Bound/Nominal Estimate from Table 5.
b. Occurrences = Work Group x Incidence, Uf is the uncertainty factor.

$$\mathrm{Uf(occurrence)} = \log^{-1} \sqrt{\log \mathrm{Uf(work\ group)}^2 + \log \mathrm{Uf(incidence)}^2}$$

tainty ranges for accident and injury occurrences. The uncertainty factors for work group size and incidence estimates were calculated by taking the maximum value of the mean divided by the lower bound or the upper bound divided by the mean. The factors for occurrences were calculated by taking a root-mean-square sum of the logarithmic values of corresponding work group size and incidence uncertainty factors. Table 7 is a summary of the resulting accident and injury occurrences for a one million BPD oil shale industry.

Table 7. Annual Accident and Injury Occurrences for a One Million BPD Oil Shale Industry

Work Group	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 and Upgrading	1.7 (.61 - 4.8)	130 (51 - 340)	300 (120 - 770)
Construction	0.77 (.54 - 1.1)	140 (100 - 190)	280 (200 - 390)
Refining	1.00 (.67 - 1.5)	78 (74 - 82)	180 (170 - 190)
Transportation	0.5 (.10 - 2.5)	140 (18 - 1100)	81 (27 - 240)
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.

Safety Comparison

All-industry incidences were calculated with total workforce size from Table 4 and occurrence estimates from Table 7. The oil shale work group incidences are shown in Figure 1. For fatalities and non-fatal occurrences with days lost (NFDL), the high and low incidences were mining and refining, respectively. For non-fatal occurrences with no days lost, the upper bound came from the construction component and the lower bound from crushing. This suggests that the majority of serious injuries occur in the extraction phase of the fuel cycle. It is possible that the relatively low number of accidents with no workdays lost (NDL) shown for extraction is due to the fact that only serious accidents were required to be reported under agency rules. Construction had the highest number of NDL occurrences. This may be attributed to the large use of tools and power equipment as opposed to the type of heavy machinery which cause major injuries. The refining and the retorting and upgrading phases did not involve many processes of physical labor or utilize large solids-handling moving machinery. These were factors which could account for the low incidence of serious injuries in these work groups of the oil shale fuel cycle.

Although a major oil shale industry does not yet exist, the risk analysis was used for comparison to present industries. Figure 1 is a set of graphs showing the relative risks of the oil shale industry with other industries in operation in the United States. The uncertainty bounds used in these graphs were derived from the total workforce size estimate and the upper and lower bounds of the total accident and injury occurrences.

Figure 1a shows the oil shale fuel cycle will experience occupational deaths consistent with other hazardous occupations, such as railroad transportation and petroleum and coal products. Figure 1b indicates a similar trend for non-fatal occurrences with days lost. Though predicted oil shale incidences for these types of accidents are not extraordinarily high, such as those encountered in heavy industries or transportation, they were above the average for all industries. The oil shale industry expected incidence for serious injuries was estimated to be greater than the average for "all industries". For occurrences with no days lost, Figure 1c shows that the estimated risks were about average for all industries. All generalizations must be made with caution due to the possibility of reporting errors and other sources of discrepancy. The oil shale industry has no current statistical data base for commercial operations and all results have assumed the validity of using statistics from surrogate industries.

Accident Severity

Further inferences about oil shale mining were made from an investigation of injury severity in U.S. underground bituminous coal mines over the period from 1975 to 1982 (6). This statistical analysis of 91,404 injuries indicated that the injury severity varies with the mining system, geographical region, circumstances surrounding the injury, the injured

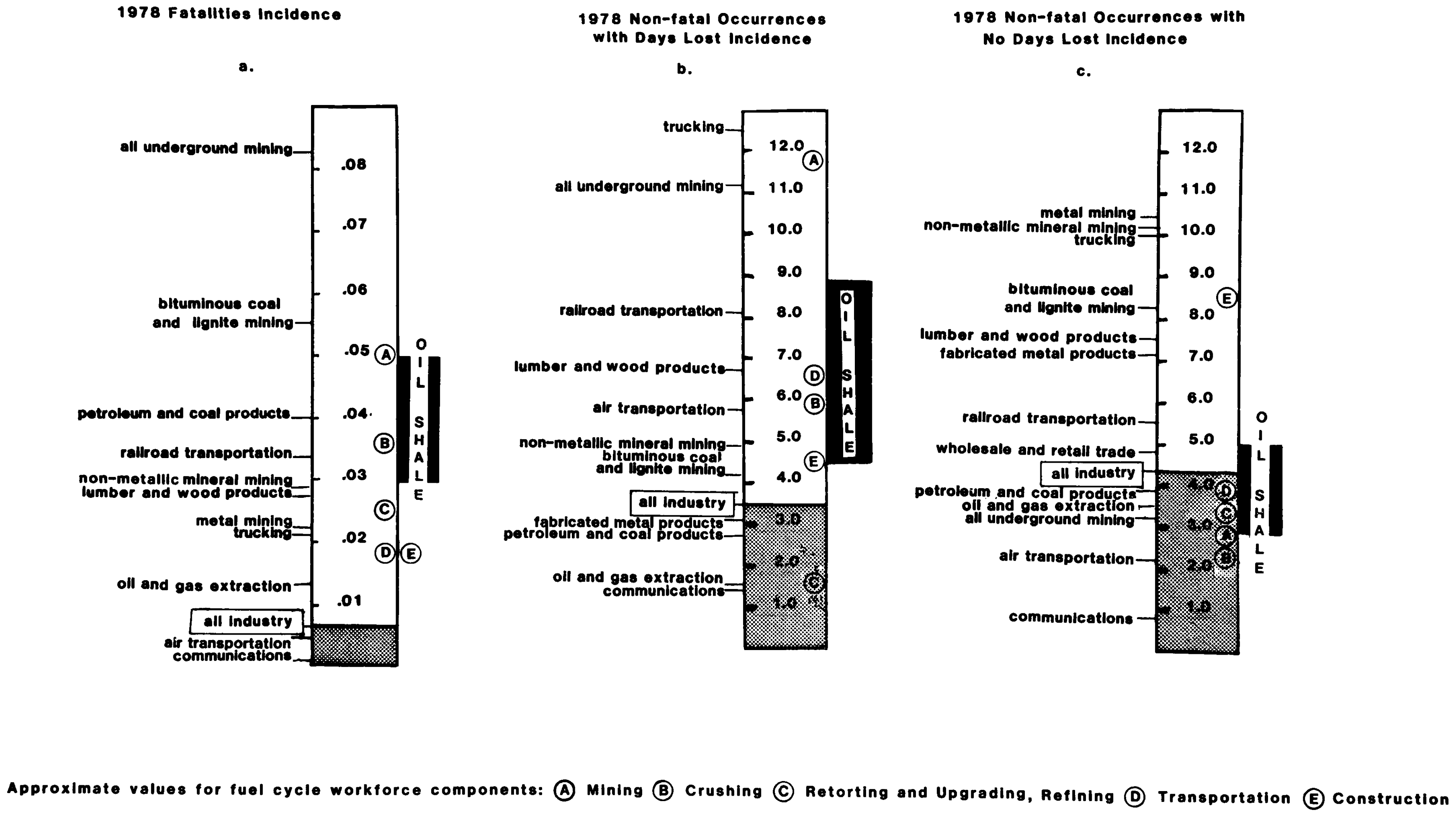

Figure 1. Comparison of Estimated Oil Shale Accidents and Injuries with Various Industries

miner's age, whether or not the miner was using powered equipment, the year in which the injury occurred, and the location in the mine where the injury happened. Injury severity was shown not to be related to the miner's total mining experience, job experience, and experience in the mine where the injury occurred. Accident severity and frequency for selected consequences are summarized in Table 8.

The underground coal mining accident severity and frequency data were used to predict the accident consequences in the oil shale scenario. Using the total estimated 1600 expected occurrences of serious accidents for oil shale mining, the underground coal mining severity surrogate yielded 13 fatalities vs. the 7.1 previously calculated (Table 7). The mine size factor used to reduce the expected fatalities for the large-scale oil shale mines may account for a large portion of this discrepancy.

Table 8. Surrogate Accident Severity and Frequency Summary

Accident Consequence	Occurrences for Underground Coal Mining [a]	Percent of Total	Predicted Oil Shale Occurrences [b]
Death	558	0.8	13
Permanent Total or Partial Disability	961	1.4	22
Restricted Activity with Days Lost	63,871	92.3	1500
Restricted Activity Only	3,786	5.5	88
Total	69,176	100.0	1600

[a] For U.S. Undergound Bituminous Coal Mines, 1975-1982 (6)

[b] Based on percent of total applied to 1600 estimated occurrences.

Safety Life-loss Expectancy

The life-loss expectancy (LLE) for oil shale accidents is defined as the average life expectancy minus the average age at death for accident victims. The calculations of this risk measure have begun but lack the average age at death for industrial-accident disabled persons and the average age at death for injured workers with restricted activity and time lost from work. Lacking these necessary statistics, only an estimate of LLE for fatal accidents has been made. The average age of an oil shale worker was assumed to be equal to the average age of underground coal miners (6), 32.3 years. Based on 13.3 total expected fatalities per year, the LLE for the safety portion of the risk was (74.9 - 32.3) x 13.3 or 567 man-years per year. Dividing the LLE by the total workforce of 41,000 oil shale workers yielded an average LLE of 0.014 man-years per worker per year. Similar results for the 14,200 oil shale miners as a group yielded a LLE of 305 man-years per year or 0.02 man-years per worker per year. These estimates assume fatal accidents occur equally in all age groups. The LLE for accidents and injuries for the oil shale work groups is shown in Table 9, indicating the high relative risk for the oil shale miners.

Table 9. Annual Accident and Injury Life-loss Expectancies for a One Million BPD Oil Shale Industry

Work Group	Life-loss Expectancy (Total Years)	Life-loss Expectancy (Man-years per Man)
Mining	305	0.021
Crushing	94	0.015
Retorting and Upgrading	73	0.0077
Construction	33	0.0099
Refining	43	0.0077
Transportation	21	0.0099

OCCUPATIONAL DISEASES

The 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) were discussed previously (1). Inhalation of dust as a result of mining, crushing, and retorting operations raised the possibility of adverse physiological reaction to dust in the oil shale workforce. The ability for self-protection and repair of injury can be exceeded. Four non-neoplastic lung responses to respirable dust particles potentially occurring in the oil shale industrial environment were analyzed: pneumoconiosis, silicosis, chronic bronchitis, and chronic airway obstruction. Simple pneumoconiosis

(0/1+) referred to all grades of simple pneumoconiosis, while complicated pneumoconiosis referred to progressive massive fibrosis (PMF) and was treated as an independent risk estimate. Pneumoconiosis dust exposure risk was estimated using the sum of simple and complicated pneumoconiosis. This risk was based on the exposure-response relationship derived from British coal industry data. The silicosis risk, another form of pneumoconiosis, was treated independently. This disease is caused by inhalation of silica (alpha quartz form).

Skin and internal cancers from hydrocarbons (7) along with internal cancers from radioactivity were also analyzed for the appropriate work groups. The potential for high frequency hearing loss was also included. Noise levels in various locations of the oil shale industry are expected to be high, especially in the underground mines where 1000-horsepower diesel equipment is planned. The current TLV expected to protect 90% of the workers was 85 dBA for an eight hours/day exposure. Age-specific data were used to generate a dose-response relationship between noise exposure and hearing impairment prevalence (1). With an assumed oil shale exposure of 85 dBA (TLV), the excess prevalence in the oil shale miners was estimated to be 5.6%, applicable to all underground miners. Based on the oil shale worker age distribution, the incidence in the 40-year working life population was 1.4 cases per 1000 per year. No quantification of risk of dermatitis, vibration disease, or adverse reproduction outcomes in oil shale workers was done because adequate dose-response relationships and exposures were not available.

The results for the occurrences of the diseases analyzed for the oil shale fuel cycle workforce are summarized in Table 10. The non-neoplastic lung diseases (8) were considered for two exposure levels, corresponding to the current nuisance dust level for oil shale mining of 5 mg/m^3 and the current free-silica threshold limit value (TLV) of 100 μg/m^3. The excess incidence of lung diseases in the oil shale miners and crushers represents a risk of primary concern if the high dust exposure level exists in the future oil shale industry.

Mortality Due to Occupational Diseases

The estimates of potential occurrence of occupational diseases were useful measures of the hazard. However, it is difficult to compare the diseases. For example, a case of squamous cell carcinoma of the skin is not easily compared to a case of respiratory silicosis. The conversion of all disease results to the number of fatalities caused by the disease improves the comparison. This conversion requires a case fatality rate for each disease.

The mortality attributable to cancers of the lung, stomach, kidney, and brain was approximated with data on 5-year relative survival as reported by Myers and Hankey (9) and Scotto and Fraumeni (10). The assumption was that those destined to die as a result of their disease will do so within 5 years of diagnosis. The fraction of cases dying within 5 years was 91% for lung cancer, 88% for stomach cancer, 56% for kidney cancer, 82% for brain cancer, 38% for melanoma, and 1% for both non-melanoma skin cancers (9, 10). Estimates of case fatality rates for occupational non-neoplastic lung diseases were derived (8) and ranged from 16% for simple pneumoconiosis to 44% for chronic airway obstruction. The rates are summarized in Table 11.

The predicted number of annual deaths for each of the occupational diseases in Table 10 is shown in Table 11. The premature fatality estimates from occupational diseases were derived by multiplying the disease occurrence estimates by the case fatality rates.

Disease Life-loss Expectancy

Life-loss expectancy (LLE) was another measure of risk computed for comparison of deaths due to accidents and death due to disease. The number of years lost for each disease is shown in Table 11. The total years of life lost due to occupational disease mortality was based on the average age at death for each disease. The distribution of ages at death for white males in 1977 (11) was used to establish the average age at death. In some instances, the precise disease entity of interest could not be used and a surrogate was selected. The average age at death was subtracted from the life expectancy for a 20 year old white male with a life expectancy of 74.9 years (11) to estimate the average number of years of life lost per death. Multiplying this by the expected number of excess deaths produced an estimated LLE for each occupational illness.

The LLE for occupational illness was dominated by the non-neoplastic lung diseases. At the extreme exposure of 5 mg/m^3, the associated 500 μg-SiO$_2$/m^3

Table 10. Excess Occurrences for Occupational Diseases for a One Million BPD Oil Shale Industry

Disease	Excess Cases per year per 1000	Work Group	Cases Per Year
Lung: Exposure A			
Pneumoconiosis			
Simple (0/1+)	6.4	MC	130
Complicated (PMF)	0.55	MC	11
Silicosis	14.5	MC	295
Chronic Bronchitis	2.0	MC	41
Chronic Airway Obstruction (FEV$_1$ <65%)	0.73	MC	15
Lung: Exposure B			
Pneumoconiosis			
Simple (0/1+)	2.1	MC	42
Complicated (PMF)	0.03	MC	0.5
Silicosis	2.0	MC	41
Chronic Bronchitis	0		
Chronic Airway		MC	0
Obstruction			
(FEV$_1$ <65%)	0	MC	0
Internal Cancers			
Lung (hydrocarbons)	0.115	RU/R	1.73
(radioactivity)	0.00087	MC	0.022
(arsenic)	0.012	MC	0.25
Stomach	0.039	RU/R	0.59
Kidney	0.022	RU/R	0.33
Brain	0.069	RU/R	1.04
Skin Cancers			
Melanoma	0.029	RU/R	0.44
Basal Cell	1.080	RU/R	16.2
Squamous Cell	0.290	RU/R	4.4
High Frequency Hearing Loss	1.4	MC	28.6

Exposure A: 5 mg (dust)/m^3 or 500 µg (SiO_2)/m^3 at 10% free silica
Exposure B: 1 mg (dust)/m^3 or 100 µg (SiO_2)/m^3 at 10% free silica
MC: Mining and Crushing Work Groups (20,400)
RU/R: Retorting-Upgrading and Refining Work Groups (15,000)

Table 11. Life-loss Expectancy (LLE) from Occupational Diseases for a One Million BPD Oil Shale Industry

Cause of Death	Cases	Case Fatality Rate (%)	Premature Fatalities per Year	Years of Life-loss/ Death [1]	Total LLE per Year
Lung: Exposure A					
Pneumoconiosis					
Simple (0/1+)	130	16	21.	3.05	63.2
Complicated (PMF)	11	23	2.6	3.05	7.9
Silicosis	295	33	97.	3.05	298.
Chronic Bronchitis [2]	41	38	15.	3.05	47.
Chronic Airway Obstruction [2] (FEV_1 <65%)	15	44	6.5	3.27	20.
Lung: Exposure B					
Pneumoconiosis					
Simple (0/1+)	43.	16	6.9	3.05	21.
Complicated (PMF)	0.5	23	.14	3.05	.4
Silicosis	41.	33	13.	3.05	41.
Chronic Bronchitis	0.	38	0.	3.02	0.
Chronic Airway Obstruction (FEV_1 <65%)	0.	44	0.	3.27	0.
Internal Cancers:					
Lung	2.	91	1.6	8.83	14.
Stomach	.6	88	.52	6.03	3.1
Kidney	.3	56	.18	9.35	1.7
Brain	1.	82	.85	16.3	14.
Skin Cancers:					
Melanoma	.44	38	.17	13.7	2.3
Basal Cell	16.2	1	.16	13.7	2.2
Squamous Cell	4.4	1	.04	13.7	.6

Exposure A: 5 mg (dust)/m^3 or 500 µg (SiO$_2$)/m^3 at 10% free silica.
Exposure B: 1 mg (dust)/m^3 or 100 µg (SiO$_2$)/m^3 at 10% free silica.

[1] Based on a life expectancy in 1977 for a 20-year old white male of 74.9 years (11)

[2] To correct for chronic bronchitis and chronic airway obstruction overlap (8), subtract when combining: 14 cases, 6 premature fatalities per year, and 19 years LLE.

exceeded the TLV and resulted in a 300-year annual LLE from silicosis, a 70-year annual LLE from pneumoconiosis, a 46-year annual LLE from chronic bronchitis and chronic airway obstruction (which includes a correction based on combined cases of chronic bronchitis and chronic airway obstruction) for a total non-neoplastic lung disease annual LLE of 416 years . At a lower dust level of 1 mg/m^3, with the associated 100 µg-SiO$_2$/m^3, the non-neoplastic lung disease annual LLE decreased to 62 years, with two thirds due to silicosis and one third due to pneumoconiosis. At this level, the LLE from cancers was about one half of the LLE from lung disease.

The uncertainty analysis for these estimates needs to be completed following the previously used methodology for safety and diseases (1, 7). The analysis will reflect the changes in the exposure uncertainties and the applicability of the surrogates chosen. The results will be useful in comparing upper bounds for the various risk measures.

COMPARISON

Comparing the estimated risks for the oil shale workforce illustrated that the mining and crushing workers are in "high risk" work groups for both accidents (Table 7) and occupational diseases (Table 11). These workers represent 50% of the workforce but account for 70% of the expected fatalities and the majority of occupational diseases. On an LLE basis, a similar relationship occurred. For the overall workforce at the 5 mg/m^3 nuisance dust level, the LLE for diseases and accidents were about equal.

At the 100 $\mu g\text{-}SiO_2/m^3$ exposure level, the hydrocarbon-induced cancers represented one third of the disease LLE. The disease LLE decreased to 15% of the total LLE. At the lower dust exposure, safety issues dominate.

SUMMARY AND RECOMMENDATIONS

Based on the magnitude of the estimated risks and the importance of the disease in terms of worker productivity and health, pneumoconiosis from silica and dust, chronic bronchitis, and chronic airway obstruction stand out among the diseases analyzed. This result stresses the need for future consideration of mine dust control. Research is needed to reduce the uncertainties in the dust related diseases, such as an improved dose-response relationship and dust exposures for oil shale workers. The free silica content of oil shale dusts inhaled by workers has been shown to be a key element for the potential risk of silicosis.

Risks which were not quantified were dermatitis, vibration disease, and adverse reproductive outcomes. More industrial hygiene data are necessary to quantify the former two while basic health effects research (epidemiology and toxicology) should provide useful data for quantifying the latter.

If the environmental dust exposure of the worker is improved, safety improvements in the mining sector are of prime importance to reduce the oil shale worker's life-loss expectancy.

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