IDENTIFICATION OF KEY RISKS UNDER DIFFERENT MEASURES FOR A FUTURE OIL SHALE INDUSTRY

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Risk management can be enhanced for a future oil shale industry by identification of the key health and environmental risks. Different risk measures and associated uncertainties can be used to establish research requirements. The risk measures analyzed were cases (occurrences of accidents or disease), premature fatalities, and life-loss expectancy. The analysis for the occupational risks in the oil shale fuel cycle resulted in silicosis from the dust environment as the worker disease of primary concern, following by other forms of pneumoconiosis, chronic bronchitis, chronic airway obstruction, internal cancer, and skin cancers, respectively. Design of mine environments at 1 mg/m^3 dust as opposed to current nuisance dust level of 5 mg/m^3 results in a balancing of the accident, cancer, and dust-induced disease risks. Comparison of safety, dust-induced disease and cancer for the workforce show safety of prime concern for cases while dust-induced diseases dominant for fatalities and life-loss expectancy. Cancer has a low priority except for the high uncertainty range estimates for life-loss expectancy. The public sector cancer risk estimates are very small although other public and environmental risks issues require further analysis.

KEYWORDS: Oil Shale, Occupational Disease Risk, Occupational Safety Risk, Risk Measurement Comparison

INTRODUCTION

The results of the 1984 oil shale risk analysis for the fuel cycle (extraction through delivery of the products) representing a steady-state, one million barrels-per-day (BPD) oil shale industry in the United States in the year 2010 are summarized using graphics to show different risk measures. The 1984 analysis (1) complements and updates the results of both the 1981 (2) and 1982 (3) oil shale risk analyses, concentrating on the recommendations of the National Academy of Sciences' review (4). The methodology to establish and prioritize key research is a useful process to aid in risk management.

OIL SHALE AND SHALE OIL

A future oil shale processing industry will not be developed until the proper economic conditions prevail. The industry will be a massive solids handling industry generating large amounts of hazardous materials. Oil shale is a sedimentary rock that produces a petroleum-like liquid through destructive distillation (pyrolysis). Oil shale deposits in the United States represent an immense fossil fuel resource. The world's premier oil shale deposit is found in the Green River geologic formation in Colorado, Utah, and Wyoming, representing proven reserves of over one-trillion barrels. Shale oil is produced from the oil shale mined from these deposits by a process called retorting. This process involves crushing oil shale into small pieces and heating for extended periods. There are many different shale retorting technologies and each attempts to produce oil and other marketable products in an efficient and economical manner. The retorting process scheduled to be the first modern commercial-sized production at Union Oil's Parachute Creek site uses oxygen free retort gases heated to 540^{o} C recycled through the shale to supply the needed heat.

OIL SHALE RISKS AND UNCERTAINTIES

Methodology

The purpose of the oil shale risk analysis was to identify those aspects of the oil shale industry which could impact human health and the environment, and which need further investigation, analysis, or research. The risk results were estimated for annual premature deaths from occupational accidents, occupational disease, and public disease. Other measures of the estimated risk include the number of cases, the life-loss expectancy, and the life-loss expectancy per man. A methodology was developed for this analysis which allows tracking of component uncertainties into the uncertainty of the risk estimate, including the objective and subjective contributions. The analysis used available information about surrogate industries. The information itself, as well as the process of extrapolation from surrogate industries, contains a number of assumptions and uncertainties. The effect of these assumptions and uncertainties was estimated by assigning an uncertainty range of the risk estimate. This uncertainty range was based on both objective and subjective considerations. In essence, a narrow uncertainty range denotes more confidence about the health risk estimate and wide uncertainty range denotes less confidence. Apart from this subjective indication of confidence, the range does not have any precise statistical meaning. Thus, relatively high risk estimate with a wide range indicates a relatively significant risk, which requires further analysis or research to reduce the uncertainty in the estimate. While these types of estimates are useful in identifying needed information and research, they are inappropriate for other uses, especially regulatory purposes.

The research recommendations for reducing the uncertainties of the risk estimates are presented in Table 1. Research needs based on lack of information to estimate a risk are summarized elsewhere (1).

Occupational Risks

The risk analysis considered two dust exposure scenarios for the occupational workforce: Scenario A representing exposures about the nuisance dust limit of 5 mg/m^3 dust and Scenario B representing exposures about the free-silica limit of 100 ug/m^3 for an assumed 10% silica content of dust (corresponding to 1 mg/m^3 dust).

A graphical depiction of the analysis results are shown in Figures 1 through 3. Figure 1 presents the results for the occupational accidents and disease discussed above. The area of the circles is proportional to the magnitude of the risk estimate. The solid circle represents the "best estimate" of the risk. The dash-lined circle represents the lower uncertainty and the dash-dot-dash lined circle the upper uncertainty. The intent of these figures is to depict how the uncertainties change for component risk areas. The corresponding risk areas (accidents, cancers, and dust-induced diseases) are denoted by the designated shading for the upper uncertainty and nominal estimates only. Both Table 1 and Figure 1 show that accidents dominate the aggregated total cases of disease and injury (although it is not informative to compare a minor industrial accident to a disabling lung disease). The uncertainty analysis for occupational disease risk shows that dust-induced disease (for both exposure scenarios) has the largest potential for reducing the uncertainty range through research. The dust-induced diseases analyzed were pneumoconiosis, silicosis, chronic bronchitis, and chronic airway obstruction (5).

Figure 2 summarizes the annual fatalities and again shows that dust-induced disease has the largest potential for uncertainty range reductions derived from research. For Scenario A, dust-disease fatalities are the dominant risk, representing 86% of the total premature fatalities and 89% for the upper uncertainty estimate. For Scenario B, the corresponding values are 47% and 59%, respectively, indicating a lesser importance of the dust at the lower scenario level and increased potential for research uncertainty reduction through cancer research.

Another risk measure shown in Figure 3, the annual life-loss expectancy in total years, indicates that the accidents dominate the total occupational risk estimate at 61%, but falls to 30% in the upper uncertainty estimate, again indicating the high potential for uncertainty reduction in the Scenario A dust-induced disease risks. For Scenario B, the accidents dominate all risks and offer the most potential for risk uncertainty reduction, followed by cancers and dust-induced disease.

Table 1. Summary of risk results and research recommendations from a hypothetical million BPD oil shale fuel cycle

Health or Environmental Effects	Exposure	Risk Per Year (Uncertainty Range) Cases	Deaths	Research Recommendations
WORKERS (Population at Risk: 41,000 persons)				
Injury	Accident with days lost	2400 (1700-3700)	13	Underground mining and crushing safety improvements; Improved workforce estimates; New Process (retorting) safety; Use of large equipment safety; Life-long expectancies for disabling injuries.
Injury	Accident with days lost	1500 (1200-2200)	NA	
Cancers	Hydrocarbons, Radiation, As	26 (0-300)	4 (0-49)	Occupational hydrocarbon exposure characterization Latency of carcinogenic effects; Comparative toxicology; Industrial hygiene characterization; Improved refinery worker cancer studies.
Silicosis	Dust*	232 (0-1070)	76 (0-387)	Dust exposure to silica; Improved silica exposure control; Characterization of exposure; Combined effects with diesel exhausts.
Pneumoconiosis	Dust*	100 (33-310)	17 (9-98)	Fundamental research on pneumoconiosis regarding causations; Relative fibrogenicity; Mine dust control; Characterization of exposure; Industrial hygiene.
Chronic Bronchitis	Dust*	41 (13-130)	15 (4-51)	Mine dust control; Characterization of dust exposure; Comparative toxicology; Industrial hygiene characterization.
Airway Obstruction	Dust*	10 (3-36)	5 (1-17)	Mine dust control; Characterization of dust; Comparative toxicology; Industrial hygiene characterization
High Frequency Hearing Loss	Noise	3 (0-8)	NA	Occupational noise level measurements

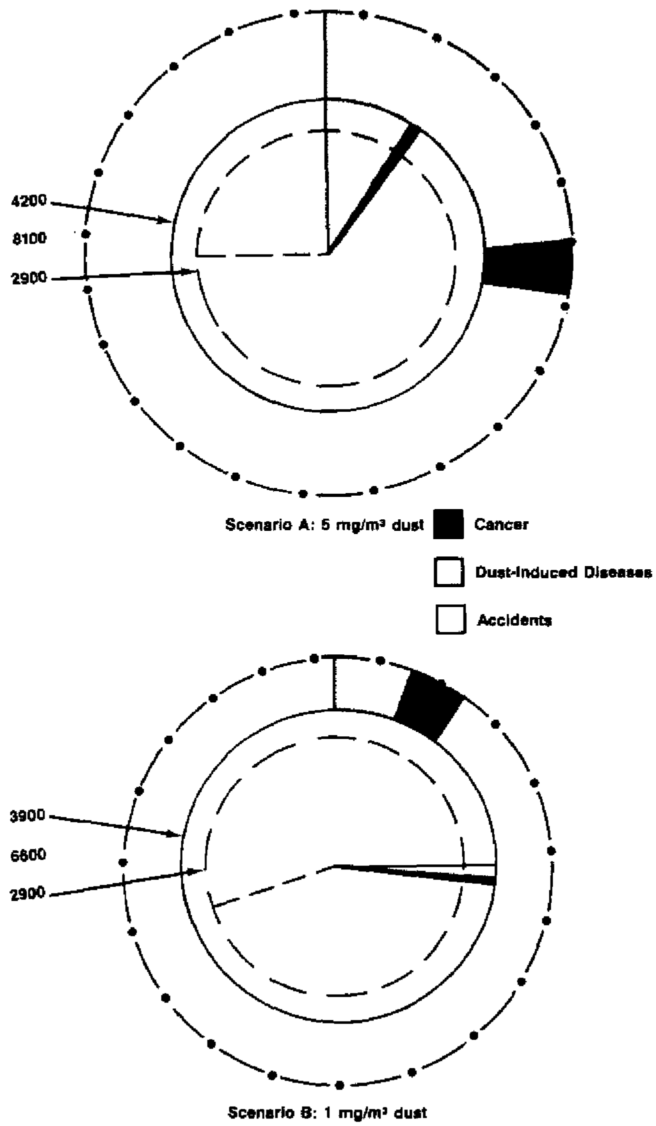

Figure 1. Annual occupational cases of injury and disease for a one million barrels-per-day oil shale industry

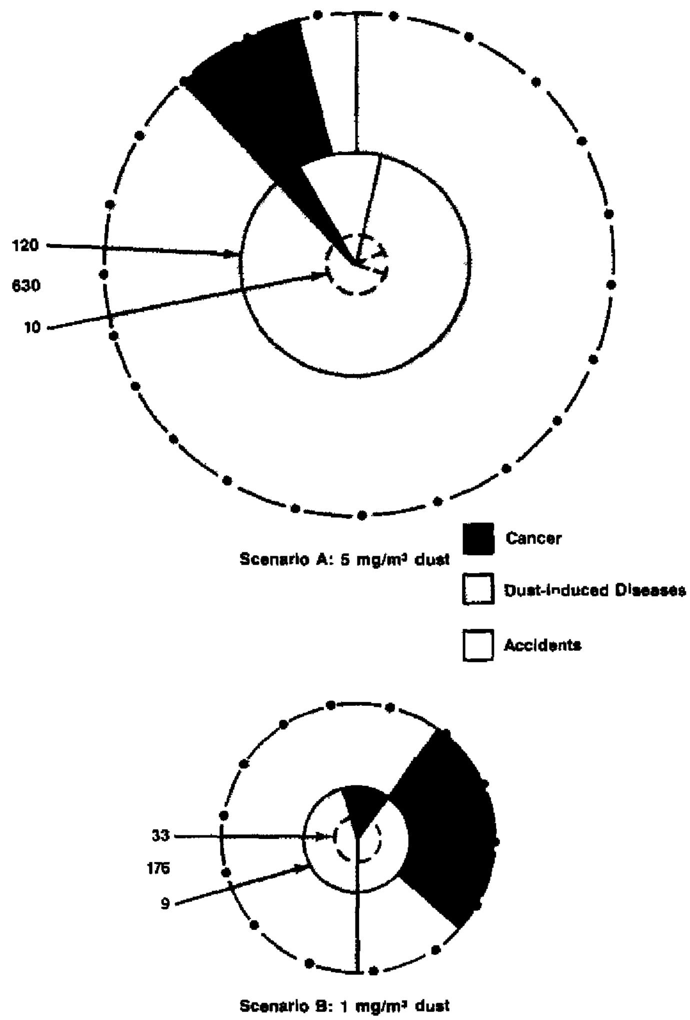

Figure 2. Annual occupational fatalities for a one million barrels-per-day oil shale industry

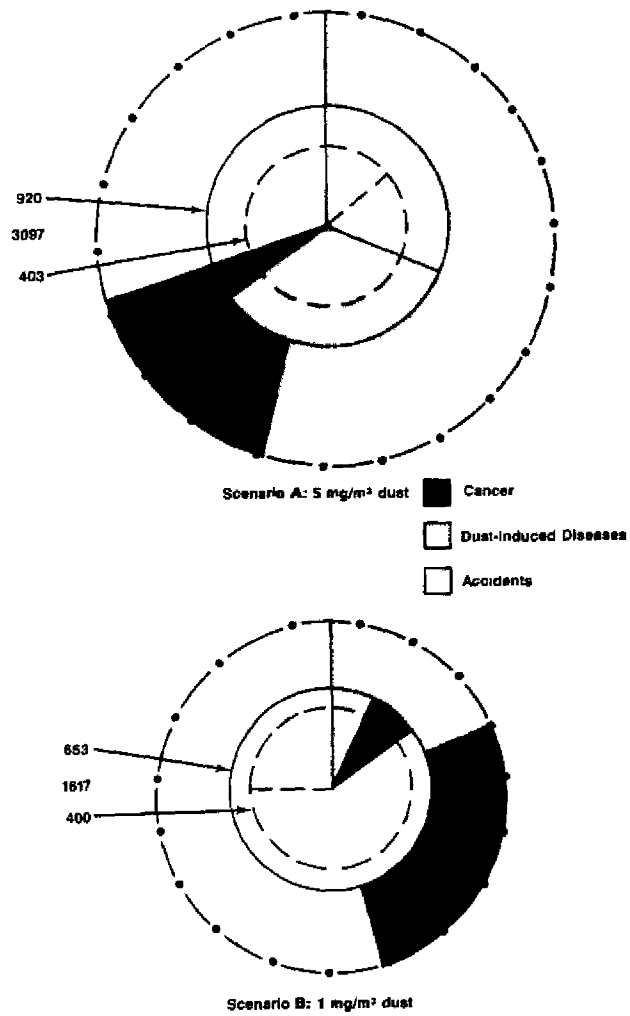

Figure 3. Annual occupational life-loss expectancy for a one million barrels-per-day oil shale industry

Life-loss expectancy per man estimates were used to establish high risk occupational groups in the oil shale fuel cycle workforce. Silicosis in mining and crushing is the key occupational concern followed by lung cancer and brain cancer from hydrocarbon exposure for this risk measure.

The risk results indicate that from safety considerations the workers in the extraction phase of the oil shale industry, mining and crushing, are at a higher risk than those in the other portions of the fuel cycle (6). When large relative uncertainties are considered, safety in the transportation and retorting/upgrade populations become of concern.

The retorting/upgrading upper uncertainty estimates are large due to the lack of relevant historical safety statistics for large-scale retorting. The oil shale industry will be a massive solids handling industry. There is no applicable surrogate for the large vessel heating of solids that occurs during retorting. Applicable data should be compiled during the commercial demonstration phase to allow these uncertainties to be reduced. The overall safety results indicate that research to improve underground mining safety is desirable. The safety aspects of the use of large equipment in the underground oil shale mines will be important to the developing oil shale industry. It is also important for oil shale mine accidents to be monitored as the industry grows because the use of coal mine data cannot accurately predict the potential oil shale accident rates.

One research area to fill a data need for occupational health and safety is the Life-Loss-Expectancy (LLE) due to non-fatal accidents. This would allow a better comparison of disease-induced LLE with the LLE from accidents. An epidemiologic study of mortality of persons with various disabilities could provide useful data.

Risks of non-neoplastic lung diseases for future U.S. oil shale worker dust exposures were estimated between 56 and 390 cases annually. In the absence of an active industry, health effects rates from surrogate industries were utilized. The risk of chronic bronchitis, chronic airway obstruction, and pneumoconiosis was quantified from British coal worker data (5). The risk of occupational silicosis in oil shale miners was estimated using worker studies from Peruvian metal mines, Vermont granite sheds, West Virginia potteries, and Utah non-ferrous metal mines. Ten percent free silica composition of the dust in the respirable range from oil shale mining and crushing was assumed (with a ±5% uncertainty range). Silicosis was the dominant pulmonary health effect, but at the Scenario A dust level, pneumoconiosis, chronic bronchitis, and chronic airway obstruction are also important risks. Designing oil shale facilities to meet the nuisance dust threshold limit value may not provide adequate protection to the future workers involved in oil shale extraction and processing.

An estimate of 26 cases of occupational cancer risks due to hydrocarbon exposure during retorting, upgrading, and refining was derived using epidemiological studies in a surrogate industry. The oil refining industry was selected as a surrogate, with an attempt to adjust the refining cancer incidence using oil shale toxicologic and exposure data. Risk estimates were derived for those cancers which may be excessive in refinery workers, namely lung, stomach, kidney, brain, and skin cancer (7,8). The magnitude of health risks for these diseases was very small, with the estimated 15,000 exposed workers suffering 4 excess internal cancers per year and 21 excess skin cancers per year. The cancer risks from the radiation dose from inhalation of radon and thoron daughters in addition to inhalation of arsenic dust by the miners and crushers was also calculated. The total occupational cancer disease is expected to produce less than 5 deaths per year.

Other occupational diseases were considered, including: hearing loss (with an excess prevalence of 8.2% for mines); dermatitis (prevalence based on hygiene practices); vibration disease (prevalence based on preventive practices); and adverse reproductive outcomes (an important future consideration for the industry).

In spite of considerable uncertainty, hydrocarbon-induced cancers are overshadowed by dust-related respiratory disease occupational health risks in the oil shale industry (6).

Public Risks

In the public sector, the fine particulate surrogate health-damage function replaced the sulfur surrogate function used in previous analyses (9). The resulting risks in the public sector were lower than previous estimates. To reduce the fine particulate health damage function uncertainty, an improved exposure index in the epidemiological study of health effects of air pollution is needed. This would couple the spatial and temporal activities of people to establish the person-exposure distributions for indoor vs. outdoors and occupational vs. public. Apportionment of the aerosol components to the health effects should also provide a means for reducing the uncertainty. Also, time series data for other parts of the United States would be beneficial for reduction of the standard errors of the damage function.

The long range transport of oil shale pollution across the entire U.S. resulted in a risk estimate of about half of the regional risk. The uncertainty of this estimate was much greater than the regional uncertainty. The source of the additional uncertainty is the exposure modeling, with the wet and dry deposition uncertainty terms dominating other modeling term uncertainties.

The public cancer risk estimates are very small, which limits the importance of any associated research recommendations. Nonetheless, the major component uncertainty is in the health dose-response functions which could be reduced by re-assessment with better epidemiologic studies of carcinogenic risk. Better extrapolation methods from high to low doses may also reduce uncertainty.

Other public health issues continue to be sources of uncertainty. The channelling of air pollution in valleys and canyons could raise pollutant concentrations above the disease thresholds during upset operating conditions or very unusual meteorological conditions. New pollutants not yet recognized as an oil shale concern could be identified. Region-specific factors could affect the dose-response relationship of know pollutants which were found to be of little consequence in this analysis. The additional quarter-million people associated with the growth of the oil shale industry, would have a significant impact on the pollution levels of the region, almost as much as the industry itself. The impact of these pollutants should be considered in further analyses.

Environmental Risks

The need to process 1 to 3 tons of shale per barrel of oil results in a major solid waste disposal problem. Retorted shale is by far the most substantial solid waste produced by a surface retort. Results of the analysis of potential impacts on the semi-arid, high altitude ecosystem yielded minimal risks from air pollutants and land disturbances, but of potential concern for aquatic systems under extreme conditions (10).

Aqueous wastes from oil shale processing originate from direct and indirect sources. Direct sources are waste waters generated from unit operations and processes. Indirect sources include: leachate from retorted shale disposal areas; run-off and erosion resulting from construction and site use activities; and run-off from mining and transport activities. Approximately 45 to 50 percent of the water required for an oil shale plant is expected to be used for moisturizing of retorted shale. Much of this water requirement will be supplied by minewater and process wastewaters. Because of the large quantities of water utilized and the exposure of retorted shale to rain and snowfall, a source of indirect water pollution may occur via leaching or run-off from retorted shale piles. Leaching experiments in the laboratory and with small field studies indicate that inorganic salts (eg. sodium, magnesium, chlorides, fluorides, and sulfates), small quantities of organic substances, and/or trace elements may be leached from both raw-shale storage piles and spent-shale disposal piles.

The impact of an oil shale industry on the water resources of the Western United States involves several controversial issues. Release of oil shale process waters, by intention or accident, may expose local area residents of toxic pollutants in drinking water. However, there is major uncertainty regarding the probability of such occurrences, the reliability of a "zero-discharge" system, and the attenuation of released pollutants in surface waters. Leaching of solid wastes is a potential environmental problem which may extend several centuries after final abandonment of an industry. Percolating water from rainfall and snowmelt through spent shale piles and abandoned in-situ retorts may dissolve a portion of the spent shale matrix. This polluted water could migrate a surface waters and ultimately to drinking water. Also, the issue of water availability is a perennial controversy due to the large amount of water needed by the industry and the limited amount of water available on the western slope.

The analysis indicated that significant water shortages begin to appear somewhere between 2000 to 2040 depending on the assumptions made about growth of non-oil shale uses. This does not imply that oil shale could not be developed; water rights can be brought and sold. However, it does mean that the economics of water rights purchase may affect oil shale development.

Research recommendations based on the water quality and solid leachates analyses include the following: a description of water management within an oil shale facility including probabilities of leaks, overflows, and accidents; characterization of leachate attenuation in groundwater; and data for waterborne organics release rates and transformation in the environment.

Risk Analysis Methodologies

Further research into risk analysis methodologies and implementations are also recommended. The dust-induced risk analysis should be extended to all types of underground mining and compared to historical statistics. The LLE for disabling accidents would allow a better comparison of occupational accidents and diseases. Finally, the results of this analysis should be tested in research planning, generation of useful results, and risk management processes. The potential utility of the current risk analysis for research planning (11) would be increased by updating with the results of current oil shale health effects research on the defunct Scottish industry (12) and measurements from commercial-scale U.S. oil shale facilities.

SUMMARY

The management of the health and environmental risks of a future oil shale industry will require a proper scientific basis for their quantification and, if necessary, mitigation. Research is needed for providing the scientific basis for this decision making process. The current risk analysis presents a methodology and the initial estimates for health and environmental risks of a steady-state million BPD oil shale industry. The effort was based on existing and novel approaches. The estimated uncertainty factors associated with the key risks can be used to assess and prioritize research needs to reduce the important uncertainties. The use of the analysis for aid in research management is a dynamic and interactive process. As new information becomes available, the risk analysis can be iterated and updated as part of the research prioritization process to focus on critical risk management issues.

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