EPIDEMIOLOGICAL FOLLOW-UP OF URANIUM MINERS IN CANADA

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INTRODUCTION

The hazards of exposure of uranium miners to high concentrations of radon and radon daughters have been recognized for several decades. Quantitative estimates of risk based on epidemiological followup of exposed miners are becoming increasingly available in recent years. The present report deals with four studies of Canadian miners; the results are compared with those of two other major studies of U.S. and Czechoslovakian uranium miners.

RISK COEFFICIENTS

Table 1 summarizes the quantitative estimates of risk of induced fatal lung cancers per WLM of exposure to short-lived radon daughters. Lung cancers appearing less than 10 years after first exposure are usually excluded in these calculations in order to ensure better comparability of the data from short and long term followup and to ensure that the risk coefficients are not too low because of the inclusion of years of followup during which no effect of radon daughter exposure is anticipated (2). These data thus represent the average risk coefficients observed between 10 years after first exposure and the end of the followup, at which time most of the miners were still alive.

A major problem in all these studies is the reliability of the exposure estimates. In general, exposure rates were highest during the earliest years of mining and were decreased, primarily by improved ventilation practices, in later years. However, monitoring of radon daughter concentrations was infrequent or absent during the earliest years of mining; the exposure histories of the early miners with the highest exposures and longest followup have necessarily been reconstructed from minimal data. In the study of 15 984 Ontario uranium miners, estimates of radon daughter concentrations were based on results of area monitoring in the mines in the early years or in cases where no reliable measurements were available, on estimates provided by three mining engineers who were familiar with the Ontario uranium mines over the early years of operation (8).

The risk coefficients derived from these studies (Table 1) vary over a range of about 10-fold. This is true both for estimates based on the relative risk model (expressed as % increase in normal incidence of lung cancer per WLM) and on the absolute or attributable risk model (expressed as excess number of lung cancers per 10^6 person-years at risk per WLM). Part of this variation is probably due to uncertainties in estimated exposures. The range of risk coefficients appears to be compatible with the average values of 1% increase in normal incidence of lung cancer per WLM or 10 lung cancers per 10^6 person-years per WLM that were suggested in ICRP Publication 50 (9).

MINIMUM LATENT PERIOD; EFFECT OF TIME AFTER EXPOSURE

Previous studies have in general not shown a significant excess of lung cancers within the first 10 years of followup after first exposure to radon daughters in uranium mines. It is therefore of some interest to note that the studies of Beaverlodge and Port Radium miners both showed zero excess of lung cancers 0-5 years after first exposure but a statistically significant increase 5-10 years after first exposure (1,7).

The effect of age at first exposure has been examined in 3 of the Canadian studies. No consistent trends in the risk coefficients were observed (1, 5, 7). Three of the 4 Canadian studies showed a trend towards a decrease in relative risk coefficient with increase in age at the time of appearance of lung cancers (1,5,6). A similar trend is probably valid for the followup of U.S. uranium miners (10). A more sophisticated risk model was also tested in a recent reanalysis of the Ontario data by Muller and co-workers (11). In this model, the increase in relative risk was assumed to be 0% during the first 5 years after each increment in radon daughter exposure and best values for relative risk were calculated for subsequent times after each exposure. The available data on Ontario uranium miners suggested an increase in relative risk per WLM of 1.6% at 5-10 years, 3.4% at 10-15 years and 0.3% at 15 or more years after each annual increment in exposure (11) . The raw data from certain other studies can also be fitted by a similar model.

EFFECT OF CIGARETTE SMOKING

Approximately 70% of the miners in all groups listed in Table 1 were cigarette smokers. The Ontario miners' study included large groups of gold miners and of copper-nickel miners as well as uranium miners. An excess of lung cancers was observed in the group of gold miners as well as the uranium miners, but not in the group of copper-nickel miners, who are believed to have a similar smoking history. The major cause of lung cancer among the gold miners was cigarette smoking, as expected, with a relative risk of 7 for smokers compared to non-smokers (12). The excess lung cancers observed in the gold miners group appeared to be correlated with exposure to high ore dust levels in the earlier years of mining before 1945. Smoking also increased the risk of silicosis (12).

Interactions between cigarette smoking and inhalation of radon daughters were examined in the study of Newfoundland fluorspar miners. The data did not permit a clear choice between the relative risk model, indicative of a multiplicative interaction, and the absolute risk model, indicative of an additive interaction (5). Limited data from the Ontario study were compatible with the hypothesis of a multiplicative interaction (11). Other data have suggested that cigarette smoking accelerates the appearance of lung cancers in exposed miners, with the result that a multiplicative interaction between smoking and radon daughter exposure is most evident at the earlier stages of followup but absent or less evident many years after exposure (4, 13).

DOSE-RESPONSE RELATIONSHIP

The data from all 4 Canadian studies are compatible with a linear, non-threshold relationship between accumulated exposure and incidence of induced lung cancer. The fluorspar miners' study did not provide any evidence of a decreased response per unit dose at high accumulated exposures in the region of 2500 WLM (5), such as has been observed in the study of U.S. uranium miners (2, 4, 13).

LIFETIME RISK ESTIMATES

The excess risk of death from lung cancers before age 70 has been calculated for male uranium miners using both relative and absolute risk models, the expected values for non-exposed males being derived from Canadian vital statistics (5,7). Using the average risk coefficients suggested in ICRP Publication 50 (9), the values are equivalent to a risk of 2.5-2.9 x 10^{-4} per WLM. A total lifetime risk of about 3 x 10^{-4} per WLM would appear to be a reasonable choice, assuming that exposure to radon daughters at any age resulted in an increased risk of lung cancer which continued throughout life. If the relative risk model were correct, the risk to non-smoking miners would of course be appreciably smaller (9). Assuming that increased risk ceased 15 years after each exposure, the lifetime risk would be closer to 1.7 x 10^{-4} per WLM for male miners exposed to 1 WLM per year from age 20 to age 55, based on the time-dependant relative risk coefficients which were derived from the study of Ontario miners. Further study of miners exposed at younger ages only would be required to substantiate this latter model.

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TABLE 1. ESTIMATES OF RISK OF INDUCED LUNG CANCER IN VARIOUS GROUPS OF MINERS

Group of miners	Average estimated exposure in WLM	Excess lung cancers appearing more than 10 years after first exposure		Reference
		% increase per WLM in normal incidence	Excess cancers per 10^6 person-years per WLM	
Eldorado Port Radium uranium	273[a]	0.27	3.1	1
U.S. uranium	1180	0.3-0.45 0.8-1.4[b]	3.5 6[b]	2,3 2,4
Nfld. fluorspar	548	0.9	6.4	5
Ontario uranium	33	1.0 1.3[c]	9.7 7.2[c]	6
Czech uranium, started 1948-52	310	1.8	19.	2
Eldorado Beaverlodge uranium	36[d]	3.3	21.	7

[a] 44% of the person-years at risk in the category with <5 WLM and with no excess lung cancers were excluded for this calculation.
[b] Calculated for groups receiving lower exposures (<360 WLM) only.
[c] Risk coefficients for the group of miners with no prior experience in gold mining. Data based on "special WLM" estimates (6,8) are not included.
[d] 74% of the person-years at risk in the category with <5 WLM and with no excess lung cancers were excluded for this calculation.