Radiation Effects

LEUKAEMIA AND LYMPHOMA AMONG CZECH URANIUM MINERS

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Introduction

Leukaemia is one of the most sensitive cancers in relation to ionizing radiation. It is surprising that in studies of uranium miners, no risk of leukaemia in relation to cumulated radon exposure was observed (Darby et al, 1995). However, when the risk among Czech uranium miners was analyzed in dependence on duration of exposure, the trend was significant. These results were based on 10 cases (Tomasek, 1993). Since then the original cohort of 4320 miners has been extended by another cohort, now including nearly 10 000 uranium miners and the follow-up is longer by 10 years. The present report aims to analyze the risk of haemopoietic cancers in the Czech cohort accounting for both external and internal doses, similarly as reported by Jacobi and Roth (1995), and using available data on metal content and airborne particulates for dose estimates.

Data and methods

Study population

The study population includes a total of 9973 uranium miners from two cohorts (S and N) described elsewhere (Tomasek et al, 2003). Main characteristics of the study are given in Table 1.

Table 1: Main characteristics of the cohort

Cohort	S	N	S+N
Number of miners	4348	5625	9973
Exposed in period	1948-63	1968-86	
Alive in 2000	20%	84%	56%
Mean time since first exposure (years)	31	27	29
Mean duration of exposure (years)	9	5	7
Leukaemias	23	7	30
SMR*	1.7	1.2	1.5
NonHodgkin Lymphomas	10	6	16
SMR*	1.3	1.7	1.4

**SMR - standardized mortality ratio of observed and nationally expected numbers*

Estimation of exposures

External gamma and long lived alpha individual data in the study are based on ambient measurements since 1970. Exposure estimates of external gamma and long lived radionuclides in uranium mines not covered by measurements were derived from annual data on uranium content and airborne particulates (Figures 1 and 2).

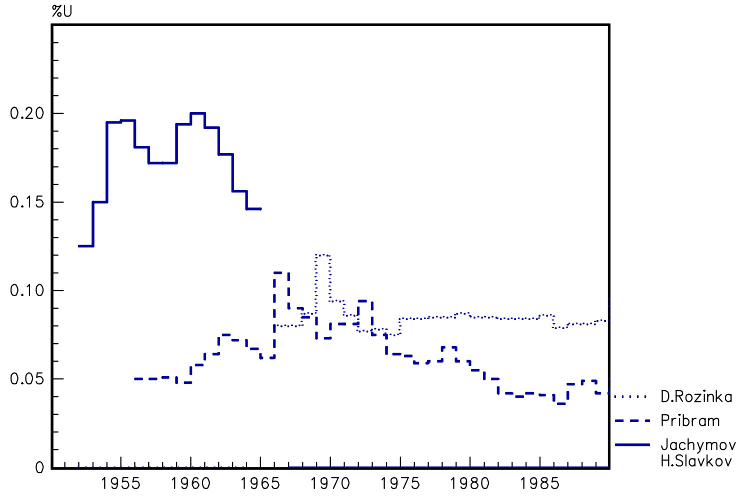

Figure 1: Annual metal content in uranium ore (%U) in Czech uranium mines

The conversions from metal content (%U) to annual external gamma dose corresponding to full time job of the hewer were derived according to a report by Lehmann et al (1998), ie. for metal content 0.09% (11.1Bq/g), the corresponding annual external doses are 7.8 mSv at 2200 hours per year and 6.4 mSv at 1800 hours per year.

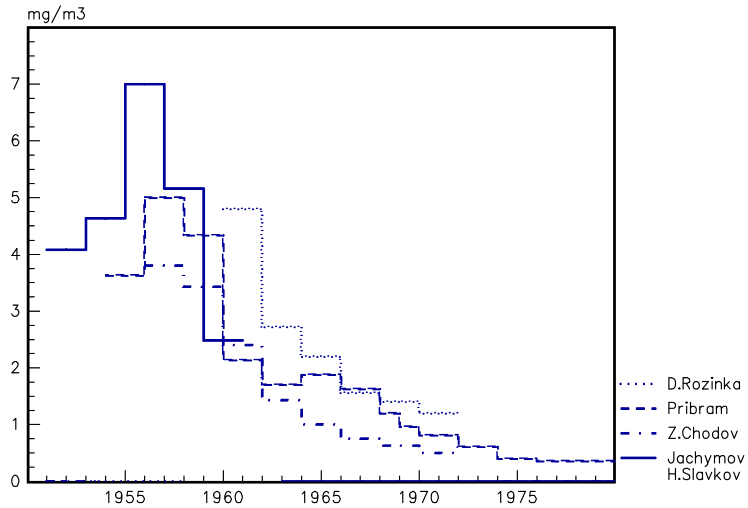

Figure 2: Annual airborne particulates (mg/m^3) in Czech uranium mines

Table 2: Specific activity (Bq/g) of long lived radionuclides in uranium ore and relative content of U in the ore

	Bq/g	%U
Příbram 1970-77	*150*	*0.06*
Elliot Lake (Bigu et al, 1992)	*160*	
Wismut 1950-60 (Lehmann et al, 1998)	*~180*	*0.10*
Wismut 1961-70 (Lehmann et al, 1998)	*~300*	*0.18*

The estimated intake of long lived radionuclides in the present study used both correlations to airborne particulates content (Table 2) in terms of specific alpha activity (Bq/g) and to external gamma exposures (Table 3) in terms of ratio of long lived radionuclides intake and external gamma dose (Bq/mSv) that were derived from different studies and data available in the Czech study after 1970. We used the conversion 300 Bq/g for Jachymov region and 200 Bq/g for other regions. For conversions from external gamma exposure to long lived radionuclides intake, we used the ratio 300 Bq/mSv. The two estimates based on airborne particulates and external gamma exposure were in each year combined into mean resulting values.

Table 3: Ratio of mean intake of long lived radionuclides to mean external gamma dose

	Bq/mSv	
Příbram 1970-85	*300*	
Dolní Rožínka 2004	*100-300*	*Algade*

Estimation of equivalent doses

Equivalent doses from long lived alpha emitters were estimated assuming equal contribution of activities of the following long lived radionuclides Th-230, Ra-226, U-234, U-238, and Pb-210 with ingrowing Po-210, similarly as was observed in US uranium mines by Harley et al (1981, 1985).

The internal dose from inhaled long lived alpha radionuclides is estimated by applying respiratory tract and biokinetic models (ICRP-66 and ICRP-68) using software ICRP (1998-2001). The type of aerosol absorption in the lungs for these radionuclides was derived using results of mine CL by Duport et al, 1991 (Table 4). Due to wet drilling in Czech mines, activity median aerodynamic diameter (AMAD) was assumed 5μm in the period 1960-70. Higher dust content in mining atmosphere in the earlier period was reflected by using AMAD=10μm, and lower dust levels in the mines after 1970 by using AMAD=3μm.

Table 4: Absorption types in three Canadian U mines (Duport et al, 1991)

	Type	EL	MW	CL
U-238	*F*	*0.33*	*0.50*	*0.25*
	S	*0.67*	*0.50*	*0.75*
Th-230	*F*			*0.15*
	S			*0.85*
Ra-226	*F*	*0.07*	*0.07*	*0.12*
	S	*0.93*	*0.93*	*0.88*
Pb-210	*F*			*0.28*
	S			*0.72*

In estimating the equivalent red bone marrow dose from radon and its progeny, we used the conversion derived by Jacobi (1994), ie. 1 WLM being approximately equal to 0.3 mSv.

Statistical model

Estimated annual doses that reflect duration of exposure, calendar period, mine, job (hewers / others), and time since exposure were implemented according to individual working history of cohort members. For each miner, appropriate time dependent dose estimates are calculated from time of first exposure till the end of follow-up (ie. date of death, loss of follow-up, or 31 December 1999) minus minimal latency period of two years. In each moment during follow-up, leukaemia risk (ie. observed cases of leukaemia and person-years from all cohort members at risk) was evaluated in relation to cumulated dose D at current time of follow-up lagged by 2 years using the linear model of relative risk RR = 1 + b D. Estimation of the parameters was based on the assumption that observed numbers in dose categories have the Poisson distribution with parameter □ = i E RR, where RR is the relative risk at given dose, E is the expected number of leukaemia derived from national mortality data according to calendar year and age. The multiplicative parameter i is an intercept allowing baseline mortality in the cohort to differ from that in the general population. Unknown parameters in the model (b, i) were estimated by maximum likelihood method using the AMFIT module of the Epicure software (Preston et al, 1993).

Results

The equivalent red bone marrow doses from long lived alpha radionuclides, radon, and external gamma irradiation in three main mining areas are given for illustration in Table 5. The main contribution at 30 years since exposure (57-67%) is from inhaled long lived alpha radionuclides in airborne particulates.

Table 5: Annual equivalent red bone marrow doses in Czech uranium mines

	Long-lived alpha [kBq]	Rn & dp [WLM]	External gamma [mSv]	Long-lived alpha (30 y*) [mSv]	Rn & dp [mSv]	Total [mSv]
Jachymov 1955	6	20	16	32	6	54
Pribram 1968	1.5	4	5	10	1	16
D.Rozinka	2.3	2.5	6	14	1	21

All figures correspond to full working time of the hewer
* equivalent bone marrow dose at 30 years since exposure

The above estimates of the equivalent red bone marrow dose in the study cohorts are summarized in Table 6. In comparison to the S cohort, the mean doses in the N cohort reflect mainly shorter duration of exposure and marginal contribution of radon exposure.

Table 6: Equivalent red bone marrow doses (mSv) in the study cohorts

	Cohort S		Cohort N	
	mean	max	mean	max
long lived alpha at the end of follow-up	166	747	43	221
external gamma	88	301	17	85
Rn & decay products	46	261	2	11
Total	301	1199	63	314

Numbers of leukaemia cases, standardized mortality ratios and mean cumulated equivalent doses are summarized in Table 7. The considerable increase of the relative risk (SMR) 20 years since first exposure reflects mainly the internal irradiation of red bone marrow from long lived alpha radionuclides. The equivalent dose 20 years since first exposure is more than doubled in comparison to the period of first 20 years. At the same time, the cumulated equivalent doses from external gamma and radon after first 20 years are practically constant because only very few miners had worked for more than 20 years.

Table 7: Leukaemia relative risk (SMR) by time since first exposure

		cases	SMR	95%CI	mean dose*
years since	1-19	7	1.0	0.4-2.1	82 mSv
first exposure	20+	23	1.8	1.2-2.7	196 mSv
	total	30	1.5	1.1-2.2	124 mSv

** person-year weighted cumulated dose lagged by 2 years*

The relative risk of leukaemia (SMR) in relation to cumulated equivalent red bone marrow dose is shown in Figure 3. The linear dependence of the risk on cumulated dose (model 1) is significant (one-sided p=0.016) with estimated ERR/Sv=3.8 (90%CI: 0.5-16.4). The present estimate is consistent with the risk estimate ERR/Sv=2.6 (90%CI: 1.5-4.3) from the Life Span Study corresponding to adult male population, which was estimated directly from the available database of RERF (1996).

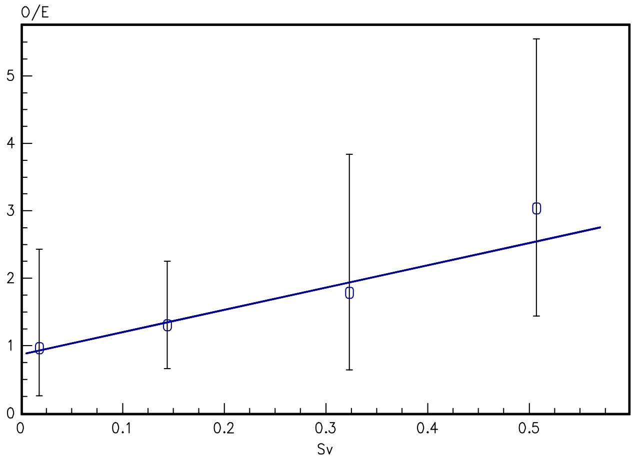

Figure 3: Relative risk of leukaemia in relation to cumulated equivalent red bone marrow dose

In contrast to leukaemia risk, the risk of non-Hodgkin lymphoma (Figure 4) was not significantly related to cumulated equivalent red bone marrow dose. The estimated ERR/Sv was 2.6 (90%CI: -1.0-25.9, one-sided p=0.173).

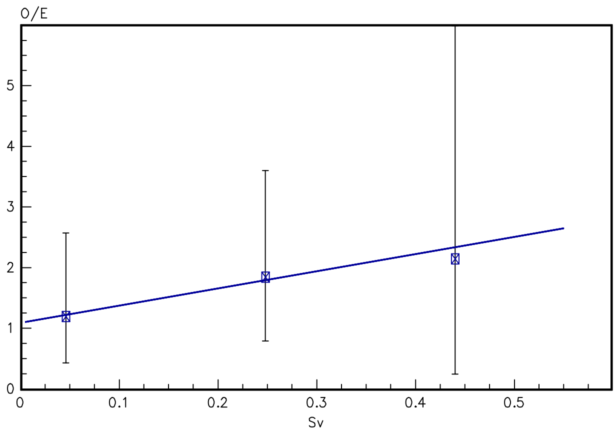

Figure 4: NonHodgkin lymphoma risk in relation to equivalent red bone marrow dose

The present estimates of doses are subject of uncertainty, which includes the composition of inhaled aerosol and its chemical characteristics. Further research is needed for more precise quantification of doses.

Conclusions

The present results of follow-up show that increased risk of leukaemia among uranium miners is significantly associated with cumulated equivalent red bone marrow doses which is dominated by exposures to long lived alpha radionuclides in airborne particulates. The increased mortality is mainly observed decades after exposure and is consistent with estimated internal dose to red bone marrow. The estimated risk coefficient for leukaemia is consistent with results from other studies, however, further studies are needed to reduce uncertainty in the risk estimates.

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