A Twenty-year Follow-up Study on Health Effects Following Long-term Exposure to Thorium Dusts

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Abstract: A twenty-year follow-up study was carried out at Baiyun Obo Rare-earth Iron Mine in China, This mine has been mined since 1958. Its ore contains 0.04% of ThO_2 and 10% of SiO_2. **Objective:** The purpose of this study is to investigate possible health effects in dust-exposed miners following long-term exposure to thorium-containing dusts and thoron progeny. **Methods**: By using the negative high voltage exhaled thoron progeny measurement system to estimate the miner′s thorium lung burden. **Results**: The highest thorium lung burden among 1158 measurements of 638 miners was 11.11Bq. The incidence of stage O^+ pneumoconiosis was increased among dust-exposed miners. An epidemiological study showed that the lung cancer mortality of the dust-exposed miners was significantly ($P<0.005$) higher than that of the controls. **Conclusion**: It is suggested that the difference results long-term exposure to thorium-containing dusts (carcinogens are ThO_2 and SiO_2) and thoron progeny. This is the first evidence in humans of the carcinogenicity after long-term inhalation of thorium-containing dusts and thoron progeny. The total person-years of observation for the dust-exposed miners and the controls were 62712 and 34672 respectively.

Key words: thorium·thoron progeny·health effects·lung cancer·epidemiology·China

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1. INTRODUCTION

Baiyan Obo Rare-earth Co-existence Iron Mine is one of the largest rare earth mine in the world. It has been mined since 1958. Its ore contains not only iron, rare-earth elements and silica dioxide but also thorium at a concentration of 0.04% SiO_2 is at a concentration of 10%. Air concentrations of thorium-containing dusts in working place are quite high. For expample, in the crushing worshop its air concentration is in the range 9.30—875.0 mg m^{-3}, the average is 188.7 mg m^{-3}. (Equivalent value of thorium in air is in the range 0.015—1.41 Bq m^{-3}, the average is 0.30 Bq m^{-3}.) The air α potential energy concentrations of thoron short-lived daughters in the crushing working area are in the range 4.20×10^{2}—6.77×10^{4}MeV L^{-1}, the average is 1.08×10^{4} MeV L^{-1}, It is higher than that of short-lived radon daughters by a factor of about 10. High gamma-ray exposures only appeared in mining workshops. The highest value was 2.31μGy·h^{-1}.

Since 1982, the relationship between thorium lung burden and health effects on miners has been investigated in this mine. The total number of miners and staff members in this mine in 2001 was 6983. Among them, 3016 miners were exposed to this dust and 3967 miners and staff members were not exposed.

2. METHODS

The method used to measure exhaled thoron activity was developed in 1982 from the experience of Argonne National Laboratory in the U.S.A.[1]. It is based on electrostatic collection onto a negatively charged Mylar disc of the daughter ^{212}Pb,85-88% of which is positively charged. The exhaled thoron activity is expressed as the activity of the freely emanating ^{224}Ra (the parent of ^{220}Rn) that would support concentration measured at the subject's mouth. A conversion factor of 3.7 Bq emanating ^{224}Ra equivalent activity at the mouth to 37 Bq of ^{232}Th was used to estimate the thorium lung burden [2].The counter background is extremely low (6 counts.d^{-1}).The overall uncertainty is strongly dependent on the emanating ^{224}Ra and ranges from ±0.013 to±0.07 Bq as the emanating ^{224}Ra ranges from 0.037 Bq to 3.70 Bq(Table 1).

Table 1. The basic performance of the electrostatic measurement system

Item	Value
Counter background (counts.min^{-1})	0.003
Minimum detection limit of thoron outside the body(Bq) (zero activity ±3σ)	0.007
Lower limit for the detection of thorium contamination in the miners'lungs (Bq)(^{224}Ra at the mouth)	0.068
Overall uncertainty depends on the value of the emanating ^{224}Ra at the mouth (Bq)	0.037-3.7 (±0.013-0.070)
Median variance coefficient(%)	±17

A total of 1301 measurements of exhaled thoron activity were carried out on 781 individuals during the period 1983-1994. Of these ,1158 measurements were performed on 638 thorium miners, and 143 measurements were made on 143 unexposed workers(controls). In addition, during this period,1158 medical examinations were performed on these same 638 dust-exposed miners[3]. As epidemiological study on the mortality rates of lung cancers in the dust-exposed miners and dust-unexposed miners was carried out in 2001[4].

3.RESULTS

3.1 Thorium lung burden estimates of the dust-exposed miners and of the dust-unexposed miners

The average value of thorium lung burden estimates for 1158 measurements of 638 dust-exposed miners was 1.60 Bq, while the average value of thoriun lung burden estimates of 143 dust-unexposed miners was 0.30 Bq. Of the 638 exposed miner for whom measurements were performed in the period from 1983 to 1994,585(91.7%)of them had a thorium lung burden less than 2.22 Bq(1 investigation level, see ICRP publication 10[5]). The highest value determined here consisted of a thorium lung burden of 11.11 Bq, which is one tenth of the permissible thorium lung burden.(Table 2) indicated in ICRP publication 10A[6].

Table 2.Summary of values for thorium lung burden estimates performed on miners (638 subjects)

Thorium lung burden estimates (Bq)	Number of subjects
11.11	1
8.89□11.07	5
6.67□8.85	2
4.44□6.63	2
2.22*□4.41	43
□2.19	585

*1 investigation level=2.22Bq

3.2 Estimated thorium lung burdens and relationship to radiography of the dust-exposed mines[3]

Our results showed that there would be a likely threshold of inhaled thorium containing dusts for inducing stage 0+ pneumoconiosis (only fibrosis but no nodules apparent on the X ray film). O^+ is a stage between stage 0, (normal), and stage 1 (pneumoconiosis).

The likely threshold is the lowest value of thorium and dust lung burden of the miners suffering from pneumoconiosis stage 0+ (table 3).

Table3. Likely threshold for lung burden from thorium-containing dusts in the induction of stage O^+ pneumoconiosis

Workshop	Miners	Cases	Thorium (Bq)	Likely threshold for dust(mg)	Year
Crushing	31	8	1.52	940*	1984
Crushing	94	26	1.30	803	1987
Mining	86	4	1.26	780	1988
Crushing	64	12	1.22	756	1994

* The data in this figure were derived as follows: l mg natural thorium=4.037 Bq; 1.52 Bq thorium =0.377mg.A concentration of thorium of 0.377mg×2500(the percentage of thorium in the dusts is 0.04%)=941 mg of dusts.

3.3 Lung cancer mortality among dust-exposed miners and dust-unexposed miners[4]

An epidemiology study on lung cancer mortality of the dust-exposed miners and dust-unexposed miners (controls) was performed in 2001. The main results are listed in Table 4.

Table 4 Standard mortality ratios(SMRs)of lung cancers (1977-2001.3)

Group	Expected	Observed	SMR	95%Limits
Dust exposed miners	4.406	27	6.13	4.41-8.52
Controls	4.201	8	1.90	0.94-3.84

Table 4 showed that the SMR of the dust-exposed miners and of the dust-unexposed miners were greater than 1. The SMR of the dust-exposed miners was much higher than that of the controls. The probability that 27 or more lung cancers would occur in the dust-exposed group, given the expected numbers and that a total of 35 occurred, is 0.0015.[7] The high SMR for lung cancers among dust exposed miners likely resulted from the inhaled thorium-containing dusts (carcinogens are ThO_2 and SiO_2) and its short-lived thoron progeny. The total person-years of observation of the dust exposed miners and the unexposed miners were 62712 and 34672 respectively.

Since 1994, 36 years after the initial operation of this mine, 10 additional lung cancers have appeared in dust-exposed miners. The probability that all ten of these would appear in the dust-exposed group, given the expectations in both groups during only this recent period, is 0.0066.

The percentage of smokers in dust exposed miners and in the controls in this mine were 81.5% and 77.2% respectively[8]. There is no statistically significant difference between them. Therefore, the 10 excess long cancers detected in this mine in 2001 were solely due to the lung-term inhaled thorium containing dusts and its short-lived thoron progeny. The confounding factor cigarette smoking is excluded.

Table 5 Standard mortality ratios (SMRs) of lung cancers (1977—1993.12)[3]

Group	Expected	Observed	SMR	95%Limits
Dust-exposed miners	3.301	17	5.15	3.36-7.89
Controls	3.480	8	2.30	1.17-4.51

Table 5 shows that even before 1994 the SMRs for both the dust-exposed and dust unexposed miners were greater than 1. The SMR for the dust-exposed miners was more than that for the controls, and the probability that 17 or more lung cancers would occur among the dust-exposed miners given the expectations in both groups and that 25 total lung cancers appeared was marginally significant($p=0.04$).[7]

3.4 Estimated thorium lung burdens and relationship to haematologic and hepatic parameters of the dust-exposed miners[9]

During the period 1983-1994, 1158 measurements of the four hematological parameters (haemoglobin, white blood cells, neutrophils and lymphocytes) and four hepatic parameters (thymol turbidity test, glutamic pyruvic transaminase, thymol flocculationtest and alkaline phosphatase) were performed on 638 dust-exposed miners, no adverse effects were observed. None of of the above mentioned 638 exposed miners had a thorium lung burden estimate higher than 11.11 Bq.

3.5 Follow-up Study (1983-1990) of the clearance of thorium dioxide from the lung of a miner having a high thorium lung burden[10]

Since 1983, a seven year follow-up study has been carried out using the exhaled thoron progeny measurement system to observe the clearance of thorium dioxide from the lung of a miner before and after leaving work. The results indicate that 44% of the initial lung burden was clearing with a half-time of 112 d and 56% was clearing with a half-time of 2553372days (~7000years). The longer half-time was attributed to the dusts (being surrounded by fibrotic tissues) in this miner’s lung. In which, only thoron gas, but not dusts, could move away from the sites of deposition. In 1985, this subject suffered from stage 1 pneumconiosis. His X ray film, showed an increase of veins and grains in the pulmonary area. Scattered small nodules appeared on the middle and lower lobes of the lung.

3.6 Health protection measures and results

The authors suggested this mine to apply the following protection measures.(1)Devices for ventilation and prevention of dusts should be improved.(2)Instructions for use of the individual protection appliances should be promoted.(3)Participation in popular sports should be encouraged. It was observed that in this mine the amount of thorium deposited in the lungs of dust-exposed miners who habitually run was generally low.(4)Job rotation is suggested for those having an estimated thorium lung burden higher than 4.44Bq. These measures achieved positive results.

4. CONCLUSION

This study showed that the highest thorium lung burden of the dust-exposed miners in this mine was 11.11Bq. The number of cases of pneumoconiosis of stage O^+ in the crushing workshop was much higher than that of the mining workshops. Epidemiological studies showed that the 10 excess lung cancers of the dust-exposed miners have clearly appeared since 1994, 36 years after the mining of this mine, although there was some prior evidence of excess lung cancers before 1994. Long-term exposure to thorium-containing dusts (carcinogens are ThO_2 and SiO_2) and thoron progeny resulted in inducing excess lung cancers, contrary to the most recent findings from an American thorium processing plant.[11] This is the first evidence in humans of the carcinogenicity after long-term inhalation of thorium-containing dusts and thoron progeny. The confounding factor cigarette smoking is excluded.

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