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Original Research

ScopeMed

Dust, radiation and diesel exhaust exposures in Ontario uranium mines and mills

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ABSTRACT

Aim: The objective of this paper was to summarize a comprehensive survey of airborne dust, radiation, and diesel exhaust in two Ontario uranium mines which was conducted by the Occupational Health Protection Branch of Ontario Ministry of Health in 1974. **Materials and Methods:** About 1000 dust samples of various types were collected from the mine and mill areas under normal routine working conditions. Dust sampling was conducted using various sampling devices including midget impingers, konimeters, and both area and personal respirable dust samplers. About 400 measurements of radon daughter concentrations were made, usually in the same area where dust samples were taken. Diesel exhaust gases, carbon monoxide, formaldehyde, and oxides of nitrogen, were measured using Dräger colorimetric tubes, as an index of diesel exposure. Unburnt carbon from diesel exhaust was determined from some of the dust samples. **Results:** The results show that dust exposure, including crystalline silica (α-quartz), was generally higher than the recommended exposure limits of the time. Radon exposure was also in excess of the exposure limits of the time in some work areas. Diesel exhaust gases were mostly below the threshold limit value of the time. **Conclusions:** The data set described in this paper would be useful in future epidemiological or health studies of the uranium miners group for establishing the work-relatedness for diseases such as lung cancer from radon exposure and silica, respiratory diseases such as silicosis and chronic obstructive pulmonary disease, and autoimmune diseases. It would also be useful in estimating exposure of individual miners for the assessment of compensation claims.

KEY WORDS: Diesel exhaust gases, lung cancer, radon, respirable dust, respirable silica, silicosis, uranium mines

INTRODUCTION

Uranium ores were mined and milled in Ontario, Canada from 1955 to 1996. During this period, 16 mines operated in this province with the majority of them being situated in the Elliot Lake area of Northern Ontario. Uranium mining operations in Ontario ceased in 1996, but it currently goes on elsewhere in Canada such as in the province of Saskatchewan. According to the Report of Royal Commission on the Health and Safety of workers in mines [1], there were 15,094 persons who worked 1 or more months in dust exposure in Ontario uranium mines in the period 1955-1974. The uranium workers cohort has been recently updated and now consists of 28,546 miners [2]. A fairly large group of workers have thus been exposed to hazards of uranium mining and milling. The health risks associated with uranium mining and milling have been well recognized and extensively studied. Uranium miners have been found to have a substantial risk of excess lung cancer deaths from radiation exposure in the form of radon progeny [3-6]. They are also at higher risk of pneumoconiosis, silicosis and other crystalline silica-related diseases such as chronic obstructive pulmonary disease (COPD) from exposure to airborne dust containing a high percentage of silica [5,7,8] which has also been classified as a carcinogen by International Agency for Research on Cancer [8]. In addition, uranium miners are exposed to diesel exhaust, a substance that has been now classified as carcinogenic [9,10]. Although uranium miners and millers face multiple hazardous occupational exposures, in the open peer-reviewed literature, almost no occupational exposure data exists for this group of Ontario workers. During our search for Ontario specific occupational exposure data, we did find a Ministry of Health Report of 1974[11] which contains a large set of exposure data related to uranium mining and milling operations. Unfortunately, this survey report was not published in the open literature, so it remains largely unknown and not easily accessible. This article summarizes those exposure data and makes then available in the open literature for the first time.

MATERIALS AND METHODS

The 1974 Ontario Uranium Mines and Mills Survey[11]

A comprehensive survey of dust, radiation, and diesel exhaust in two active mines and mills of Ontario was conducted by the Occupational Health Protection Branch of the Ontario Ministry of Health in 1974. Almost 1000 dust samples of various types were collected under normal working conditions. Both area/and personal samples were collected. About 400 measurements of radon daughter concentrations were made, usually in the vicinity of concurrent dust sampling. Not all of the dust and radon samples have been included in this paper because some were duplicates and some were quality control and some were side by side samples with companies' samples. A total of 756 dust samples and 293 radon samples have been summarized.

Diesel exhaust exposure was assessed by measuring exhaust gases such as carbon monoxide, formaldehyde and oxides of nitrogen by using colorimetric Drager tubes. The two mines where the survey was conducted were Rio Algom Ltd.'s New Quirk Mine (will be referred as Rio Algom) and Denison Mines Ltd.'s Denison Mines. The two mines were located north of the town of Elliot Lake. Both mines employed about 800 workers each within underground mines and surface mills. Uranium ore was mined from a 10 foot thick gently inclined bed of interbedded quartzite and conglomerate using a modified room and pillar mining method employing electrical, air and diesel powered drilling, haulage and force equipment. The broken ore was then loaded into ore rail cars and transferred to the mill. At the mill, the ore went through primary jaw crusher, then through secondary gyratory crushers and into the fine ore storage bin. From here it passed through the rod and ball mill's grinding circuits and, finally, on to the chemical treatment plant for separation of uranium compound from the ore, in the form of a yellow precipitate. The resulting uranium "yellow cake" was transferred for drying, packaging, storing and shipping.

Dust Sampling

Dust sampling was conducted by several methods including the use of midget impingers, konimeters, U.K. Mine research establishment (MRE) gravimetric respirable dust samplers, and personal respirable dust samplers (Micronair and Casella). Furthermore, bulk total dust obtained from dust collectors and bulk respirable dust obtained using Hexhelet respirable dust samplers were collected for the determination of free silica (crystalline silica) in airborne dust.

Midget Impinger Samples

In North America, at the time of this survey, the use of impingers for collection of aerosols was the accepted sampling method and the midget impinger was widely used for this purpose. The airborne dust was drawn through liquid contained within the glass impinger and the dust particles collected were subsequently counted under a microscope. The results were given in millions of particles per cubic foot (mppcf) of sampled air. The details can be found in several publications [12,13]. The results in mppcf were compared to the then American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs) [14]. The impinger count TLV was based on an equation which took into account % of crystalline silica in airborne dust.

In Ontario mines prior to 1980, routine assessment of airborne dust was made using a konimeter since 1958. The konimeter has a sampling duration of a fraction of a second and gave results in particles per cubic centimeter (ppcc). The details of sampling and analysis procedure are given elsewhere [15].

MRE Gravimetric Respirable Dust Samplers

This gravimetric respirable dust sampler used horizontal elutriation, in which dust laden air passed through a series of horizontal parallel plates, where larger particles settle out before the respirable fraction of the dust is eventually captured on a filter. The respirable dust collection characteristics meet the British Medical Research Council (BMRC) respirable dust criteria. This was a bulky sampler and could only be used as an area/location sampler. The air was drawn through a 25 mm diameter silver membrane filter at a flow rate of 1.9 Lpm. The details of MRE sampler and its operation can be found elsewhere [12,16]. Collection on a silver membrane filter allowed for the subsequent determination of crystalline silica content by X-ray diffraction. Airborne concentrations of respirable dust and respirable silica from the sampler are expressed in terms of mg/m^3.

Personal Respirable (Micronair) Dust Samples

Although not stated in the report, these samples were most likely taken using the Bendix Micronair Permissible sampling pump coal mine dust personal sampler, which was extensively used in USA coal mines in conjunction with a 10 mm nylon cyclone sampler [16,17]. The sample was collected on a pre-weighed membrane filter paper at a flow rate of 1.8 Lpm. The results are expressed as mg/m^3.

Personal Respirable (Casella) Dust Samples

These samples were taken by the personal portable metal cyclone sampler which was designed to meet BMRC respirable dust criteria, the details of which can be found elsewhere [18]. Airborne dust was sampled at a flow rate of 2.1 Lpm on to a pre-weighed 25 mm diameter silver membrane filter. The respirable dust in mg/m^3 was obtained by reweighing the sampled filter. Some of the samples were also analyzed for silica content using X-ray diffraction[19] by the Elliot Lake Research Laboratory of the Government of Canada's Department of Energy Mines and Resources.

Bulk Samples

Since large quantities of dust were needed for analyses of crystalline silica by the colorimetric method [20], and in those years (1970's), bulk total dust samples were obtained from dust collectors and other locations for this purpose. Bulk respirable dust was collected using a Hexhelet respirable dust sampler which is a horizontal elutriator and samples airborne dust at a flow rate of 100 Lpm [12]. It collected a large amount of sample, sufficient for analysis of crystalline silica (α-quartz) by the colorimetric method. All bulk samples were analyzed by the Government of Ontario's occupational health laboratory.

Radiation (Radon) Sampling

The procedure for measuring radon daughter concentrations in the survey mines was the Kusnetz method [21]. Air was drawn through a 47 mm diameter membrane filter at a flow rate of 10 Lpm for 2-3 min using a battery operated pump. After sampling, the filters were covered, stored and counted for alpha activity, at 40-90 min after sampling using a Transcint Model 1001B (Nuclear Enterprise Ltd., Winnipeg, Canada) and Impulse counter Type 1200 IC (Nuclear Enterprise Ltd., Winnipeg, Canada). This was a portable battery operated zinc sulfide alpha scintillation counter. On each day, a background count was taken and the counting efficiency of the Transcint was determined using a calibrated Am^{241} source. The radon daughter concentrations were calculated in working levels (WL) using the Kusnetz procedure [21]. One WL is defined as that concentration of short-lived Radon daughter products in a liter of air that will yield 1.3×10^5 million electron volts of alpha energy in decaying through Ra C.

Diesel Exhaust Sampling

Indirect measures of diesel exhaust were assessed by sampling at the breathing zone of work area for carbon monoxide, formaldehyde, and oxides of nitrogen by Drager colorimetric tubes. Unburned carbon was also determined from some of the dust samples by ashing and reweighing.

RESULTS

Dust Samples

The results of impinger samples are given in Table 1. In Table 2, the results of konimeter samples are shown. In

Table 1: Summary of the impinger samples in mppcf

Mine	Operation	*N*	0-5.0	5.1-10.0	10.1-15.0	15.1-20	>20	% >5 mppcf
Rio Algom	Drilling	44	0	9	16	10	9	100
	Loading, dumping, and mucking	23	1	7	7	4	4	96
	Slushing	24	1	6	11	3	3	96
	Crushing	8	0	0	0	0	8	100
	Services	9	0	2	4	2	1	100
	Milling	11	0	1	4	2	4	100
	Laboratory	1	0	0	1	0	0	100
Denison	Drilling	47	0	5	15	12	15	100
	Loading, unloading, mucking, and slushing	29	0	1	12	7	9	100
	Crushing	18	0	3	5	4	6	100
	Conveyor belts	18	0	1	5	6	6	100
	Servicing	31	2	9	13	3	4	94
	No operation areas	12	0	2	4	4	2	100
	Milling	36	6	19	10	1	0	83
	Leaching	11	0	9	0	0	2	100

mppcf: Millions of particles per cubic foot, *N*: Number of samples

Table 2: Summary of the konimeter samples in ppcc

Mine	Operation	*N*	0-150	151-176	177-200	201-300	>300	% >176
Rio Algom	Drilling	65	13	6	2	12	32	71
	Loading, dumping, and mucking	30	14	1	1	5	9	50
	Slushing	37	9	1	0	5	22	73
	Crushing	17	10	2	0	3	2	29
	Services	21	6	1	1	2	11	67
	Milling	14	7	2	2	1	2	36
	Laboratory	1	0	0	1	0	0	100
	No operation areas	7	3	1	2	0	1	43
Denison	Drilling	90	40	5	6	21	18	50
	Loading, unloading, mucking, and slushing	40	7	5	6	9	13	70
	Crushing	48	6	3	2	9	28	81
	Conveyor belts	17	1	2	1	2	11	82
	Air ventilation	7	4	0	0	2	1	43
	Servicing	39	14	3	3	7	12	56
	No operation areas	15	10	0	4	0	1	33
	Milling	24	7	1	1	4	11	67
	Leaching	11	3	3	1	3	1	45

N: Number of samples, ppcc: Particles per cubic centimeter

Table 3, the MRE Gravimetric respirable dust sample results are listed. Table 4 lists the results of personal Micronair sample and Table 5 provides the results of personal Casella sampler. Most of the respirable dust samples listed in Tables 3 and 5 were analyzed for respirable silica (α-quartz) by XRD and they are listed in Table 6. The respirable quartz as % of respirable dust is given in Table 7. Four bulk samples taken from primary crushers and ore passes of the two mines gave a median % free silica of 47.0% and mean of 43.5% (individual values being 27.8, 43.9, 51.1, and 51.5) in total dust. One bulk sample of respirable dust collected by Hexhelet gave a result of 46.6%.

Radiation (Radon) Samples

The result of radon levels within the stated range of WL in various types of areas in Rio Algoma and Denison mines are shown in Table 8.

Diesel Exhaust Samples

There were no actual results given in the report [11]. There was a statement that almost all samples of carbon monoxide, formaldehyde, oxides of nitrogen, and carbon black were below the then respective ACGIH TLVs and respective criteria.

Table 3: Summary of the gravimetric (MRE) respirable dust samples in mg/m³

Mine	Operation	*N*	0-0.27	0.28-0.54	0.55-0.81	0.82-1.08	>1.08	% >0.27
Rio Algom	Drilling	2	0	0	0	1	1	100
	Loading, dumping, and mucking	9	0	4	1	0	4	100
	Slushing	7	3	2	2	0	0	57
	Crushing	6	0	2	3	0	1	100
	Milling	4	1	1	0	0	2	75
	No operation areas	1	1	0	0	0	0	0
Denison	Drilling	1	1	0	0	0	0	0
	Loading, unloading, mucking, and slushing	2	0	1	0	0	1	100
	Crushing	2	0	1	0	0	1	100
	Conveyor belts	2	0	1	0	0	1	100
	Servicing	2	0	0	1	1	0	100
	No operation areas	2	0	2	0	0	0	100

N: Number of samples, MRE: Mine research establishment

Table 4: Summary of the person Micronair respirable dust samples in mg/m³

Mine	Operation	*N*	0-0.27	0.28-0.54	0.55-0.81	0.82-1.08	>1.08	% >0.27
Rio Algom	Drilling	6	0	0	1	1	4	100
	Loading, dumping, and mucking	2	1	0	0	0	1	50
	Slushing	2	0	0	1	0	1	100
	Crushing	2	0	0	0	0	2	100
	Services	2	1	0	0	0	1	50
	Carried by Ministry Personnel	2	0	0	0	1	1	100
Denison	Drilling	6	0	0	1	0	5	100
	Loading, unloading, mucking, and slushing	2	0	0	0	0	2	100
	Crushing	2	0	0	0	1	1	100
	Conveyor belts	1	0	0	0	0	1	100
	Servicing	8	3	1	1	0	3	63
	Milling	2	1	1	0	0	0	50

N: Number of samples

Table 5: Summary of the personal Casella respirable dust samples in mg/m³

Mine	Operation	*N*	0-0.27	0.28-0.54	0.55-0.81	0.82-1.08	>1.08	% >0.27
Rio Algom	Drilling	12	3	2	1	4	2	75
	Loading, dumping, and mucking	11	5	2	2	1	1	55
	Slushing	13	6	3	0	3	1	54
	Crushing	5	2	0	0	3	0	60
	Services	6	0	2	3	0	1	100
	Milling	3	0	2	3	0	1	100
	Carried by Ministry Personnel	7	5	2	0	0	0	29
Denison	Drilling	6	0	2	2	1	1	100
	Loading, unloading, mucking, and slushing	5	0	1	1	1	2	100
	Crushing	7	1	1	2	2	1	86
	Conveyor belts	3	0	1	2	0	0	100
	Servicing	7	1	3	2	0	1	86
	No operation areas	12	0	4	7	1	0	100
	Leaching	2	0	1	0	0	1	100

N: Number of samples

Table 6: Summary of the X-ray diffraction analysis for respirable free silica samples in mg/m³

Mine	Operation	*N*	0-0.10	0.11-0.20	0.21-0.30	0.31-0.40	>0.40	% >0.10
Rio Algom	Drilling	14	11	3	0	0	0	21
	Loading, dumping, and mucking	21	15	4	0	1	1	29
	Slushing	21	18	1	1	1	0	14
	Crushing	12	8	1	1	1	1	33
	Services	6	3	2	0	1	0	50
	Milling	6	6	0	0	0	0	0
	No operation areas	1	1	0	0	0	0	0
	Carried by Ministry Personnel	6	5	1	0	0	0	17
Denison	Drilling	9	8	0	0	1	0	11
	Loading, unloading, mucking, and slushing	6	6	0	0	0	0	0
	Crushing	11	5	3	0	0	3	55
	Conveyor belts	5	4	1	0	0	0	20
	Servicing	9	9	0	0	0	0	0
	No operation areas	16	15	1	0	0	0	6
	Leaching	2	2	0	0	0	0	0

N: Number of samples

Table 7: Summary of the X-ray diffraction analysis for percent (%) free crystalline silica in respirable dust

Mine	Operation	*N*	0%	5%	10%	15%	20%	25%	30%	35%	40%	45%	50%	55%	60%	65%	70%	75%	80%	85%	90%	95%	100%
Rio Algom	Drilling	14	4	4	1	2	1	1															1
	Loading, dumping, and mucking	23	2	2	5	3	2	1	2		3				2								1
	Slushing	24	3	3	3	1	3	2	6		1		1										1
	Crushing	11	2	1	1	1	1		1		1		1						1	1			
	Services	6			2			2	1		1												
	Milling	7	3	1	1		2																
	No operation areas	1						1															
	Carried by Ministry Personnel	8				1	1	1	1	1	1			1									1
Denison	Drilling	7		5		2																	
	Loading, unloading, mucking, and slushing	6	1	3	2																		
	Crushing	11	1	1	3	1	1	2	1		1												
	Conveyor belts	5			2	2		1															
	Servicing	9		5	3			1															
	No operation areas	14	2	8		2		1	1														
	Leaching	2		1	1																		

N: Number of samples

Table 8: Summary of measurements within stated range of WL in various areas of the two mines

Rio Algom									
Area type	***N***	**0-0.1**	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**
Production areas (stopes, raises)	68	21	22	9	6	3	4	2	1
Haulage	15	14	1	0	0	0	0	0	0
Fresh airways	5	5	0	0	0	0	0	0	0
Lunch rooms	8	7	0	0	0	0	0	1	0
Mill and crusher	23	23	0	0	0	0	0	0	0
Miscellaneous*	39	32	3	2	0	1	0	1	0

Denison																
Area type	***N***	**0-0.1**	**0.1-0.2**	**0.2-0.3**	**0.3-0.4**	**0.4-0.5**	**0.5-0.6**	**0.6-0.7**	**0.7-0.8**	**0.8-1.0**	**1-2**	**2-3**	**3-4**	**4-6**	**6-8**	**8-10**
Production areas (headings, drifts, etc.)	38	0	11	10	6	3	6	1	0	0	1	0	0	0	0	0
Travel ways	5	1	1	2	0	0	0	0	0	0	1	0	0	0	0	0
Fresh airways	3	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Exhaust airways	3	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Refuge stations	12	6	0	2	0	0	1	0	1	0	1	1	0	0	0	0
Leaching	11	0	0	0	0	0	0	1	0	0	2	0	2	4	1	1
Miscellaneous*	27	14	4	1	2	2	0	0	2	0	2	0	0	0	0	0

*Miscellaneous includes conveyors, sumps, skip, bulkheads, workshops, grizzlies, U/G crusher, etc., WL: Working levels, N: Number of samples

DISCUSSION

Midget Impinger Samples

The TLV adopted for the midget impinger sample was derived by the ACGIH's[14] formula of:

$$\text{TLV in mppcf} = \frac{300}{\%\ \text{quartz} + 10}$$

Percent quartz to be used in the formula was taken as an average of 50%. This was based on many bulk samples analyzed by the Ontario Occupational Health Laboratory from Elliot Lake Uranium Mines ranging between 50.8% and 70.5%, and analysis during this survey showed median value of 46.6% [11]. The TLV calculated was 5 mppcf. Almost all samples were above this limit as shown in Table 1.

Konimeter Samples

Since 5 mppcf is equal to 176 ppcc, 176 ppcc was selected to use as the guideline for assessing the konimeter counts. It was noted that this figure is not very different from 200 ppcc that has been used as MAPAO's guideline for uranium mines [1]. As can be seen in Table 2, for most of the operations, exceedance with respect to 176 ppcc ranges from 29% to 100%. The survey by konimeter in the uranium mines dates as far back as 1958 [Figure 1]. More detailed data can be found in the table D2 of the Royal Commission's Report [1]. The value of these konimeter data is that it provides a link to the past conditions to the beginning of the uranium mining in Ontario. The konimeter counts in the uranium mines can be converted to modern day respirable silica concentration by the conversion equations and tables provided by Verma *et al*. [22].

MRE Samples

The TLV for MRE respirable dust samples depended upon the respirable dust free silica content. The chemical analysis of a bulk sample of respirable dust gave a silica content of 46.6%. There were also additional data from X-ray diffraction analyses with a mean value of 18.9% and median value of 10%. X-ray diffraction results were considered less reliable. Considering the two results (chemical analyses and X-ray diffraction) a value of 35% for respirable quartz was considered reasonable for use. The TLV of respirable dust was determined by the formula:

$$\text{TLV}\left(\text{respirable dust}\right) = \frac{10}{\%\ \text{respirable quartz} + 2}$$

$$= \frac{10}{35+2} = 0.27\,\text{mg/m}^3$$

As shown in Table 3, most of the results exceeded the calculated TLV of 0.27 mg/m^3 (exceedance ranging from 50% to 100%).

Personal Micronair Respirable Dust Samples

The results of Micronair samples listed in Table 4 indicate a high percentage of exceedance when compared to the respirable dust TLV of 0.27 mg/m^3 (mostly ranging from 50% to 100%).

Personal Casella Respirable Dust Samples

The results summarized in Table 5 also show a high percentage of samples over the TLV of 0.27 mg/m^3. The percentage of samples that exceeded the TLV of 0.27 mg/m^3 ranged from 29 to 100% (mostly over 50%).

Respirable Silica Samples by X-Ray Diffraction

The TLV adopted for respirable silica (respirable quartz) was 0.10 mg/m^3. When compared to this TLV, the percentage of samples over the TLV is 0-55% [Table 6]. The exceedance is much lower than those of respirable dust samples of Tables 4 and 5. It should be noted that there was a comment in the report[11] that the results by X-ray diffraction were very erratic and thus considered somewhat less reliable. Although the significant percentage of respirable silica results by XRD of Table 6 is lower than the TLV of 0.1 mg/m^3, they are far in excess of the current ACGIH TLV[23] of 0.025 mg/m^3.

Percent Free Silica by X-Ray Diffraction

The variation in the results of % free silica by XRD on various operations is shown in Table 7 where they range from 0% to 100%. A means value of 18.9% was calculated.

Radiation (Radon) Samples

The occupational exposure limit for radon exposure was set by the Ministry of Natural Resources of Government of Ontario and at the time data was collected it was 6 WLM year. Any area with a concentration reading > 0.5 WL would render it unacceptable for full-time occupancy since it would lead to the annual exposure of > 6 WLM (0.5 WL × 12 months = 6 WLM). At the Rio Algom Mines as shown in Tables 8 and 9 out of 135 underground areas were found to have readings above

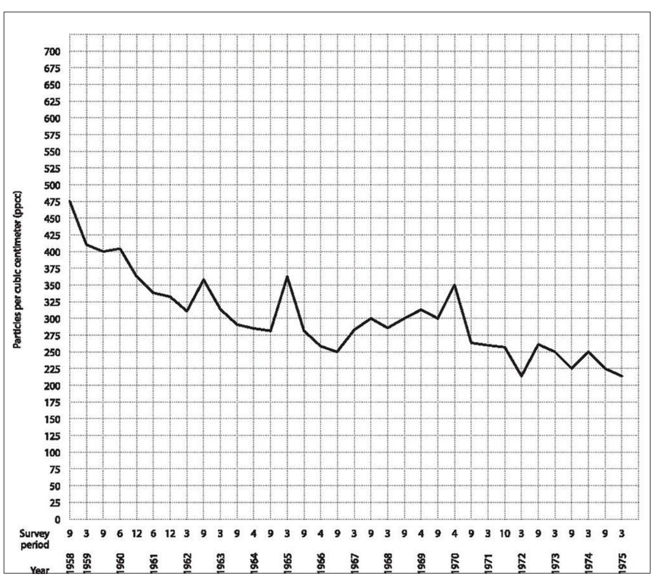

Figure 1: Average dust count by konimeter in Ontario uranium mines 1955-1975 (reproduced from Royal Commission Report) [1]

0.5 WL. At Denison Mine [Table 8], 30 out of 99 underground areas including leaching were found to have readings over 0.5 WL. More areas would have been judged unacceptable if they were compared to the current occupational exposure limit of 4 WLM year [23,24] (i.e., areas having exposures > 0.34 WL). At both mines, all above ground measurements in mills and crusher areas were < 0.1 WL. Figures 2 and 3 shows average radon daughter concentrations in stopes of various mines in Ontario from 1958 to 1974.

Diesel Exhaust

The TLVs used for comparison for carbon monoxide, formaldehyde, nitrogen dioxide, and carbon black exposures were the 1974 ACGIH TLVs. Of 50 ppm for carbon monoxide, 2 ppm for formaldehyde, 5 ppm for nitrogen dioxide, and 3.5 mg/m^3 for carbon black. The report[11] did not give any measurement data, but it provided a statement that the diesel exhaust gases carbon monoxide, formaldehyde, and oxides of nitrogen and carbon particulates were all generally below the then TLVs.

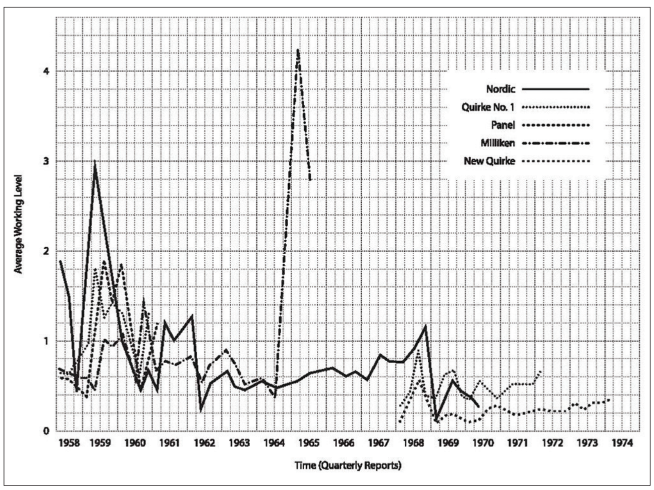

Figure 2: Average radon daughter concentrations in Nordic, Quirk No. 1, Panel, Milliken, and New Quirke Mines (reproduced from Ontario Ministry of Health Report) [11]

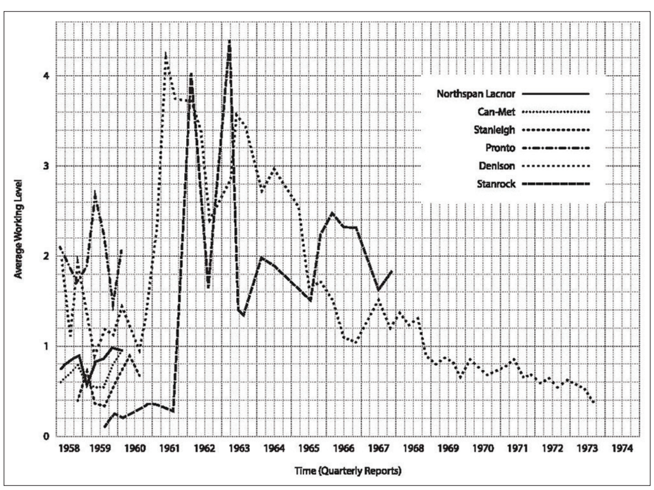

Figure 3: Average radon daughter concentration in stopes of Northspan Lacnor, Can-Met, Stanleigh, Pronto, Denison, and Stanrock Mines (reproduced from Ontario Ministry of Health report) [11]

Strength and Limitation

The strength of the study described is that it was conducted by various departments of Ontario and Federal government research laboratories, who collectively probably had the necessary high degree of expertise, resources, instrumentation, and laboratory facilities to conduct such a study. The data should thus be a valid representation of the exposure for that time period. The main limitation is that the study was conducted over 40 years ago when techniques of the time were not as advanced as today. For example, if one were to assess diesel exhaust in mines today, the most likely method selected would be the measurement of total carbon and respirable elemental carbon [25,26].

CONCLUSION

In Ontario, uranium mining and milling operations had been conducted from 1955 to 1996. During this period, approximately 28,500 workers would have been exposed to radiation, silica dust, and diesel exhaust. There is little or no occupational exposures data in open peer-reviewed literature related to Ontario uranium mining. The data described in this article would be useful in future epidemiological and health studies. It would also be useful in estimation of exposure for individual miners when assessing compensation claims, and in establishing work-relatedness of diseases such as lung cancer from radiation (radon) exposure and silica-related diseases such as silicosis, COPD, and autoimmune diseases.

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REFERENCES

1. Ministry of the Attorney General of Ontario. Report of the Royal Commission on the Health and Safety of Workers in Mines. Toronto: Government of Ontario; 1976. p. 276.
2. Navaranjan G, Kone A, Berriault C, Do M, J Villeneuve P, Marrett L, *et al.* 0388 An update of mortality and cancer incidence among Ontario uranium miners exposed to radon progeny. Occup Environ Med 2014;71 Suppl 1:A112-3.
3. Kusiak RA, Ritchie AC, Muller J, Springer J. Mortality from lung cancer in Ontario uranium miners. Br J Ind Med 1993;50:920-8.
4. Finkelstein MM. Clinical measures, smoking, radon exposure, and risk of lung cancer in uranium miners. Occup Environ Med 1996;53:697-702.
5. Pinkerton LE, Bloom TF, Hein MJ, Ward EM. Mortality among a cohort of uranium mill workers: An update. Occup Environ Med 2004;61:57-64.
6. Bissett RJ, McLanghlin JR. Radon. Chronic Dis Can 2010;29 Suppl 1:20.
7. Roscoe RJ. An update of mortality from all causes among white uranium miners from the Colorado Plateau Study Group. Am J Ind Med 1997;31:211-22.

8. IARC. Silica, some silicates, coal dust and paraaramide fibrils. IARC Monographs on the Evaluation of the Carcinogenic Risk of Chemicals to Humans. Vol. 68. Lyon: International Agency for Research on Cancer; 1997.
9. Scheepers PT, Vermeulen RC. Diesel engine exhaust classified as a human lung carcinogen. How will this affect occupational exposures? Occup Environ Med 2012;69:691-3.
10. Vermeulen R, Silverman DT, Garshick E, Vlaanderen J, Portengen L, Steenland K. Exposure-response estimates from diesel engine exhaust and lung cancer mortality based on data from three occupational cohorts. Environ Health Perspect 2014;122:172-7.
11. Ontario Ministry of Health. Survey of Dust, Radiation and Diesel Exhaust in Uranium Mines and Mills at Elliot Lake Ontario. Toronto: Ontario Ministry of Health; 1974. p. 95.
12. Vincent JH. Aerosol Sampling: Science Standards Instrumentation and Applications. West Sussex, England: John Wiley and Sons; 2007. p. 361, 365, 366.
13. Lippmann M. Size selective health sampling. In: Air Sampling Instruments: For Evaluation of Atmospheric Contaminants. 8th ed., Ch. 5. Cincinnati, OH: ACGIH; 1995. p. 81-119.
14. American Conference of Governmental Industrial Hygienists (ACGIH). Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1974. Cincinnati, Ohio: ACGIH; 1974.
15. Verma DK, Sebestyen A, Muir DC. Evaluation of konimeter performance-II: A field comparison of konimeters. Ann Occup Hyg 1987;31:451-61.
16. Verma DK, Sebestyen A, Julian JA, Muir DC. Field comparison of respirable dust samplers. Ann Occup Hyg 1992;36:23-34.
17. Respirable Dust Control. Proceedings, Bureau of Mines Technolgy Transfer Seminars, Pittsburg Pa. September 21, 1976 and St. Louis, Mo. Available from:http://www.archive.org/stream/respirabledustc00bure/respirabledustc00bure_djvu.txt. [Last accessed on 2105 Feb 20].
18. Verma DK, Rajhans GS, Malik OP, des Tombe K. Respirable dust and respirable silica exposure in Ontario gold mines. J Occup Environ Hyg 2014;11:111-6.
19. Knight G, Stefanich W, Ireland G. Laboratory calibration of a technique for determination of respirable quartz in mine air. Am Ind Hyg Assoc J 1972;33:469-75.
20. Talvitie NA. Determination of free silica: Gravimetric and spectrophotometric procedures applicable to air-borne and settled dust. Am Ind Hyg Assoc J 1964;25:169-78.
21. Kusnetz HL. Radon daughters in mine atmospheres; a field method for determining concentrations. Am Ind Hyg Assoc Q 1956;17:85-8.
22. Verma DK, Sebestyen A, Julian JA, Muir DC, Schmidt H, Bernholz CD, *et al.* Silica exposure and silicosis among Ontario hardrock miners: II. Exposure estimates. Am J Ind Med 1989;16:13-8.
23. American Conference of Governmental Industrial Hygienists (ACGIH). Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure indices. Cincinnati, Ohio: ACGIH; 2014.
24. Code of Federal Regulation. Mine Safety and Health Administration 30 CFR & F7.5038 Annual Exposure Limit. Available from: http://www.msha.gov/30cfr/57.5038.htm. [Last accessed on 2105 Feb 20].
25. Coble JB, Stewart PA, Vermeulen R, Yereb D, Stanevich R, Blair A, *et al.* The diesel exhaust in miners study: II. Exposure monitoring surveys and development of exposure groups. Ann Occup Hyg 2010;54:747-61.
26. Noll J, Gilles S, Wu HW, Rubinstein E. The relationship between elemental carbon and diesel particulate matter in underground metal/nonmetal mines in the United States and coal mines in Australia. J.Occup Environ Hyg 2015;12:205-211.

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